FOG ATTACK

FIREFIGHTING STRATEGY & TACTICS – AN INTERNATIONAL VIEW

BY PAUL T GRIMWOOD

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FOG ATTACK
Firefighting Strategy & Tactics
— An International View

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Paul T. Grimwood

Edited by Simon Hoffman
Deputy Editor, 'Fire' Magazine

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Redhill, Surrey

To my sons Paul and Richard

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"I have no ambition in this world but one, and that is to be a fireman. The position may, in the eyes of some, appear to be a lowly one; but we who know the work which a fireman has to do believe that his is a noble calling. There is an adage which says 'Nothing can be destroyed except by fire'. We strive to preserve from destruction the wealth of the world, which is the product of the industry of men, necessary for the comfort of both the rich and the poor. We are the defenders from fire, of the art which has beautified the world, the product of the genius of men and the means of refinement of mankind. But, above all, our proudest endeavour is to save lives – the work of God himself. Under the impulse of such thoughts, the nobility of the occupation thrills us and stimulates us to deeds of daring, even at the supreme sacrifice. Such considerations may not strike the average mind, but they are sufficient to fill to the limit our ambition in life and to make us serve the general purpose of human society."

Edward F. Croker
Chief of Department
New York City
1899-1911

The painting on previous page is the famous work 'Saved' by Charles Vigor (1890). It shows a fireman of the Metropolitan Fire Brigade carrying out a rescue, and now hangs in the dining hall of the Fire Service College, Gloucestershire, England.

PREFACE

As a firefighter I have been fortunate enough to have served on both sides of the Atlantic. Over a period of 20 years I have attended thousands of fires in some of the busiest and most deprived areas of the USA and England and I have studied the profession throughout the world.

It has been demonstrated that it is perfectly feasible to tackle common situations in different ways and it has been, and always is, my intention to investigate the various options, and attempt to influence others on what I believe to be the best way. I only do this where personal experience has justified such an approach.

Our work is forever becoming more complex and I have always considered it important for us all to document our own experiences in some way, for the benefit of others, and future generations of firefighters. This book represents a view of 'fire strategy and tactics' as seen by the firefighters of the world. During its compilation it was difficult not to inject my own points of view on the various methods, techniques and procedures as detailed. However, I have always attempted to present an all-round view, detailing the negative side as well as the positive. This work has also presented an opportunity to develop one or two theories which I feel are well placed within the context of the overall project. They are original ideas and do not, to my knowledge, appear anywhere else.

The 'circle of knowledge' has always seemed so wasteful to me and I sometimes wonder if what we are learning now has all been learned before. With this in mind I also considered it useful to review several books written by chief fire officers in the nineteenth and early twentieth centuries. I was fascinated by their experiences and became truly inspired by Sir Eyre Massey Shaw's feeling for the memorable phrase which is common to all masters of English prose. It is impossible to read a page of his writing without at once noticing this gift. It is also impossible to read Sir Eyre's works without wanting to quote him indefinitely, and I make no apologies for doing so. Former chief fire officer (London) Major C. C. B. Morris, CBE, wrote in his book *Fire* (1939) of former Chief Massey Shaw:

> 'Sir Eyre Shaw was a tall, distinguished-looking man, and a strong disciplinarian. He realised that firefighting was a skilled art, and he regarded his profession in the same light that naval or military officers regard theirs. He further realised that to be a successful firefighter, it was necessary to employ sound strategy and tactics. His strategy and tactics are as sound today as they were in his time. . . . It was he who said that anyone could 'drown a fire out', but it took a fireman to 'put it out'.

In his book *Fires and Fire Brigades* (1889) Massey Shaw archived one of his most memorable statements: "It has been said that there is as much difference between a man who has not trained and cultivated his intellect and one who has, as between a dead man and a living, and the same contrast may be made between those who have not studied fire brigade work and those who have." Well, Sir Eyre, we are gathered here now, about to study our profession. I would think this former chief would have very much approved of this fact, however, I wonder how he would have viewed this elucidation of twentieth century strategy and tactics – I shudder to think!

London
April, 1992

Firefighting strategy and tactics – some definitions

STRATEGY: 'The art of directing movements so as to secure the most advantageous positions and combination of forces'; or 'the way objectives are achieved, ie governing the manner in which forces are used to achieve objectives'. Strategy is primarily concerned with the highest level of control, ie 'policy'. It is the plan, or the 'war on the map'. Strategy may apply to fireground operations over a wide area, ie brigade policy, SOPs, operational notes, etc; these are all formulated strategy.

TACTICS: 'The art of manoeuvring forces in contact with the enemy (fire)'; or 'the employment of troops (firefighters) on the battlefield (fireground)'; 'matters relating to lower levels of the corps (fire force) are tactical'. The employment of companies, crews, teams, etc, on site, relates to tactics. They make up the battle-plan (operation), which in turn must conform to strategic policy.

OPERATIONS: Operations may be defined as the actual 'battle-plan' as it occurs *on site*. The overall operation at an incident is putting brigade policy (strategy) into effect on the fireground by resorting to the use of various tactics.

Author's note

•The views expressed throughout the text are those of the author, and not necessarily those of his employer. At times, it may appear the text is somewhat critical of specific fireground incidents, as reported. It has never been the intention to direct such criticism at any particular fire brigade, department, or individual. Moreover, the purpose is to censure particular methods or techniques used, while suggesting alternatives. This is a learning process that is based upon individual opinions and experience. The reader is urged to examine the text carefully. It is often only with hindsight, following a personal experience, that important points become highly relevant. The experience of others is here for you to learn – but you must be fairly intense in your study if the work is to be beneficial.

The author would also like to point out that throughout this book firefighters are referred to as being male. This merely reflects the fact that the vast majority of firefighters are men, and also avoids ugly phrases such as 'he or she', 'his or her', etc. It does not indicate any degree of sexism from the author, who is only too aware that women are joining the fire service in increasing numbers.

ACKNOWLEDGEMENTS

While researching this book I have travelled many thousands of miles. Along the way I have had the good fortune to visit over 100 fire stations, responding alongside fellow firefighters to observe their varied methods and techniques. I have made many good friends and could not begin to mention them all. However, I believe the following deserve a mention for without their collective help this book would never have reached you the reader:

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1
FORCE DEPLOYMENT

'From the remotest periods of antiquity to the present time, the business of extinguishing fires has attracted a certain amount of attention; but it is a most curious fact that, even now, there is so little method in it, that it is a very rare circumstance to find any two countries, or even any two cities in one country, adopting the same means, or calling their appliances by the same name.'

Sir Eyre Massey Shaw, KCB
'Fire Protection' 1876

The optimum deployment of a fire force within a community entails a programme that requires continual monitoring in order to reflect the changing needs of the society it serves. Such a community protection plan is constantly under the influence of social change, economic climate, building control, and modern innovations relating to equipment and techniques. The implementation and development of such plans are constantly faced with new challenges and they must conform, or adapt, to meet the needs of each particular situation.

There is often much common ground among major cities in the way risk categorisation affects such deployments, although there may sometimes be a variance in meeting the final commitment. However, it is very difficult to make any reliable comparison of the success rates of the various systems – ie in reducing life and property losses – as there are so many influential factors involved: social attitudes, levels of poverty, structural designs and construction, local problems, etc.

What is generally common to such inner city deployments is the requirement to get firefighters and equipment on scene, usually within five minutes of the initial emergency call. This general requirement dates back many years, and it is interesting to note that such a demand was made of the London Fire Brigade as far back as 1897, following the major fire at Cripplegate when 122 warehouses were destroyed by fire. Since the turn of the century, and even during the horse-drawn era, there has been a general requirement for the London Fire Brigade to attend within five minutes and muster 100 firefighters (if needed on scene) within 15 minutes (although the former requirement is superceded by British Home Office legislation).

Another common factor is in the type of equipment that responds to an inner city fire call – usually in the form of two to three pumpers, supported by an aerial appliance. However, following on from this, there is a wide variance in manpower arrangements and also in the strategies and tactics employed by the fire force during the initial stages of a fire.

Of the 26 metropolitan fire authorities reviewed in this chapter, the six most densely populated areas are served by the fire departments in New York, Amsterdam, Tokyo, San Francisco, Miami and Boston. Although Hong Kong is the seventh in terms of population density, a more reliable estimate would recognise that the majority of its population occupies just 38 of the 413 square miles covered by the fire authority!

In general terms these six cities reflect extremely well in relation to the concentration of fire stations, pumpers, aerials and firefighters they provide. It is fascinating, comparing the strengths (and weaknesses) of the world's foremost fire forces. (NB: My figures relate to the situation at each brigade c1989-90):

Tokyo Fire Department

Area:	670 sq miles
Population:	11,500,000
Fire stations:	288
Firefighters:	17,447
Pumpers:	548
Aerials:	88
Ambulances:	165
Fires:	6,687
Other emergencies:	2,963
Alarms:	5,785
Rescues:	4,234
Ambulance response:	392,210
Pumper capacity:	2,000 LPM
Water carried:	20 per cent of pumpers=1,000 l
Attack hose:	40 mm (fog), 50 mm, 65 mm
Supply hose:	75 mm 10 m flexible suction
Specialist fleet:	19 rescue trucks, 9 fireboats, 5 helicopters
High-rise buildings:	58 over 100 m tall.

London Fire Brigade

Area:	620 sq miles
Population:	7,000,000
Fire stations:	112
Firefighters:	7,000
Pumpers:	200
Aerials:	17
Fires:	45,000
Total calls:	150,000
Pumper capacity:	5,909 LPM
Water carried:	1,365 l
Attack hose:	45 mm, 70 mm, 19 mm hosereels
Supply hose:	70 mm twin line

New York Fire Department

Area:	320 sq miles
Population:	8,000,000
Fire stations:	217
Firefighters:	12,000
Pumpers:	275
Aerials:	130
Fires:	95,000
Total calls:	300,000
Pumper capacity:	7,500 LPM
Water carried:	1,900 l
Attack hose:	38 mm, 65 mm
Supply hose:	100 mm

Amsterdam Fire Brigade

Area:	39 sq miles
Population:	800,000
Fire stations:	17
Firefighters:	550
Pumpers:	17
Aerials:	8
Pumper capacity:	3,000 LPM
Water carried:	1,500 l
Attack hose:	65 mm, and 19 mm hosereels
Supply hose:	65 mm, 75 mm

Boston Fire Department

Area:	48 sq miles
Population:	700,000
Fire stations:	34
Firefighters:	1,165
Pumpers:	33
Aerials:	22
Fires:	6,605
Total calls:	46,265
Pumper capacity:	5,679 LPM
Water carried:	2,800 l
Attack hose:	38 mm, 65 mm
Supply hose:	100 mm, 125 mm

Pretoria Fire and Rescue

Area:	244 sq miles
Population:	848,870
Fire stations:	8
Firefighters:	228
Pumpers:	33
Aerials:	5
Pumper capacity:	2,200 LPM
Water carried:	4,000 l
Attack hose:	19 mm, 44 mm, 65 mm
Supply hose:	65 mm
Total calls:	5,666

Chicago Fire Department

Area:	300 sq miles
Population:	3,000,000
Fire stations:	103
Firefighters:	4,500
Pumpers:	101
Aerials:	60
Fires:	16,000 structural
Total calls:	60,000

Pumper capacity:	4,725 LPM
Water carried:	1,890 l
Attack hose:	38 mm, 65 mm canvas
Supply hose:	100 mm, 125 mm

Singapore Fire Service

Area:	220 sq miles
Population:	2,500,000
Fire stations:	12
Firefighters:	1,000
Pumpers:	33
Aerials:	6
Fires:	9,700
Pumper capacity:	4,500 LPM
Water carried:	1,800 l
Attack hose:	38 mm, 63 mm
Supply hose:	63 mm

Los Angeles Fire Department

Area:	456 sq miles
Population:	3,200,000
Fire stations:	109
Firefighters:	2,700
Pumpers:	98
Aerials:	48

Cape Town Fire and Rescue

Area:	117 sq miles
Population:	1,292,787
Fire stations:	7
Firefighters:	341
Pumpers:	24
Aerials:	4
Fires:	3,566
Pumper capacity:	4,000 LPM
Water carried:	2,000 l
Attack hose:	45 mm, 65 mm
Supply hose:	65 mm

San Francisco Fire Department

Area:	49 sq miles
Population:	750,000
Fire stations:	41
Firefighters:	1,400
Pumpers:	41
Aerials:	18
Fires:	6,000
Total calls:	60,000 incl EMS
Pumper capacity:	4,800-5,700 LPM
Water carried:	1,890 l
Attack hose:	19 mm, 38 mm, 75 mm
Supply hose:	90 mm, 100 mm, 125 mm

Zurich Fire Brigade

Area:	36 sq miles
Population:	360,000
Fire stations:	2 (incl 1 part-time)
Firefighters:	164 (incl 30 part-time)
Pumpers:	7
Aerials:	5
Total calls:	3,200
Pumper capacity:	2,800 LPM
Water carried:	2,400 l
Attack hose:	40 mm (also 36 mm HP hosereels)
Supply hose:	75 mm

Las Vegas Fire Department

Area:	82 sq miles
Population:	266,000
Fire stations:	9
Firefighters:	300
Pumpers:	11
Aerials:	4
Fires:	2,215
Total calls:	27,344 incl EMS
Pumper capacity:	5,700 LPM
Water carried:	1,890 l
Attack hose:	19 mm, 38 mm, 45 mm, 65 mm
Supply hose:	125 mm

Oslo Fire Brigade

Area:	175 sq miles
Population:	458,300
Fire stations:	8
Firefighters:	60 (on duty)
Pumpers:	7
CABA vans:	4
Aerials:	3
Fires:	778
Pumper capacity:	2,500-3,000 LPM
Attack hose:	38 mm, 65 mm
Supply hose:	65 mm

Seattle Fire Department

Area:	95 sq miles
Population:	500,000
Fire stations:	33
Firefighters:	950 (10 per cent female)
Pumpers:	33
Aerials:	11
Fires:	13,600 incl alarms
EMS calls:	31,000 (incl 10,850 paramedic)
Pumper capacity:	6,600 LPM
Water carried:	570 l

Attack hose:	45 mm, 65 mm
Supply hose:	100 mm

Oulu Fire Brigade (Finland)

Area:	150 sq miles
Population:	110,000
Fire stations:	2
Firefighters:	105
Pumpers:	9
Aerials:	2
Total calls:	889
Pumper capacity:	2-3,000 LPM
Water carrier:	6,000 LPM
Water carried:	2,000 l (9,700 l on water carrier)
Attack hose:	38 mm, 50 mm
Supply hose:	75 mm, 125 mm

Phoenix Fire Department

Area:	420 sq miles
Population:	980,000
Fire stations:	41
Firefighters:	1,200
Pumpers:	44
Aerials:	11
Total calls:	110,000 (70 per cent EMS, 20 per cent fires)
Pumper capacity:	5,700 LPM
Water carried:	1,890 l
Attack hose:	38 mm, 50 mm, 65 mm
Supply hose:	100 mm

Vienna Fire Brigade

Area:	160 sq miles
Population:	1,200,000
Fire stations:	24
Firefighters:	1,500
Pumpers:	47
Aerials:	10
Total calls:	30,000

Metro Dade Fire Department (Florida)

Area:	1,924 sq miles
Population:	1,900,000
Fire stations:	38
Firefighters:	1,371
Pumpers:	29 (incl 11 'squirts')
Aerials:	6
Total calls:	111,000 (75 per cent EMS)
Pumper capacity:	5,700 LPM
Water carried:	2,800 l
Attack hose:	45 mm
Supply hose:	125 mm

Honolulu Fire Department

Population:	1,000,000
Fire stations:	40
Firefighters:	1,000
Pumpers:	39
Aerials:	10

Miami Fire Department

Area:	34 sq miles
Population:	500,000
Fire stations:	12
Firefighters:	700
Pumpers:	18
Aerials:	9
Total calls:	56,803 (72 per cent EMS)
Pumper capacity:	5,700 LPM
Water carried:	1,890 l
Attack hose:	45 mm, 65 mm
Supply hose:	90 mm, 125 mm

Dallas Fire Department

Area:	378 sq miles
Population:	1,000,000
Fire stations:	53
Firefighters:	1,539
Pumpers:	62
Aerials:	23
Total calls:	212,029 (mainly EMS)
Pumper capacity:	4,700 LPM
Water carried:	1,890 l
Attack hose:	45 mm
Supply hose:	90 mm, 125 mm

Hong Kong Fire Service

Area:	413 sq miles (main populated area=38 sq miles)
Population:	6,000,000
Fire stations:	58
Firefighters:	4,883
Pumpers:	111 pumps/pumps-HPs
Aerials:	20
Fires:	23,299
Additional services:	15,637
Pumper capacity:	4,500 LPM
Water carried:	1,350 l
Attack hose:	19 mm, 38 mm, 70 mm
Supply hose:	70 mm, 100 mm

Stockholm Fire Brigade

Area:	72 sq miles
Population:	750,000
Fire stations:	8

Firefighters:	330
Pumpers:	16
Aerials:	8
Pumper capacity:	1,800 LPM
Water carried:	1,200 l
Attack hose:	38 mm, 65 mm
Supply hose:	65 mm

Melbourne Fire Brigade

Area:	850 sq miles
Population:	3,500,000
Fire stations:	44
Firefighters:	290 (on duty)
Pumpers:	47
Aerials:	9 (also 5 'Telebooms')
Fires:	10,000 (structural)
Pumper capacity:	3,800-8,000 LPM
Water carried:	1,360 l
Attack hose:	30 mm (HP), 38 mm, 65 mm
Supply hose:	65 mm, 90 mm, 120 mm

Paris Fire Brigade

Area:	295 sq miles
Population:	2,057,000
Fire stations:	78
Firefighters:	7,197 (Military)
Pumpers:	147
Aerials:	79
Pumper capacity:	1,000 LPM
Water carried:	1,000-3,000 l
Attack hose:	45 mm, 70 mm, 110 mm
Supply hose:	70 mm, 110 mm

Density of Population (Per square mile)

1	New York	25,000
2	Amsterdam	20,512
3	Tokyo	17,164
4	San Francisco	15,306
5	Miami	14,706
6	Boston	14,583
7	Hong Kong	14,527
8	Singapore	11,363
9	London	11,290
10	Cape Town	11,049
11	Stockholm	10,416
12	Zurich	10,000
12	Chicago	10,000
14	Vienna	7,500
15	Los Angeles	7,017
16	Paris	6,972
17	Seattle	5,263
18	Melbourne	4,117
19	Pretoria	3,478
20	Las Vegas	3,244
21	Dallas	2,645
22	Oslo	2,618
23	Phoenix	2,333
24	Metro Dade (Miami)	1,039
25	Oulu (Finland)	733

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Duty Firefighter's Life Responsibility

1	Paris	1,285
2	San Francisco	1,609
3	Boston	1,678
4	Dallas	1,949
5	Seattle	2,109
6	Miami	2,145
7	Oulu (Finland)	2,222
8	Phoenix	2,450
9	Las Vegas	2,660
10	New York	2,688
11	Chicago	2,727
11	Vienna	2,727
13	Tokyo	3,432
14	Los Angeles	3,555
15	Honolulu	4,000
16	London	4,032
17	Hong Kong	4,037
18	Metro Dade (Miami)	4,376
19	Amsterdam	4,444
20	Leningrad	4,583
21	Zurich	5,900
22	Oslo	7,513
23	Singapore	7,575
24	Stockholm	10,416
25	Melbourne	12,068

Duty Firefighters (Per square mile)

1	San Francisco	9.5
2	New York	9.3
3	Boston	8.7
4	Miami	6.8
5	Paris	5.4
6	Tokyo	5.0
7	Amsterdam	4.6
8	Chicago	3.7
9	Hong Kong	3.6
10	London	2.8
11	Vienna	2.7
12	Seattle	2.5
13	Los Angeles	2.0
14	Zurich	1.7
15	Singapore	1.5
16	Dallas	1.3
17	Las Vegas	1.2
18	Phoenix	1.0
18	Stockholm	1.0
20	Oslo	0.3
20	Oulu (Finland)	0.3
20	Melbourne	0.3
23	Metro Dade (Miami)	0.2

Minimum Crewing Standards

	Pumper	Ladder
San Francisco	4	5
London	4	2
Amsterdam	7	2
New York	5	6
Boston	4	4
Chicago	5	5
Los Angeles	4	5
Las Vegas	4	4
Seattle*	3/6*	4/6
Phoenix*	4/5*	4/5
Metro Dade (Miami)	4	4
Miami	4	4
Dallas	4	4
Stockholm	3/4	2
Zurich	5	
Honolulu	6	7
Vienna	6	
Oulu (Finland)	6	
Cape Town	5	

Singapore	8	
Pretoria	7	4
Tokyo	4	4
Hong Kong	7	6
Melbourne	3/4	2
Paris	5/8	2

*These cities operate on the 'expanded response system' that places extra fire-fighters on 'downtown' engines where the building concentration, and life risk, are highest.

Initial Response – Inner City Fire Call

		Firefighters	Pumpers	Aerials
1	Tokyo	57	9	3
2	*Seattle	40	5	2
3	Leningrad	36	8	4
4	*Phoenix	30	4	2
5	New York	27	3	2
6	Chicago	25	3	2
7	Los Angeles	24	3	2
8	Hong Kong	24	1	2
9	Vienna	23	3	1
10	San Francisco	22	3	2
11	Dallas	20	4	2
12	Las Vegas	20	3	2
13	Melbourne	19	5	1
14	Metro Dade (Miami)	16	3	1
15	Cape Town	16	2	1
15	Amsterdam	16	2	1
17	Singapore	16	2	–
18	London	15	3	1
19	Paris	15	2	1
20	Boston	12	2	1
20	Miami	12	2	1
22	Stockholm	9	2	1
22	Oslo	9	2	1

*'Expanded response system' in operation to cover high-rise risk.

Square Miles per Fire Station

1	San Francisco	1.2	12	Vienna	6.6
2	Boston	1.4	13	Dallas	7.1
3	New York	1.5	13	Hong Kong	7.1
4	Amsterdam	2.2	15	Stockholm	9.0
5	Tokyo	2.3	16	Las Vegas	9.1
6	Seattle	2.8	17	Phoenix	10.2
6	Miami	2.8	18	Zurich	18.0
8	Chicago	2.9	19	Singapore	18.3
9	Paris	3.8	20	Melbourne	19.3
10	Los Angeles	4.2	21	Pretoria	30.5
11	London	5.4	22	Metro Dade (Miami)	50.6
			23	Oulu (Finland)	75.0

Square Miles per Pumper

1	New York	1.2	12	Hong Kong	3.7
1	San Francisco	1.2	13	Los Angleles	4.6
1	Tokyo	1.2	14	Zurich	5.1
4	Boston	1.4	15	Stockholm	5.5
5	Miami	1.9	16	Dallas	6.0
6	Paris	2.0	17	Singapore	6.6
7	Amsterdam	2.2	18	Pretoria	7.4
8	Seattle	2.8	18	Las Vegas	7.4
9	Chicago	3.0	20	Phoenix	9.5
10	London	3.1	20	Melbourne	18.0
11	Vienna	3.4	22	Oulu (Finland)	18.7
			23	Metro Dade (Miami)	66.3

Square Miles per Aerial

1	Boston	2.2	10	Seattle	8.6
2	New York	2.4	11	Stockholm	9.0
3	San Francisco	2.7	12	Los Angeles	9.5
4	Miami	3.7	13	Vienna	16.0
4	Paris	3.7	14	Dallas	16.4
6	Amsterdam	4.8	15	Las Vegas	20.5
7	Chicago	5.0	16	Hong Kong	20.6
8	Zurich	7.2	17	Singapore	36.0
9	Tokyo	7.6	18	London	36.5

Pumper to Aerial Ratio

1	Zurich	1.4-1	14	Seattle	3.0-1
2	Boston	1.5-1	15	Honolulu	3.9-1
3	Chicago	1.7-1	16	Phoenix	4.0-1
4	Oslo	1.7-1	17	Oulu (Finland)	4.5-1
5	Paris	1.9-1	18	Vienna	4.7-1
6	Stockholm	2.0-1	19	Metro Dade (Miami)	4.8-1
6	New York	2.0-1	20	Melbourne	5.2-1
6	Amsterdam	2.0-1	21	Hong Kong	5.5-1
6	Los Angeles	2.0-1	21	Singapore	5.5-1
6	Miami	2.0-1	23	Cape Town	6.0-1
11	San Francisco	2.3-1	23	Tokyo	6.0-1
12	Dallas	2.7-1	25	Pretoria	6.6-1
13	Las Vegas	2.8-1	26	London	11.0-1

2
WATER SUPPLIES

'In order to carry on your business properly, it is necessary for those who practise it to understand not only what they have to do, but why they have to do it; and the whole course of my instructions is framed to lead to this end.
'No fireman can ever be considered to have attained a real proficiency in his business until he has thoroughly mastered this combination of theory and practice.'

Sir Eyre Massey Shaw, KCB
'Fire Protection' 1876

The availability, and adequacy, of a water supply on the fireground will determine the effectiveness of a responding force of firefighters to the point where their ability to function is at stake. Surely, no other aspect of fire control, or suppression, can be more influential on the final outcome of a situation than this. While there are various options that may be utilised to flow water onto the fire, there are few fire departments who can stake a claim that the supply available to them is used to its optimum level.

The diversity of engineered hydrant grid systems around the world serve to provide the fire force with an 'on tap' source of supply. The effectiveness of the hydrant grid will depend on:

(a) Size and condition of mains.
(b) Pressure available in the system.
(c) Distance between fire hydrants.
(d) The techniques utilised to flow water from the hydrant to the fire.

While the firefighter may have little influence over points (a) to (c), it is up to him to effect (d).

Where fire hydrants are sited some distance from a fire, or unavailable, then the firefighter must decide on the best method for transporting the necessary amount of water to the fire. The options open to him involve: closed and open circuit water relays; tanker shuttle system; or alternative supplies.

A brief review of how several major cities have installed their hydrant grid systems is of interest:

London

Water resources in England are obtained from river intakes, impounding reservoirs that collect water from high ground, streams and rainfall, as well as underground sources such as wells, boreholes and springs. The local water authority will transport supply to consumers via underground mains ranging from 75 mm (3 ins) to 600 mm (24 ins) although 150 mm (6 ins) is the most common size.

The fire authority take their water for firefighting direct from hydrants fitted to these public mains. Except in high-risk areas, or rural areas, fire hydrants are normally spaced at intervals of between 90 m (300 ft) and 180 mm (600 ft).

These domestic mains of minimal diameter often fail to meet the demands of a major fire, and water supply on the fireground – particularly during the early stages of a large fire – is often inadequate. Water relays are often necessary to tap resources some distance from the fire.

Hong Kong

The territory of Hong Kong comprises Hong Kong Island, Kowloon Peninsula, and the New Territories, and – including some outlying islands – gives a total land area of about 1,000 sq km (413 sq miles) and accommodating a population of about six million.

Because of the geographical layout, there is no major river course in the territory, and when the city developed in the last century reservoirs were constructed to catch rain water to supply piped potable water to the first residents in the urban area. By the turn of the century the demand for piped water supplies began to grow, but it was not until 1975 that a water de-salting plant to distil fresh water from sea water was installed. This gives a maximum daily output of 181,000 cu m of water. Even with this supplement, the demand for fresh water still exceeded the rain water caught in reservoirs. This problem was solved by the Chinese, who agreed to pump water into Hong Kong from their rivers.

Because of inadequate fresh water supplies, and periods of drought, the majority of fire mains in Hong Kong are now tapped into salt water supplies. The fire department also has an array of appliances to pump direct from open-water supplies, ranging from 4,500 LPM pumpers, through 9,000 LPM heavy pumps, to 47,000 LPM fireboats!

Currently there are five types of fire hydrant in use in Hong Kong:

(a) Pedestal – a pillar-type hydrant with one 100 mm V-thread outlet and two 65 mm round thread outlets, supplied from a minimum 150 mm main; fresh water painted red, salt water yellow.

(b) Ground – a traditional ground hydrant as found in London, sub-surface, with a minimum supply main of 100 mm, used in conjunction with a portable stand-pipe.

(c) Swan-neck – 76 mm pipe in swan-neck shape, single round thread outlet on a minimum 100 mm main.

(d) Twin outlet – 100 mm standpipe on 150 mm main, fitted with twin instantaneous f/m couplings, usually found on elevated motorways.

(e) Heavy draw-off – 'jumbo' type pedestal hydrant similar to US design. Fitted with eight 100 mm V-threaded outlets, four 65 mm round thread outlets, with three supply mains not less than 460 mm each. These type of hydrants are only fitted on aircraft 'flight path routes' in heavily populated areas – running at pressures in excess of 8 bars (116 lbs psi).

Fire hydrants in Hong Kong are spaced 75 to 100 metres apart.

San Francisco

The City of San Francisco is blessed with a more than adequate supply for its fire force. The hydrant grid is gravity-fed from reservoirs placed high on the hills that predominate the city.

The **low-pressure** system provides more than 7,000 hydrants sited above 100 mm or 150 mm mains, although all new hydrants on this system are being sited on 200 mm mains, as this is now considered the minimum requirement for adequate fire flows. Such hydrants are sited to protect each 51,000 sq ft of downtown space, or 99,000 sq ft in other districts. The supply is tapped from the domestic mains.

The **high-pressure** installation is expanding, presently furnishing protection to 15 square miles of the city. The 1,400 HP hydrants and the water in the 115 miles of pipe-line are for the sole use of the fire department. If the fresh water supply to the system were to fail, salt water can be pumped in from the bay.

The potential for an earthquake is San Francisco demands additional water supplies for use under such conditions. These come in the form of 150 underground cisterns, strategically located throughout the city. This emergency supply has a total storage capacity of approximately ten million gallons of water.

	LPM	*GPM (US)*
Chicago	7560	2000
Dallas	7560	2000
Boston	6615	1750
Oslo (Norway)	4000	1058
Miami	3780	1000
Hong Kong	2000	530
Tokyo	1500	400
Singapore	1500	400
Pretoria (SA)	1500	400
Amsterdam	1500	400
Zurich (Switz)	1200	317
London	1200	317
Cape Town (SA)	1150	300
Oulu (Finland)	1000	260

Table 2:1 – Output expected from 'average' hydrants

A fireground flow requirement of 10,000 LPM (2645 GPM US) is not uncommon by any standards. In fact, much larger flows can sometimes be required to control a major fire. It then becomes apparent that certain fire departments are faced with a water supply problem. While some fire departments in the above chart *(Table 2:1)* have attempted to utilise fireground techniques that will optimise their hydrant grid supply, many are still operating under restrictive procedures that are outdated and ineffective.

For example, while the Oulu Fire Brigade in Finland can only expect an average flow of 1,000 LPM from a fire hydrant, their utilisation of large diameter hose (LDH), between hydrant and pumper, will enable them to maximise the flow and get more water to the nozzle, than other fire departments with a slightly better grid system who still twin 70 mm supply lines.

The fire that occurred at the Stardust Disco in Dublin, Ireland, on the night of 14th February 1981, is an example of ineffective use of the hydrant grid system. The fire killed 48 people, and the public enquiry that followed questioned firefighters' claims of "inadequate" water pressure on the fireground.

Evidence established that hydrants in the city area were normally located at distances of approximately 100 m apart and were, in addition, usually to be found at road intersections. It was further established that three hydrants (sub-surface) adjacent to the fire building were ineffectively marked and were overlooked by first-arriving firefighters.

This led to a hydrant run of some 200 m (666 ft) to an attack pumper. It was estimated at the hearing, that by using 70 mm hose to supply the attack pumper from the hydrant, and failing to boost the initial supply from the hydrant by the placement of an additional 'in-line' pumper, approximately one half of the hydrant's residual pressure was lost before it reached the attack pumper. Fortunately, the main in use was a particularly large one (229 mm/9 ins) that flowed over 2,000 LPM at the twin outlets in use. If the main had been less efficient, the effect on the fireground could have been disastrous.

Estimating hydrant performance

The maximum flow an individual hydrant will provide is of direct interest to a firefighter or pump operator. If operating at a fire, such information will enable him to evaluate the flow capabilities of his apparatus at any one time. Modern innovations have led to flowmeters being installed on certain pumpers and an estimate of LPM/GPM flowing in from the hydrant, and out through the various deliveries will appear in a read-out on the pumping panel. Where this equipment is not provided, the firefighter must depend on his pressure gauges to furnish him with the answers – can he supply another 20 mm nozzle or will he need to run in more water first?

To do this he must resort to some minor calculations. Now while I am the first to admit that complicated hydraulic formulae have no place on the fireground, this minor effort is extremely productive, as is shown below. The days of pump operators treading on their hoselines to gauge incoming flow and pressure are gone – it is unprofessional and totally inaccurate.

The flow capability of any particular hydrant can be ascertained by means of a portable flowmeter. This device is connected directly, in conjunction with a pressure gauge, to the outlet of the hydrant, or standpipe head. A residual (running) pressure and a flow in LPM (GPM) can then be recorded for the hydrant in question. This figure denotes the maximum flow available from this hydrant at that particular time of the day. No technique, other than drafting (suction), will improve this output unless the water authority is able to boost the pressure in the main. ('Drafting' a pressure fed hydrant may damage the mains and will only provide an extra five per cent flow at best – this technique is advised against.)

Many firefighters seem to develop a false conception that the flow capability of a fire hydrant is directly linked to the throttle control of the pumper, and fail to understand that neither a large diameter main, nor a high static pressure (SP) recorded at the hydrant, are any guarantee of the number of hoselines the hydrant can be expected to supply. Quite simply, it is the changes in residual (flowing) pressures (RP) as water is discharged from the hydrant that indicates the volume (LPM) remaining available.

Even though the firefighter will not have access to sophisticated flow-testing apparatus while operating on the fireground, by clever utilisation of his equipment, and pump gauges, he will still be able to obtain reasonably accurate estimates of value, relating to hydrant flow capability.

Example One:

By resorting to basic hydraulics, the motor pump operator (MPO) is able to calculate the potential (LPM) for any hydrant by using the following method:

(a) Connect a branch fitted with a 25 mm (1 in) nozzle direct into a discharge outlet (delivery) of the pump.

(b) Open the delivery and allow the water to flow through the nozzle at hydrant pressure, recording both the hydrant's static pressure (SP) and residual (flowing) pressure (RP).

(c) Calculate the flow taking place through the nozzle:

$LPM = 0.67d^2\sqrt{P}$

$GPM\ (US) = 29.7d^2\sqrt{P}$

For example: if the SP recorded 3 bars (45 lbs psi) and the RP recorded 2 bars (30 lbs psi) as the flow took place through the nozzle, by resorting to the formula where 'd' is the diameter of the nozzle (25 mm or 1 in), and 'P' is the residual pressure (RP) (this also being the pressure at the nozzle [NP] as water flows) we arrive at an answer of 592 LPM (162 GPM US).

(d) Now, to estimate the amount of water the hydrant in use can supply us with, use the formula:

$$\text{LPM (or GPM-US)} \times \sqrt{\frac{SP}{LOP}}$$

where 'LPM' is the flow that took place through the nozzle, 'SP' is the static pressure as recorded, and 'LOP' is the loss of pressure that occurred as flow took place, ie: SP minus RP=LOP.

When applied to the above example the answer would be 1025 LPM (280 GPM US). This final figure would roughly conform with the figure obtained by use of a flowmeter.

Example Two:

An alternative method of assessing a hydrant's flow capability requires less effort and provides a good 'rule of thumb' estimate for fireground use. The difference between the static and residual pressures is the sum of the resultant losses in the connection from the hydrant to the pump, as well as the losses at the hydrant and in the main leading to it. At working flows, these losses increase approximately as to the square of the proportionate increase in discharge. The following example demonstrates this effect:

As a pump is charged from the hydrant a static pressure (SP) of 4 bars (60 lbs psi) registers on the compound gauge. As the first delivery is opened to charge an attack line flowing 250 LPM (70 GPM US), the residual pressure (RP) registers 3.75 bars (56 lbs psi) – an LOP of 0.25 bar (4 lbs psi).

This loss of pressure (LOP) may be used in approximating the additional water available from the hydrant. To do this we must calculate the LOP as a percentage of the initial SP:

$$\frac{SP}{LOP} = Z \qquad \frac{100}{Z} = \%$$

This becomes:

$$\frac{4}{0.25} = 16 \qquad \frac{100}{16} = 6.25\%$$

Now refer to the 'capability chart' to estimate the amount of water still available at the hydrant *(See Table 2:2 – p32)*.

From this table we are able to determine that the 6.25 per cent LOP suffered as the first attack line was charged should still allow us to supply three more attack lines each flowing 250 LPM.

This is demonstrated over *(Figure 2:1)* where as each line is charged, the LOP increases increase as to the square of the proportionate increase in discharge. For example: double the flow = four times the original LOP; treble the flow = nine times the original LOP; quadruple the flow = sixteen times the original LOP.

0–10%	Three more times the amount of water currently being delivered is still available.
11–15%	Twice the amount of water being delivered is still available.
16–25%	An equal amount of water to that already being delivered is still available.
Over 25%	More water may be available, but not as much as is currently delivered.

Table 2:2 – Hydrant capability chart

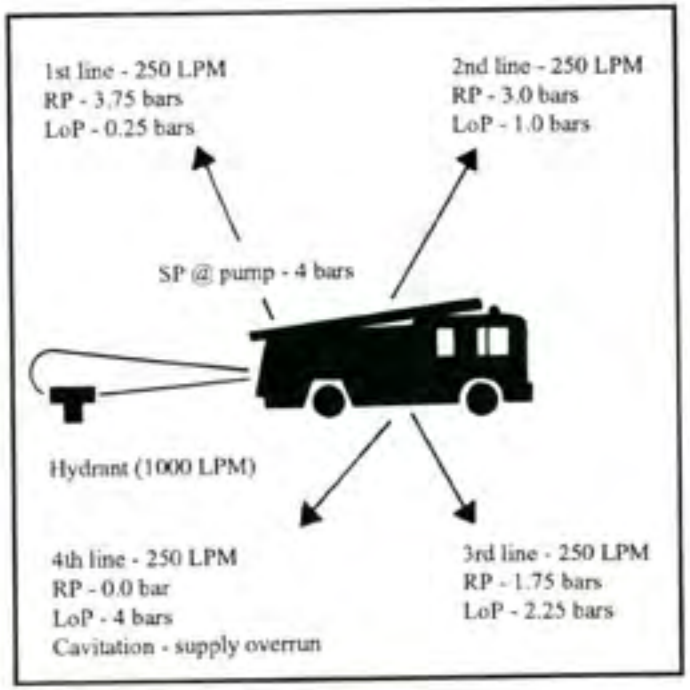


Figure 2:1 – Water supply example.

In this particular example, the supply begins to overrun as the fourth line is charged and cavitation causes the MPO to throttle back slightly.

It is important to remember that the percentages in the hydrant capability chart *(Table 2:2)* are only guidelines. At exactly ten per cent there is not an abrupt change from three times the amount available. Also, I have said nothing about what the residual pressure would be when the maximum flow is reached. As the percentage approaches the upper limit the residual pressure at the intake gate will be low when maximum estimated flow is reached. Again, this is just a fireground guide for when a request comes in for additional flows, or lines, from your pumper – it beats treading on hose!

Example Three:
It is generally impractical, and often impossible, for the MPO to note the SP from a hydrant prior to the first attack line being charged, such is the urgency of initial attack. He may even have flowed the line from the tank *before* the hydrant supply came into the pump. In this case, it is still possible, at any stage, to calculate what the SP would have been by utilising this method:

(a) Note the RP on the compound gauge with the first attack line flowing.
(b) Place a similar nozzle flowing the same LPM into a delivery and note the drop in RP as the delivery is opened.
(c) Divide the drop in RP by two and add the resulting amount to the RP that was noted with a single nozzle in operation. This is the estimated SP.

For example, with one attack line in operation the RP registering on the compound gauge is 3.4 bars (50 lbs psi). By placing a second similar nozzle into operation from a delivery, the RP drops to 2 bars (30 lbs psi). This shows an additional LOP of 1.4 bars (20 lbs psi). Now, by dividing this figure by two, results in 0.7 bar (10 lbs psi) – this added to the original RP noted (3.4 bars or 50 lbs psi) results in an estimated static pressure of 4.1 bars (60 lbs psi).

The decrease from the original SP of 4.1 bars (60 lbs psi) to an RP of 3.4 bars (50 lbs psi) demonstrates a drop of 17 per cent, and reference to the hydrant capability chart *(Table 2:2)* will inform us that an equal amount to that being delivered is still available at the hydrant.

Quick Fireground Method:
Alright! alright! I can hear you die-hards now: "Hydraulics has no place on the fireground." I am the first to agree. But these techniques are really quite simple in practice and a little practice really will make perfect!

But for those of you who still refuse to resort to calculations on the fireground, the basis of the technique can still be relied upon to give you a better estimate of flow capability than treading hose. If a request for another attack line comes to your pumper, simply take the nozzle required, and connect it directly into a free delivery outlet. Then open the outlet fully and watch the RP on the compound gauge. If the RP falls below 0.7 bar (10 lbs psi), then the water is not available for an additional line. Either reduce the nozzle sizes or flow in more water. (An RP of at least 0.7 bar [10 lbs psi] is required to prevent cavitation at the pump.)

Obtaining Maximum Hydrant Flows

As was mentioned earlier, many fire departments around the world are forced to suffer from low pressure, and low outputs, from their hydrant grid systems. It is perhaps somewhat frustrating that many of these fire forces are failing to take advantage of modern flow techniques to optimise their system and are leaving an estimated 50 per cent of the flow (LPM) at the hydrant. When you do not have a good source in the first place that is a lot to lose.

There are five basic techniques that can be effected to optimise flows from a fire hydrant:

(a) **Pulling a Vacuum** – by 'drafting' or 'suction'. This technique is sometimes utilised in the USA but usually in conjunction with special 'suction' hydrants. If a vacuum is pulled on a low-pressure hydrant, the mains may be subjected to severe damage. For this reason it is advised against. The increase in supply using this technique is minimal – around five per cent.

(b) **Twin Supply Lines** – many fire departments who still use 70 mm hose to flow water from the hydrant to the pumper are forced to lay twin-lines. By failing to do this, an enormous amount of water will be left at the source as hydrant pressure is used up in trying to overcome the frictional losses caused in the hose.

(c) **Large Diameter Hose (LDH)** – many fire departments are now enjoying the benefits of LDH where supply lines of 100 mm (4 ins), or larger, reduce frictional losses to such an extent where residual pressures at the pumper are almost unaffected, allowing the full flow from the hydrant to reach the fireground.

(d) **Full-flow Couplings and Connections** – the provision of large-diameter 'full-flow' couplings on LDH, and the enlargement of hydrant outlets and pump inlets, prevent further restrictions that reduce a hydrant's ability to flow water. Remember, as the water leaves the hydrant it is the hydrant's pressure capability that is used up in tranporting water to the pumper. The pumper itself provides no assistance to the hydrant in flowing water.

(e) **Booster Pumping** – one of many line pumping techniques that fire departments resort to to transport water on the fireground. Booster pumping requires the siting of a pump immediately adjacent to the hydrant, from where the hydrant's full flow is taken and 'boosted' in pressure, to overcome the frictional losses that may occur before reaching the attack pumper sited adjacent to the fire.

The use of Large Diameter Hose LDH *(point (c))* is nothing new. Fire departments world-wide have transported water in relays through various sized hose-lines ranging from 90 mm (3½ ins) upwards. However, its most recent application has becomed popular throughout the USA, and other countries are realising the potential of LDH as a supply line from hydrant to pumper, in both long and short runs.

The American National Fire Protection Association (NFPA) currently defines LDH as: 'hose 90 mm or larger, designed to move large volumes of water to supply master stream appliances, portable hydrant manifolds, standpipes and sprinkler systems, and fire departments pumpers from hydrants, and in relay'.

In practice, the most commonly used sizes in the USA are 100 mm (4 ins) and 125 mm (5 ins). It is beyond doubt that LDH will substantially reduce frictional losses between hydrant and pumper, and also serve to maintain high residual pressures at the pump, thereby ensuring that a hydrant's full flow is utilised.

Not only does more water become available on the fireground, with less effort, but large monitors achieve greater striking power, and water can be transported further using less equipment and manpower. Such savings can prove extremely economical in the long term. It has been said that low-volume hydrants will not support big hose but this is a fallacy as many US departments have proved by utilising LDH in conjunction with their low-pressure grids.

However, there are a few disadvantages of LDH and it would be correct to discuss these briefly before going on to the many advantages and benefits that may be enjoyed by converting to LDH supply.

Disadvantages of LDH:

- Both 100 mm and 125 mm hoselines are too heavy to lift when charged with water. This means that once LDH is laid in use, that is where it stays until operations cease.
- Driving over fire hose of any size has always been discouraged. Although LDH is strong enough to be driven over, it should only be done as a last resort and with certain precautions taken. If the line is charged it should be approached from an angle, so that one wheel goes over at a time. This should be done at a very slow speed, because at faster speeds the sudden impact and release will set up a surge in the line, which in turn will lead to serious water hammer. It should also be noted that LDH is a lot larger than conventional hose, therefore the clearance on some vehicles may not be sufficient to drive over without damage occurring.

- Because of the possibility of water hammer (as much as seven times the static pressure in the system!), MPOs must take extreme care when opening hydrants, or deliveries into relays, to prevent damage being caused to the pump.
- Because fire pumpers in the USA are designed to 'drop' hose from their hosebeds (as a hoselayer would) the weight of LDH is not of such great concern to the US firefighter as it may be to his European counterpart, who so often lays hose by hand. However, it is considered that 25 m lengths of 100 mm (30 kg or 65 lbs) or 125 mm (37 kg or 80 lbs), compared to 25 m lengths of 70 mm hose (13.6 kg or 30 lbs), can be easily laid by firefighters using the 'Dutch-Roll' technique (as used by London Fire Brigade).

There is no doubt that one line of LDH laid manually from hydrant to pump would take less manpower and less time than conventional twin-lays of 70 mm hose, and would be far more effective in transporting water for firefighting.

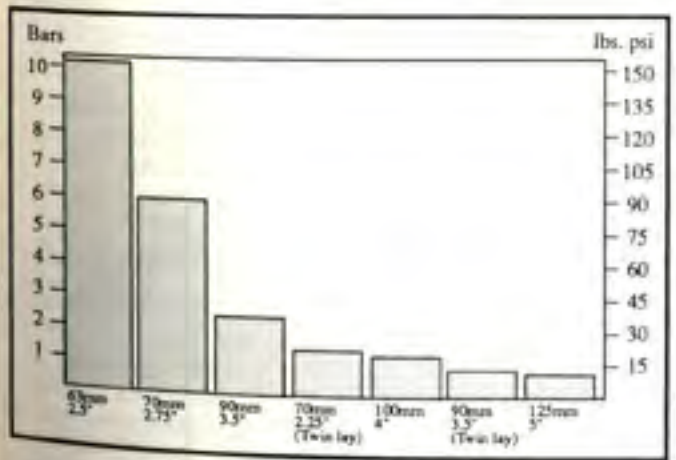


Figure 2:2 – Frictional loss in hoselines 100 m (333 ft) in length flowing 1,500 LPM (400 GPM US).

Once the decision is taken by a fire department to convert to LDH the question must be asked: "What size is best?" The Las Vegas Fire Department has been extensively involved in reviewing the various options and LVFD firefighter Paul Shapiro has become somewhat of an authority on the subject, spearheading a programme of tests over a period of years. The results of these tests appeared through the pages of *American Fire Journal* during the late 1980s. *(Bibliography 2:1)* Mr. Shapiro's findings demonstrate some interesting facts about LDH:

(a) At average flows in hydrant – pump lays, friction loss in 125 mm hose is only one quarter of that in 100 mm hose, and 125 mm hose can flow six times more water than 70 mm hose at the same pressure.

(b) Long flows of 5,500 LPM, or more, require twin lays of 100 mm hose, or close spacing between pumps, whereas single lines of 125 mm hose can transport the same amount over 100 metres without loss of flow.

(c) To pump the same amount of water, 100 mm hose requires some 34 per cent less pressure than 70 mm hose – likewise, 125 mm hose requires 52 per cent less.

The chart on p35 *(Figure 2:2)* represents frictional losses in hoselines of various diameters. It is based on calculations derived from FL formulae. It should be pointed out that such formulae are used to provide fireground estimates. The accuracy of such calculations is dependent on internal hose linings, which will vary among manufacturers.

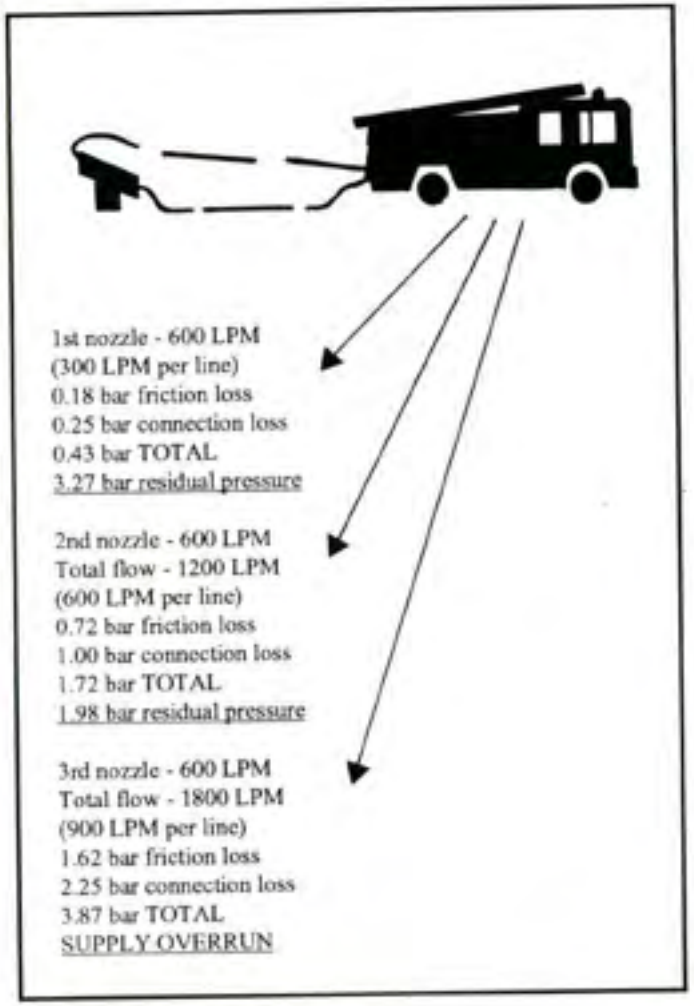


Figure 2:3 – Hoselay # 1 – twin 70 mm.

The following examples *(Figures 2:3 to 2:5)* may help to put the use of LDH into perspective where used in hydrant-to-pumper runs:

A fire pumper sets into a hydrant sited above a 200 mm main, some 75 m (three hose-lengths away). The hydrant provides a normal static pressure of 3.7 bars and flows approximately 1,800 LPM in tests. This would normally be enough water to supply three 20 mm nozzles at their optimum nozzle pressure (NP) of 5 bars.

In hoselay # 1 *(Figure 2:3)* we can see the results where a 'typical' twin-lay of 70 mm hoselines conveys the water to the pumper. The first and second nozzles are supplied with adequate amounts of water and pressure, but it should be noted that much of the hydrant's pressure is lost to friction loss in the hose, and restriction loss at 65 mm connections. This effect is so pronounced that there is insufficient pressure to flow water from the hydrant as the third nozzle is opened.

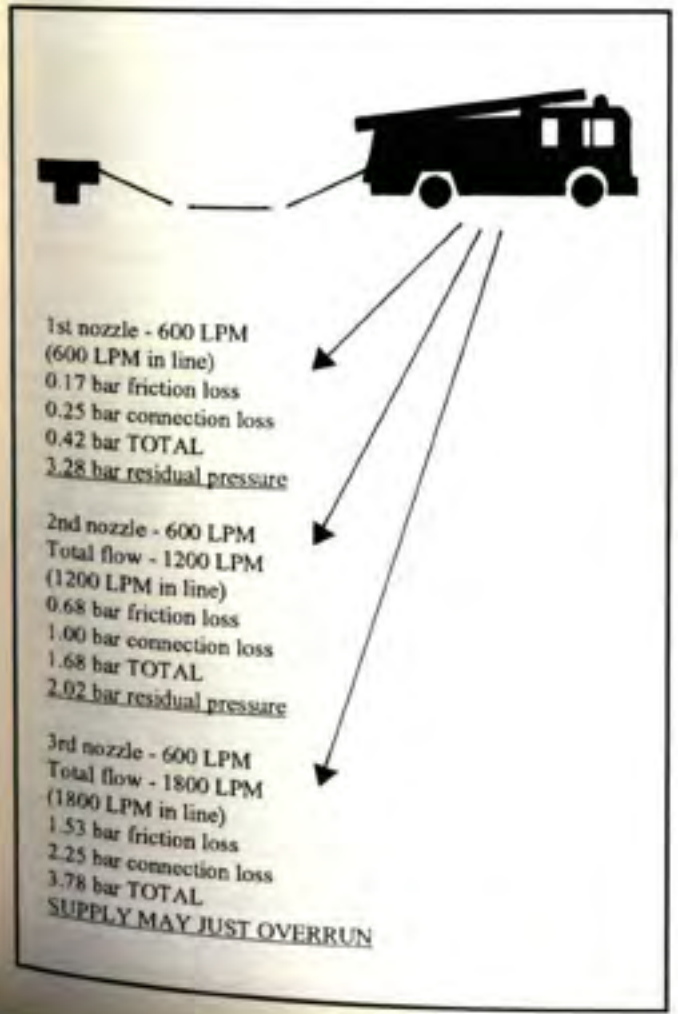


Figure 2:4 – Hoselay # 2 – single 100 mm.

In hoselay # 2 *(Figure 2:4)* the single line of 100 mm hose is more easily laid, enabling more firefighters on the initial attendance to deploy in 'attack' roles. The LDH handles the flow of water better than the twin-lay of 70 mm hose and losses (LOP) are not so pronounced. However, as the third delivery is opened the supply overruns again; although in this case, there would probably be enough pressure left to supply all the nozzles at a slightly reduced flow.

In hoselay # 3 *(Figure 2:5)* the single line of 125 mm handles the full flow of 1,800 LPM from the hydrant with minimal frictional loss. As the third line is charged the remaining residual pressure is sufficient to effect the full potential of the hydrant and no water is left behind.

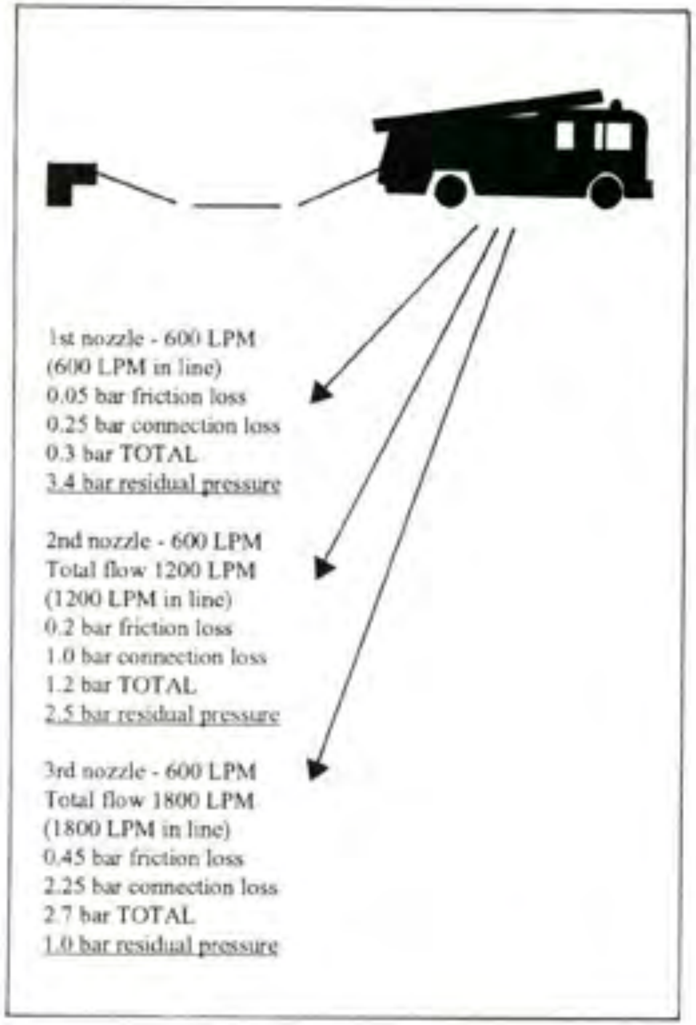


Figure 2:5 – Hoselay # 3 – single 125 mm.

The effectiveness of LDH in a short 'hydrant-pump' run becomes clearly apparent in the preceding examples. The hydrant's full potential was only realised by using the 125 mm supply line although the 100 mm set-up did flow an efficient amount, capable of supplying a third attack line.

125 mm (5 ins)	*100 mm (4 ins)*	*90 mm (3½ ins)*
Boston	New York	Los Angeles
Chicago	Boston	San Francisco
San Francisco	Chicago	London
Las Vegas	Seattle	
Metro Dade	Phoenix	
Miami	Hong Kong	
Dallas		
Oulu (Finland)		
75 mm (3 ins)	*70 mm (2¾ ins)*	
Metro Dade	London	
Oulu (Finland)	Amsterdam	
Zurich (Swiss)	Oslo (Norway)	
Miami	Hong Kong	
Amsterdam	Pretoria S.A.	
Tokyo	Cape Town S.A.	

Table 2:3 – Hydrant-pump supply lines (hose size)

Many fire departments are changing to LDH for 'hydrant-pump' runs, in addition to relay operations. San Francisco is one of many who are equipping all their new pumpers with 125 mm (5 ins) supply hose, while Boston will only utilise 125 mm lines if the operating pumper is within 6 m (20 ft) of the hydrant. Failing this, they will resort to a 100 mm (4 ins) line. In contrast, London Fire Brigade will always run twin 70 mm lines from the hydrant to the pumper although they have a facility on logistically placed 'hose-layers' to augment the supply using 90 mm lines.

Pressure Relief

The pump operator (MPO) can seldom predict when a nozzle is going to be shut-down, nor can he foresee sudden pressure surges from his supply. Therefore, some method is required to prevent excessive pump pressures from developing. In North America such a facility is generally engineered into the pump in the form of a pressure control device. However, European firefighters often have to be alert, and able, to deal with the problem of excess pump pressure by resorting to manual techniques. Where LDH is concerned, the higher pressures transported to the pump make this point even more important.

The primary purpose of a pressure control device is to protect men at the nozzles from a dangerous pressure rise; while a secondary purpose is to protect the hose and pump itself. For example, if more than one line is in operation and one of the lines is shut down, engine speed will increase as load is reduced; consequently, discharge pressure will also increase. Consequences of the rise in pressure may be serious, particularly if a line is being operated from a precarious position. On occasions, even if the MPO were able to anticipate the temporary closure of a nozzle, or monitor, the incoming supply pressure may be so high that he will be unable to 'throttle down' sufficiently to deliver safe pressures to the other nozzles being operated from his pump. Under these conditions the excess pressure at the pump *must* be dumped.

Excessive discharge pressures are automatically prevented by using one of the following devices:

(a) An automatic relief valve that opens a by-pass between the suction and discharge sides of the pump.

(b) A pressure-operated governor to control the speed setting of the throttle on the engine.

(c) Pressure-reducing valves on each discharge gate.

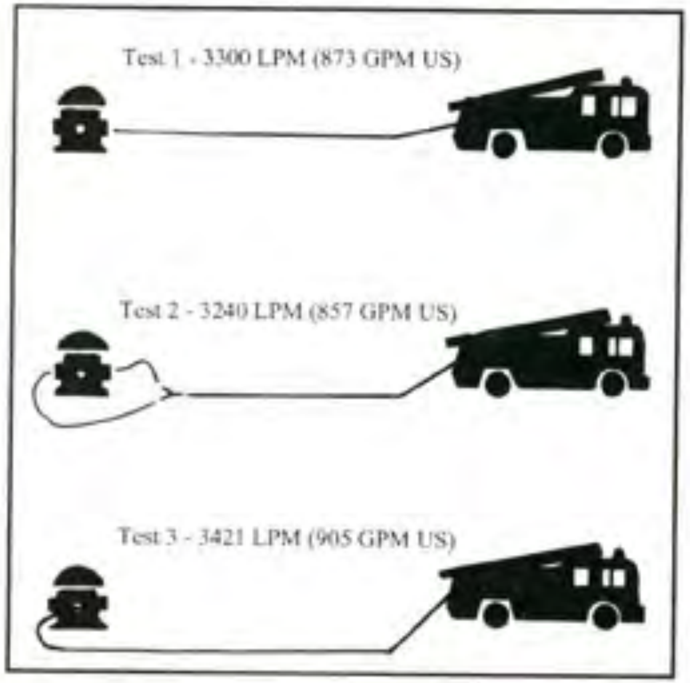
Where such devices are not fitted, there are three basic methods that can be used to dump the excess pressure at the pump, where throttling back is not possible:

(1) Allow excess water (and pressure) to run to waste by opening a spare delivery (discharge port).

(2) Using the same technique, run a short line from a spare delivery into the hydrant fill connection (if fitted). This will divert the waste flow away from the MPO, through the pumper's water tank.

(3) Open the gate valve (tank-pump) to allow the incoming supply to enter the water tank. As the required amount is discharged, the excess will overflow and run to waste.

Alternatively, partially closing the deliveries in use will reduce water (and pressure) reaching the nozzles. While such methods will serve – in effect – to prevent high amounts of 'nozzle reaction', they are all subject to various disadvantages. However, where automatic 'pressure relief' is not engineered into



Figures 2:6 – Results of Starkville flow tests.

the pumper, it may be necessary to resort to these last ditch techniques to protect firefighters at the nozzles when flowing water on the fireground.

Getting all the Water

Many firefighters will rightly question the effectiveness of attempting to flow large amounts of water through LDH that is hooked up at either end to 65 mm (2½ ins) connections at the hydrant and pump intake/discharge ports.

The Starkville Fire Department was the first in the American state of Mississippi to use large-diameter (100 mm) Storz-coupled hose. This very successful innovation is now standard equipment on all apparatus, but the hydrants in Starkville were fitted with 65 mm (2½ ins) discharge ports. To assess the losses at such connections the SFD carried out some tests *(Bibliography 2:2)* using three configurations of hose lay. The first was a simple hook-up of the 100 mm line directly through an adaptor to a 65 mm outlet on the hydrant. The second test involved two 3 m sections of 75 mm (3 ins) hose (with 65 mm couplings) leading from the two 65 mm hydrant outlets into a siamese (collecting breeching), which then led to the 100 mm line into the pumper. The third hoselay was able to run the 100 mm line direct from a 100 mm 'steamer' outlet on the hydrant.

Despite minor variations in engine speed, all tests were run with the pump in volume and with a 0.7 bar (10 psi) residual pressure at the pumper.

The results of the Starkville flow tests *(Figure 2:6)* were surprising. They demonstrated that a 65 mm hydrant connection could flow almost as much as the 100 mm connection, and that the turbulence created in the siamese actually *reduced* the flow when twin 75 mm lines fed into a 100 mm line.

The Las Vegas Fire Department also researched into flows using LDH in conjunction with 65 mm connections *(Bibliography 2:3)*. Their tests showed that an average flow range of 3,780 LPM to 4,536 LPM (1,000 to 1,200 GPM US), can result from a single 65 mm discharge using LDH. In addition, these flows were accomplished at a very efficient rpm range.

So why use twin 65 mm discharges into a line of LDH when a single will work just as well? The answer lies in the fact that, even though a reduction in frictional loss will be achieved in the pumper's discharge plumbing by dividing the total flow into two discharges, that same amount will be added right back when the water flows through the hose and equipment needed to connect to the LDH.

There is, however, a situation that *would* benefit from using two 65 mm deliveries over a single discharge. The plumbing installed into some pumpers is lengthy and has bends in the design that will create excessive frictional and turbulence losses. This type of discharge installation will demonstrate high losses at flows in excess of 3,000 LPM (800 GPM US), and in this situation, two deliveries siamesed into a larger diameter hose relay line will produce better results.

This effect was demonstrated by LVFD firefighter, Paul Shapiro *(Bibliography 2:3)* when flows were passed through two 1,250 GPM pumpers (one with long discharge plumbing bends) to compare output through both single and twin 65 mm deliveries, while feeding into LDH. The pumper with discharges that had no bends, and was short in length, was able to flow 1,137 GPM through a single delivery, while under the same supply set-up the flow dropped to 1,056 GPM when twin deliveries were used. The pumper with long discharge plumbing would flow 1,000 GPM through a single delivery at 210 psi but was also able to flow the same amount through twin deliveries at 160 psi – a reduction in pump pressure of over 3 bars!

The use of LDH, in conjunction with 65 mm connections at both hydrant and pump, will restrict the full flow potential when transporting water on the fireground. Tests carried out in Las Vegas have even suggested that up to 20 per cent of a hydrant's flow capability may be left in the hydrant where the smaller connections are used. This will greatly depend upon individual hydrant design and flow potential.

However, such losses are generally considered to be minimal and should not distract from the benefits that may be enjoyed when LDH is put into use, even with restrictions in the connections.

Safety Precautions with LDH

(a) If an automatic 'pressure relief device' is not fitted the MPO must be prepared to 'dump' pressure manually, or control discharge to the nozzles.

(b) Because 'water hammer' is so pronounced when using LDH, the MPO must take great care to open and close hydrants and pump deliveries *slowly*.

(c) Firefighters using LDH in the USA are advised by the NFPA not to exceed a maximum working pressure of 185 lbs psi (12 bars). The NFPA also recommend that wherever LDH is used, a pressure relief device with a maximum setting of 200 lbs psi (14 bars) should be fitted on pump intakes.

(d) Some manufacturers also recommend, as an additional safety feature, the provision of a pressure relief device at the beginning of every LDH discharge line – either fitted to the pump, or portable in nature – set to operate above 185 lbs psi.

(e) The fitting of 45 degree elbow adaptors on all connections where

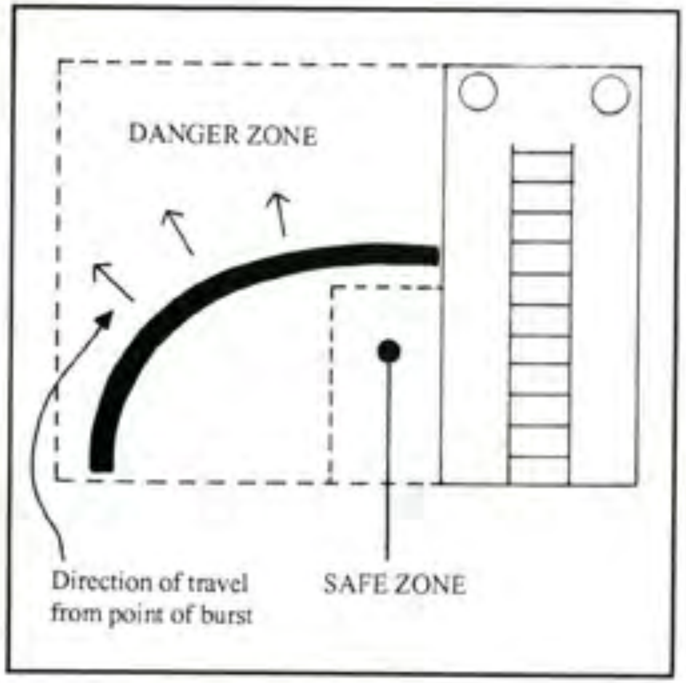


Figure 2:7 – Las Vegas safety zone.

LDH is used will serve to take the strain at such points, where the hose is angled down instead of connecting straight in.

(f) Some screw or hermaphrodite couplings have been known to twist apart, breaking connection, due to twists in the line as water flows. Some manufacturers are now fitting 'swivel' type couplings that absorb the hose's twisting effect. Others utilise 'locking' devices that prevent the hose parting at connections.

(g) One of the biggest fears connected with LDH is the possibility of the hose either bursting, or becoming disconnected, and whipping around like the smaller hose can do. To assess this possibility, the Las Vegas Fire Department carried out a series of tests that involved parting LDH lines that were flowing 2,000 GPM (7,500 LPM). They found that the hose *will not* whip around but rather straighten itself, and in some cases move back a few feet. The most likely place this may happen is at the pumper discharge, where pressure is highest. For this reason the LVFD recommend a 'safety zone' in the pump panel area if the MPO (or anyone) is working in the vicinity of the LDH discharge *(Figure 2:7)*.

(h) While not a safety precaution, a good tip is to keep one or two shortened (8 m – 25 ft) lengths of LDH on the pumper to cope with the situation where a laid line of LDH falls just short of its destination. This will save time and effort.

Line Pumping Techniques

As a force firefighters responds to an incident there are several options open to the first arriving pumper as to how the source of supply will be effected. These variable line pumping techniques are usually pre-determined by individual department SOPs. The following methods are in regular use in the USA: (1) 'Quick Water'; (2) 'Forward' Lay; (3) 'Reverse' Lay; (4) 'Dual' Pumping; (5) 'Tandem' Pumping and (6) 'Booster' Pumping.

(1) Quick Water:

This form of attack is commonly utilised throughout most of Europe where the 'quad' style pumpers – that carry a selection of ladders – are ideally sited in front of, or adjacent to, the fire building. From this position, the attack lines can be run directly from the pumper's tank supply (usually 3-500 g or 1-2,000 l).

The benefits of the quick water technique include:

(a) Attack lines can be advanced on the fire at a very early stage.

(b) Low pump pressures are required as friction loss in attack lines is minimal.

(c) Maximum use can be made of high-pressure hosereel (booster) attack.

(d) The MPO generally has full eye contact with the structure.

(e) The pumper is ideally situated for prompt use of ladders and other portable equipment (including lighting).

(f) Secondary pumpers can augment the initial tank supply from their own.

The quick water technique has generally failed to gain popularity in the USA, although San Francisco is one department that utilises the principle. The Chicago Fire Department responded in quick water style until recently where it was found that pumper placement often interfered with aerial ladder access, particularly in narrow streets that fronted the structure. Another problem arose where their high-flow attack lines soon exhausted the tank supply. This situation rarely arises in Europe where firefighters so often mount a tactical attack utilising one, or several, high pressure (low flow) hosereels (booster lines). For example, London firefighters can run twin hosereels for a minimum of ten minutes – at *constant* flows – direct from tank supply (1,365 litres – 360 gallons US). If a fog attack is being mounted, as such, a constant flow of water would *not* be applied, therefore extending the duration by some minutes. Within this time scale, a hydrant supply will be run in.

If, however, a 70 mm (2¾ ins) attack line is run off the tank using a 20 mm (¾ ins) nozzle, the tank supply will provide the line with 2½ minutes of water. In this time a secondary pumper will connect into the attack pumper and 'dump' his water in to increase flow time to five minutes – enough time to run a hydrant in.

With the increasing trend towards 'quad' style pumpers in the USA, with their combination ladder/pumper complement, the 'quick water' technique may find its way back into popularity.

(2) Forward Lay

The increasing use of large diameter hose (LDH) makes this technique ever more popular, where the first arriving pumper hooks to a nearby hydrant and then runs a forward lay of 4 or 5 ins hose, towards the fire building, from where it receives the hydrant's supply. Although the supply line may be quite long the use of LDH minimises frictional loss and near maximum flows (particularly with 5 ins LDH) are gained from the hydrant.

Nearly all fire departments in Canada and America have adopted the technique of dropping their supply lines from a hose-bed as the pumper proceeds. This method is ideal where (a) hydrant runs are of some distance, or, (b) water relays are to be set-up, or, (c) large diameter hose is laid. However, most city fire departments throughout Europe, the Far East, and Australia tend to lay supply hose by hand, and only resort to pumper lays under specific conditions (water relays etc) although some provide a hose-drum facility on front-line engines.

The laying of hose supply lines by hand entails a manpower factor directly related to the length of lay. An average inner city lay of 75 m (250 ft) may require six lengths (6×25 m lengths) of 70 mm hose to complete the run. With hose normally stowed in 'Dutch-rolls' or 'coils', a team of three firefighters will take about three minutes to manually lay a twin line feed from hydrant to pump.

The 'forward lay', or 'running stretch' as it is also known, is a technique used in the USA to position the pumper as near to the fire as possible, while ensuring its water supply at an early stage. A forward lay may be used where a hydrant is located near the fire *before* the pumper reaches the structure. In other words, if the pumper arrives at the fire building without a supply line run-in, then its options are (a) quick water, (b) reverse lay.

(3) Reverse Lay:

As its name implies, the 'reverse lay' simply means that the hose is laid from the fire to the source of water, the opposite of the forward lay.

Where a pumper arrives at the fire building and observes an attack pumper operating in quick water mode, or an aerial tower requiring water feed, a reverse lay will be run towards the water supply. The benefit of running a reverse lay is recognised when the pumper arrives at the hydrant and hooks up to boost the supply, ensuring its full capability (LPM) arrives on the fireground.

(4) Dual Pumping

With fire pumpers rated in general realms of 1,000 to 1,500 GPM (3,500 to 5,500 LPM), it is possible that an extremely good hydrant may offer more water than a single pump can handle. This occurs in several parts of the USA and a method has been devised to enable the full-flow of the hydrant to be effected.

In America, fire hydrants are designed for establishing dual usage; this means that two pumpers can connect to a single hydrant via (a) one large outlet, and (b) two smaller (2½ ins) outlets. However, where individual gates are not facilitated, the hydrant must be shut down before a second pump can connect. The techniques of dual pumping enable a second pump to position itself alongside, and connect to an intake port of the pumper adjacent to the hydrant, from where it will draw off – and utilise – the excess supply.

For dual pumping to achieve optimum advantage, the hydrant in use must provide an available fire flow of at least one and half times the rated capacity of the two pumpers, with a minimum of 20 lbs psi (1.5 bar) residual pressure. For example, two 1,000 GPM pumpers require a hydrant with a flow of at least 3,000 GPM. Suitable hydrants should be marked, or designated in some way.

Fire pumpers in the UK, and many parts of Europe, are unable to adapt to 'dual' pumping techniques where only one intake port is fitted.

(5) Tandem Pumping

The technique known as tandem pumping entails a short relay operation in which the pumper taking water from a supply source pumps into the intake of a second pumper. The second pumper boosts the pressure of the water to pressures higher than would be possible by utilising a single pumper, while still maintaining the required volume.

The ability to boost supply pressures in such a way may have many uses on the fireground. One that comes to mind is a 'back to back' operation to pump into a rising main (standpipe) to overcome losses created through friction, and excess height, enabling high volumes of flow (LPM) to reach the fire floors.

(6) Booster Pumping

The technique of booster pumping demands that the pumper is sited as close to the hydrant as possible. From this position, frictional losses are minimised and full-flow is achieved from the supply. The pumper is then ideally situated to boost supply pressures to a level that overcomes any frictional loss in the attack lines. Where such lines are 400 to 500 ft (8 to 10 lengths) long, this 'boost' in pressure is essential if the full flow achieved at the source is to reach the nozzles.

If the supply pumper is also serving as the attack pumper, as described above, the MPO will be at a disadvantage where he is not in visual contact with the fire building. Where the MPO is supplied with an effective fireground communication link the problem is alleviated to some extent. However, the pumper is poorly sited for equipment support on the fireground and various items will have to be transported as required. The time taken to lay attack lines, is another factor that hinders such a strategy.

However, where a pumper is sited to boost pressure before flowing water to a fireground attack pumper, the optimum effect is achieved. This simple technique can be operated by *any* force of firefighters but is so often overlooked even at the largest fires.

The following example will demonstrate the effect of running attack lines in an average set-up – both with, and without, a booster pump sited at the hydrant *(Figure 2:8)*.

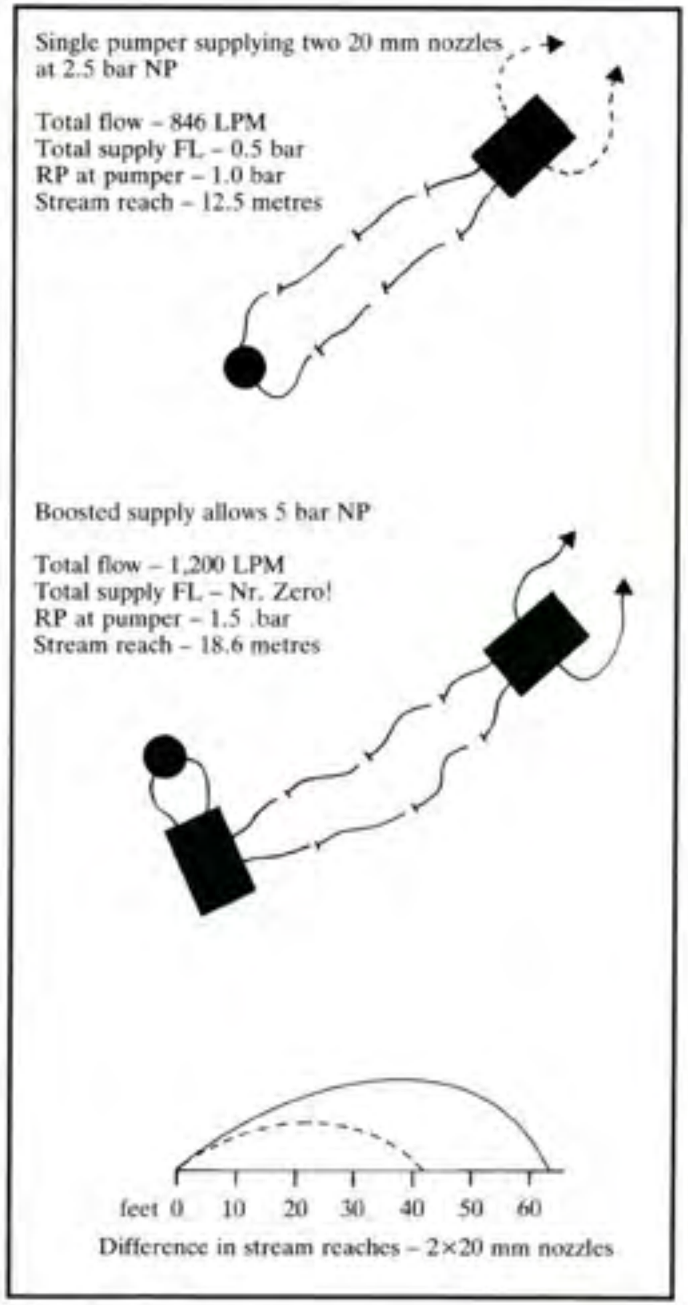


Figure 2:8 – Effect of booster pump

A fire hydrant on a 200 mm (8 ins) main demonstrated a flow capability of 1,600 LPM (425 GPM US) when tested, also registering a Static Pressure (SP) of 3 bars (45 psi).

When a fire occurred in the vicinity the responding pumper sited itself adjacent to the structure in an attacking role, some 100 m (333 ft) from the hydrant. This position required a four length (4×25 m) supply run of 70 mm (2¾ ins) hose, which had to be twin-laid – totalling eight lengths in all. From here the pumper supplied two 20 mm (¾ ins) nozzles operating on the fire, and with water flowing the residual pressure at the *hydrant* was now 1.5 bars (22 psi).

As the MPO attempted to flow the 600 LPM (160 GPM US) required at each nozzle (total 1,200 LPM-320 GPM) at a Nozzle Pressure (NP) of 5 bars (75 psi), the Friction Losses (FL) suffered in the twin lengths of supply hose (1.0 bar-15 psi) depleted the Residual Pressure (RP) at the hydrant and the supply appeared to be overrun. To prevent cavitation entering the pump the MPO was forced to throttle back to an acceptable discharge pressure. Eventually, at a Nozzle Pressure (NP) of 2.5 bars, the flows in the two attack lines had been reduced to 423 LPM (112 GPM) each (total 846 LMP-225 GPM). At these flows, the Friction Losses (FL) in the eight supply lengths were reduced to 0.5 bar (7 psi), leaving a Residual Pressure (RP) at the attack pumper of 1.0 bar (15 psi). The pressure was now sufficient to ensure an adequate flow of water through the pump but the effective reach of the two streams (according to Freeman's formula – *see Glossary)* has been reduced to 12.5 m (41 ft).

However, if the full capability of the hydrant had been utilised by (a) an LDH supply line, or (b) the siting of a 'booster' pump at the hydrant, then the optimum NP could have been used, providing full flow capability at the nozzles coupled with a much improved stream reach of 18.6 m (62 ft).

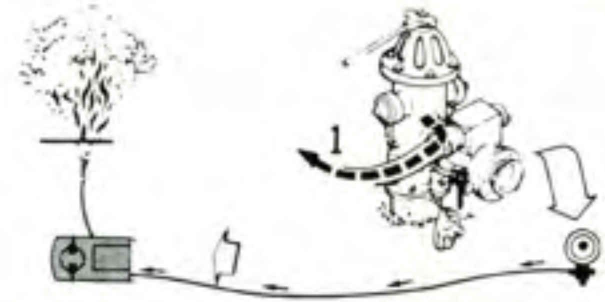
It never ceases to amaze me just how firefighters can continue to ignore the benefits of a boosted hydrant supply by failing to take advantage of this simple, and basic, technique. The next time your brigade or department is transporting water from a hydrant source onto the fireground, evaluate the situation and see if the supply is being utilised effectively. A poor attack stream is so often blamed on a poor hydrant source – but its not always the hydrant at fault – moreover, its the way we choose to use it that needs rectifying.

Hydrant Assist Valves (HAV)

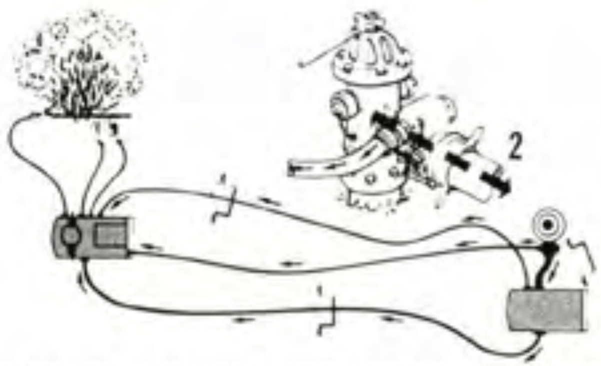
Once a pumper has connected to a hydrant and run a 'forward lay', it is impossible for a second arriving pumper to connect at the hydrant in a 'boosting' role – unless your department uses a hydrant assist valve (HAV), also known as 'Humat', 'Hydrassist', or 'Four-way' valve. *(Figure 2:9).*

This clever innovation is finding its way onto many frontline US fire pumpers for it is yet another way the full flow capability from a hydrant can be realised. During the initial stages of a fire, when pumpers are positioning for maximum effect, it is often not practical to site a booster pump at the hydrant, particularly where a fleet of European 'quads' are surrounding the structure for attack and equipment placement. It is often the case that the supply line is run into the attack pumper (or by the attack pumper in a forward lay), without first siting a booster. It may appear that the opportunity has then gone for utilising the technique – unless you carry an HAV!

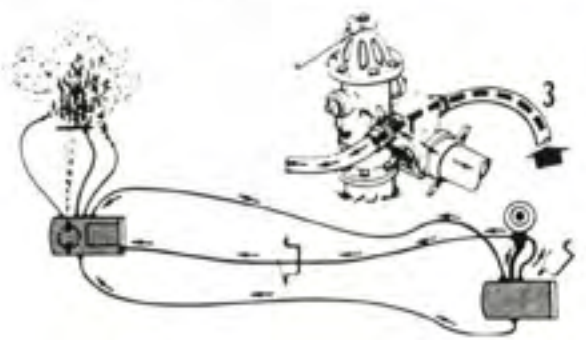
A single line of hose is initially taken from the hydrant, where a four-way (HAV) valve is attached to an outlet. The supply line is then laid into an attack pumper sited adjacent to the fire and a limited amount of water is available from source. As the second pumper arrives, it connects to the HAV at the hydrant using a short



First engine drops preconnected valve at the hydrant and stretches line to the fire. Valve is connected to hydrant, smaller chamber is positioned up or down depending on location of fire and hydrant is opened.



Second engine lays two lines from fire to hydrant, connects sleeve to valve and opens valve to supply those lines through the pump.



Line is connected from pump discharge to valve to bring initial supply line up to pump pressure.

Figure 2:9 – Hydrant assist valve.

length of LDH into the pump intake. A twin feed of small diameter hose (or single LDH) is laid between the two pumps. When all connections are made the lever is operated on the HAV at the hydrant and an uninterrupted flow commences through the booster pump, and on to the attack pump. The benefits of a boosted supply can now be enjoyed at the nozzles.

The HAV can also be used in relay operations and laid in-line at strategic points, enabling later arriving pumps to connect into the relay and boost the pressure. The Las Vegas Fire Department have been involved in testing various HAVs and noted, in some cases, an actual decrease in output where an HAV was fitted at the hydrant. Depending on its design, the loss can occur either in the initial supply line mode, which receives water directly from the hydrant, or in the relay mode, which receives water from the pumper at the hydrant, boosting the pressure in the supply line. Some HAVs have a restriction problem in the waterway which creates turbulence and additional friction loss. The LVFD tests demonstrated that by operating the booster pump at high pressures (at least 12 bars) the losses caused by a restriction in the relay mode can be overcome. If LDH is being used this creates a problem, as the maximum working pressures are around 12 bars (185 psi). The LVFD suggested connecting a short length of 100 mm (4 ins) 'attack' hose between the pumper discharge and the HAV. The higher pressure rating of attack hose will allow such an increase in pressure if required.

The San Francisco Fire Department have adopted a similar technique of allowing booster pumps to site after a hydrant has been connected to the attack pumper. The SFFD utilise a 'Hydrant Jumper' *(Figure 2:10)* – a similar, although simplified version of the HAV. Like the Hydrant Assist Valve, the SFFD 'Jumper' can also be laid in-line for later pumps to boost pressure in a relay set-up.

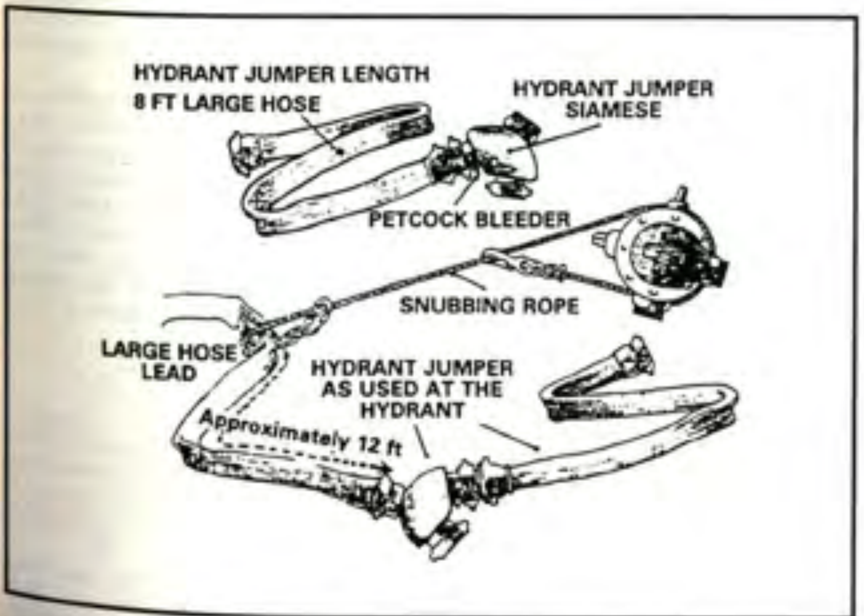


Figure 2:10 – SFFD hydrant jumper.

Maxi-water Systems

What procedures will your brigade or department adopt if the mains serving the hydrant grid fail for some inexplicable reason? What contingency plans will your firefighters put into operation under such circumstances?

Besides the multitude of grid systems in Hong Kong, the fire department there are able to pump large amounts of water by utilising the fireboats, with flow capabilities ranging up to 47,700 LPM (12,600 GPM US). They may also resort to the use of eight heavy duty pumpers – each capable of flowing 9,000 LPM (2,400 GPM US). Under similar conditions, the Dutch firefighters in Amsterdam would be able to pump from any of their canals that flow through all major parts of the city area.

Many cities are sited on major earth faults and must prepare for the possibility of an earthquake. San Francisco and Tokyo are two such cities that consider one of the top priorities as being the protection of the firefighting water supply. Both cities have embarked upon an underground network of cisterns. In San Francisco, over ten million gallons of water is sited in 150 underground cisterns, strategically placed throughout the city. In addition to this network, the SFFD enjoy a high-pressure hydrant grid that is specifically provided for firefighting. The hydrants on these mains can flow enormous amounts of water at pressures up to 21 bars (300 psi). When connecting a pumper to one of these HP hydrants, a 93 lbs 'Gleeson Valve' is first connected to the hydrant outlet – reducing and controlling the output to manageable levels. Such flow capability enables the SFFD to lay a 'fire main' *(Figure 2:11)* above ground by utilising various hose (3½ ins and 5 ins), siamese adaptors, and portable hydrant manifolds.

The Seattle Fire Department (SFD) is another that often lays into their Hanson Manifold *(Figure 2:12)* – portable hydrant system. By running twin feeds of LDH into the 'Hanson' sited in front of the fire building, up to six attack lines (more if siamese dividers are used) can be run into the structure. This set-up enables the front of the building to be kept clear of fire pumpers etc, enabling aerials and other equipment to site with ease.

In New York City, the FDNY operate a 'Maxi-Water' system that is based around their famous Superpumper – capable of flowing 33,250 LPM (8,800 GPM US) – that is more than 37 tons of water a minute, with the potential of supplying 30 attack hose-lines! This is backed by six engine companies, strategically placed throughout New York, Which are each capable of flowing 7,500 LPM (2,000 GPM), and are equipped with various manifolds, monitors, and water maps. These pumpers operate a dual-role, responding as normal in their own areas and functioning as the 'Maxi-Water' systems they are, at larger incidents. By utilising the LDH (4½ ins) as carried, they are capable of flowing large amounts of water onto the fireground.

Water Relay Versus Shuttle

When faced with a water transportation situation, from source to fireground, if the distance is great there may be several options to consider. Many fire departments choose to relay water overground through hundreds of metres of hoselines, with fire pumpers sited at strategic points to boost pressure in the system, overcoming the losses caused through friction, turbulence and gradients.

Other brigades rely upon water shuttle systems, utilising tankers that load, transport, and dump the water into portable tanks sited along the way. This particular technique is popular in rural situations where access to water supplies and roads, are good.

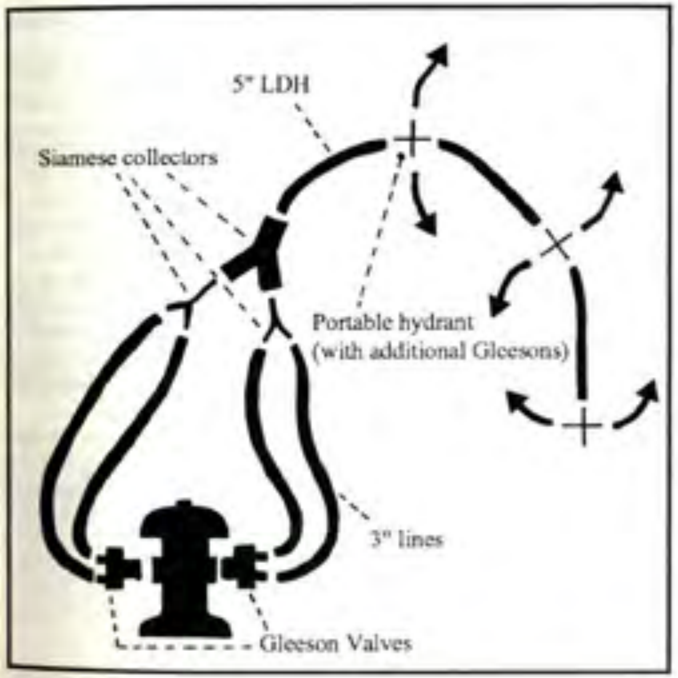


Figure 2:11 – San Francisco HP system.

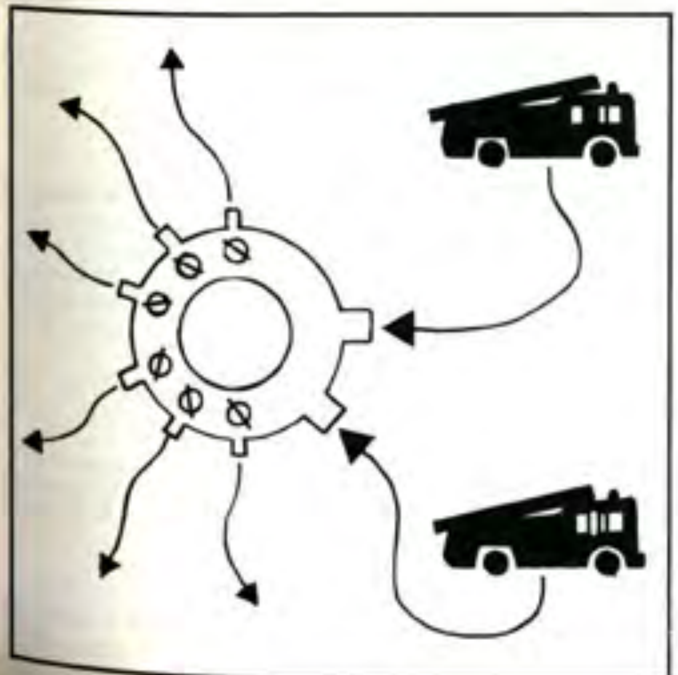


Figure 2:12 – Seattle's Hanson manifold.

The following examples will demonstrate the various options, and by setting a target we are able to compare the results:

In an effort to transport 2,270 LPM (600 GPM US) over a level 2,400 m (8,000 ft) (that is about 1½ miles) we will lay down a set operating pressure of 10.5 bars (150 psi) where water relays using hose are utilised.

It should be borne in mind that it is impossible to calculate friction losses with any great deal of accuracy when dealing with Fire Service hose, as there are a number of factors which affect the result. For example, hose will increase both in diameter and in length when under pressure; in addition, snaking, bends and hose fittings, etc. will all have an effect in causing variations in pressure loss. There is also a marked variance between different manufacturers' hose, depending on the roughness of interior rubber linings. Because of these variances, frictional loss formulae can provide results that are 50 per cent inaccurate! It is important to understand this point and relate to friction loss formulas as a fireground 'rule of thumb' method – unless such formulae were specifically designed for a particular manufacturer's hose.

The figures for friction loss given in the following examples are based on tests completed, using best quality rubber-lined fire hose. Rough internal lining is liable to increase such losses by as much as one half – however, for the purposes of comparing technique, these figures are acceptable.

Example # 1 – Water Relay of 63 mm (2½ ins) hose (twinned)
Relay Distance (RD) – 2,400 m (8,000 ft)
Flow – 2,270 LPM (600 GPM US)
Operating Pressure (OP) – 10.5 bars (150 psi)
Friction Loss per 100 m hose length – 4.87 bars
Total Friction Loss (FL) – 117 bars (1,696 psi)

$$\frac{FL}{OP} = \frac{117\ (1{,}696)}{10.5\ (150)} = 12 \text{ pumpers required to achieve flow.}$$

$$\frac{RD}{Pumps} = \frac{2{,}400\ (8{,}000)}{12} = 200 \text{ m (700 ft) spacing between pumps.}$$

Example # 2 – Water Relay of 70 mm (2¾ ins) hose (twinned)
Relay Distance (RD) – 2,400 m (8,000 ft)
Flow – 2,270 LPM (600 GPM US)
Operating Pressure (OP) – 10.5 bars (150 psi)
Friction Loss per 100 m hose length – 3.4 bars
Total Friction Loss (FL) – 83 bars (1,203 psi)

$$\frac{FL}{OP} = \frac{83\ (1{,}203)}{10.5\ (150)} = 8 \text{ pumpers required to achieve flow.}$$

$$\frac{RD}{Pumps} = \frac{2{,}400\ (8{,}000)}{8} = 300 \text{ m (1,000 ft) spacing between pumps.}$$

Example # 3 – Water Relay of 90 mm (3½ ins) hose (single)
Relay Distance (RD) – 2,400 m (8,000 ft)
Flow – 2,270 LPM (600 GPM US)
Operating Pressure (OP) – 10.5 bars (150 psi)
Friction Loss per 100 m hose length – 5.5 bars
Total Friction Loss (FL) – 132 bars (1,914 psi)

$$\frac{FL}{OP} = \frac{132\ (1{,}914)}{10.5\ (150)} = 13 \text{ pumpers required to achieve flow.}$$

$$\frac{RD}{Pumps} = \frac{2{,}400\ (8{,}000)}{13} = 185 \text{ m (615 ft) spacing between pumps.}$$

Suggest 14 pumpers at 175 m (600 ft) spacing to align with hose lengths.

Example # 4 – Water Relay of 90 mm (3½ ins) hose (twinned)
Relay Distance (RD) – 2,400 m (8,000 ft)
Flow – 2,270 LPM (600 GPM US)
Operating Pressure (OP) – 10.5 bars (150 psi)
Friction Loss per 100 m hose length – 1.37 bars
Total Friction Loss (FL) – 33 bars (480 psi)

$$\frac{FL}{OP} = \frac{33\ (480)}{10.5\ (150)} = 4 \text{ pumpers required to achieve flow.}$$

$$\frac{RD}{Pumps} = \frac{2{,}400\ (8{,}000)}{4} = 600 \text{ m (2,000 ft) spacing between pumps.}$$

Example # 5 – Water Relay of 125 mm (5 ins) hose (single)
Relay Distance (RD) – 2,400 m (8,000 ft)
Flow – 2,270 LPM (600 GPM US)
Operating Pressure (OP) – 10.5 bars (150 psi)
Friction Loss per 100 m hose length – 0.30 bar
Total Friction Loss (FL) – 7.28 bars (105 psi)

$$\frac{FL}{OP} = \frac{7.28\ (105)}{10.5\ (150)} = 1 \text{ pumper will provide the required flow.}$$

It is suggested, to ensure full flow is achieved, that a booster pump is sited additionally to the number of pumps as estimated in examples 1-5. This is reflected in *table 2:4*.

Example # 6 – Water Shuttle with Tankers
While there may be several options involving 'tanker shuttle' alone, a fire department is generally restricted in the amount, and type, of tankers available to

	Pumps	No. of lengths Hose (25 m)	Hose (50 ft)
Twin 63 mm	13	192	320
Twin 70 mm	9	192	320
Single 90 mm	15	96	160
Twin 90 mm	5	192	320
Single 125 mm	2	96	160

Table 2:4 – Equipment requirements – Water Relays

them. In the US seven Hampshire County (Massachusetts) fire departments participated in a drill to demonstrate the effectiveness of their water shuttle programme.

The comparison of this demonstration is well suited to the five water relay examples for the transportation distance was 1½ miles (approx 2,400 m or 8,000 ft), and the delivery target was again, 2,270 LPM (600 GPM US). The shuttle required seven tankers to maintain the required flow.

The operation, which was reported in detail in the October 1981 edition of *Fire Engineering*, resulted in an average flow of 2,300 LPM (610 GPM US) over the one hour 45 minutes' duration.

A flow of 1,135 LPM (300 GPM) began just four minutes after arrival and the full 2,270 LPM (600 GPM) was delivered within 14 minutes.

The seven tankers operated as follows:

	Litres capacity	*Fill-time (mins/secs)*	*Unload time (mins/secs)*	*Method*
(1)	13,230	2 . 36	3 . 56	dump
(2)	7,560	1 . 48	6 . 45	pump
(3)	3,780	1 . 05	2 . 36	pump
(4)	3,780	1 . 45	2 . 20	pump
(5)	3,780	1 . 14	2 . 0	dump
(6)	3,780	no data	no data	dump
(7)	2,835	1 . 17	2 . 38	pump

Other equipment needed to run the operation included: two folding water tanks of 5,670 and 7,938 litre capacity; lightweight portable pumps; several lengths of hard *and* soft suction hose; and a water jet siphon.

At all times during the operation tankers were kept moving by an efficient filling operation. The tankers were on the loading area for less than five minutes each time – there was some waiting time at fill points and one tanker actually became bogged down.

A useful formula that can be used as a 'rule of thumb' fireground guide to estimating a water shuttle's flow-rate is the following:

$$F = \frac{L\ (\text{or } G)}{60 \times (D/S) + T_F + T_E}$$

Where:

F = Flow-rate in LPM or GPM
L = Tanker capacity in litres
G = Tanker capacity in gallons

D = Return distance in miles
S = Average speed of tanker on road (MPH)
T_F = Time taken to fill tanker
T_E = Time taken to empty tanker

As an example, for tanker # 1 the formula would rate it as follows:

$$F = \frac{13{,}230\ (3{,}500)}{60 \times (3/30) + 2.6 + 4}$$

The answer would provide tanker # 1 with a flow rating of 1,050 LPM (277 GPM).

When the formula is applied overall to the above operation as carried out by Hampshire County fire departments, the estimation provided is not too far out. *(Table 2:5)*.

Tanker	*Formula Rating*
1.	1,050 LPM (277 GPM)
2.	517 LPM (136 GPM)
3.	394 LPM (104 GPM)
4.	382 LPM (100 GPM)
5.	406 LPM (107 GPM)
6.	NO DATA
7.	286 LPM (75 GPM)
Total –	3,035 LPM (800 GPM)

Table 2:5 – Formula Estimation for Hampshire Shuttle

The estimated flows of 3,035 LPM (800 GPM) were over-estimated when compared with the actual average flow of 2,300 LPM (610 GPM). However, one must take into account the fact that tankers were forced to wait, on occasions, before filling or dumping. Also, one tanker became bogged down, preventing its use for a period. It is also worth noting that at high points, the Hampshire County shuttle was delivering in excess of 2,800 LPM (750 GPM). The formula predicts a shuttle operating under 'perfect' conditions. Taking this into account, it is still reasonably accurate for assessing shuttle effectiveness on the fireground.

Water Relay Technique

When setting out to run a water relay onto the fireground the necessary manpower and equipment is rarely on site during the initial stages. The urgency for water on the fire demands a relay to be set up straight away to deliver a steady, and continued, flow of water.

A technique favoured by British firefighters is demonstrated overleaf *(Figure 2:13)*. By utilising 25 m (75 ft) lengths of 70 mm hoseline and three fire pumpers on the initial attendance, a flow of 1,000 LPM (2645 GPM US) can be delivered over a level 400 m (1,335 ft) to the fireground attack pumper. As further pumpers respond they are able to connect into the relay, as seen below, to deliver over 3,000 LPM (795 GPM) at a system pressure of just 7 bars (100 psi).

As the 3,000 LPM is flowed through the 400 m of 70 mm (twinned) hoselines the incoming pressure gauges on each pump will read 0.9 bars (13 psi). The remainder of the 7 bars (100 psi) operating pressure is directed at overcoming friction loss in the hose. It is important for firefighters to understand the principles involved where hoselines are twinned – velocity and flow is halved when operating

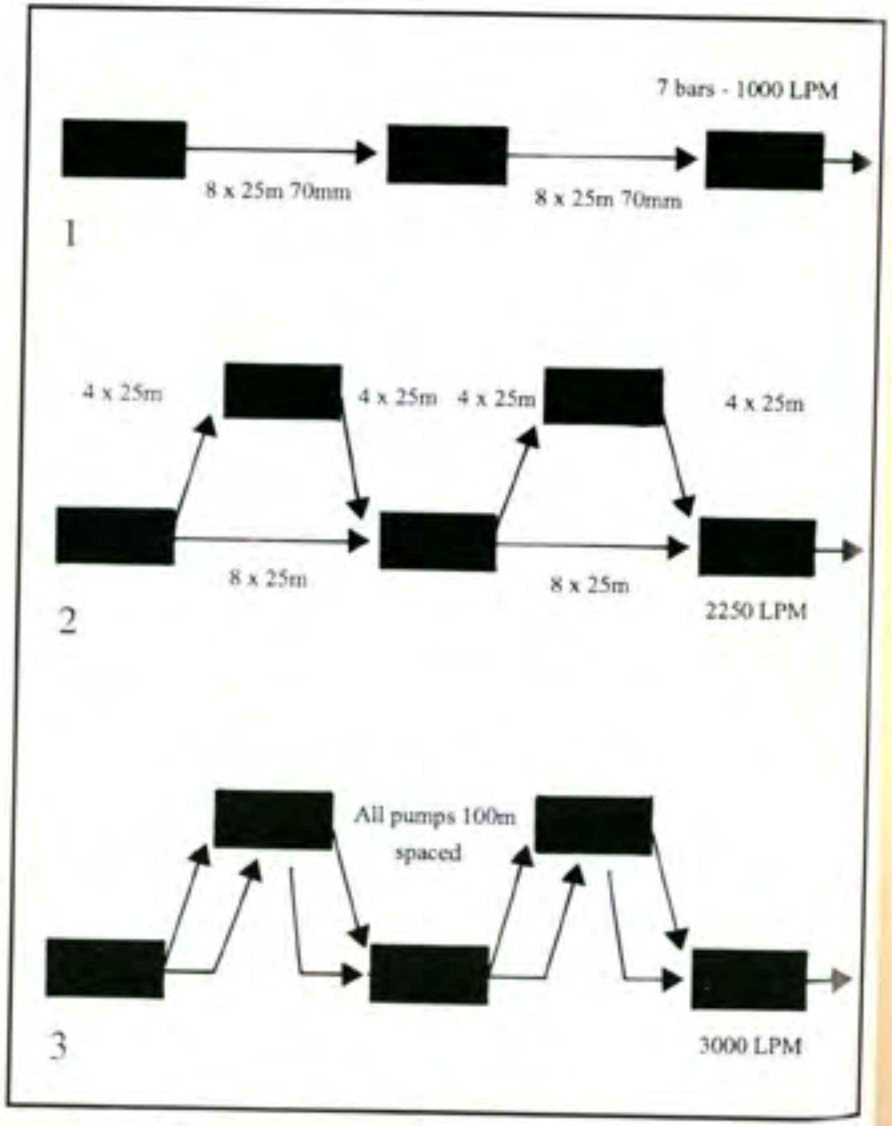


Figure 2:13 – Pump spacing for water-relay system.

at the same pressure and the loss in pressure between the two ends of the hoselines is reduced to one quarter of that suffered by a single line.

This effect is demonstrated where a single line of 70 mm hose flows 1,200 LPM, causing 1 bar friction loss. By twinning the lines, the flow in each is reduced to 600 LPM and the friction loss is reduced to one quarter – ie, 0.25 bars. If a hydrant

was supplying the flow from an original 2.5 bar static pressure, the flow through twin lines would leave a residual at the hydrant of 2.25 bars.

The SFFD 'Jumper', mentioned earlier, can also be utilised in a relay line to enable additional pumps to hook-up and boost the pressure in-line, as shown below (*Figure 2:14*).

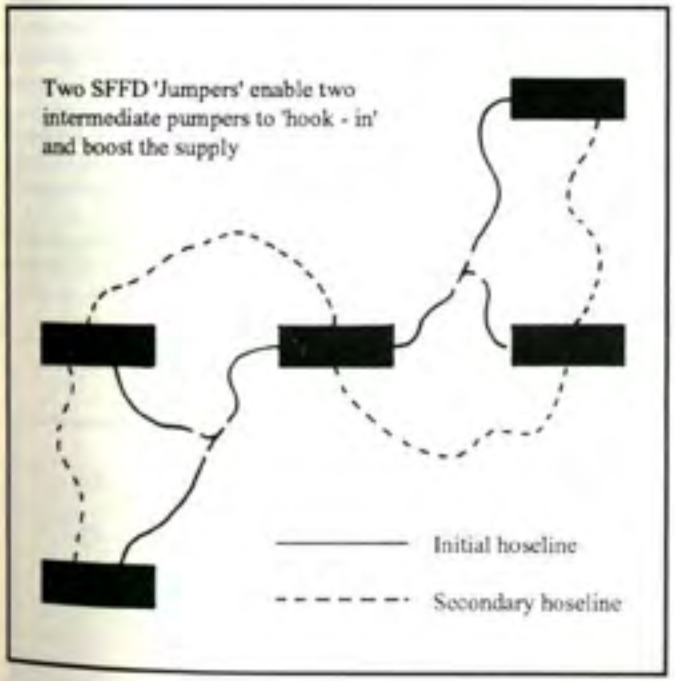


Figure 2:14 SFFD water relay utilising 'jumpers' in line.

Hydrant Identification

As fire appliances arrive on scene and site themselves for the initial attack, if the fire is rapidly escalating the need for large amounts of water – almost immediately – is a priority. If a quick-water attack is applied, depending on the output, the firefighters on the nozzle may only have a minute or two before the tanks run dry. If the source of supply is to come from the hydrant grid it is essential for firefighters to locate the nearest hydrant as a matter of urgency.

In many parts of the world the pillar hydrant is sited above ground in a prominent position and is normally fairly easy to locate. However, in many European cities firefighters must search for sub-surface hydrants that are not so prominent, particularly in a dark street, or where snow has covered the lid. In London, the sub-surface hydrants are generally identified by a wall-mounted plate consisting of a black 'H' on a yellow (6×8 ins) background. The plate will denote the distance to the hydrant (usually a metre or two.)

Even though the position of these sub-surface hydrants is often marked, firefighters continually have problems finding them, and often note after the fire has been extinguished that the hydrant used was not the nearest! The public enquiry into the Stardust Disco fire in Dublin, Ireland, in 1981, raised this very point. While it was realised that the installation, throughout Dublin, of pillar style hydrants was totally uneconomical, the tribunal recommended that fire hydrants should be clearly marked, after firefighters had failed to utilise the hydrants nearest to the fire building.

Where fire hydrants are located, particularly where they are of sub-surface design, they should be clearly marked with some form of retro-reflective, and fluorescent, indicator that is visible from all directions within a street. This may take the form of a band sited around a nearby lamp-post, or similar. It is equally important for markings to be painted on the road/pavement to give a clear warning not to obstruct the hydrant in any way.

Perhaps we should go further still with our marking system and utilise a method that is gaining popularity in the USA where hydrants are colour coded according to their flow potential. Such coding will vary between cities for not all enjoy such high flows as found in parts of America.

The 'coding' of hydrants would be of great use to the firefighter for he would then have the ability to choose his source of supply. By painting the head of the pillar hydrant, or lid *and* outlet of the sub-surface hydrant, we are able to rate hydrants under a class system.

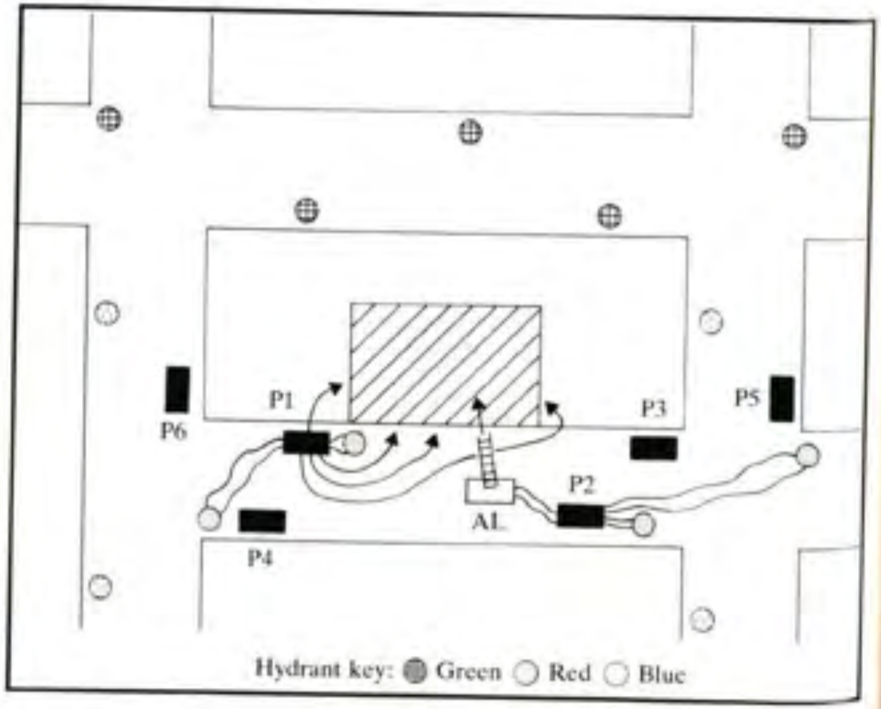


Figure 2:15 – Ineffective use of hydrant grid.

Example

Class 'A'	over 1,500 LPM	Green
Class 'B'	900-1,500 LPM	Blue
Class 'C'	below 900 LPM	Red

Such information can be utilised by the firefighter as demonstrated by these examples *(Figures 2:15-2:16)*.

In the plan opposite *(Figure 2:15)* of a 'typical' European fireground, P1 is attempting to feed four 20 mm nozzles working on the fire. Even with twinned hoselines from two nearby hydrants (red – below 900 LPM) the flow into the pump is only 1,100 LPM. This flow will not give adequate streams from 4×20 mm so two nozzles are reduced to 12.5 mm. At nozzle pressures of 2 bars the 12.5 mm nozzles will each deliver 148 LPM with a horizontal stream of 9.3 m (31 ft), and the 20 mm nozzles will each flow 379 LPM with an 11 m (37 ft) stream reach. The aerial ladder (AL) is also poorly supplied from two (red) hydrants supplying a total of 800 LPM. If using a 30 mm nozzle an NP of 1.5 bars will flow 738 LPM with a 11.7 m (39 ft) stream.

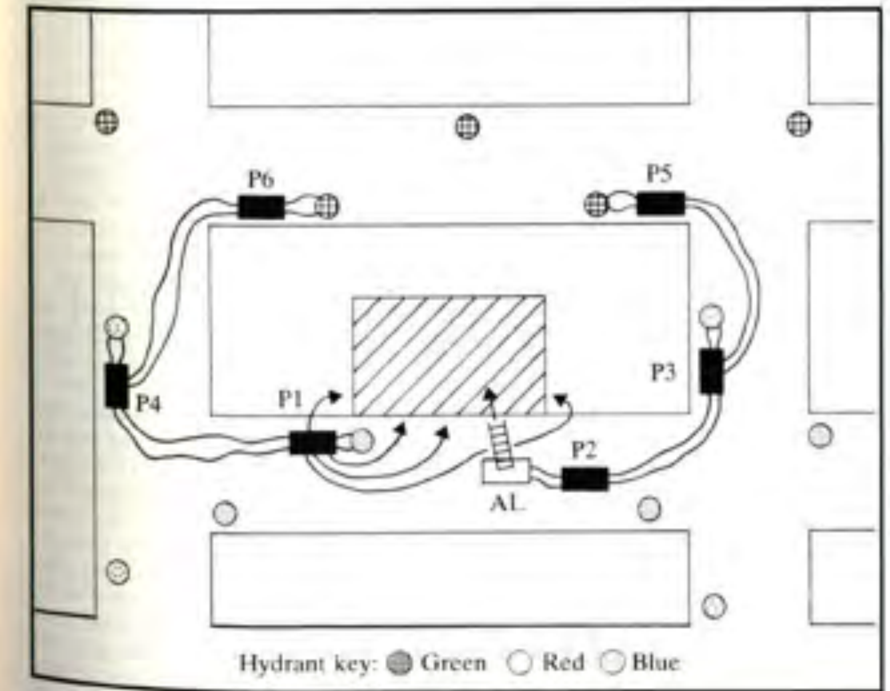


Figure 2:16 – Optimum use of hydrant grid.

The six pumpers attending the fire *(Figure 2:16)* have spaced out and utilised themselves well. Quite naturally, the first arriving attack pumper (P1) spotted on the nearest hydrant and adopted a quick-water attack. His supply was augmented by the fourth pump to arrive and backed up by P6. Even without P6's help, P1 can now flow sufficient water to feed 4×20 mm nozzles, but by additionally utilising the green hydrant a nozzle pressure (NP) of 3 bars will flow 464 LPM to each nozzle, giving them an improved stream reach of 14.4 m (48 ft). The aerial ladder is also well supplied and able to flow 1,350 LPM at 5 bars NP with a 24 m (80 ft) reach. It might be argued that major roads are affected by the operation, leading to traffic build-up. However, if fire vehicles are correctly sited, and hose protection ramps are used, both the equipment and manpower are on hand to provide an effective and contained attack on the fire.

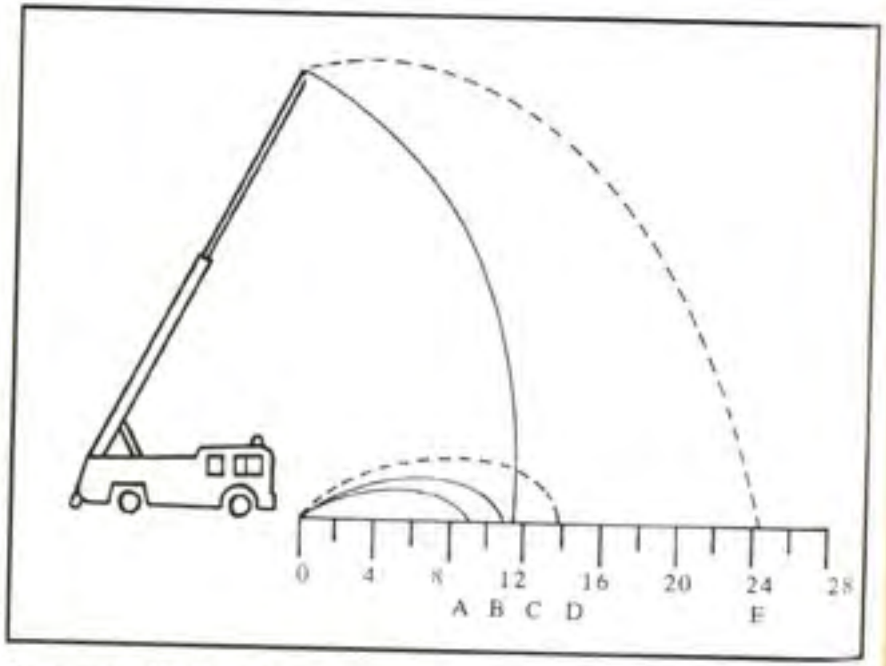


Figure 2:17 – The effect of fire stream power.

What it actually meant in stream power:

(A) – Initial 12.5 mm nozzle from red hydrants.
(B) – Initial 20 mm nozzle from red hydrants.
(C) – Initial AL stream from red hydrants.
(D) – 20 mm nozzles working from blue and green hydrants.
(E) – Aerial Ladder working from blue and green hydrants.

It becomes clear, particularly where low pressure grids exist, the opportunity to choose the hydrant for a particular role – ie, (A) initial attack, (B) aerial stream or large calibre streams, (C) high-flow hoselines and (D) nozzles, etc – is most useful to the firefighter on scene.

It should also be pointed out that the same flow capabilities, and stream power,

would have been achieved by omitting both P3 and P4 from the lines.

A water officer should be assigned on all large fires and his role is to ensure the hydrant grid, or other source, is utilised to its optimum effect. The next time your firefighters complain of low pressure supplies, check their hose layouts!

Pump Designs

Fire pumpers in service in many parts of Europe, Australia and the Far East are of a basic design and have failed to progress to encompass many of the innovations found on pumpers in other parts of the world, particularly the USA.

One aspect of pump design that is common in some parts of the world provides a facility where the hydrant supply is fed directly into the pumper's water tank rather than into the eye of the pump. The supply from the inlet port to the tank is regulated by an automatic tank fill system similar to a cistern ball-cock. The system may be pneumatically controlled and have depth sensors fitted to measure when the tank is full so that the tank feed valve can be turned off. The system may also register when the tank is less than three-quarters full so that the valve can be turned on. If the pump is over-running the supply, or a burst occurs in a water relay, the MPO has time to supplement the supply, or reduce the delivery pressure before running out of water. In addition to the tank acting as a reserve, other benefits of this method of operating are:

(a) it is possible to compensate for the variations in water supply.
(b) the constant conditions at the inlet of the pump greatly increase the ability to induce additives into the pump at a consistent rate.
(c) the problem of water loss at the nozzle caused by air being forced into the eye of the pump when a pressure fed supply is used, is overcome.

This type of system is popular in Italy, for example, while fire departments in America and the UK prefer to use the pressure from the hydrant to boost the supply as it is fed into the eye of the pump. Where water enters the pump at a 2.0 bar pressure from the hydrant, only 1.0 bar is necessary from the pump itself to achieve an output at 3 bars.

An important feature often missing from basic pumps is that of large bore pipework leading from the inlet ports to the tank, and from the tank to the eye of the pump. The use of large bore pipework enables the pump to be used at full capacity and overcomes the problem of restricted water supply.

Another facility (already mentioned) is the provision of pressure relief devices. The techniques used by many European firefighters to 'dump' excess pressure have already been discussed. Many pumpers in Europe are fitted with Universal Multi-Pressure (UMP) pumps where a high pressure (40 bars) flow can be delivered to the hosereels (booster lines) at the same time a low pressure flow (say 5 bars) is delivered to any hoselines in use from the same pump. This facility of dual high/low pressure delivery is extremely useful where a quick water attack via HP hosereel fog-gun is changing to a main stream attack. However, the control of pressure to either is regulated by the same throttle control – to reduce pressure on one means reducing it on the other, and vice versa. This may not be acceptable to the MPO who may choose to run a short line from a spare discharge port into the pumper's hydrant-tank connection. Then, by flowing off some of the excess pressure from the low pressure side into the tank, the pressure on the HP side is maintained.

Accuracy of flow indicators

With a large flow of water taking place through the pump, firefighters tend to take readings from flow indicators on the pumping panel, or the results from painstaking hydraulic calculations, as an *exact* figure (LPM-GPM) and few allow for the inevitable inaccuracies that occur at such high flows.

It is certain that most firefighters are aware of the effects of diminished pump efficiency at various pressures; or high altitude affecting lifting water (drafting). The fact that warm water will affect the actual working suction lift by reducing a pump's ability to lift for each degree over 15C, is also well-known. However, how many are alert to the condition of 'interior pump pressure loss'?

So often – particularly when flowing large amounts – firefighters are puzzled after making hydraulic calculations on the blackboard, when they discover they are unable to deliver the desired flow through a single outlet. This is because, any time, a large amount of water is flowing through a single discharge opening, part of the total pressure built up can not be discharged. When flow-rates exceed 2,000 LPM (500 GPM US) through a single discharge, the design of the pump and piping may prohibit some of the pressure from being released. This is called 'interior pump pressure loss'. This inability to move all the pressure from the pump can be observed where a port discharge gauge is compared with the main pump pressure gauge. When water begins to move the two gauges will register the same pressure. As the flow rate increases above the 2,000 LPM level the port discharge gauge will begin to register a lower pressure of the two. The actual loss in pressure will vary among individual pumps, depending on design, however a rule of thumb demonstrates pressure losses of 0.3 bar (5 psi) at flows of 2,000 LPM and 2 bars at 4,000 LPM through a single discharge. Therefore, the accuracy of pressure gauges, and hydraulic formula based on gauge readings, may not always reflect the true output of a fire pump.

Even without taking the aforementioned into account, the gauges themselves are seldom 100 per cent accurate. In fact, the manufacturers of such gauges inform us that individual gauges may be subject to some inaccuracies, for example 2 per cent inaccurate at 40 bars (600 psi). Again, such inaccuracy, while minor, will have an effect on actual flows through the pump.

While striving to achieve pinpoint accuracy at the pump many fire departments have, for some years, experimented with 'flowmeters' fitted to every discharge (delivery) port. Such equipment will display flows through a discharge port in LPM (GPM). Besides providing the MPO with more accurate estimates of pump output, flowmeters actually served to make most hydraulic calculations redundant! Many of the early flowmeters fitted to fire pumpers had been adapted from industrial uses, such as measuring the precise flow of chemicals used in manufacturing processes. Measuring flowing water seemed as easy as recording alcohol flow, for example, but mains water was not as pure, and industrial meters were kept at one location and not carried over rough roads in a fire pumper. Eventually the fire flowmeters clogged up and became extremely inaccurate, or unusable.

Over the years, the clogging problem was solved and flowmetres are now accepted as a reliable form of registering flows.

Testing of flowmeters has taken place on fire pumpers in Britain. The systems utilised paddlewheel flow sensors that gave a digital display of flow taking place. The equipment was fitted to both low pressure discharge ports and high pressure hosereel systems, achieving excellent results at both locations.

Advantages of flowmeters:

(a) high level of accuracy.
(b) lower engine speeds can be used to achieve effective firefighting streams.
(c) the MPO has more confidence in his flows and safety is improved at the nozzle.
(d) bursts in hoselines, kinks in hoses, and vandalised rising mains, can all be detected earlier.
(e) each discharge port can flow variable quantities of water, and flow is not reliant on one main pressure gauge.

The New York Fire Department have fitted flowmeters to the majority of their fire pumpers. One technique they use is to estimate the number of sprinkler heads that have actuated on a fire floor. The FDNY, like most US fire departments, have a facility for supplying a sprinkler system from a fire pumper. By dividing the flow (GPM) into the system by 20 (LPM by 75) a reliable estimate is given. Such information is often useful to the incident commander, informing him of the fire's potential at a given point.

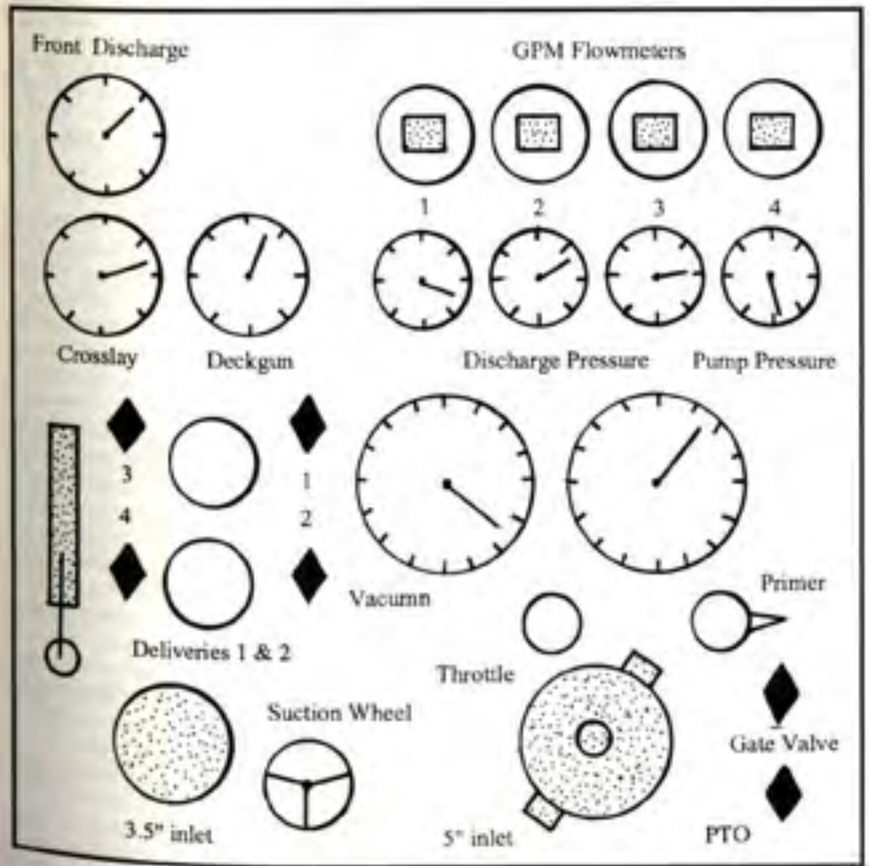


Figure 2:18 – New York firefighters have benefit of this pumper control panel.

Pumper control panels

The pump control panels on various pumpers around the world reflect the variance in adaption, ranging from the 'basic' to the 'innovative'. In the USA, a 'typical' pumper control panel will demonstrate the 'state of the art' finger-touch controls that are now available. Gone are the days of pulling down hard on vibrating levers and twirling wheel valves to open ports! Now it is all done by the flick of a finger, a twist, a turn, a button pushed and, hey presto, we have water!

The FDNY panel shows individual pressure gauges, and flowmeters, for each of the four deliveries, each opened by a 'pull' valve. The 'crosslay' (pre-connected line) and 'deck-gun' (top mounted monitor) each have their own gauges. Primer and throttle controls are twist-knobs, reflecting the simplicity of all controls on the modern pumper.

Chapter 2 – Water Supplies – Bibliography

2:1 **Shapiro, P.** (Las Vegas Fire Department) – Notably – *American Fire Journal* (February, June, August and October 1988 editions).
2:2 **Wilkins, B. and Rosenhan, A. K.** (Starkville Fire Department, Mississippi) – *Fire Command Journal* – July 1987 pp 22-23.
2:3 **Shapiro, P.** (Las Vegas Fire Department) – *American Fire Journal* – June 1990 pp 12-19.

3
FOG ATTACK

'In order to extinguish a fire properly, it is necessary for the firemen to approach it for the purpose of putting the water wherever it is most wanted. Any attempt to extinguish a fire from a distance almost invariably proves a failure.'

Sir Eyre Massey Shaw, KCB
'Fire Protection' 1876

Water has been known as an extinguishing agent as long as fire has been known to man. However, its full potential as an aid to firefighting has yet to be applied, for while the heat absorption capacity of water is greater than practically any other substance available, the ideal application has never been achieved on the fireground.

Many hundreds of years ago, the direct extinguishing of a major fire was impossible because no methods for applying water from a safe distance existed. To bring such conflagrations under control the people would create firebreaks and soak nearby properties to keep them cool.

With the introduction of manual fire pumps, the water could then be used to greater effect by applying the stream at the base of the flames. This technique – termed the direct attack – has been the most common approach utilised to extinguish fires of all sizes and has progressed in its effectiveness in line with technological advances in pumps, nozzles, and hose design. With stream reaches in excess of 40 m, combined with greater striking power and penetration properties, the 'direct' attack has enabled firefighters to advance into large buildings to complete extinguishment of the fire from a safe distance. However, the degree of efficiency for such an approach has been estimated between 10 to 20 per cent. In other words, up to 90 per cent of water applied (on target) at the base of a fire will have no actual extinguishing effect.

During World War II, the United States Marine Corps (USMC) developed a new technique for extinguishing compartment fires on board ships. In contrast to a direct attack at the flame-base, the USMC concentrated the water application onto hot surfaces within the compartment. This had the effect of creating large amounts of steam which, in turn, created a non-flammable atmosphere.

The application of the method was somewhat limited by the fact that the temperature must first become sufficiently high within the compartment for this type of extinguishing to succeed, which would only occur in an un-ventilated area.

The production of water vapour was achieved by applying the water through long applicator spray pipes, attempting a 10 to 35 per cent mix of vapour with the fire gases in the room.

The theory behind the method is explained in the following example: A room with a floor area of 40 sq m and a ceiling height of 2.5 sq m, includes 100 cu m of flames, that is to say if it is completely full of burning gases. In order to provide a 10 per cent mix of water vapour, what is needed in practice is the evaporation of 5 litres of water=5×1,700 l (vapour) + a certain surplus temperature.

This may appear to be simple on condition that hot areas are available in the room. Now let us calculate the heat utilised: water requires 4.18 kWs per degree heating, (90 deg=380 kWs); evaporation requires 2,360 kWs; the heating of steam to a temperature of 180 deg C. requires 80×2=160 kWs. The total heat requirements=

5×(2,360+160+380)=14,500 kWs

If it is considered that the heat is obtained instantly from the ceiling surfaces closest millimetre and the heat capacity of this is 1 kWs/kg deg C. and the density is close to 1, then an area of 50 sq m must be drenched with water in order to provide sufficient evaporation heat. In effect, this means an application rate of 0.1 l/sq m. In practice, a fast moving spray with a wide-angle nozzle, and a flow of 75 to 100 LPM, would make the occurrence of flames in the room impossible within five seconds. Normally the firefighter would use much more water than required and much more than is reasonable from the viewpoint of extinguishing technique. A total dosage of 0.1 l/sq m hot surface is sufficient, and is also the largest amount of water that this surface is normally able to evaporate.

After about ten seconds, if necessary, corresponding dosage can be applied since the surfaces may once again become hot, partly through the influence of the heat itself and partly through heating from material behind. If too large a volume of water is used for drenching purposes, instead of the water evaporating, the heat will merely be used to warm up the water whereby the heat in the surfaces disappears without sufficient formation of water vapour occurring. If the rate of drenching exceeds 0.5 l/sq m, this risk is imminent.

This technique developed by the USMC became known as the indirect attack and its popularity flourished in the 1950s and 1960s. Fire departments all round the world were impressed by the instantaneous 'knock-down' effect and the reduction in water damage, offered by this unique form of fire attack. Much emphasis was placed on the use of water fog at fires and a never-ending armoury of fog nozzles began to emerge from the manufacturers.

The technique of this indirect form of attack is still filed today in the City of Los Angeles Fire Department's SOPs (Standard Operating Procedures) where bulletin #1, dated 2 February 1954, describes a series of LAFD tests in over 100 burns of 13 derelict properties. During these test-burns piles of timber boards were ignited in both one and two-roomed fires, ranging from 1,000 to 8,000 cu ft in total volume. The fires created temperatures at floor level of over 1,000 deg. F.

Crews of LAFD firefighters advanced 1 ins lines into the structures and by utilising engine pressures of 125 psi, 250 psi or 400 psi, they delivered estimated flow-rates of 25-35-45 GPM respectively, although actual application rates were very much lower. By using a 30 degree cone angle from the fog-nozzle in use, most of the fires were extinguished within ten seconds. The following are typical examples of such tests:

(a) Two rooms totalling 5,000 cu ft containing timber boards to comprise the fireload; wood doors in place; ceiling in place; 75 per cent of window area covered with wood boarding – 100 per cent fire involvement. Engine Pressure (EP) 125 psi (8.6 bars); flow-rate of 25 GPM (95 LPM); nine second application made through window extinguished fire; total application of 3.75 gals (14 l) – minor fire remained in wood pile.

(b) Same two rooms, with fire load; EP 250 psi (17.2 bars); flow-rate of 35 GPM (132 LPM); 10 second application made through window; total application of 5.8 gals (22 l) – minor fire remained in wood pile.

(c) Same two rooms, with fire load added, although fire was allowed to enter the attic space, partially ignite the roof, and push out of the windows. EP 400 psi (28 bars); flow-rate of 45 GPM (170 LPM); fire self-vented through roof causing indirect attack to fail; larger line used in a direct attack.

The LAFD tests approved the indirect approach to extinguishing fires but realised its limitations. They recognised the fact that ventilation openings nullify the effect of vapour expansion and reduce the levels of fire control. It was also noted that the vaporised zone was uncomfortable for firefighters to enter after the water has been applied.

During the next few years, firefighters across the USA revelled in this boom of fog attack, as its popularity appeared to be increasing by the hour. There were, however, those who doubted the theory of such a technique that filled a compartment with scalding steam at an expansion ratio of 1,700-1. Surely such an approach would result in someone getting badly hurt? – it did!

Over a period of time, hundreds of firefighters suffered at the hands of indirect attack techniques. The rapid expansion of water to steam, when applied to super-heated surfaces within sealed compartments, inevitably led to severe burns and discomfort. It was also noticed that a pressure wave was set up inside a structure, ahead of the fog stream, that was capable of pushing the fire into uninvolved areas. The indirect form of applying water to a fire was beginning to lose its appeal to the masses – fog attack was on its way out!

William E. Clark, a former battalion chief with the FDNY wrote in his book, *Firefighting Principles and Practices (Bibliography 3:1)*, 17 pages explaining, from his viewpoint, why fog attack should be outlawed. The fog advocates, in his mind, had set the cause of ventilation back 50 years, urging that the fire building be closed up tight to prevent the steam escaping. Mr. Clark then referred to tests that had been made by the Joint Fire Research Organisation (JFRO) in England, where 12 fires in furnished rooms of 42 cu m volume were extinguished. The purpose of these tests was to compare the effectiveness of straight streams with spray patterns in controlling the fires. The report stated that no such difference appeared and that straight streams performed equally well with spray patterns in the tests. As Mr. Clark quite rightly pointed out, rooms of such small dimensions were supposedly ideal for indirect attack and yet the test results did nothing to support that claim.

However, the JFRO tests failed to conform to the golden rule concerning dosage. As previously mentioned, the ideal dosage for an effective indirect attack is 0.1 l/sq m. This application rate can be increased slightly but where drenching of hot surfaces exceeds 0.5 l/sq m the heat will not be absorbed fully by the water and complete evaporation may not occur. The excessive flow-rates used by JFRO – for example 405 LPM (107 GPM) applied in four seconds – would most likely lead to a situation where over-drenching occurs.

The LAFD tests mentioned earlier were so effective because flow-rates conformed with the application principle. The LAFD firefighters applied total flows of 14 and 22 l into the rooms' upper stratas, giving a dosage rate of 0.2 and 0.3 l/sq m. Mr. Clark then went on to report how the compartment needed to be effectively sealed for the fog attack to work. In the case of indirect attack this is true to a great extent, although the LAFD reported effective operations even where openings comprised 25 per cent of the outer wall space, providing the openings were distributed.

Mr. Clark continued his condemnation of fog attack by referring to a series of tests completed in the USA during the 1960s, where one-room 'burns' were used to compare the effectiveness of various applications:

(a) High-pressure fog nozzle operating at 55 bars (800 psi) and delivering a 113 LPM (30 GPM) flow-rate.
(b) Low-pressure fog nozzle operating at 7 bars (100 psi) NP and delivering a 227 LPM (60 GPM) flow-rate.
(c) Solid stream nozzle with 12.5 mm (½ ins) tip operating at 4.5 bars (66 psi) NP and delivering a 227 LPM (60 GPM) flow-rate.

In each case, the ceiling temperature reached 1,200 deg F. before 57 l (15 gals) was discharged from the nozzle in use. In each case the fire was extinguished with minor smouldering remaining at points. The solid stream's performance appeared the most effective. A hole had been cut at the floor's lowest point and a catch basin had been placed beneath it to collect water run-off. The two fog applications had each left 2.8 l in the basin while the solid stream had allowed a one litre run-off.

As the dimensions of the rooms used in the tests were not given, it is not possible to calculate the dosage rates. However, the poor performance from both fog nozzles can be explained by their methods of application. In both cases, the fog application was too long – 30 seconds in (a) and 15 seconds in (b). This would upset the thermal balance and lead to over-cooling, preventing a complete evaporation and creating a heavy 'run-off'.

In all applications of water fog, the nozzle operator must control the flow-rate, maintaining short, sharp, bursts into the upper strata. It is in this application that so many fail to understand the basic principles of fog attack.

Mr. Clark demonstrated further misconceptions when he referred to water fog application and may have assisted in putting such techniques back 50 years!

However, to be fair, a lot of the negative points raised were based on sound experience. The normal 'banking' down of heat layers is disrupted by an indirect application of water on to hot surfaces and the temperature, combined with the increase in humidity, places the firefighter in an uncomfortable situation. Much was said also of the pressure-wave that moves ahead of the fog stream, and two excellent photographs demonstrated this effect. However, practical fog application techniques, and equipment technology, have progressively altered to quench such undesirable effects and the firefighters of today are able to revert to successful fog attacks with relative safety.

As we progressed through the 1970s, the concept of fog attack began to lose momentum in the USA following an accumulation of bad experiences. The solid stream would out-perform the fog nozzle when faced with a fire in a timber-framed property that threatened to escalate rapidly unless promptly checked. This, coupled with the steam burns often associated with an interior fog application, resulted in the demise of fog as an attack weapon. The 'booster-line' (hosereel tubing) gradually disappeared from front-line pumpers and the modern concept of fire suppression in the USA promoted 'high-flow', medium diameter, hoselines that carried the punch desired from a solid stream attack. While nozzles were designed to incorporate both solid stream, and fog facilities, the application of spray patterns was encouraged more for firefighter protection, outdoor fires, or overhauling after the main fire had been extinguished.

Meanwhile, firefighters throughout Europe were revelling in fog application techniques. The low-flow delivery rates suited the 'quad' style pumpers that needed to site immediately adjacent to the fire building for ladder placement and lighting operations. The first-aid water tank, carrying a few hundred litres, was ideal for

the 'quick-water' principle where the tank supply would last for several minutes, when used in conjunction with a fog-gun working from a hosereel tubing. The lightweight hose was easily advanced into structures, often being hauled into position up the exterior wall of the building and in through a window below the fire floor. The early indirect approach was ideally suited to the traditional forms of construction common throughout Europe. The fact that most European fire brigades were opposed to opening a structure for ventilation purposes, prior to the fire being brought under control, conformed to the indirect fog approach and there was never any conflict. The concept was to flourish!

During the following years various bodies conducted tests, both in the laboratory and in actual structural compartments, to assess different types of fog-gun, flow-rates, application rates, nozzle pressure effects, and various application styles and techniques. While some tests were based upon sound scientific principles, they often failed to relate, in any way, to real fire conditions, and the data was unreliable. However, this was later rectified and more realistic data began to emerge.

There is now a considerable amount of literature that predicts, with great accuracy, delivery and application rates for various types of compartment fires. However, one factor that continually emerged as a variable was 'operator skill'. This most important, and influential, aspect of compartmental fire suppression was always ready to fluctuate as different operators displayed varying levels of skill in the techniques used. Another important variable that had some effect in the test results was related to the level of protective clothing used by the operator. The whole concept of compartmental fire suppression, utilising a fog application, places demands upon the operator to get close to the fire and remain there while the fog is discharged. This requires a high standard of protective clothing for the operator to be successful.

Before we discuss the various tests, and the resulting data, it is important to define some terms used that may be unfamiliar to the reader. It may be worthwhile making a mental note of these for they will emerge later on in relation to other points.

- **Flow Rate:** This is the amount of water passing through from supply to destination. It may be from a hydrant to a pumper, or from an open source to the fireground, or from a pumper to the nozzle, etc. It is quantified in LPM or GPM.
- **Delivery Rate:** This is the amount of water being applied to a fire at any one time. Its measurement may vary, some preferring to use LPM/sq m or GPM/sq ft. For the purposes of this book, the author has felt it more applicable to use the LPM/cu m, or, GPM/10 cu ft to present data.
- **Application Rate:** This is the amount of water, in total, used to extinguish a fire. It is quantified here in l/cu m, or gals/10 cu ft. Therefore, if a *flow* of 1,000 LPM was *delivered* on to a fire rate at a rate of 0.5 LPM/cu m for three minutes, the amount of water actually *applied* would be 1.5 l/cu m.

Fire Flow Tests

One series of tests, conducted by Kokkala, *(Bibliography 3:2)* involved a small wood crib that was burned in a 3.6×2.4×2.4 m (11.8×7.9×7.9 ft) room lined with combustible materials. After flashover was achieved within the compartment, the fire was extinguished with solid streams applied by a firefighter, at flow rates between 18 LPM (4.7 GPM) and 45 LPM (12 GPM) *(Table 3:1)*.

The Kokkala tests were based in a laboratory environment and were confined to a very small compartment. The flow-rates used would normally be inadequate for fireground use and a real fire of similar proportion within the confines of a structure would present a different set of data. Even so, this series of tests were highly

Floor Area	8.64 sq m	93.2 sq ft
Volume	21 cu m	736 cu ft
Flow Rate	18 LPM	4.7 GPM
Control Time	2.2 minutes	Same
Delivery Rate	0.8 LPM/cu m	0.06 GPM/10 cu ft
Application	1.8 l/cu m	0.1 gallons/10 cu ft
Flow Rate	45 LPM	12 GPM
Control Time	12 seconds	Same
Delivery Rate	2.14 LPM/cu m	0.1 GPM/10 cu ft
Application	0.4 l/cu m	0.02 gallons/10 cu ft

Table 3:1 – Kokkala test results.

representative in demonstrating effective flow-rates and minimum application rates required for fires of this size.

Another series of tests *(Table 3:2)* was undertaken by Salzberg *(Bibliography 3:3)* aimed at determining minimum water requirements for the suppression of room fires. The tests were conducted in two rooms of equal size, 3.7×3.7×2.4 m (12×12×8 ft), with wooden and upholstered furniture, books, and clothing used for fire load.

Tests were conducted with fire in one, or both rooms. They were extinguished after the onset of flashover using a 25 mm (1 ins) fire brigade hosereel operating at 7 bars (100 psi) NP. Water was delivered in a fog pattern at a constant flow.

	ONE ROOM	
Floor Area	13.7 sq m	144 sq ft
Volume	33 cu m	1,152 cu ft
Flow Rate	25 LPM	6.6 GPM
Delivery Rate	0.8 LPM/cu m	0.06 GPM/10 cu ft
Flow Rate	68 LPM	18 GPM
Delivery Rate	2.06 LPM/cu m	0.1 GPM/10 cu ft
	TWO ROOMS	
Floor Area	27.4 sq m	288 sq ft
Volume	66 cu m	2,304 cu ft
Flow Rate	68 LPM	18 GPM
Delivery rate	1.03 LPM/cu m	0.08 GPM/10 cu ft

Table 3:2 – Salzberg test results.

In the one-room fires it was noted that the 25 LPM (6.6 GPM) flow rate produced the most effective results in terms of water usage. However, the increased control time, coupled with the amount of physical punishment suffered by the firefighters in terms of thermal exposure suggested that a somewhat higher application rate needed to be used. By increasing the flow-rate to 68 LPM (18 GPM) the operational effects were eased.

For the two-roomed fire a delivery rate of 68 LPM (18 GPM), which had sufficed for the one room fire, was again somewhat under-powered and the firefighters endured an amount of physical punishment. For this amount of fire a higher flow-rate of 112 LPM (30 GPM) was recommended as a minimum for comfort and safety. This conforms to a delivery rate of 1.7 LPM/cu m (0.1 GPM/10 cu ft). When an exact replica of the laboratory fire was set in a structural environment, firefighters required up to twice the amount of water used in the laboratory setting to extinguish the fires!

The study concluded by suggesting that delivery rates for small compartment fires should not fall below 0.8 LPM/cu m (0.06 GPM/10 cu ft) although firefighters had suffered at this rate.

The Fire Experimental Unit (FEU) *(Bibliography 3:4)* in Great Britain undertook some further evaluations of water-fog applications. Prior to live burns, they assessed various hosereel fog-guns at both low pressure (4 bars – 60 psi) and high pressure (35 bars – 500 psi) flows, measuring cone angles, droplet size, velocity, forward projection, and other important factors. Then, in a number of test fires, they utilised a remotely-operated rig to give a uniform assessment of each application. Previous manned trials had shown that the operator, a trained firefighter, would generally enter the fire room after about two minutes of fog application. The skill of the individual operator directly influenced the level of achievement.

The FEU conclusions from their tests were:

(1) The way in which a fog-gun is used in such a fire has far more effect upon the outcome than any differences in droplet sizes or velocities. The versatility and manoeuvrability of the gun appear to be the most important factors.

(2) In this particular trial, the differences in fire suppression performance between a low pressure spray and a high pressure fog were not outwardly marked or obvious.

(3) High pressure application was more effective in providing (1) smaller droplets, (2) better projection, (3) better heat absorption and cooling effect where correctly applied.

The FEU test room provided an interior volume of 50 cu m (1,764 cu ft), with an open doorway and two open windows. The fire load consisted of half a tonne of wood which was allowed to burn fiercely before the attacks progressed. Although the nozzle pressures varied widely, a constant flow-rate of 100 LPM (26 GPM) was delivered across the whole range of fog-guns, working on a 26 degree cone angle. The actual delivery rates in the FEU tests were constant at 2 LPM/cu m (0.1 GPM/10 cu ft), while the application rates were – in most cases – in excess of 10 l/cu m (0.5 gals/10 cu ft).

The 26 degree cone angle was selected for the tests because of its versatility, meaning it was the most effective single spread that had good effects on both cooling the general environment as well as the burning cribs. The report recognised the fact that in reality, a combination of indirect air cooling and a direct hit with a straight stream at the base of the flames would prove most effective. The FEU report noted a distinct trend emerge in the fire suppression efforts and they labelled this as the Three Phase Attack *(Figure 3:1)*:

● **Phase One:** Cooling the room prior to entry where a rapid reduction of air temperature took place as the first water to be applied was turned to steam. Average (chest high) temperatures at the doorway registered between 500-600 deg

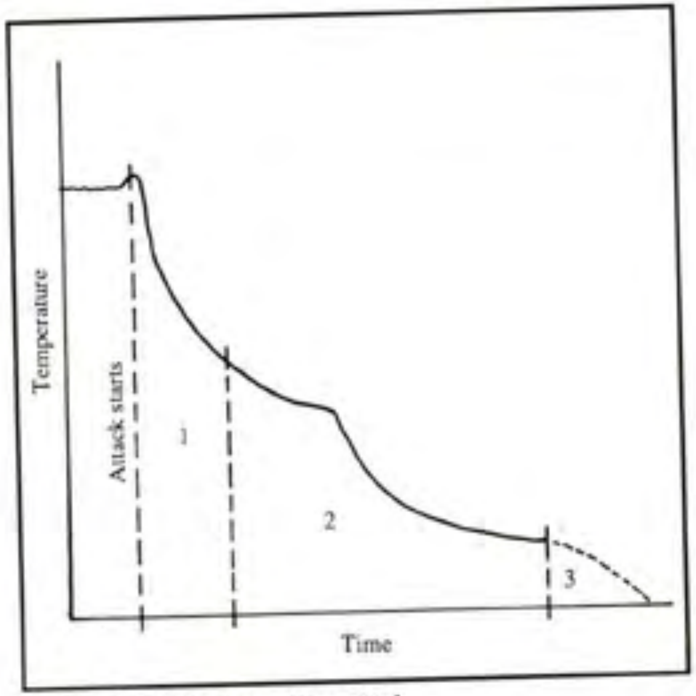


Figure 3:1 – FEU's three phase attack.

C. and generally increased by about 70 deg C for two to five seconds as the water was directed through the door. However, within 30 seconds of a continuous application the temperature at the doorway had roughly been halved to about 250 deg C (about a 10 deg C reduction per second). It is interesting to note that during manned tests the firefighter was unable to last for more than a few seconds in this extremely humid and hot environment, taking over seven minutes to finally enter and control the fire. *(Figure 3:2)*.

● **Phase Two:** Following the initial cooling period of 60 seconds the reduction in air temperature began to 'peter out'. At this stage the remote rig would advance into the room and begin an attack on the fire in an effort to bring it under control.

● **Phase Three:** Final extinction would take place, achieved in manned trials by local attack on hot spots.

A very broad trend was observed (although it was not conclusive) that a finer spray (smaller droplets) would have the effect of cooling further and faster. It was again apparent in 'manned' trials that operator skill most often affected the outcome of any tests, in relation to application rates and time to control. The FEU tests demonstrated that 14 'learning' fires were required before an operator's learning curve levelled out. The study further concluded that evidence from these trials indicated the way a fog nozzle was used to fight a fierce single room fire was more important than any differences in droplet sizes or velocities. This implies that fire brigades would achieve better results by evolving more effective tactics and techniques in their methods of attack.

As comprehensive as the FEU report was, it failed to address several important points relative to applying fog into a real fire situation. One of its failings was a

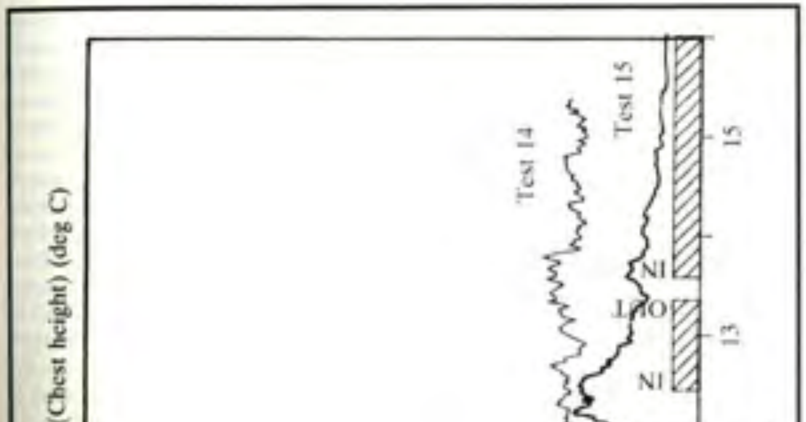


Figure 3:2 – How temperature affects performance.

presumption that firefighters would enter the fire room standing up, hence the doorway temperature measurements at chest height. An ideal entry to such a compartment would be in a crawling position. Even so, the report did provide some extremely useful information.

While research such as Kokkala's, Salzberg's, and that of the FEU in Great Britain, provides useful data on which to base fire flow assessments, all of these tests failed to address the most important factor of all – being 'application technique'. While some opted for an indirect approach, others followed a direct attack with spray patterns. However, many failed, even in their basic application, to observe simple rules. Where constant flows are discharged into the compartment the thermal balance will fail to support evaporation of the water and the fog effect is lost. The FEU tests, among others, demonstrated the effectiveness of various fog-guns in a direct attack mode, failing to utilise the actual benefits of a correct fog application.

Meanwhile, work was progressing in Germany, Sweden, and other parts of Scandinavia, where the principles of fog application were becoming highly advanced. During the 1980s, the advances made in fog attack prompted a reversion by many fire departments who had repudiated such tactics some years before. Two Swedish fire engineers, Krister Giselsson and Mats Rosander, advanced some excellent theories *(Bibliography 3:5)* based on work begun in the 1950s by Oskar Herterich in Germany. Their work was supported by much practical experience and the most modern technique of offensive firefighting was established.

Offensive Fog Attack

When it evaporates, water provides considerable quantities of water vapour which can result in surplus pressure in the room. A surplus pressure of this type can have both negative and positive results. One negative result is that the hot gases and vapour flow easily out of the opening, the risk being that the firefighter on the nozzle could be injured. A positive consequence is that the surplus pressure prevents air from flowing into the room, avoiding the possibility of flame-up. This is the principle upon which the indirect method was based – the creation of a surplus pressure within a compartment through the production of steam.

However, if the water fails to reach hot surfaces and evaporates in the super-heated fire gases, then a low pressure results. It is true to say that a litre of water still provides about 1,700 l of water vapour but the contraction of the fire gases is even greater than the amount of water vapour formed. This can be explained as follows:

1 lb of air at 1,000 deg F occupies 38 cu ft.
1 lb of air at 1,000 deg F would have sufficient heat to vaporise 0.24 lbs of water which, as steam, would occupy:

$$\frac{0.24 \times 1{,}700}{62.5} = 6.528 \text{ cu ft}$$

The 1 lb or air now at 212 deg F occupies 16 cu ft. Now add 16+6.528
It can be seen that the injection of water into the fire gases has produced a decrease in total volume to 22.5 cu ft – a reduction of a third.

A low pressure formed in this way can, as in the case of surplus pressure, be both negative and positive. A positive aspect is that firefighters operating on the nozzle are not subjected to the wave of hot gases and water vapour passing out through the door, a flow of air *into* the room being more likely. A negative aspect is that the low pressure created can give rise to an uncontrolled air-flow in other, more remote, parts of the compartment or structure.

This technique – where water fog is injected into the fire gases – is termed 'offensive firefighting'. It differs from the indirect approach in both its application and method of extinguishment. To mount an offensive fog attack it is necessary to have a fog nozzle, or gun, capable of producing extremely small droplets, preferably less than 0.3 mm in diameter. When applied in this state, the fog will appear as a 'mist' and will hang in the fire gases for several seconds. If the nozzle design is capable of producing extremely small droplets, the absorption and cooling effect is

increased. If the droplet diameter is halved, the number of droplets increases to eight and the rate at which the fog falls from its suspension in the fire gases is decreased. On the whole this means that the amount of cooling particles in the burning gases can reach a value where flammability is made impossible.

Because of the fog's ability to hang in the air, the demand on a sufficiently high temperature within the compartment is no longer necessary for a fog attack to be successful. Further still, the room no longer needs to be sealed, as is the case for an indirect approach, offensive attack functioning equally well in ventilated spaces and even outdoors. Ventilation and extinguishing can be carried out at the same time and re-ignition of the gases during the ventilation phase can easily be prevented where the atmosphere is inerted before it mixes with the outside air.

Rules for Offensive Firefighting

The term 'offensive firefighting' is used to describe a technique of applying fog into a compartment. It implies that the method demands a more offensive approach than that of indirect application, where the fog pattern was usually injected into the compartment from outside, or from a doorway. The correct application of the offensive technique demands that the operator enters the room, behind a defensive spray if necessary, to inject the fog into the fire gases. Depending on nozzle design, the most effective cone angle for an offensive operation will be around 60 deg.

It will be necessary, for the best cooling effect, to hold the nozzle low, aiming upwards at a 45 deg angle from the floor and moving the stream in a backwards and forwards motion towards the fire room. Such action will allow the droplets to pass the maximum distance through the fire gases and cool off the penetration route. It is *essential* that the fog is applied in short bursts of two to four seconds with about a six second pause between applications. This will ensure an optimum effect in cooling and inerting the fire gases, and maintain an extremely low level of water run-off.

When entering the fire room, if possible, get a position about one metre inside from the penetration opening. This will be a good location from where to mount the attack, cooling the gases again in four second bursts with a fast moving nozzle.

With modern fog nozzles giving stream projections of 5 to 10 m (15 to 30 ft) when in a spray setting, in actual practice it would be difficult to avoid some of the fog striking hot surfaces within an average room of, say, 50 cu m (1,700 cu ft). However, this is perfectly desirable to create an optimum effect in extinguishing the fire. In fact, the ideal fog application is a mixture of offensive, indirect and direct injection:

(a) By concentrating the application of the fog patterns into the upper strata of fire gases in an *offensive* style, a negative pressure is created within the compartment as the gases are cooled and inerted.

(b) It is inevitable that by utilising a fast moving nozzle technique in a sweeping motion, with stream projections in excess of 5 m, an amount of water will strike hot surfaces within the compartment. This will have the effect of creating a surplus pressure in some remote areas of the room. However, any expansion of water vapour through minor *indirect* application to hot surfaces will be counteracted by the negative pressure created as fire gases contract.

(c) Whatever the fire load is, in the compartment, it will require some amount of cooling itself if it is to be prevented from forming additional fire gases. Where the pressure in the compartment is kept constant there can be no smothering effect, nor will water vapour play a big part in such control. It will therefore become necessary to account for this when sweeping the nozzle and a *direct* hit should be aimed briefly at the source of the fire load.

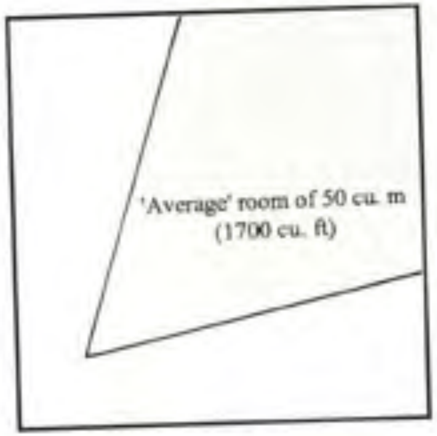


Figure 3:3 – Offensive fog attack.

During an offensive fog attack, a 60 deg cone spread from an effective nozzle, directed at 45 deg, will suspend 16 cu m (571 cu ft) of fine droplets in the upper strata. If operating at a 100 LPM flow, a four second 'burst' will place 6.6 l (1.7 gals) into the cone. Of this amount, two-thirds will suspend in the gases and one-third will find its way on to hot surfaces.

This will have the following effects: 2.2 l (0.56 gals) will strike hot surfaces, evaporating about 3.6 cu m (130 cu ft) of water vapour, while 4.4 l (1.13 gals) will suspend in the gases to cool and reduce their volume by a third – (16 cu m (571 cu ft) of gas/air are reduced to 9.5 cu m (338 cu ft) as the gases contract.)

9.5	338
3.6+	130+
14.2 cu m	468 cu ft

It can be seen that the four-second spurt has reduced air-volume in the compartment by six per cent – this effect being proportional to both nozzle flows and any sweeping action.

While this style of offensive fog application has been very much a Swedish innovation, following a course of development throughout the 1980s, there have been several recent studies in the USA that may have moved some way towards addressing these modern techniques of fog attack. Notably, some electrical cable fire tests in 1985 *(Bibliography 3:6)* also reported in some scientific literature in 1986 *(Bibliography 3:7)*. Similarly, the US coastguard gave mention to what they described as the 'short water burst' technique, during tests sponsored by the Naval Sea Systems Command (NSSC) of the US Navy in 1990 *(Bibliography 3:8)*. During this course of testing, wood cribs were burned both in the open and within the confines of a 20 cu m (687 cu ft) compartment, to evaluate 'low-flow water hose streams'. This series of assessments were a graduation of earlier tests that had been

completed by the US Coastguard in 1988 *(Bibliography 3:9)*. Various equipment ranging from portable extinguishers, lightweight hosereel systems, and mid-sized (40 mm) handlines, were compared in their effectiveness, as were several application techniques. There were descriptions of firefighters applying short bursts of water fog into the compartment and then crouching low between bursts to enable the steam cloud to pass over them and out of the compartment, thus avoiding any excessive build-up of steam or pressure within.

During 17 'burns' completed within the compartment where pre-burn times of eight to 15 minutes enabled temperatures in excess of 500 deg C (932 deg F) to be reached at the ceiling and 200 deg C (392 deg F) at chest height, the options of direct or indirect attack, coupled with continuous stream flows, or short water burst techniques were all analysed. The NSSC tests concluded with several lessons learned, or reinforced that:

- Anything from 15 to 50 times more water was used to extinguish the same sized fire when contained within a compartment, as opposed to being in the open.
- As firefighters gained experience through the natural learning process of the test-burns their effectiveness increased dramatically.
- It was suggested that time would be well spent in improving firefighter training, tactics, and application techniques.
- High-flow (280 LPM – 74 GPM) mid-sized handlines would register far higher application rates than low-flow (57 LPM – 15 GPM) 19 mm hosereels. For example:
  Two hosereel tests (11 and 12) required application rates of 7.5 l/cu m (0.58 gals/10 cu ft).
  Typical handline flows registered application rates of 19 l/cu m (1.45 gals/10 cu ft), and 45 l/cu m (3.49 gals/10 cu ft).
- Data from the tests suggested that the short burst technique demonstrated better efficiency in terms of cooling, flame knockdown, total extinguishment time, and the amount of water used.
- A continuous application would most certainly engulf the firefighter in steam, possibly causing serious burns.
- The levels of protective clothing, as worn by firefighters, would determine his ability to get in and remain there while the fire was extinguished. This included gloves and full face hoods.

While it may appear that the short water burst technique is the same as an offensive application, in effect, the USA studies, to date, have failed to address the concept. In the NSSC tests, little attention was paid to cooling ratios (ie: 2-1 air-surface). In fact, the test compartment was not suited to a true offensive fog attack where the room volume was small and compact, and a low ceiling (2 m) existed. Also, there was much floor to ceiling furniture within the compartment and any cone spread, under these conditions, would be bound to favour the hot surfaces, resulting in excessive steam production. In fact, the high application rates demonstrated throughout these tests can certainly be attributed to the layout of the test compartment, where access to the fire was purposely restricted.

Airflow Creates Pressure Wave

As William E. Clark had so graphically demonstrated in his book, an undesirable by-product of confined fog applications was the pressure wave that moved ahead of the stream. This forced flow of fire gases within a compartment, or structure, would often result in the fire intensifying and escalating into uninvolved areas. The force of this air movement would, occasionally, drive the fire out of openings to the rear, allowing the flames to extend under the eaves and into the attic, or creating an exposure hazard to nearby structures. This effect could also force occupants trapped in the rear to jump out of windows in an effort to escape the sudden escalation of the fire.

This unwanted wave of heat, smoke and flames created many problems at fires and, again, firefighters had good reasons to doubt this wonder approach to extinguishing a blaze. The problems were caused by: (a) excessive water vapour created by an indirect attack; and (b) an in-flow of air into the compartment as it became entrained into the fog stream. These two factors, combined with the velocity of the fog stream, allowed an excess pressure of some proportion to move ahead of the stream and exit through natural openings. Where such outlets were non-existent, the fire would 'envelope' back towards the advancing firefighters.

However, correct application of offensive techniques will prevent such an effect from occurring and avoid the many problems associated with an indirect approach. We have already seen how a negative pressure can be created within a compartment by resorting to offensive fog techniques although the calculations failed to take account of any air entrainment into the stream. It is well understood that an in-flow of air occurs but just how much is actually entrained?

The University of Maryland completed some tests on air entrainment into fog streams, and demonstrated the effect of a fog nozzle sited 2 ft beyond an opening (window). This would correspond with a nozzle sited 2 ft inside a doorway – an ideal position from which to mount an offensive attack. The nozzle used in the test was flowing 60 GPM (227 LPM) at a NP or 100 psi (7 bars). This could be considered an average flow for a fog nozzle. The amount of air moved through the opening, at these settings, was 1,961 cu ft per minute (cfm).

Now, if we refer back to our calculations of vapour expansion, and air contraction, where an offensive application is made into an average sized room, we may observe that a four-second burst of fog reduced the air volume within the compartment by 103 cu ft, or six per cent. If we assume that an air-flow of 1,961 cfm is entrained into the stream, then this amounts to an additional 130 cu ft of air in the room. In effect, the original air volume within the compartment has now been raised by 1.6 per cent since a four-second burst was applied, although such a small increase in pressure will hardly be felt in a compartment of this size. While the air volume may continue to increase for each burst, unless relieved through ventilation, there is a knock-on effect. As the atmosphere is cooled, each additional burst will bring more air into the compartment. The finely divided mist mixes with this air to prevent sudden flame-up and increases the cooling effect on the fire. As the atmosphere is cooled, and inerted, with subsequent bursts there is less evaporation and the ever-increasing in-flow of air reduces the humidity level and the whole environment becomes more comfortable.

This example clearly illustrates exactly how offensive fog attack and ventilation tactics complement each other on the fireground. It is no longer necessary, nor is it recommended, that a compartment remain closed while a fog attack is mounted. Although the increase in air volume experienced within the compartment is minor, a ventilation opening made in conjunction with an offensive operation will optimise the overall attack and maintain a comfortable environment for building occupants.

It becomes apparent that a *constant* flow of any fog pattern discharged into a structure will create a pressure wave ahead of the stream, even where heat is unable to vaporise the water. Such an application may occur with inexperienced operators and every effort should be made to discourage such action, for fear of directing the

fire towards uninvolved areas. By applying the pattern in short bursts, pausing and advancing, and then applying again, the pressure wave effect will not occur.

On occasions, an offensive application has been known to create a true negative pressure within the fire compartment. This effect is sometimes noted by fire investigators following the fire's suppression. Window glass has been observed to have imploded into the structure, rather than exploding, or bowing, in an outwards direction. Such an occurrence may serve as an indicator of a successful application, creating a reduction in compartment pressure.

While applying such techniques, it should be remembered that the cooling and inertion of the fire gases, whether they are burning or not, is the main aim of the operation. This immediate hit into the upper strata will reduce flashover potential and cool the compartment for comfort. If, while working in a room, the formation of water vapour is excessive simply cool the gases with a quick burst, allowing their contraction to absorb the excess pressure.

Figure 3:4 – Types of fog nozzle teeth.

Fog Guns and Nozzles

Fog and spray type nozzles have been in use since the 1940s. Most of these fog nozzles had one trait in common – they all relied on stream impingement or some form of fog teeth to produce the wide fog pattern.

The earliest style of fog nozzles used square faced metal teeth *(Figure 3:4 bottom right)*. Two problems existed with this design: (1) the square faced teeth left gaps, or 'fingers', in the fog pattern which allowed heat to pass through to the operator; and (2) the metal teeth were susceptible to damage when dropped.

The next generation of fog nozzles used spinning teeth *(Figure 3:4 bottom left)* which appeared to eliminate the fingers of the wide fog. However, although this design greatly reduced the amount of radiant heat transmitted through to the operator, high-speed photographs proved that they were still there. The spinning teeth design was most effective in creating fine water droplets, ideal for offensive fog operations. The mist produced was so fine it was capable of suspending these ultra-fine droplets in air for several seconds.

This state of droplet suspension is not possible with conventional fog nozzles that produce more of a spray than a fine mist. To create such a fog will normally require flows in excess of 100 LPM (26 GPM) from a nozzle designed specifically for the purpose. Where fog guns are used in conjunction with hosereel tubing systems the actual flow is of less importance than the amount of pressure required to produce the necessary droplet size. Systems operating on low pressure (7 bars – 100 psi) are unlikely to produce an effective fog for offensive purposes. Hosereel systems working at 20 to 40 bars (290 to 580 psi) high pressure are more suited to such operations. Such systems generally consist of 19 mm (¾ ins) bore lengths of reinforced rubber tubing wound on to a drum. The advantages of such equipment are obvious in its versatility, light weight, manoeuvrability, low nozzle reaction and speed of deployment, and placement within the fire building. The European concept of fire suppression is strongly established around the hosereel system and firefighters have become masterly in mounting their tactical fog-attacks with one, or several hosereel tubings. In London, for example, over 50 per cent of occupied building fires are handled with the high-pressure hosereel system, generally utilising the 1,365 l (360 gallon) water tank for complete control. However, the one disadvantage of this sytem is in frictional losses. London firefighters have been restricted to 20 bars (290 psi) pump pressure as the standard operating pressure for this type of equipment at fires.* *(See footnote)* At this pressure the 'Hyperfog' nozzle will discharge 70 LPM in either a solid stream or fog pattern. (Higher flows will result at higher pressures.)

The Fire Experimental Unit (FEU) based at the Fire Service College in Gloucestershire, England, carried out some extensive testing *(Bibliography 3:4)* of hosereel systems fitted to fire pumpers and showed that the pressure loss through smallbore tubing can be excessive at certain flows. Where London firefighters operate their 'Hyperfog' nozzle at a pump pressure of 20 bars, the pressure loss through three lengths of 18.3 m, 19 mm bore, tubing will total 4.5 bars. So as the pressure gauge on the pumper registers 20 bars (290 psi) the actual pressure reaching the nozzle is only 15.5 bars. In effect, this has reduced the flow from 90-70 LPM (24-18 GPM) *(Figure 3:5)*.

Since the days of low-pressure hosereel systems, the provision of multi-stage pumps and high-pressure tubing and guns have become standard. However, pipework between the fire pump and hosereel drums has failed to keep pace with modern flow requirements and the internal bore of both hosereel tubing, and

*This restriction was enforced following a mechanical problem with a particular type of pump. This has now been rectified and the restriction on pressure is being rescinded. The Galena 'Hyperfog' nozzle is designed to operate at an optimum nozzle pressure of 20 bars. this will require a *pump* pressure of about 35 bars to flow 90 LPM at the nozzle.

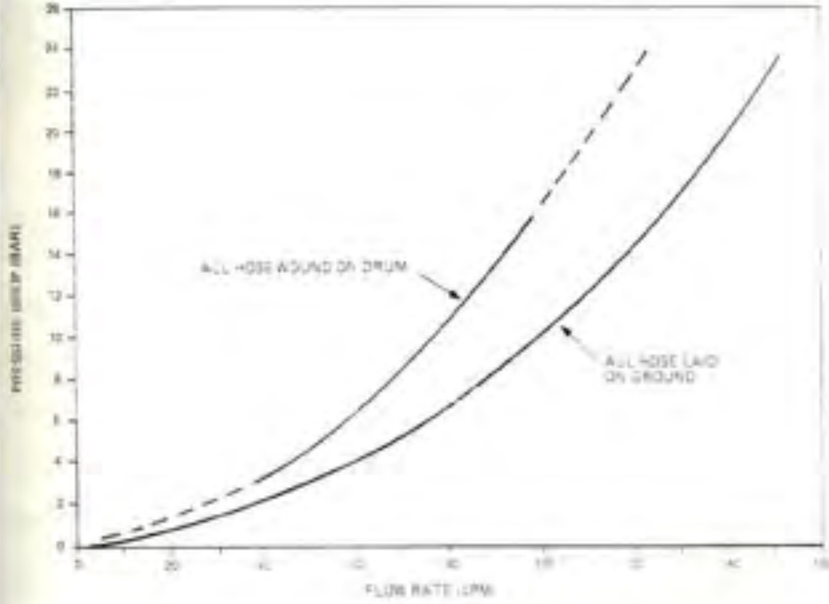


Figure 3:5 – Pressure losses versus flow for three 18.3 m lengths of 19 mm bore hosereel.

internal pipework, now serve to restrict the high-pressure flows. This becomes even more important where set operating pressures of 40 bars at the pump can mean only 30 bars at the nozzle. The fire departments in Milan, Amsterdam, Zurich, and Cape Town, South Africa, are among many who adopt high set pressures within this range. The potential for a 25 mm bore tubing is currently being evaluated by the FEU in England. *(Figure 3:6)* Although flow-rates, stream reach, and pump efficiency will be improved with the larger bore, the additional weight of charged lines, and extra storage space on the pumper, are most certainly the negative aspects.

A further development of fog nozzles introduced a double row of teeth *(Figure 3:4 top)* where it was attempted to fill the gaps between the teeth by creating another point of deflection. However, the second row formed 'fingers' of its own and therefore left gaps in the pattern.

Task Force Tips (USA) claim to be the first to develop moulded rubber fog teeth as an integral part of the bumper. The strong, pliable fog teeth resist damage by springing back to their original shape after impact. Such teeth are essential to producing a good fog pattern. The use of computer aided design has allowed TFT to create a fog pattern that has full fill to the cone without fingering *(Figure 3:7)*. Each fog tooth has been shaped to form a small nozzle with the proper stream spread so as to overlap the next tooth. The face of the bumper is specially engineered to 'pull' the water to a wider pattern. The tremendous pulling effect can be seen when slowly moving from partial fog to the wide fog pattern. The TFT rubber tooth

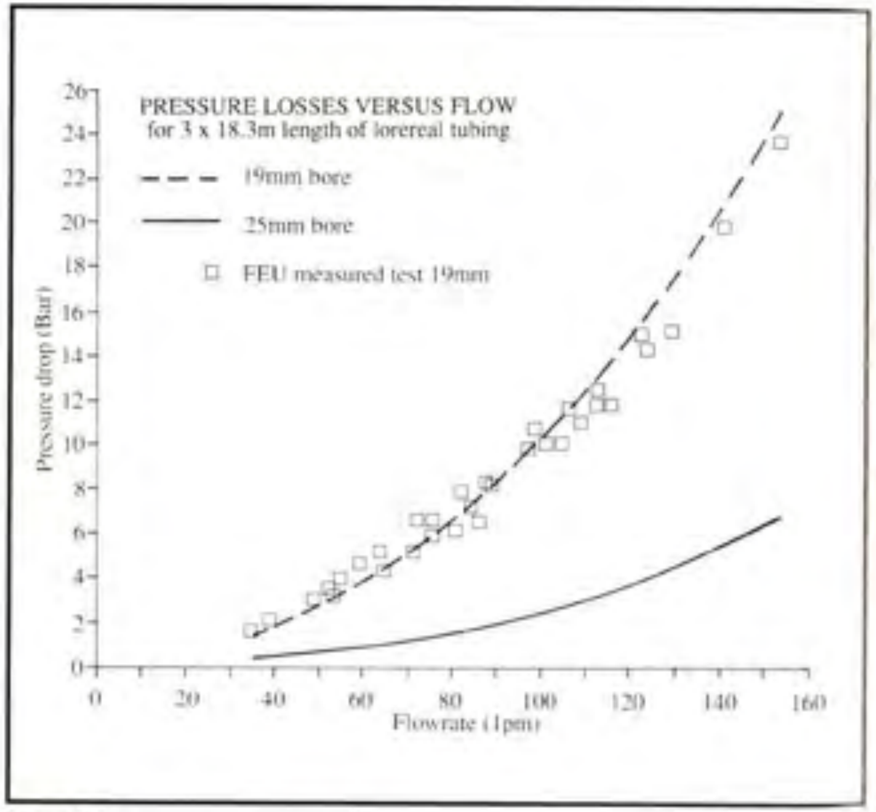


Figure 3:6

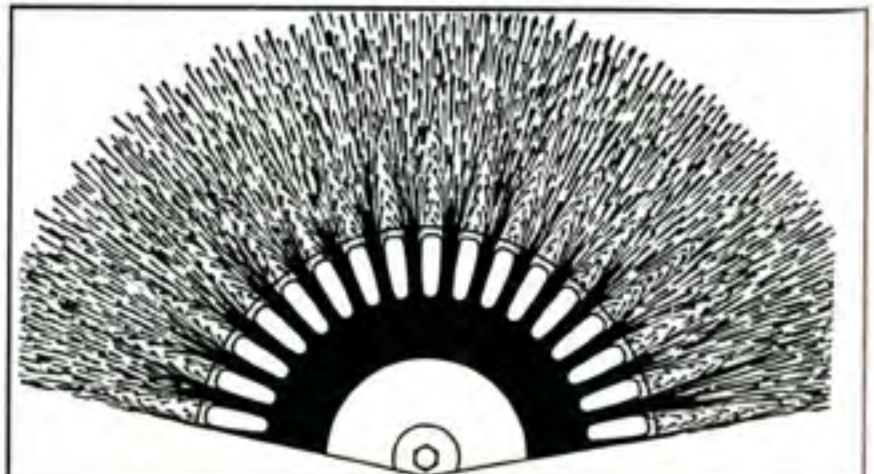


Figure 3:7 – Fog pattern-moulded rubber teeth provides full fill to the cone with no 'fingering'.

is designed to produce a wide range of droplet sizes, from moderately coarse to extremely fine. The pattern has excellent heat absorption, due to the fine droplets, yet produces large droplets for maximum reach and projection. The combination of these two effects provide a densely filled outer cone of water. This outer cone blends with the inner ball of water created from the fronts of the fog teeth to form TFT's 'Power Fog'.

LPM	*Nozzle type*	*GPM (US)*
709	20 mm (¾ ins) smooth bore 7 bars – 70 mm hose	187
650	Hyperfog 150 7 bars – 70 mm hose	172
567	H Task Force Tip V 7 bars – 65 mm hose	150
500	Fogfighter I 7 bars – 52 mm hose	132
450	Hyperfog 450 7 bars – 70 mm hose	120
400	Hyperfog 100 7 bars – 70 mm hose	105
350	Fogfighter II 7 bars – 38 mm hose	93
278	12.5 mm (½ ins) smooth 7 bars – 45 mm hose	74
205	Tokyo FD Fog Gun 15 bars – 40 mm hose	54
90	Hyperfog (London) 20 bars – hosereel	24

Table 3:3 – Typical flow rates.

Radiant Heat Effects at the Nozzle

As a firefighter advances on a major fire-front, whether it be an interior or exterior situation, he relies upon his equipment to protect him. If his protective clothing forms the basis for his last line of defence, the effectiveness of the fog pattern in use will certainly represent his front-line defences.

The Naval Research Laboratory (USA), were responsible for a series of tests *(Bibliography 3:10)* that evaluated the heat obscuration capabilities of two nozzles. The results of their tests demonstrated, and confirmed, that higher nozzle pressures reduced the amounts of radiated heat passing through the fog pattern, although there are other factors involved. Obviously, the amount of water discharging is a relevant factor, as is the density of the fog. Where 'fingers' formed in the pattern, heat obscuration was less efficient and higher amounts of radiated heat were recorded behind the nozzle. As a rough rule of thumb guide, it may be presumed that the percentage of radiation penetrating the fog pattern will conform to 70 per cent of the heat flux at 10 psi NP, reducing by 10 per cent for each 10 psi added to the NP, until 80 psi is reached, where the penetration is near zero *(Figure 3:8)*.

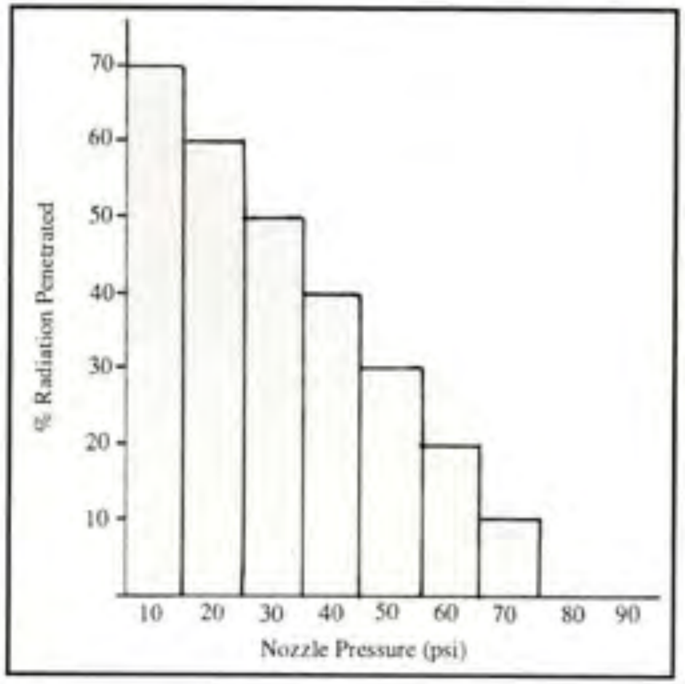


Figure 3:8 – Effect of radiant heat on the nozzle.

Another factor worthy of consideration is 'cone spread' angle. While a 60 degree cone is ideal for mounting an offensive attack, a reduction in cone angle will divert more force into the stream and drive the flame front away from the operator. However, a situation may arise when the cone angle is too narrow, allowing some radiated heat to penetrate around the cone's edges.

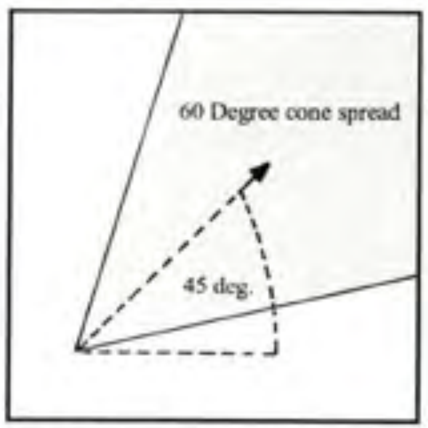


Figure 3:9 – Cone-spread.

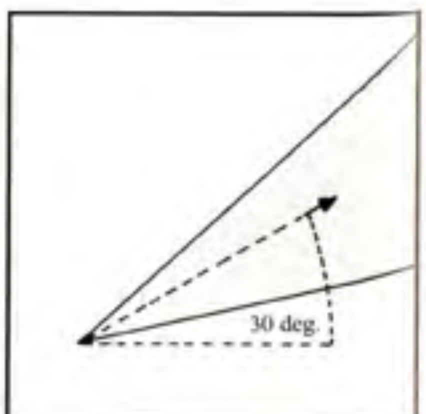


Figure 3:10 – 30 degree cone-spread.

As a recent nozzle manufacturer proved, even a reduction in nozzle pressure from 100 psi (7 bars) to 75 psi (5 bars), or an increase in cone spread from 95 deg to 110 deg may allow additional radiant heat to penetrate the spray pattern.

Cone angles are important when fog is applied and firefighters should familiarise themselves with the various patterns and effects. Spray patterns of 120 degrees are commonly found and many nozzles provide a twist grip control to reduce sprays down to a concentrated solid stream. Some have settings that provide a choice of two or three cone angles at the flick of a wrist. The Swedish principle of a 60 deg cone for offensive operations is based around the 'Fogfighter' nozzle that produces an ideal droplet size at that angle. The coverage at this setting, if applied 45 degrees to the floor, gives a 2-1 cooling ratio (fire gases to hot surfaces). That means that two-thirds of the cooling effect is applied into the upper level of fire gases. The remaining third of the water will strike surfaces, and some evaporation will occur. However, the extremely fine particles will ensure the maximum contraction of heated gases and prevent excess pressures within the compartment from driving steam at the operators.

The angle of cone-spread that provides the optimum fog pattern, ie, the smallest droplet size, will vary between manufacturers. The 'Fogfighter' nozzle gives optimum results around the 60 degree spread. To ensure the cooling of fire gases is optimised, the pattern should be applied at a 45 degree angle to the floor. In effect, this can be achieved by aiming the nozzle at an imaginary centre-point on the ceiling.

It is important to understand what might happen if the cone spread is altered. By widening the spread the amount of water evaporated in the fire gases increases. This, in turn, reduces the total air volume within the compartment, possibly creating a true negative pressure. Alternately, a narrowing of the spread will increase air volume even more. While minor increases are not a problem, excessively high levels of air volume may be undesirable. The ways of relieving excessive build-up of air volume within a compartment are: (a) ventilation, or (b) widening the cone spread.

A narrow angled cone-spread, such as the 30 degree pattern, is used by many firefighters. While the coverage again favours the fire gases by a 2 to 1 ratio, the droplet size may not be as efficient at this setting. The 30 deg cone should be applied at a more shallow angle to the floor, around 30 to 35 degrees. To achieve this in an average sized room (50 cu m) the operator should aim the centre of the fog pattern at the far upper corners of the room. In all cases, an upwards pattern at a 90 degree angle is not recommended as the amount of surface area cooled may outweigh the cooling effect applied to gases, creating an imbalance in compartment pressure where excessive water evaporation occurs.

It is worth noting that tests on cone angles have shown that any cooling effect at the room entrance doorway is likely to be reduced by widening the cone. This is probably because the amount of air entrainment is lowered.

Flow Calculations

So far we have discussed how it is possible to extinguish a compartment fire with water application rates as low as 0.1 to 0.3 l per sq m, using the indirect method of applying fog. With the advent of offensive tactics it is suggested that gas/flame mixtures can be extinguished, or inerted, with an application rate of 0.25 l per cu m, and we have seen applications ranging from 0.4 to 10 l per cu m in both laboratory, and structural compartment test settings.

It is extremely useful for firefighters, or fire engineers, to be able to assess fire flow requirements. There are numerous opportunities to use such information, for example: when assessing the fire flow capabilities of standpipe water rising mains, or fire hydrants, or when assessing the needs on the fireground for any particular situation, or when testing new nozzles or fog guns, etc, the list goes on.

Several attempts have been made – particularly in the USA – to develop a reliable formula that firefighters or engineers could resort to when calculating such flow requirements. In 1963 a fire flow formula was devised by K. Royer and F. W. Nelson of Iowa State University. This work was based very much on scientific theory and the heat absorption capabilities of water. The formula told us that:

$$\text{GPM} = \frac{\text{Fire Area (cu ft)}}{100}$$

Therefore, the average room used in previous examples (1,700 cu ft) would require a minimum flow of 17 GPM to bring it under control. If a large structure of 100,000 cu ft became fully involved in fire, the formula tells us that a flow-rate of 1,000 GPM is required on the fireground.

During the early 1980s the National Fire Academy (NFA) of the USA, expanded upon the Royer/Nelson theory and developed their own formula *(Bibliography 3:11)* for estimating flow requirements at a fire. A number of modifying factors were added to the original formula to account for variables such as occupancy, exposures, and per cent of involvement. Unfortunately, the formula became so complex in its mathematical operation, its suitability for the fireground suffered. This was rectified some years later when the NFA recognised the need for a quick form of calculation that would assist the fire officer on scene in assessing water requirements. An updated formula was devised by the NFA's course development team from a study of articles describing fire department actions at numerous fires. By working with the formulas for volume and area, it was found that the actual fire flow that was applied to real incidents most closely approximated:

$$\text{GPM} = \frac{\text{length} \times \text{width (ft)}}{3}$$

Applying this formula to the previous two examples tells us that the 'average' room requires 70 GPM while the large structure will require 3,333 GPM for control. This would suggest that the original Royer/Nelson formula was very under-estimated.

In my own experience, I find both of these fire flow formulas provide *over-estimates*! Of the two, the Royer/Nelson theory is closest to real fire requirements. This led me to develop my own formula, based upon both scientific theory *and* practical experience at fires. I believe it provides a much closer estimate to water flow requirements, both at fires of a minor domestic nature and the larger conflagration. It is important to remember it is a rough fireground 'rule of thumb' and is open to variables at any fire that may affect its reliability, for example: levels of high fire load will place the formula under strain to meet requirements. It is based upon a normal office fire load and excessive loads are not accounted for. Also, levels of skill, of nozzle operators, will affect the outcome, occasionally using *less* water than the formula suggests. However, as a fireground aid, I feel the formula is extremely useful to the fire officer on scene and is worthy of many other uses in the field of fire protection.

Following some extensive studies of fire flows at actual incidents, both in England

and the USA, it became apparent that the figure of 0.5 LPM/cu m (0.04 GPM US/10 cu ft) was a very close average to the actual demands of firefighters on scene. Where flow requirements were excessively higher there was generally a good reason for such a variance. For example, the high flow requirements at the Empire State Building fire in July 1990 can be explained by the severe 'blowtorch' effects on the fire floor, created by winds entering and fanning the fire during firefighting operations. A survey of six major high-rise office fires demonstrates the flows required on upper floors to bring such conflagrations under control *(Table 3:4)*. In four of the cases the flow-rate was near, if not exact, to the 0.5 LPM/cu m mentioned earlier.

Building – and No. of Floors Involved	*Total Fire Zone* ft^3	m^3	*Flow-rate* *GPM*	*LPM*	*Delivery-rate* *GPM/10* ft^3	*LPM/*m^3
Interstate Bank – Los Angeles. 4.5 floors	800,000	22,400	2,200	8,300	0.03	0.4
Twin Towers World Trade Centre – New York. 1 floor	100,000	2,800	600	2,268	0.06	0.8
New York Plaza 2.5 floors	400,000	11,148	2,100	7,938	0.05	0.7
Empire State Building – New York. 1 floor	9,160	260	450	1,700	0.5	6.5
Westvaco Building – New York. 1 floor	60,000	1,680	1,050	3,969	0.17	2.3
Churchill Plaza – Hampshire, Eng. 2.1 floors	439,000	12,300	1,600	6,000	0.04	0.5

Table 3:4 – Fire Flows at High-rise Office Fires

If we look back to the Kokkala and Salzberg test burns, we may observe several delivery rates used to extinguish the fires ranging from 0.8 LPM/cu m (0.06 GPM/10 cu ft) to 2.14 LPM/cu m (0.1 GPM/10 cu ft). The conclusions of these tests were that, although fires could be extinguished at delivery rates of 0.8 (0.06), firefighters suffered undue amounts of physical punishment at such levels and higher rates would be advised in practice. As a metropolitan firefighter, I cannot remember a fire where I did not suffer undue amounts of physical punishment!

A professional assessment of our role, other than rescue, would be to extinguish a structure fire with the minimum amount of water damage resulting, while maintaining a safe approach at all times. In achieving such an objective firefighters must be prepared to suffer some physical punishment. I am certain the immense tasks performed by firefighters on the upper floors of blazing high-rise buildings caused them all to suffer varying amounts of physical stress – this is our occupation. Obviously, any opportunity to reduce such stress should be grasped, but this should not normally mean washing the building down the road!

It can be argued that a higher delivery rate (LPM/cu m) will result in a lower application rate (l/cu m). This means a delivery of 2.14 LPM may extinguish a fire in seconds, while a lower rate of 0.8 LPM may take a couple of minutes. In effect, by using the higher rate (2.14) a lesser amount of water is actually applied. At larger fires – where water flow is available – this fact is probably true, but when dealing with compartment fires, it is my experience that, in general, the opposite effect results.

Therefore, if we presume that 0.5 LPM/cu m (0.04 GPM/10cu ft) is the delivery rate required to control a fire in a structure, large or small, of average fire load with no immediate exposure problem, the formula for calculating the required fire flow is:

$$\text{LPM} = \frac{\text{Volume (cu m)}}{2}$$

OR:

$$\text{GPM (USA)} = \frac{\text{Volume (10 cu ft)}}{27}$$

If we apply the Royer/Nelson, NFA, and above, formulas to the six high-rise office fires we get the following results (given in US GPM):

Fire	*R/N*	*NFA*	*Mine*	*Actual*
Interstate	8,000	26,666	2,962	2,200
Twin Towers	1,000	3,333	370	600
NY Plaza	4,000	13,333	1,851	2,100
Empire State	92	305	34	450
Westvaco	600	2,000	222	1,050
Churchill	4,390	14,800	1,626	1,600

Note: The nearest estimates to the actual are underlined.

In an effort to assess the formula's (V/2) reliability it was applied to 100 fires, selected at random, as they occurred in London over a six week period *(Table 3:5)*. All fires were large enough to request additional engines, above the initial attendance, before control was gained. The structures, generally of brick and joist traditional construction, ranged from private houses, to multi-storey apartment blocks, modern office buildings, large single and two storey factories, and several large warehouses with open-plan floor space. The actual areas involved in fire ranged upwards from 40 to 4,300 cu m, with an overall average of 786 cu m.

While 34 per cent of the fires were controlled by firefighters utilising one, or several, hosereel (booster) lines, the remaining 66 per cent of fires required larger hose streams using both 12.5 mm (½ ins) and 25 mm (1 in) nozzles. On two occasions, aerial water towers were in use. It was apparent that several outstanding 'firefights' had occurred, based on fog attacks, notably: ● 200 cu m of fire on four floors; extinguished by two hosereel lines; ● 200 cu m of fire on three floors, and roof void; extinguished by two hosereel lines; ● 480 cu m of fire on two floors; extinguished by two hosereel lines.

It is also worthy of note, that when applied to fires in office buildings the formula calculated the flow requirements almost exact on most occasions. (Remember, it was originally based upon normal office fire loads.)

Looking at *Table 3:5*, it is most notable that at 41 per cent of the fires surveyed the formula suggested flows that were either exact, or too high, to actual flows used. This in turn would suggest that fires *can* be extinguished with delivery rates

of 0.5 LPM/cu m (0.04 GPM/10 cu ft) and the formula is fairly reliable for estimating flow requirements. On the 59 occasions the actual flows were in excess of formula prediction, either:

(a) The building contained a high fire-load, requiring greater striking power from heavy streams.
(b) The structure itself became involved in the fire in addition to the compartment's fire-loads. Remember, the formula is based on office compartment fire loads. Where structural elements are additionally burning, more water will be required.
(c) It is likely that, on occasions, a delivery rate in excess of actual requirements was used to extinguish the fire (reflecting an operator skill factor).

By resorting to the V/2 formula, and taking the above points into consideration, the incident commander will be able to asses his resource requirements with a good degree of reliability.

● **25 per cent**	The formula estimates corresponded almost exactly with actual delivery rates 25 per cent of the time. The 'actual' flows were occasionally higher, but by no more than three per cent.
● **21 per cent**	Higher rates actually flowed on the fireground than the formula predicted, and 21 per cent of the time the actual flow registered a figure 50 per cent higher than calculated by formula.
● **21 per cent**	On 21 per cent of occasions a much higher flow (12 per cent higher) was required than suggested by formula.
● **17 per cent**	On a further 17 per cent of occasions, flow rates up to three times the amount predicted by formula were used to control the fire.
● **16 per cent**	At sixteen fires, 'actual' flow-rates were lower than predicted by the formula, sometimes 50 per cent lower.

Table 3:5 – 100 fire survey, London

Water Flow-rates Scenario

The following scenario is based on the author's actual fire experience and presents a comparison of expected delivery and application rates for a standard fire.

A traditionally constructed building of four storeys has full fire involvement of the timber stairway between three levels (totals 60 cu m). Additionally, three stair landing/halls (each of 30 cu m) and two rooms (each of 100 cu m) at different levels are also fully involved. The total of 'post-flashover' fire involvement within the structure is 350 cu m. The fire load involvement consists of normal wall, floor and ceiling linings, average room furniture of timber, plastic and polyurethane foam, and the timber stairway between three levels. The fire has self-vented through a skylight sited at the head of the stairs.

● **Attack 1:** A single line of 45 mm hose flowing 200 LPM through a 12.5 mm nozzle is advanced into the structure. In practice, it will take four firefighters about four to five minutes to advance this line to the top floor, extinguishing fire on the way. Presuming a constant delivery rate 80 per cent of the time, an application of 800 l has been discharged into the building.

● **Attack 2:** A single line of 45 mm hose flowing 100 LPM through a 'Fogfighter' nozzle is applied in offensive fashion on a 4/6 second spurt/pause cycle. At this rate it will take four firefighters four minutes and 30 seconds to advance this line to the top floor, extinguishing fire on the way. The total amount used to extinguish the fire is 180 l.

● **Attack 3:** A single line of 19 mm hosereel tubing flowing 70 LPM through a 'Hyperfog' nozzle is applied in offensive fashion on a 4/6 second spurt/pause cycle. At this rate it will take three firefighters six minutes and 20 seconds to advance this line to the top floor, extinguishing fire on the way. The total amount used to control the fire is 177 l. To achieve maximum effect, two hosereel lines advancing to the top floor, working in unison, would take five firefighters about half the time to deliver the same amount of water.

	Flow LPM	*Control Time*	*Delivery LPM/cu m*	*Applied L/cu m*
Attack 1	200	5.00	0.57	2.28
Attack 2	100	4.30	0.11	0.5
Attack 3	70	6.20	0.08	0.5
Attack 3 (Twin lines)	140	3.10	0.16	0.5

Table 3:6 – Water flow scenario.

The formula (V/2) informs us that such a fire would require a flow-rate of 175 LPM for control. It can be seen above that offensive fog applications reduce this requirement quite substantially. In fact, offensive firefighting also reduces both delivery and application rates to extremely low levels that were barely obtainable under ideal laboratory conditions! However, the single line hosereel attack (Attack 3) would certainly struggle with this amount of fire, even with good operators, and would require a secondary back-up for direct extinguishment of the burning sources, ie, furniture, etc.

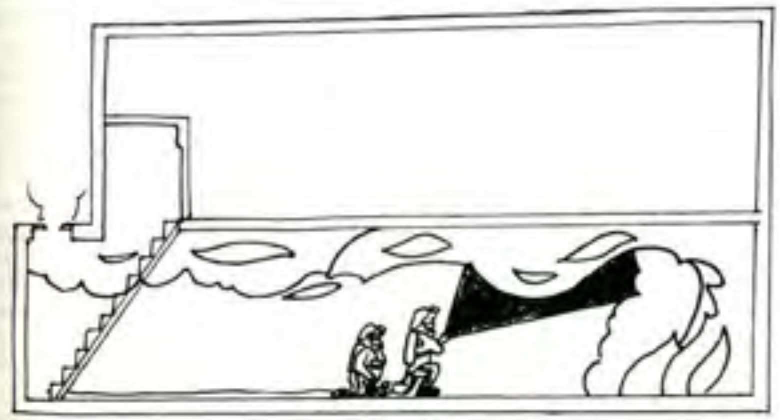
Control of this fire is achieved offensively because the 350 cu m is broken up into smaller compartments. A single open-plan compartment of 350 cu m (12,500 cu ft), fully involved by fire, would require heavier streams before control was gained. An offensive approach would be unlikely to succeed under such circumstances, even with multiple lines in use. However, where structural penetration is difficult through smoke-logging, or heat build-up, a main line can be advanced into position under cover of an offensive line for cooling and safety purposes. It is difficult to assess the upper limits of offensive extinguishing but as a 'rule of thumb', compartments containing average fire loads, up to 120 cu m (4,285 cu ft), may be offensively approached.

Fog Tactics

European firefighters have developed an expertise in the application of fog techniques over the past 30 years. Nowhere is this more obvious than London where over 50 per cent of occupied building fires are effectively handled by mounting a

tactical fog attack in true European style. A collation of relevant statistics have already demonstrated this fact and it is not unusual for London firefighters to mount a twin, or multi, line 'Hyperfog' hosereel attack on several levels of a fire involved structure. In my experience, such an approach promotes a high element of safety for crews working inside the building as well as an effective method of fire suppression.

In the preceding scenario, attack #3 demonstrated the most impressive results. In actual fact, the original attack line would be advanced into the structure by two firefighters and the lightweight hosereel would be fed up the stairways by a member of the support crew. This initial line would operate in offensive fashion (dependent on operator skill level) to cool the environment, knockdown the main fire-front and reduce any flashover potential. This line would be advanced aggressively with speed, not waiting to complete extinguishment of any deep-seated burning. The



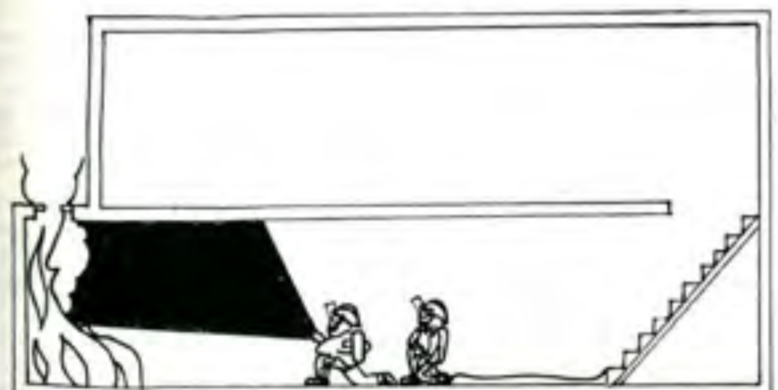


Figure 3:11 – Basement fires.

secondary (support) line would follow the initial line in with two more firefighters. Usually this back-up line would be another high-pressure 19 mm hosereel but at the request of the first-in attack team, this may be 'upped' to a 45 mm line with 12.5 mm nozzle (or larger). The support line will make a slower advancement behind the main attack line, ensuring a complete suppression effort at each level.

This concept allows the first line to advance with speed, concentrating on the main body of fire. This rapid level of advancement may prove critical if there are persons trapped at upper levels. It also promotes confidence in the minds of firefighters who will be aware that a safety line is not too far away. Such tactics work well at most fires and the lightweight hosereels ensure that the manpower is generally available on the first-arriving wave of firefighters, although this may not always be the case.

A basement, or cellar, fire is a prime example where a twin-line attack should function. The purpose of the support line in a basement is to cover the advancement of the initial line. Basement fires are renowned for their lack of ventilation openings, often prompting a hot fire with the potential for a smoke explosion. For these reasons alone I prefer the support line to be a 45 mm with 12.5 mm nozzle, just to give that added punch while maintaining some manoeuvrability. At *all* basement fires, do not hesitate to lay out that second line at street level as soon as you can, ready for its location behind the main attack line as soon as manpower allows. It is important to remember, where pavement lights exist, not to ventilate behind the advancing firefighters *(Figure 3:11)*. This action could draw the fire towards the attack team and place them in a dangerous position. The main principles of offensive fog attack are the same for most basement fires. However, be aware that access points may be confined and a burst of fog is likely to impinge more on hot surfaces than in the average room. This would have the undesirable effect of creating much steam and an excessively high compartment pressure. Also, avoid fog attack where high-piled storage exists, as is so often the case in basements. This type of fire load will promote much deep seated burning requiring a main-line stream to penetrate the base of the flames.

A fire that originates in an attic, or roof void, can be a problem, particularly if handled incorrectly. Where a fog pattern is directed straight up into the attic at a 90 degree angle, a 2-1 ratio in favour of *hot surfaces* results, creating a massive steam expansion! Where a fire lays dormant in an attic utilise a thermal image camera (where available) to locate the main area of involvement. Open the access hatch just enough to apply a fog nozzle into the opening. A four-second burst of high-pressure fog applied horizontally into the attic space will do more good than harm. If the fire has taken a hold it will be safer, and more efficient, to ventilate the roof from above before proceeding with an attack.

There will be occasions when the fire-front deceives the attack team into believing that a fog nozzle will handle the situation on its own. A classic example is illustrated in *Figure 3:12*. A raging fire on a lower floor is 'torching' up a structural void and existing in front of the main attack line. The firefighters, unaware of the situation below them, may be deluded into believing that a single line will handle the situation. When the fire keeps coming they will call for a bigger line before they realise the source of the problem.

Another example of a twin-line attack working in unison is that used by aircraft firefighters when firefighting in civil passenger aircraft *(Figure 3:13)*. As the crew advances behind the protection of a water-spray curtain a main stream from a secondary line is directed through to penetrate in a direct attack. Similar techniques can be utilised at stubborn tunnel or corridor fires.

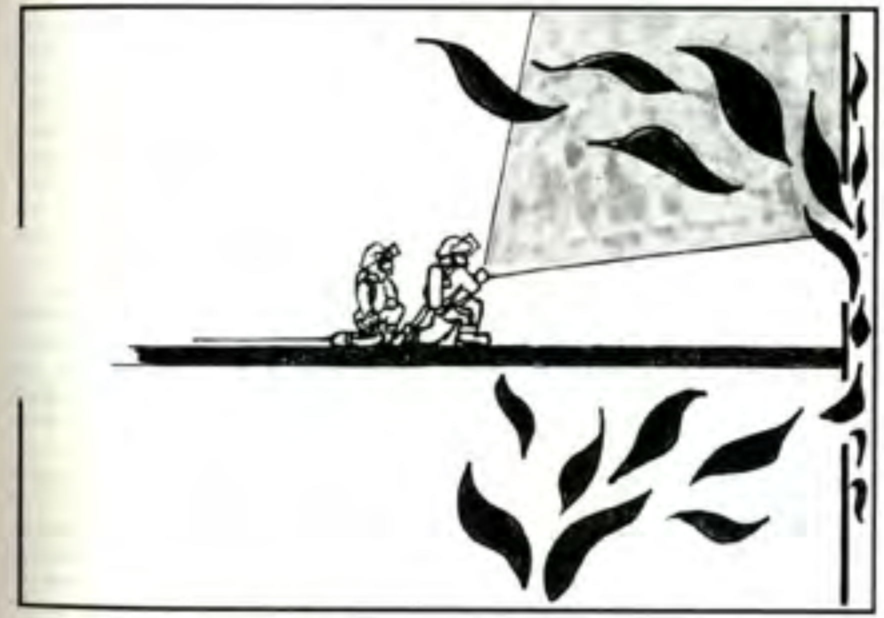


Figure 3:12 – Structural void fire.

Figure 3:13 – Twin-line attack.

Foam Additives and Wetting Agents

Much research has been devoted to the potential of foam additives, or wetting agents, being mixed with water for use in small compartment fires. This concept has been tried, and tested, across the USA for some years and produced varying levels of success. A project was recently undertaken by the Fire Experimental Unit *(Bibliography 3:12)* at the Fire Service College in Great Britain as part of the UK government's Home Office Fire Research Programme. It evaluated the various options, and types of agent, suitable for such applications and tested them in both small and large scale fires.

The following additives, in solution, were used:

- Fluoroprotein (FP)
- FP Alcohol Resistant (FP-AR)
- Film Forming FP (FFFP)
- FFFP Alcohol Resistant (FFFP-AR)
- Aqueous Film Forming (AFFF)
- AFFF Alcohol Resistant (AFFF-AR)
- Synthetic (S)
- 'Halofoam' Wetting Agent
- 'Fireout' Wetting Agent

Most additives were tested, both aspirated and non-aspirated, and compared with water. The performance of each solution was measured in terms of control time. The large scale tests took place in the 50 cu m FEU brick and concrete test compartment with wood cribs forming the fire load. The applications were made via an unmanned rotatable rig to ensure consistency, and adopted a 26 degree cone spread flowing 100 LPM through an Angus Superfog hosereel nozzle.

The general conclusions were that the use of additives would have negligible effect on a reduction in the air temperature within the room, when compared with water. However, control times were effectively reduced by most of the additives, particularly the Halofoam and AFFF types, when compared with water. The actual reduction in water damage, because of reduced control times, was minor and the decision to use additives for compartment fires should be based solely on the merits of a reduction in the time taken to control a fire.

The FEU report failed to address the use of additives during the overhaul phase of operations where US firefighters have noted the high penetration capability of such agents to soak into furniture, and materials, helping to prevent re-ignition. Neither did the FEU tests take offensive fog applications into account, their own applications being constant and in excess of requirements.

Fog Attack – International Views

Cape Town: Cape Town firefighters in South Africa utilise 19 mm hosereel tubings from their 'quad' style pumpers, working on a 'quick-water' principle, operating at 35 bars (500 psi). (Small structure fires only.)

Amsterdam: High-pressure hosereels run at 40 bars from these Dutch 'quads', operating in quick-water style on most structural fires.

Pretoria: High-pressure fog attack not utilised.

Hong Kong: All new appliances have high-pressure fog equipment.

Singapore: While pumpers are fitted with hosereel fog equipment, this is rarely used on structure fires.

Milan: High-pressure hosereels operate at 40 bars from the Italian 'quads'. Used to good effect on structure fires.

Tokyo: The Fire Suppression Division issued instructions to firefighting units in 1983 on the use of high-pressure (15 bars) fog guns, used in conjunction with standard 40 mm hoselines. They encourage the use of such equipment where the fire remains confined, presumably in an indirect attack mode. They apply fog at either 30 or 40 degree cone spreads with a flow-rate range of 140 to 195 LPM. The nozzle effects a fine mist with droplets down to 0.2 mm.

Zurich: High-pressure fog guns at 40 bars utilising 36 mm hoselines.

Oslo: Quick-water system used on small structure fires utilising 25 mm hosereels with fog gun operating at 20-25 bars.

Oulu: These firefighters in Finland operate a quick water system utilising low-

pressure fog attack with standard hose.

USA: The hosereel (booster line) has gradually disappeared from US fire pumpers. Fog attack in the USA is not generally operated on structure fires although modern nozzles offer good protective spray patterns.

London: High-pressure fog attack is practised widely with over 50 per cent of occupied building fires being handled by 19 mm hosereel lines operating from 'quad' style pumpers. A pressure of 20 bars flows 70 LPM to the 'Hyperfog' nozzle and large fire areas are often handled by multi-line attacks.

Stockholm: Most Swedish firefighters are trained in advanced fog attack techniques and operate their 'Fogfighter' nozzle at low pressure in conjunction with 40 to 50 mm hose. Much work is progressing into advanced fog application methods, and techniques of applying an 'offensive' pattern from an exterior position is being explored.

Fog Attack – How Effective?

Over the past 30 years the art of successful fog attack has flourished in the structural environment throughout Europe and firefighters in Amsterdam, Stockholm, Milan and London – to name a few – have revelled in its use. A close analysis of annual fire statistics clearly provides the evidence that reflects the overall success of such an approach. In Great Britain, for example, where the annual number of structural fires has remained fairly constant (100,000) over the past 15 years (except for minor fluctuations), there has been a steady increase (one per cent) in the number of fires that were confined to the room of origin. As the levels of fire protection built into

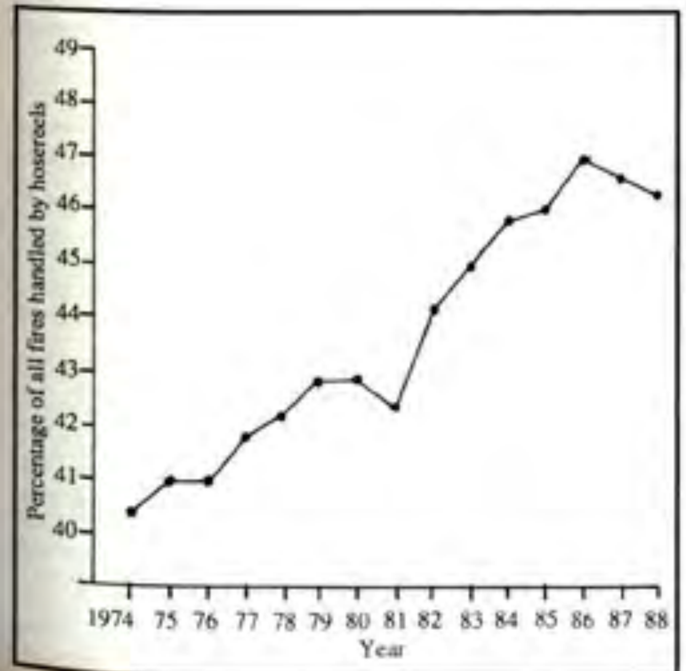


Figure 3:14 – Percentage of total fires (UK) extinguished by hosereel (booster line) attack.

structures is progressively improved such an increase is only to be expected. However, since the widespread introduction of high-pressure hosereel systems in the early to mid 1970s, a clear trend has emerged that demonstrates a 30 per cent reduction (to date) in the use of large hoselines (45 to 70 mm) to control fires. In line with this, and equal in proportion, is an increase in the number of fires controlled by one, or more, hosereel lines *(Figure 3:14)*. This suggests that while the amount of structural damage caused by fire is not greatly affected by application tactics, the amount of consequential loss caused through water damage is greatly reduced.

An added benefit to be derived through the application of tactical fog attack is the reduction in demands on manpower and resources. The gradual development of high-pressure fog tactics by London firefighters has had a marked effect on the larger working type of fires. During the course of a year the London Fire Brigade are faced with about 900 fires that cannot be handled by the original attendance, who summon the assistance of additional fire appliances and firefighters to control the blaze. This figure of assistance fires has dramatically decreased over a 20 year period (1971-1991) by 48 per cent *(Figure 3:15)*. The ten year period, 1977-1987, represents the learning period of high-pressure tactics and demonstrates an even more impressive 25 per cent reduction. This clearly suggests that high-pressure fog equipment enables fewer firefighters (ie, initial attendance of eight to 15 firefighters) to handle larger fires without resorting to any requests for assistance. This is despite the fact that the number of fires in London has remained fairly constant over the period in question at 48,000 annually. The author considers that the demands upon manpower and resources, and the consequential losses caused through water damage, could be reduced even more if firefighters were effectively trained in application techniques. Such training would also serve to increase firefighter safety when operating at real fires.

An increase in the number of fires controlled by one or more hosereels is clearly apparent since 1974 when high-pressure hosereels were introduced:

Percentage of all fires			
1974	40.7	1982	44.1
1975	41.0	1983	44.7
1976	40.9	1984	45.8
1977	41.8	1985	46.0
1978	42.1	1986	46.8
1979	42.6	1987	46.4
1980	42.6	1988	46.2
1981	42.0		

Ref: Table 4 – UK Fire Statistics (British Home Office).

Table 3:7

The number of 'assistance' requests (make-up fires) has steadily decreased during the 20 year period (1971-1991), from over 1,400 in 1971 to 724 in 1991. This represents a 48 per cent reduction which suggests London firefighters are now able to tackle larger fires with fewer personnel and less equipment, by resorting to 'high-pressure' fog attacks.

It is important *not* to credit passive fire protection measures with such a reduction; remember, statistics suggest that nine per cent of fires still spread beyond the room of origin – a reduction of only one per cent in 20 years, despite the fact that the number of fires in London during this period has remained fairly constant.

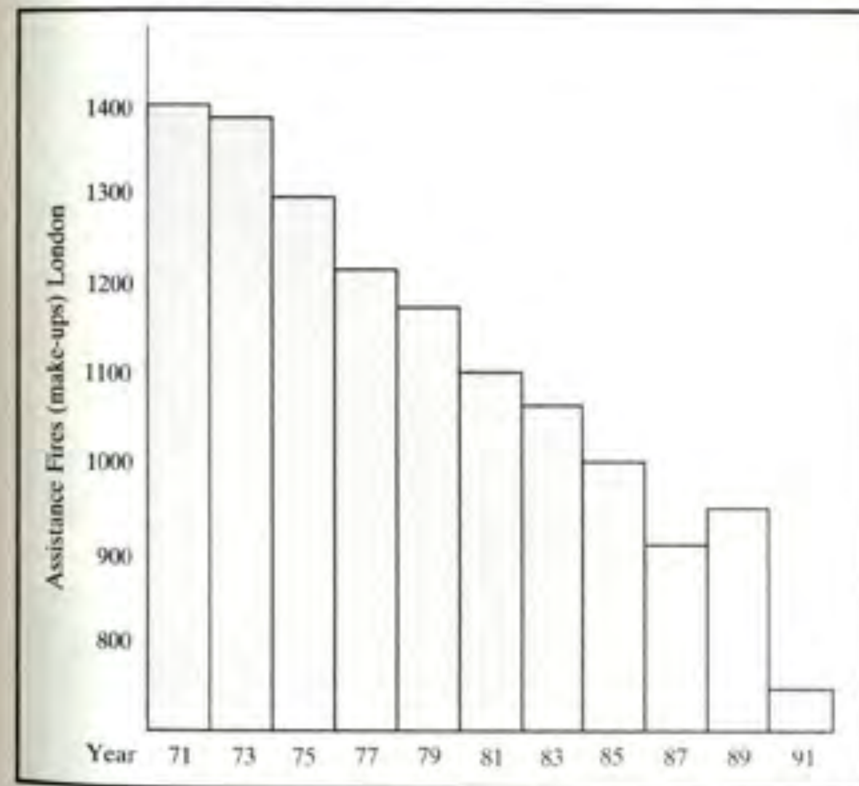


Figure 3:15 – Major fires, London '71-'91.

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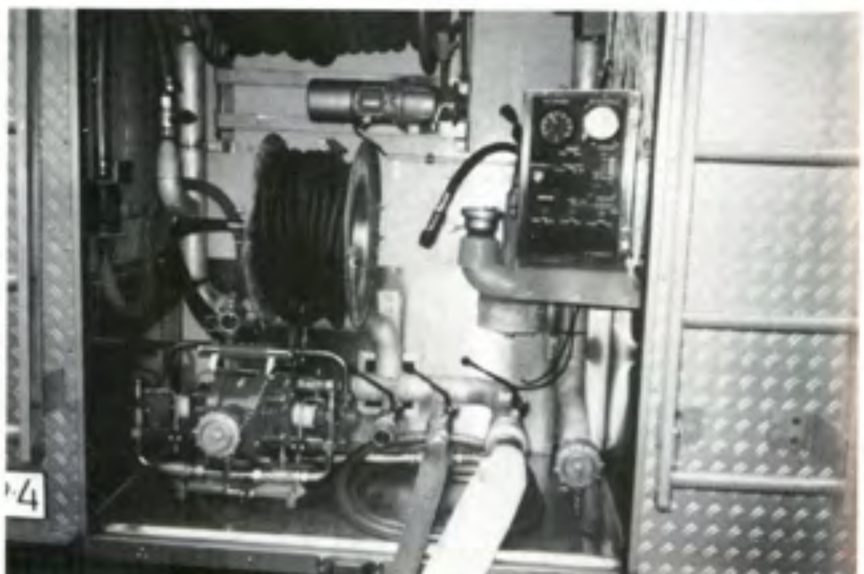
NB: Figs 3:1, 3:2, 3:5 and 3:6 are reproduced with kind permission from the Home Office Fire Experimental Unit – Moreton-in-the- Marsh, England. (Research Report 36.)

The author (centre) on detachment to the Chicago Fire Department in 1990.

A Boston fire pumper sites directly on the hydrant to boost the supply. A line of 125 mm hose is also used to reduce frictional loss and maintain a high residual pressure at the pump, enabling the full flow (LPM) to be drawn from the hydrant – ***see Chapter 2.***

This MPO is operating at a major fire in London, using a pumper rated at 5,900 LPM. With twin 70 mm supply lines coming into the pump, and two 70 mm attack lines in operation. The delivery with the tag PL1 (immediate right of operator) is unused, while that tagged PL2 (next to PL1) is shut down. The pressure gauges suggest a minimum output of 1,200 LPM is taking place. However, with just 2 bars residual pressure (RP) showing on the compound (incoming) gauge, he would be hard pushed to supply the third line with an optimum flow without risking cavitation at the pump. The PL1 delivery cannot be used unless more water is flowed into the pumper – *see Chapter 2.* *(Photo by London Fire Brigade).*

Above **– A pressure relief valve fitted to a Boston pumper's intake to protect the pump where long lays of LDH are in use.** ***Right*** **– A 'Hanson Manifold' – as used by Seattle firefighters to lay a portable hydrant system.** ***Below*** **– A 10,000 l water 'pod' unit, as used by firefighters in Stockholm. The unit is able to shuttle the portable tanks (as seen) between the water source and the fire –** ***all photos refer to Chapter 2.***



Top left **– Although this Miami MPO is sited some distance from the fire, he is in direct contact with the firefighters on the nozzle.** ***Top right*** **– The 'basic' pumper control panel of an Amsterdam fire pumper (3,000 LPM).** ***Above*** **– The 'basic' pumper control of a Stockholm fire pumper (1,800 LPM) –** ***all photos refer to Chapter 2.***

The 'Hi-tec' control panel fitted to the very latest line of fire pumpers in Miami (6,000 LPM). There is a flowmeter that registers total output (LPM) and each of the ten discharge ports, including the 'Deck-Gun', have their own pressure gauges. Output is initiated through finger-tip control knobs (as seen under each pressure gauge) – ***see Chapter 2.***

This major fire in London kept firefighters busy through the night. *(Photo by London Fire Brigade).*

A Swedish firefighter with Fogfighter nozzle. He is an expert in the art of offensive fog attack.

London firefighters are experts at mounting a tactical fog attack behind the protection of their Hyperfog nozzle – *all photos refer to Chapter 3.*

The effect of 'fingering' is clearly apparent in the fog stream on the right, when compared with the full fog pattern on the left – see *Chapter 3.*

The effects of radiant heat at the nozzle are apparent through the 'fingered' pattern on the left – *see Chapter 3.*

During the past 20 years, the number of annual 'make-up' fires attended by London firefighters has reduced by 48 per cent, from over 1,400 in 1971 to 724 in 1991. The increased use of high pressure fog equipment is mainly responsible for this achievement – *see Chapter 3.* *(Photo by London Fire Brigade).*

4
VENTILATION SUPPORT

'It is most dangerous for any persons who happen to be in the other rooms of the house, particularly those above and at the back, into which, after once a front window has been cut through (broken), it is probable, if not almost certain, that the fire will penetrate before the firemen can reach them.'

Sir Eyre Massey Shaw, KCB
'Fire Protection' 1876

In December 1984, the Building Research Establishment (BRE) of Great Britain presented a paper (IP 22/84) based on fire studies conducted by the Field Investigation Section at the Fire Research Station (FRS) in Borehamwood, England, entitled *Smoke Spread Within Buildings*. Therein it was stated that:

> 'Venting of smoke by design is very rare in fires visited by the Field Investigation team. It is common for first attendance fire services to comment on the serious degree of smoke-logging and of the need to vent the building to aid firefighting and evacuation. In one case, the substantial and non-combustible construction of a bowling alley roof prevented smoke (and hot gases) venting through it. The source of the fire could not be identified and, to aid firefighting, the building had to be deliberately vented through large windows. This action caused the fire to flashover. In many other incidents, where it was not possible to vent the building, typical widespread damage was encountered and in most cases could be attributed to the substantial fire resistance of the roof deck. The fire in the hotel staircase, referred to earlier [in the report], may not have claimed the life of an occupant as smoke escaped to the bedroom landings, had it been possible to vent the roof and reduce lateral transfer to the landings.'

Ventilation applied to firefighting is the planned and systematic release and removal of heated air, smoke and gases from a fire involved structure, and the replacement of these products of combustion with a supply of cooler, cleaner air. This objective can be achieved in many ways, ideally through prior installation of automatic or manually-operated roof vents. Such equipment would serve to great advantage, in easing the efforts applied to firefighting operations, reducing eventual damage and possibly in saving lives, should a structure become involved in fire.

While the principle of releasing combustion products from a fire building is universally accepted, both by fire engineers and firefighters alike, the practice of actually doing so is considered highly controversial by many. Where fire ventilators are designed into the structure it is generally accepted world-wide that to release combustion products to the exterior of a structure is a great aid to firefighters on scene. This appears true for most situations although there is some train of thought on the inter-action of ventilators and sprinkler systems. Some US fire departments also oppose automatic ventilators for they wish to choose exactly where and when they will release the smoke from the structure. However, when the positive pressures building up inside a structure are suddenly unleashed, the resulting effects within may prove catastrophic!

As a fire is vented, either under controlled conditions, or by its own action, there is a 70 per cent chance that smoke will turn to flame as more air flows into the fire zone. This may increase the rate of burning within the structure and it would appear that the action of venting has worsened the situation. Even so, fire forces in the USA have practised forced ventilation techniques for decades and more often than not with a great deal of success.

It is somewhat in contrast that many European, far eastern, and Australian firefighters refuse to accept the strategy of tactical ventilation, having labelled it as 'dangerous' or 'unnecessary'. However, many firefighters tend to keep an open mind on the matter, refusing to adopt such practises themselves but acknowledging the potential of such theories. But to the American firefighter it is certainly not theory, and veteran firefighters around the USA will describe the benefits that can be derived inside a structure as the roof is 'opened up'.

My own experiences lead me to believe that the US firefighters' operations at roof level are carried out with great skill, precision and courage, although, all too often the hole he has cut has served no purpose at all! It so often seems that a hole is cut in the roof simply to comply with what the book says! The co-ordination and precision needed to successfully ventilate a roof can only be gained by experience, and a comprehensive understanding of all aspects of fire behaviour within a structure. However, it is also my experience that so many fire situations are worsened for *failure* to ventilate a structure at all and the opportunity to 'save' a building is often missed.

There are occasions when the opening of a roof to vent combustion products is a mistake. There are also instances when it is the only means open to the firefighting force to save a structure from fire. In Britain, such venting operations are guided by the *Manual of Firemanship (Book 12)*, where it is stated that rooftop operations and cutting holes in roofs to ventilate should only be undertaken as a 'last resort'. However, no further guidance is given on where, when, and how to ventilate roofs, and with the necessary equipment missing from front-line appliances – ie power saws – one finds it hard to imagine British firefighters attempting such a strategy successfully, or safely, even though the UK governmental BRE paper IP 22/84 clearly demonstrates the need.

There are three main reasons why firefighters oppose forced ventilation techniques:

(1) Many believe that an internal water fog attack will be countered by opening the building up. The days of indirect fog application are past and it is no longer necessary for the compartment to be sealed for an effective fog attack to succeed. New techniques involving an offensive fog application will work equally well when used in conjunction with forced venting.

(2) The fear of intensifying the fire prevents many from making openings in the roof, or breaking windows, to release the products of combustion from the compartment. This fear is not unjustified for there will be occasions when the risk is not worth taking. If a fire exists at the base of an open staircase and a life hazard exists on upper floors, the forced venting of the head of the stairs may create a 'chimney effect' on the stairway, spreading the flames upwards and into the occupied floors. However, when occupant load is not a relevant factor, and the situation is prompting urgent venting, the responding fire force must ensure that covering hoselines are laid out in anticipation of any fire intensification prior to the building being opened up. This is an essential feature of a well co-ordinated, and effective operation.

(3) Where firefighters are working above the fire, for whatever reason, their courage is tested to the limit, for this is undoubtedly the most dangerous place to be! However, in opening the roof to relieve conditions within the structure they are serving to make the fireground safer for others working underneath that very roof.

Although, on occasions, we are appalled to read of firefighters plunging to their deaths as the roof upon which they were working collapsed, one must analyse each individual case. It is generally found that golden rules were broken, or mistakes were made on scene.

As an example, since six New York firefighters fell to their deaths in 1979 as the roof they were venting collapsed beneath them, the hazards of the 'bowstring truss' have become more widely acknowledged. Not that its potential for collapse was unknown – Francis Brannigan's book *(Bibliography 4:1)* on building construction had documented the hazards some years before.

Although we may believe American firefighters are placing themselves at great risk when operating on the roofs of burning buildings, by analysing statistics concerning firefighter deaths in both the USA and the UK, this fear may appear to be somewhat of a fallacy!

In the five years, 1979 to 1983, only 9.6 per cent of the 593 US firefighter deaths recorded were attributed to 'structural collapse' (and not all of these were involved in venting operations). The situation in the UK over a 20 year period (1960-1980) demonstrates a much higher percentage of firefighters (28.5 per cent of 98 men killed) that died as a direct result of structural collapse.

Advantages of forced ventilation

A review of the tactics and strategic policies, as implemented by US fire departments, to ventilate a fire-involved structure reveals four main advantages:

(1) **Aids life-saving and rescue:** Correctly applied, ventilation simplifies and expedites the rescue of victims by removing smoke, heat and gases which may endanger occupants that are trapped or unconscious and makes the environment safer for firefighters.

(2) **Speeds attack and extinguishment:** The removal of smoke, gases and heat from a building permits firefighters to locate the fire more rapidly and proceed with its control and extinguishment. Effective ventilation of a building further enables firefighters to determine the path of travel of the fire, and take steps to prevent extension throughout the structure.

(3) **Reduces the chances of smoke-logging, flashovers, backdrafts, uncontrolled fire spread, and structural collapse:** Correctly applied ventilation reduces the dangers of smoke inhalation, alleviates the possibility of a flashover where super-heated gases are mushrooming in the upper strata, and a backdraft where a sudden inrush of oxygen may create an explosive atmosphere. It further reduces the potential for rapid uncontrolled fire spread that may result in an eventual structural collapse. A. M. Grice's excellent work into structural collapse at fires *(Fire Engineers Journal* [UK] – March/June 1984) cites several instances where a lack of ventilation resulted in buildings collapsing on the fireground.

(4) **Reduces damage caused by fire, heat, smoke and water:** When correctly applied, ventilation reduces the levels of damage sustained by a fire involved structure by controlling the spread and

direction of the fire, removing the smoke and heat from the structure, and reducing the amount of water required to extinguish the fire.

As well as revealing the positive approach to the strategy of forced ventilation I feel it is also necessary to discuss the negative side as well, for not only is this important to gain a clear understanding of the techniques described, but it is upon the negative side which many – quite naturally – base their opposition to forced ventilation. Having said that, there are many who will base an argument around the four main advantages just described, suggesting that venting may *increase* the life hazard, lead to flashovers or backdrafts, and generally intensify the fire, creating *more* damage and raising the potential for structural collapse.

At a later stage in this chapter I will discuss several actual fire case histories, which show that forced ventilation techniques most certainly do have a place on the fireground. The reader may feel that in these reports there is a strong positive bias – in fact they were specifically collated for that very purpose: they are mostly situations just crying out for some form of venting to take place!

I have fought fires on both sides of the Atlantic and I have observed major fire operations where the fire force has practised forced ventilation techniques with a huge amount of success. I have also seen vented buildings burn to the ground! Over the years I have struggled through thick blinding smoke to reach the seat of the fire and often been forced back to the street as the flames took a hold of the structure.

After every incident I questioned the effectiveness of our actions: "Could this fire have been handled better with some form of forced ventilation?", or, "Did the action of tactical venting worsen the outcome?".

It is worth noting that my answers were positively in favour of venting 95 per cent of the time.

Scientists and fire engineers who studied the spread of fire at the 1981 Stardust Disco fire in Dublin, Ireland, were in no doubt of what the outcome would have been had the fire *not* self-vented at an early stage. The fire, which took the lives of 48 people as it raced across the upper strata of the dance floor, breached the suspended ceiling almost immediately on reaching it, and broke through the roof just seconds later. The scientific report stated that, had the ceiling and roof remained intact, the rate of burning and fire spread in the ballroom would not have been determined by the amount of available fuel but by the air available within the building and the way in which this mixed with fuel gases. Thus, if all the material in the area of origin was burning at once at the maximum measured rate, sufficient fuel gases would have been produced for a heat output of 100 MW. If all this fuel had been burnt, it would have reduced the oxygen content of the air in the building to 14 per cent (when flaming combustion becomes problematical) in about eight seconds. Had the ceiling remained intact conditions on the dance floor would probably have deteriorated to the extent that life would have been impossible within a period of less than 30 seconds after initial flame-up. The fact that the fire *did* breach the ceiling and roof probably resulted in many more survivors than if it had not.

The major objectives of any fire service are to reach the scene of the fire as quickly as possible, rescue trapped victims, locate the fire and apply suitable extinguishing media with a minimum of damage resulting. If firefighters had been on scene during those vital first few moments of the Stardust fire, and had vented the roof (had it not self-vented) it would undoubtedly have been the best thing they could have done to save lives in this situation.

Of course, if it had been the case that firefighters had been in this position there

are other influencing factors to consider: was the roof safe to work on?; where was the best place to vent?; what would be the outcome if the roof was vented in the wrong place?

We are now back dealing with the negative phase of roof venting operations, but rightly so in this case. If the roof was constructed so that it failed within minutes of the fire originating, then it was most certainly of insufficient strength to support a team of firefighters attempting to 'cut-in'. Even if it had been safe to work on, would there have been sufficient indication from the exterior as to where the cuts should be made? The effect of breaching a roof is to draw the flames towards that exit point, so if the ventilation opening was made in error, at the opposite end of the fire, it is possible that conditions within the structure may have worsened.

Therefore it is correct for a fire officer to be strongly influenced by the negative, for the one who is will base his decisions with the safety of his team in mind. However, it is equally important to keep the positive in mind, for if the roof in this scenario *had* been of a substantial construction, and *had* there been a reliable indication of the main fire's location below it, the act of venting the fire alone may have saved many lives.

The following case histories are based partly on written reports of fires, while others are the author's own first-hand experiences. They are analysed where (a) forced venting was applied correctly, resulting in a successful attack; (b) forced venting was applied, but the strategy was incorrect, resulting in an inevitable disaster; (c) no forced venting took place.

Case History Listing

1. Brighton Furniture Factory (England).
2. Liverpool Cold Store (England).
3. Liverpool Shopping Centre (England).
4. Office Building (Wales).
5. Sheffield Warehouse (England).
6. London Mews House (England).
7. London Factory (England).
8. London House in Multi-Occupancy (HMO) (England).
9. London Church (England).
10. Hertfordshire Bowling Alley (England).
11. Shrewsbury Historic Building (England).
12. Baltimore town-house (USA).
13. Hackensack NJ Automobile Dealership (USA).
14. Chicago Electronics Store (USA).
15. Kent Mattress Store (England).
16. London town-house (England).
17. Syracuse 'balloon construction' Student Hostel (USA).
18. Gillender Street Fire-Hays Business Services (England).
19. Prior Park College (England).

Case No. 1: Brighton Furniture Factory Fire, UK
(Fire Magazine (UK) – Feb 1989, p.22)

A serious fire and subsequent dust explosion in a reproduction furniture factory gave East Sussex Fire Brigade severe access and ventilation problems, according to the then CFO Peter Rodgers. The building involved was a purpose built, single-storey, flat roofed treatment plant 40 m×3 m used for the treatment of waste sawdust. The construction of the walls and roof was of galvanised steel with a

100 mm layer of compressed glass fibre sound insulation, separating the inner skin of perforated zinc. The building was connected via metal trunking to the adjacent main furniture factory, which was 150 m×100 m.

On arrival, the officer-in-charge was confronted with a serious fire with large volumes of smoke issuing from the access doors to the premises. Pumps were made four and an initial attack on the fire was made by a breathing apparatus crew using a 45 mm line. Twenty-nine minutes had passed since the initial time of call (0950) when a dust explosion occurred – two firemen were injured. At this stage, the firefighting crews were experiencing great difficulty in penetrating into the building, due to the excessive heat and smoke. Access was restricted to doors at either end and there were no openings or other means of ventilation.

At 1038 pumps were made six and it was then decided to cut into the roof to allow hot gases to escape. Due to the construction, this proved extremely difficult and a rescue vehicle was mobilised with specialist cutting equipment.

Further problems were encountered when the fire spread through the trunking and smoke entered the main factory building. At one stage, the heat was such that a sprinkler head activated in the factory, causing water to penetrate the office accommodation, including the computer suite.

At 1111, pumps were made eight to assist in preventing fire spreading into the main factory building by the use of covering jets.

Four ventilation holes were subsequently cut into the roof, greatly assisting the crews inside the premises, who were then able to penetrate into the building to extinguish the fire. A total of four jets, two hosereels and ten breathing apparatus sets were employed during the incident.

Comment:
While the structure design was somewhat 'unusual', this was a classic venting situation. The absence of front line equipment (eg power saws) on the initial attendance prevented any early venting to be carried out. The subsequent delay (at least one-and-a-half hours) led to a dust explosion in which two firefighters were injured, and much damage occurred to the main building, offices and computer suite. US firefighters would, I believe, have been better prepared to handle this unusual situation, which would have resulted in a more rapid and safer conclusion, with less damage occurring.

Case No 2: Single-Storey Cold Store – Liverpool, UK
(Fire Magazine (UK) – July 1984, pp.15-18)
On 25 March 1984, a fire occurred in a Liverpool Cold Store that came within a hair's breadth of killing or maiming a number of Merseyside firemen. The fire involved a 20-year-old single-storey cold store that was – at the time of the fire – in occasional use for general storage. The building was steel-framed, with a corrugated asbestos pitched roof. Overall dimensions were 50 m×30 m. An insulated ceiling suspended on steel hangers created a large undivided roof void, while the walls had a thermal insulation gap of approximately 100 mm.

On arrival, smoke was observed issuing from the store at door height, and breathing apparatus (BA) crews were committed. Due to the structure and insulation in the premises, the controlled venting of the fire proved difficult.

Approximately 35 minutes after arrival, conditions inside the building worsened. The evidence of the BA teams involved, showed that the temperature rose considerably. With the temperature rise there would be a corresponding increase of pressure in the store. Smoke conditions worsened and became thick and black, while a rumbling noise likened to a roll of thunder was heard above their heads,

and a wall of flame was observed spreading rapidly across the surface of the false ceiling. The fire vented itself with explosive force and the light asbestos roof failed. Firemen inside the building managed to escape, several suffered burns to varying degrees in the process.

The onset of the backdraft appeared to have been caused by flammable gases evolving in the fire, and percolating into the roof void and wall cavities where a plentiful supply of oxygen would have existed. When the fire broke into these areas, the mixture ignited with explosive force, creating subsequent flame spread and increase in temperature with a corresponding pressure rise in the structure. It is considered that only the comparatively flimsy construction of the corrugated asbestos roof venting the explosive effect avoided an even more serious incident.

Comment:
One of the main reasons of roof venting operations, is to prevent flashovers and backdrafts occurring. In this situation, the light roof construction would not have provided a safe platform for firefighters; but I believe that the possibility may have existed for crews to operate from elevated working platforms (ie, hydraulic platforms) to vent the explosive gases from the roof void. Again, the availability of power saws would have greatly facilitated such a strategy.

Case No. 3: Shopping Centre Complex – Liverpool, UK.
(Fire Magazine (UK) – December 1979, p.378)
In 1977, a fire occurred in a Liverpool shopping centre complex. The first appliances to arrive – at 1731 – experienced smoke logging in the malls down to waist level. Later conditions deteriorated until smoke was down to floor level. The extreme conditions meant that, even with breathing apparatus, crews were unable to approach or see the fire. Fixed venting installations existed, but failed to operate, and it was over an hour before firefighters were able to locate two rooflights that, when vented, markedly improved conditions in the malls enough for firefighters to advance on the fire and complete extinguishment.

Comment:
The forced ventilation by firefighters was the only strategy available to enable an advance on this fire. However, it was only considered later on, when all else had failed.

Case No. 4: Large Office Building (Listed) – South Glamorgan, UK
(Fire Magazine (UK) – July 1984, p.47.)
When fire broke out in a large office building at Barry Docks, the main problem facing firefighters was the rapid spread of fire via a disused lift shaft, and the lack of any fire stopping in the roof void. These problems, combined with a stiff breeze, made firefighting conditions both difficult and hazardous.

The building was listed as being of special architectural interest, and was constructed with stone and brick load-bearing walls, concrete floors, and felt and slated roof.

On the arrival of the fire service, an intense fire in the base of the lift shaft was seen to be spreading vertically upwards. Within five minutes of their arrival, the roof became involved and the fire began to spread laterally. Fire passing through the roof void over the heads of fire crews, made operations on the top floor particularly difficult. The strong breeze and lack of cavity barriers in the roof space, made rapid fire spread inevitable.

Thirty-two minutes after fire service arrival, a flashover occurred in the roof void, which caused progressive roof collapse, making conditions extremely hazardous for firefighting crews. Re-building costs were estimated at approximately £1 million.

Comment:
An aggressive roof venting operation may have prevented lateral spread and would, I believe, have reduced the chances of flashover and structural collapse.

US firefighters are conditioned to gaining immediate access to the roof area where they await further instructions before venting. In the Barry Docks fire, an early venting operation was essential and something needs to be said on the efficiency of the US 'military' style assault on a fire building where engine/ladder companies know their 'general role' before arrival. Much time can be saved under such circumstances.

Case No. 5: Storage Warehouse – Sheffield, UK
(Fire Magazine (UK) – March 1985, p.11)
In December 1984 a fire occurred in a storage warehouse in Sheffield, putting 22 firefighters on the sick list, through smoke inhalation. According to the then CFO Wright, two of the main causes for the "amount of damage by the fire" and the "hazards to personnel undertaking necessary firefighting operations" were:

(1) The undivided area between the roof lining and the structural roof, which allowed ready passage of flames throughout the roofed area, and caused its early collapse; and
(2) The rapid fire spread caused mainly by the falling of burning bituminous roof lining on to combustible materials.

Partial roof collapse occurred 12 minutes after the arrival of the brigade, causing rapid evacuation of crews inside the building. Some 40 minutes later, the fire was still spreading through the undivided and unprotected roof cavity to affect adjoining premises, although determined efforts by firefighting crews finally enabled complete extinguishment, several hours later. The estimated fire loss exceeded £20 million.

Comment:
Another fire that created problems once it reached the roof void.

Case No. 6: Three-storey Mews House – London, UK
(Author's experience)
The fire occurred in the early hours and involved a large three-storey mews house in London's West End. The brick and timber joisted structure measured 15×20 m under a pitched to flat slated roof. On arrival, crews were faced with heavy smoke issuing from around all 13 windows on the frontage of the building, even though all windows were intact. A serious fire was in progresss at the rear of the ground storey and two BA crews set to work with hoselines as other firefighters in BA attempted to search the upper storeys using the internal stairway for access. However, smoke and heat – combined with cluttered storage – hampered firefighters on the first floor. When interviewed afterwards, these firefighters talked of "severe heat conditions" and "zero visibility" that created a very slow 'search and progress' pattern.

The building was just begging to be vented, but even though a hydraulic platform was ideally situated at the front of the premises, fire officers at the scene were reluctant to vent "in case it intensified the fire on upper floors". If fire had reached the upper floors it would have done so externally by rear window flame projection, or internally through the timber floors or any voids that might exist. As it turned out there was no fire on upper floors and the refusal to ventilate led to a 22 minute time delay before the first BA crew reached the second floor from the ground. Once the windows on the second floor were opened from within, the building cleared its smoke and heat in seconds.

Comment:
Another 'ventilation classic' where the officer in charge was faced with a decision – to vent or not to vent?
Points worth making:

(1) No smoke was issuing from the eaves so it seemed unlikely that the roof void had become involved. Therefore, roof ventilation in these circumstances was not required.
(2) The fear of intensifying the fire was based on an assumption, that the fire had reached the upper floors. Reliance was being placed on firefighters in BA finding the fire before it reached its flashover stage on the upper floors.
(3) Firefighters on the upper floors were experiencing punishing conditions and progress was slow. These men were facing great danger if the officer in charge's assumption of firespread was correct.
(4) If occupants had been located in the rooms on the first and second floors or on the second floor landing, they would have inevitably died, and yet, may have been alive on brigade arrival.
(5) US strategy would have entailed the venting (through breakage) of the top floor windows first. If fire had spread to the upper floors then it may well have intensified to some extent but the 'knockdown' would have been rapid. BA crews would advance on the fire in a safer environment and the chances of locating 'live' victims would greatly increase.

Case No. 7: Two-storey Factory – London, UK
(Author's experience)
The building was of brick and timber joist construction with a shallow pitched and slated roof, measuring 20×10 m. The fire had originated at one end of the building on the ground floor, and was spreading through the timber floor above to involve the upper storey.

A BA crew took a hoseline into the upper storey via the only stairway. This took them to the end away from the fire – an ideal vantage point. However, their attempts to move against the fire were severely hampered as heavy wired glass windows were holding the heat in. Roof and end window ventilation was called for to assist the firefighters' advance, but was not forthcoming. An eventual flashover knocked the firefighters off their feet and prompted a hasty retreat back down the stairs. The roof eventually vented itself and this enabled crews to finally advance and complete extinguishment.

Comment:
Had roof and end window ventilation been used, I believe that the knockdown would have been rapid and easy, and the flashover would not have occurred. The resulting damage to the structure would have been much less severe. This was a simple, straightforward little blaze – made hard.

Case No. 8: House in Multi-Occupancy – London, UK
(Author's experience)
A four-storey brick and timber joist property, consisting of two buildings interlinked at all floors. All floors were occupied as bed-sits.

On arrival, a serious fire was spreading up one of the stairways from the ground floor. The other stairway and upper floors were heavily smoke logged. Access to the rear was difficult and a large number of rescues were completed at the front by ladders.

BA crews faced punishing conditions on the stairways and upper floors, again slowing progress. No venting was initiated until some time after the fire had been extinguished but when rooflights were opened over the stairways, crews experienced much relief inside.

Comment:
Again, the officer in charge refused to initiate venting of the stairways for fear of sending the fire upwards. This, I believe, is an arguable point and may be the correct decision. If the pressure in the stairwell above the fire is keeping flame travel at bay (this phenomenon is known as 'barrier effect') in a large building then it may be dangerous to vent. On the other hand, to prevent the possibility of lateral spread the venting of the stairway in the early stages is essential. US strategy would be to ventilate, but the controversy may rage on this one.

Case No. 9: Church Fire – City of London – UK
(Author's experience)
A well developed fire in the roof void of a Wren church gave City firefighters a night-long battle as the fire spread through the horse-hair and hessian insulation. The fire, that originated in one end of the void, travelled to surround a central bell tower. Access to the roof provided a stable platform to work from but firefighters' attempts at cutting holes in the thick outer lead covering were in vain as the fire continued to spread.

The eventual collapse of the entire roof some seven hours after initial attendance was the result, and a famous piece of architecture was gone forever.

Comment:
Churches are one type of structure that generally benefit to great extent if force vented. This is explained in an article I wrote for the UK's *FIRE* magazine (December 1988 – pp.27-28). In this case, the requirement was to ventilate in the form of 'trenches', ahead of the fire spread. The heavy lead roof could not be breached adequately by axes; the only way would have been by power saws.

It is somewhat worrying to note that this church was a 'prototype' for St. Paul's Cathedral and that, if faced with a similar fire in the domed roof of the Cathedral, the result might be the same – that loss would be tragic.

The construction is also common to many other old City of London churches and, I believe, it is only a matter of time before the problems are encountered again.

Case No. 10: Bowling Alley Complex Fire – Hertfordshire, UK
(FIRE Magazine (UK) – May, 1982, p.653)
On arrival, the officer-in-charge of the first machine found a bowling alley heavily smoke-logged. The bowling alley formed part of the top level of a shopping precinct. Adjacent to it were several offices and a multi-storey block of flats. Beneath it were more shops, a petrol station and a car park. It had been built in 1968 and was

constructed largely of concrete with a corrugated steel/asphalt roof. It was approximately 20 m×60 m.

BA crews gained entry with two lines but were unable to penetrate far because of the intense heat and heavy smoke logging. Some large windows were vented by crews but this caused the fire to flashover. Eventually the roof collapsed and extensive destruction occurred.

Comment:
Familiar smoke-logging, as discussed in the UK governmental BRE report, and reliance on BA crews to 'find' the fire were reasons, I believe, that progress was slow. The lateral venting provided was possibly a mistake – a vertical rooftop opening may have prevented the flashover and reduced the overall damage that occurred.

Case No. 11: Multi-Occupancy – Shrewsbury, UK
(Britain's Fire Protection Association)
A fire, discovered in the early hours of the morning, reduced a historic building to a shell despite the prolonged, and exhausting, efforts made by fire service personnel.

There was very little effective structural protection to prevent either lateral or vertical fire spread. The blaze is believed to have originated in a first floor office, and spread horizontally downwards and upwards involving the roof space, even in the first stages of development.

Because a major part of the internal timber staircase had burned away, access to fight the fire was made through the windows to the first and second floors. Opening the windows drew fresh air into the building, and the fire intensified dramatically. The structure weakened and crews had to be withdrawn. Eventually the roof collapsed.

Comment:
What may appear in theory to be a blatant mistake, where openings are made below the fire, is in fact a common action in Britain, where firefighters are not conditioned into opening at upper levels first. This a a classic mistake and the immediate intensification of fire resulted in eventual destruction. US strategy correctly applied, would forsee the dangers and open the roof first. (NB: Roof slated on timber).

Case No. 12: Two-storey Brick House – Baltimore City, MD, USA
(Fire Engineering – October 1986, p.50)
Heavy smoke was pushing from around first floor windows and doors of the two-storey brick 'row-house' as Baltimore City firefighters arrived at the scene. Despite the heavy smoke, no fire was visible from outside.

Lieutenant Nelson Taylor of Engine Co. 8, and two firefighters with a pre-connected handline, crawled into the kitchen through a rear door in an effort to locate the fire. They had made their way approximately five feet into the smoke-filled room and were nearing an interior stairway leading to the basement, when an "explosion" occurred, causing the basement to erupt into flames.

A typical backdraft situation one might have thought, but this was definitely *not* the typical backdraft. Lt. Taylor was pulled or 'sucked' into the flaming basement by the sudden events, not blown outward! Lt. Taylor was severely burned over 65 per cent of his body, and suffered a head injury when he fell downstairs. He succumbed to his injuries about 12 hours later.

Comment:
The hazards of the flashover and the backdraft are most relevant to the topic of ventilation. They are also hazards that firefighters are well aware of – or are they?

•**Flashover:** Most firefighters have experienced a flashover, where the thermal radiation level becomes high enough to spontaneously ignite combustible materials in the lower part of a room. The effect of a flashover is extremely rapid combustion likened to a rolling type fire.

•**Backdraft:** It is only recently that British firefighters have become aware of the difference between a flashover and a backdraft. One tragic fire, where two firefighters lost their lives, brought attention to the risk of backdraft (termed 'smoke explosion' in Britain). Until the 1980s there had been no reference to this hazard in UK fire service literature (now referred to in the *Manual of Firemanship Book 12*, p.159), although the phenomenon has been formally described elsewhere since 1914.

The backdraft, or smoke explosion, is the result of oxygen suddenly being introduced into an oxygen starved fire zone. This can occur in either cold or hot smoke conditions and the effect will be full explosion, possibly with pressure waves.

It is worth – in the case of Lt. Taylor – studying the unusual circumstances that led to a reversed backdraft:

The two-storey structure was a row-house (terraced), the end unit of a block-long series of inter-connected dwellings. It was constructed of brick, but the brick had been covered with vinyl siding. The dwelling had been built on a gently sloping parcel of land so that the first floor was approximately 5 ft above grade in the front and at ground level in the rear. This placed the basement about one half below grade in the front, and almost fully below grade in the rear. There were very small basement windows in the west wall, and a larger one in the front; the rear and east basement walls were without any windows.

Basement fires are known for generating great quantities of smoke and carbon monoxide, and for oxygen levels that drop quickly. The proper procedure, as I see it, for attacking a smouldering basement fire that is generating heavy smoke, is exactly the same as that for minimising the backdraft potential in any other type of occupancy. First, establish vertical ventilation at the highest point, and then get a hoseline in position as quickly as possible to protect vertical openings – the interior stairway between the kitchen and basement, for example – to prevent upward extension of the fire.

This is precisely what Lt. Taylor and his team were trying to do. Here, then, is where the situation at this particular fire began to deviate from the usual events leading to a backdraft:

The firefighters in the kitchen, having determined that the seat of the fire was in the basement, approached the door to the basement stairs, fully anticipating that they would be met by heavy smoke and superheated gases venting *upward* toward them when the door was opened. Instead, there was an immediate flow of air *from* the kitchen, *down* the stairway to the fire in the basement. It seems probable that the fire had vented itself, probably through one or more of the basement windows, just as the firefighters were opening that fateful door upstairs. An outward flow of smoke and heated gases from the windows was thus established as the door was being opened. The suddenly opened doorway in the kitchen then provided the channel for cool air to enter, and a replenishing oxygen supply to flow *into* the fire area. It was this flow of cool air that knocked the firefighters off balance, causing Lt. Taylor to fall or to be swept into the burning basement.

In effect, then, this incident was the reverse of the 'typical' backdraft. The primary ventilation was probably accomplished through a basement window, the lowest point, when the fire self-ventilated. The interior stairway from the kitchen above then became the channel for air – and oxygen – to flow into the fire.

(NB: Further discussion of the backdraft hazard occurs in Case No. 15.)

Case No. 13: Automobile Dealership – Hackensack, NJ, USA
(Fire Command – October 1988)

Five Hackensack, NJ, firefighters, engaged in interior fire suppression efforts at an automobile dealership, were killed when portions of the building's wood bowstring truss roof suddenly collapsed. The incident occurred in the summer of 1988, the initial caller (1459) reported smoke and flames coming from the roof of the building.

On arrival (1500), heavy smoke was coming from a rear portion of the roof and "lighter" smoke was issuing from under an open overhead door. A 1½ ins handline was taken into the building, but access to the roof void was difficult to start with. Crews eventually located two ceiling hatches – one at the east end of the building, and one at the west end. Initial actions were to direct a jet into the east end hatch where fire could be seen.

At the same time, a ladder company was situated on the roof for venting operations. No signs of fire were obvious other than heavy smoke issuing from an attic ventilation fan, which was situated almost above the east ceiling hatch. At 1506 the ladder company were ordered to cut a hole in the roof around the fan. They did this, and moderate smoke continued to issue from the opening.

While firefighting continued at the east hatch, crews had attempted to take a handline in through the west hatch, but were beaten back by intense heat. At 1522 the ladder company reported fire issuing from the vent hole.

By 1527 the battalion chief began preparing for a defensive strategy in placing major streams externally and, at 1534, he ordered all internal crews out of the building. At 1535 the fire was reported burning through the roof and at 1537 a partial roof collapse occurred, killing the five firefighters who remained in the building.

Comment:
Bowstring wood truss roofs have been involved in several major collapses in the past, some resulting in multiple firefighter deaths. While the construction is reviewed in the British *Manual of Firemanship, Book 8* (p.77) there is no mention of the US experience of its behaviour under fire conditions. However, it is quite well documented in American literature that the bowstring truss is, in common with most roof trusses, extremely likely to collapse when under severe fire attack.

One author has written that: "If enough fire exists to justify calling for mutual aid, then a bowstring truss roof is *unsafe to work on or under.*" Another has stated the same, if "enough smoke exists to justify roof ventilation".

Hazards of the truss:

(1) The failure of any element of the truss may lead to its complete collapse.
(2) The tying of adjacent trusses together is common, and successive truss failure becomes likely.
(3) Voids located within trussed roofs are likely areas for backdraft explosions.
(4) An early collapse without warning is likely, if well involved in fire.
(5) Cutting into such a construction may result in an 'unsupported platform' being created below the roof men.
(6) 'Trenching' a trussed roof may weaken individual chords *or* the

'tying in' effect.

With such clear guidance so well-documented, coupled with several previous case histories, it appears that the firefighter that ventures on to/under such a roof in a well advanced fire, is quite clearly placing himself at great risk.

While many would draw the conclusion that this fire is a clear lesson why firefighters should *not* be situated on roofs for general venting strategy, it should be remembered that, in this instance, there was, I believe, contravention of safety policy. Close analysis will reveal that this is nearly always the case where firefighters are injured or killed while engaged in roof top operations.

Case No. 14: Electronics Store and Dwelling – Chicago, USA
(Firehouse – April 1985, p.58)

Three Chicago firefighters were killed and four others injured, one critically, when the roof of the electronics store they were operating on suddenly collapsed.

The fire building was narrow and long, measuring 25 ft wide and over 100 ft deep. Built of brick and wood joist construction, the front of the building consisted of two storeys, with the Vicstar electronics store on the ground floor, and an occupied apartment above it.

Access through locked gates was initiated by a ladder company using power saws with metal-cutting blades. Smoke was issuing from the roof but crews were unable to locate the fire. Laddermen on the roof opened skylights, and proceeded to cut a vent hole, but the strategy appeared uncoordinated and had little effect on smoke conditions. A later arriving ladder company was ordered to the roof to assist in venting but were hampered by snow and ice across its deck.

A chief then gave the order for some top floor windows to be vented. The firefighter assigned to this task stated: "I punched out some windows and looked in – the smoke was sucking back into the building. I knew something was wrong, so I got down right away and went up the ladder the others had used. There was a lot of smoke over the roof – then the fire blew."

The roof collapsed into an inferno below. After the collapse the entire rear one-storey section was on fire.

Possible reasons for the collapse were the weight of snow and ice on the roof; the size and weight of a roof-top air conditioning unit; and modifications made to the structure.

Comment:

It is difficult to analyse this particular incident with any accuracy, as important details – such as the extent of the fire, and roof construction etc – were not provided in the magazine's report.

What does become clear, through the sequence of events described, is the fact that the roof collapse was probably the result of a backdraft explosion. The classic signs were all there:

(1) Heavy smoke-logging on arrival.
(2) Structure vented through windows – possibly below the fire.
(3) Smoke was "sucking" back into the building.
(4) Heavy smoke conditions reported across the roof.

Following the tragedy, one Chicago chief was quoted as saying: "I didn't learn anything from this fire. If we fought the same fire again, I would have followed the same tactics."

His intention was to leave the impression that these were sound tactics and every act was based on a good safety policy. It may be that this was one of those occasions when the hand of fate played its inevitable role on the poor unfortunates. However,

good safety policy might question: (a) an uncoordinated venting plan; and (b) the venting of windows, particularly with firefighters on the roof above.

It is important to note that not one firefighter was caught *below* the collapse. One wonders if this would have been the case if the fire had been fought under British strategy.

Case No. 15: Chatham Dockyard (Mattress Store) – Kent, UK
(Fire Safety Journal – No. 3 – 1980/81, p.3)

As a result of a fire, which has become known as the 'Chatham Mattress Fire' – which led to two firefighters losing their lives, and four being injured by an unexpected explosion – there was much concern about, and interest in, circumstances in which hitherto unexpected explosions occur.

Clearly, it is important for firefighters to be able to recognise on arrival at a fire those conditions which may result in an explosion, either spontaneously or as the result of some positive action by fire crews; action which, under the circumstances, would normally be routine and safe to perform.

Some explanation of the meaning attributed to the term 'explosion' in the context of this review is required. It will be seen that the term embraces more than one phenomenon.

The mattress store was located on the ground floor of a three- and four-storey building that was used as stores, offices, and sleeping accommodation. On arrival, the ground floor was found to be smoke-logged. Two firefighters wearing BA entered the store and opened several windows while searching for the source of the fire. An explosion then occurred, which not only injured the two men in the store, but also four others who were outside. It was followed by intense fire. The two men died later and the other four suffered from shock and burns.

The fire had led to the formation – by smouldering of rubber latex mattresses – of an atmosphere of flammable pyrolysis products. This mixture is thought to have contained materials having a wide variety of molecular weights. The high molecular weight materials, being of low volatility, would condense as a mist (low molecular weight materials would remain as vapours). Because of the presence of the mist, the atmosphere may be regarded as being a smoke; albeit a flammable smoke. If an explosible smoke/air mixture is formed – as at Chatham, where air was admitted to the fire – then an explosion in the normally understood sense of the rapid propagation of flame through a mixture of flammable gas or vapour with air or suspension of flammable particles or droplets in air, accompanied by pressure effects, will occur if a source of ignition is present.

This particular type of explosion has been called a 'smoke explosion' or backdraft. Such an explosion may produce pressures of the order of 5-10 kN/m^2, or higher, which could result in structural damage accompanied by flame production. It is a phenomenon normally – but not exclusively – associated with smouldering fires in which temperatures are often deceptively low at the discovery stage. Smouldering can continue at low rates in vitiated atmospheres; conditions which are conducive to low rates of heat release and consequently low temperatures. The situation may be severe enough for the concentration of flammable products to be above the 'upper explosible limit'. If such a situation is entered, oxygen (as air) is introduced and mixed with the flammable products, bringing them into the explosive range.

If the seat of smouldering is discovered, and physically exposed, it may already be incandescent and therefore acts as a potential ignition source. A lower rate of smouldering may be increased on exposure to additional air, leading to the formation of a source of ignition. Explosions (as discussed above) and the rapid spread of flame may therefore occur simultaneously.

More generally, flashover may be defined as a stage of fire development in which a developing fire within an enclosure rapidly becomes more active, causing the combustible gases to ignite and produce flaming across pre-heated, combustible surfaces within the enclosure.

The description 'developing fire' is used here in the sense just indicated, ie one increasing in intensity and producing high gas or air temperatures. There is, therefore, a wide range of conditions under which smoke explosion (backdraft)/rapid flashover can occur and the distinction between the two is very often blurred, especially at the eyewitness level.

Comment:

While conditions resulting in backdraft may be common, it is important to distinguish between the 'low and high temperature' situations and the likely effects of forced venting under such circumstances.

The Chatham fire was a slow smouldering type of fire, creating the typical smoke-logging and low temperature effect associated with foamed rubber latex. However, more explosions result from fires involving cellulosic materials than any other material (eg, varnished, painted and polished woodwork) and more firefighters are killed in explosions associated with developing fires than with smouldering fires. But while the risk of a 'cool' smoke explosion might be rare, the problems faced by firefighters in tackling such a situation are immense and I am unaware of any sound advice, based on experience, on dealing with an incident of this type.

The guidance given in the British *Manual of Firemanship Book 12* is limited to one paragraph and suggests that conventional ventilation techniques are "particularly important in lessening the risk" [of backdraft] where smouldering foamed rubber is involved, but such a strategy "should be conducted with great care."

Francis L. Brannigan writes, in his book *Building Construction for the Fire Service:* "At a stable fire in New York in 1938, the author witnessed an explosion of carbon monoxide that had accumulated in void spaces. The violent explosion took place an hour and a half after the first alarm. It was pre-signalled by dense clouds of 'boiling black smoke', and a long-time observer of fire told us, 'It's going to blow'."

The blast caused the collapse of a side wall, and the loss of one officer's life. There was actually a detonation. Apparently, the gas-air mixture was just in the right proportion. The building had been vented according to standard procedures. It was just unacceptable to the investigating committee that a backdraft explosion could occur one and a half hours after the first alarm in a vented building.

He goes on to say: "In 1946, New York firefighters were battling a fire in an abandoned icehouse [cold store]. Gas accumulated in a 9 ft cockloft and exploded. The back wall came down on an apartment house at the rear – 39 persons were killed. More recently, the author [Francis Brannigan] observed a fire in a row of stores. The building was vented; the front window of the store was completely out. There was a bright fire which was suppressed with hose streams. The wind shifted. Heavy black smoke boiled out. Like the old-timer mentioned above, the author said to a companion: 'It's going to blow.' It did. Fortunately, the firefighters were just knocked down." It is interesting to compare the 'boiling black smoke' theory with the firefighter witness reports in Merseyside, UK (Case No. 2).

The UK's Building Research Establishment (BRE) give further advice in dealing with potential backdraft situations *(Fire Safety Journal*, 3, 1980/81, p.17) where it is suggested that: "possible means of alleviating the likelihood of an explosion could lie in the injection into the fire area of water fog or sprays, inert gases or high expansion foam. However, this would have to be achieved without the introduction of fresh air into the fire area by entrainment which might otherwise rekindle the smouldering fire and, at the same time, bring the explosive gases and vapours into a critical condition."

General Conclusions:

(1) Conventional ventilation techniques rely on high temperatures creating excessive pressures that force the smoke out of the involved structure. In the case of smouldering fires, particularly where foamed rubber is concerned, it is most unlikely that conventional ventilation will be effective where the smoke is going to stratify (stack effect).

(2) To reduce smoke-logging in these circumstances, it would firstly be necessary to increase atmospheric pressure inside the structure or control and direct air flow.

(2a) **Water fog and sprays:** As the fire is smouldering, the production of water vapour would be minimal – if any – and no suplus pressure would be achieved. Such an application could be used to direct air flow in the building, sending smoke towards any openings made. However, this would inevitably bring about the introduction of fresh air by entrainment, and the risk of backdraft would be increased.

(2b) **Inert gases:** In a compartment of any great size the technique would be impractical unless fixed installations existed therein.

(2c) **High expansion foam:** This strategy might prove highly effective where the dangerous gases are forced ahead of the foam, to exit from ventilation points made to complement the application. Firefighters would have to enter the foam to complete extinguishment of the smouldering. While air displacement is a natural consequence of 'hi-ex' application, the 'free' air entrainment risk is minimal.

(2d) **Positive pressure ventilation:** A last resort technique, under these circumstances, where air (and oxygen!) is forced into the building to increase atmospheric pressure and force the flammable gases out. Nevertheless, if a backdraft does occur, there will not be any firefighters inside the building!

(3) It is essential that British fire services use their powers under Section 1 (1) d, of the UK's *Fire Services Act 1947*, to enable the identification of potential 'low temperature' smouldering risks. Firefighting strategy for these particular structures should preclude conventional ventilation techniques.

(4) On a smaller scale, in a private house in Huddersfied, UK, on 26 July, 1975, a foamed rubber mattress fell on to an electric fire and the room filled with smoke. When the fire brigade arrived, two firemen wearing BA entered the room and found the heat tolerable. The mattress was hot and glowing and as one of the firemen applied a hosereel jet, an explosion occurred which blew him out of the room. The other fireman escaped by jumping out of a window. Both of them were injured.

In the case of a 'one room' smouldering fire, the pre-entry external venting of the room is essential *unless* 'persons are reported' trapped inside, when preventing a backdraft is the priority.

(5) A fire at a cinema in Maidstone, UK, on 28 June, 1955, resulted in a smoke explosion in the roof space. Hot gases rising from burning seats in the circle had entered the roof space through ventilation grilles in the ceiling.

In the circumstances of a developing fire, the early ventilation of the structure at the highest point (ie the roof) is the key to success.

Case No. 16: Six-storey Town House – London East Central, UK
(Author's own experience)

A fire that occurred in a derelict six-storey town house, in the east central section of London, took the life of a young female who was living there at the time.

First arriving firefighters were faced with a severe body of fire involving two rooms on the ground floor and heavy smoke-logging on the upper floors. The fire was soon brought under control, but firefighters involved in search and rescue operations on the top floor were hampered by a build-up of heat that had accumulated from the fire several floors below. It was realised, some 12 minutes after arrival, that additional living space had been constructed into the roof void. Access to this area was by means of a narrow stairway. It took firefighters a further six minutes to gain entry to this room in the roof due to the severe heat that had been unable to leave the structure. On entering, one firefighter located the body of a woman lying face down on the floor, while another vented the room by breaking a wired glass window set in the inclined wall, which was actually the roof itself.

Comment:

The time taken to reach the room in the attic space (18 minutes after arrival) was unacceptable. There is no saying that this woman was still alive on the fire brigade's arrival, but a team of firefighters sent to the roof at the outset of operations would have been ideally sited to vent the attic window as soon as water was applied to the ground floor fire. Such an action would have greatly assisted firefighters in their approach to the upper levels, possibly reducing the time taken to reach the attic space by several vital minutes.

To achieve optimum effectiveness at an incident of this type, it is essential that firefighters are placed in position on the roof almost immediately, in anticipation of a venting operation. Then, if they are required to 'open-up', the co-ordination between interior and exterior operations can be timed to perfection. By deciding to ventilate at a later stage, and then instructing firefighters to position themselves as such, is wasting valuable time, and the effectiveness may be nullified. Remember, it is not wasting resources to position a roof team at such an early stage of operations – they are there for more than one reason (see Chapter 8).

Case 17: Three-storey Balloon Wood-frame Building – Syracuse, New York, USA
(As reported by the NFPA – USA)

The three-storey, balloon wood-frame building was located near the campus of Syracuse University. Its ten apartments were occupied by college students. The building contained major combustible concealed spaces both in the walls and above the third floor ceiling. A partial automatic sprinkler system had been installed protecting the basement, means of egress, a storage area, and a portion of the combustible concealed space above the third floor corridor.

The fire originated in a second storey apartment, then spread into the combustible

Figure 4:1 – The Syracuse fire – April 1978, New York, USA.

concealed space above the third floor ceiling. During firefighting operations, four firefighters on the third floor became trapped and died. It is believed a delay in roof venting operations contributed towards the firefighter's deaths.

Upon arrival, Syracuse firefighters found light smoke showing from windows on the top two floors, and around the eaves. The initial attack was made in the room of origin but the amount of fire was minimal in this area, although it was observed that the fire had entered the concealed space behind the wall. A report of an occupant remaining on the third floor led a team of firefighters to search this area.

Initially they found very little smoke and no heat although the fire began to develop in the concealed space above them, causing a sprinkler head to actuate. Within minutes the conditions on the third floor deteriorated rapidly and a hoseline was called for urgently. By the time it arrived the fire in the concealed spaces and the attic, was breaking out on to the floor, in search of more oxygen, adequately provided by the open windows at that level *(Figure 4:1)*.

At this stage firefighters were ordered to evacuate the third floor, on account of the extensive fire in concealed spaces. However, during the evacuation the hallway at that level became untenable and – despite rescue attempts – four firefighters became trapped and died. At this stage of the fire the roof had not been ventilated.

The first ventilation hole was cut at 0106, 16 minutes after fire department arrival. As the roof was opened the heat from the fire was drawn to the opening and a sprinkler head actuated directly below the cut, nullifying the venting effect. A second cut made six minutes later was similarly affected by sprinkler actuation. A third and final cut, made near to the void where the fire had spread from, was more successful at 0115, and the relief was felt by firefighters attempting to regain entry to the third floor corridor as the barrier of heat lifted, allowing them back on to the floor *(Figure 4:2)*.

Comment:

A fire concealed within voids, behind walls, below floors and above ceilings, is probably one of the most difficult, and dangerous, types of fire a firefighter can face. The timber balloon-type construction, so common to many parts of the USA, is unique in its style. However, we all have voided properties at risk in our own areas. You probably will not find out they are there until they burn!

Once a fire has entered concealed spaces it must be chased. It is common for a void fire to create large amounts of smoke as it searches for a plentiful supply of oxygen to support its growth. Alternatively, the void may act like a chimney and the fire will roar within, exiting at natural openings for a short period, only to be sucked back into the void as air flows fluctuate. The unnatural behaviour of a fire propagating within a voided structure is an experience that may shock even the most seasoned of firefighters!

To get at a fire in concealed spaces, the building must be 'opened-up', that is – the spaces must be cut open. It is almost certain the fire will be heading for the roof space, provided access allows it, and 80 per cent of such fires will reach their destination in multi-storey buildings unless they are halted at a very early stage. The light smoke issuing from the eaves is a 'classic' indication that should have pointed Syracuse firefighters to the attic. If the fire's in the roof it must be opened up from above first. This must be carefully co-ordinated with a water application from below.

Of course, by opening the roof there is no guarantee that the fire will be controlled. The fire will probably intensify with the 'chimney' effect but the main hazards of backdraft and flashover have, hopefully, been avoided. As well as opening the roof, all walls and floors should be opened for inspection. The location of the fire will be aided by crews equipped with thermal image cameras and hoselines should be laid into all floors. You can be fairly certain that if you do not go looking for the void fire, in time, it will come looking for you! An aggressive approach is the answer.

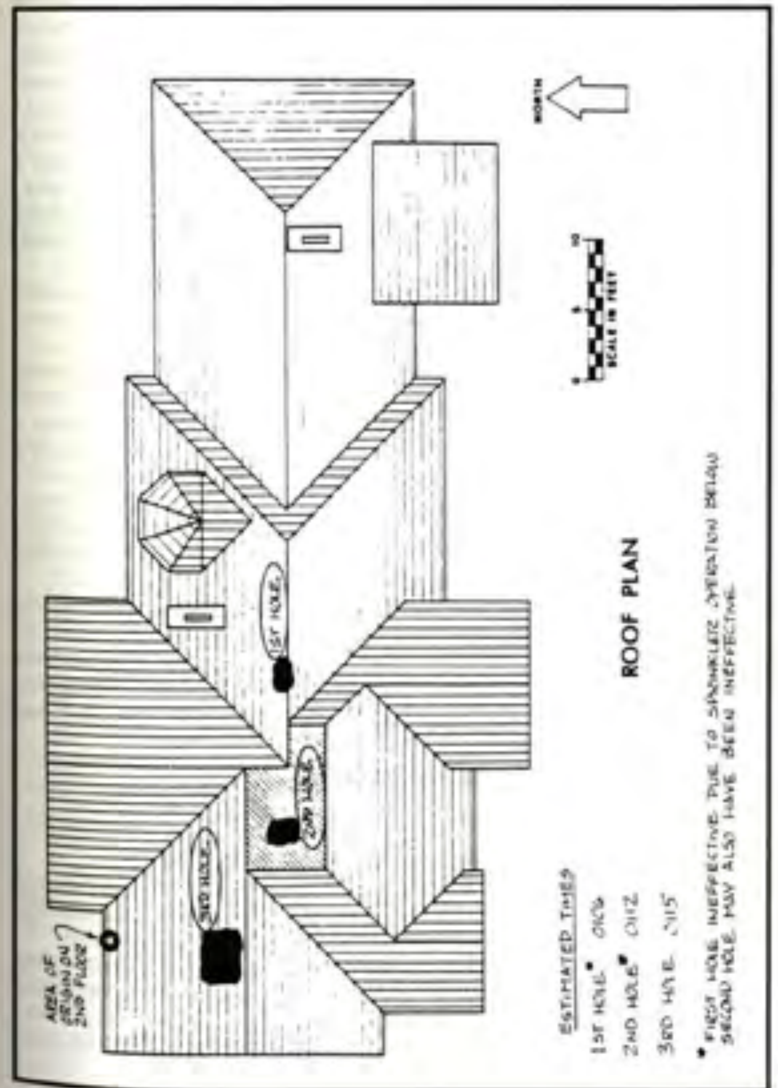


Figure 4:2 – Location of roof cuts – Syracuse balloon-frame fire, New York 1978.

Case No. 18: Gillender Street (Hays Business Services) – London, UK *(Author's own findings)*

What became known as the Gillender Street Fire represented a true fireground tragedy, for two London firefighters died during the suppression effort.

The seven-storey building occupied a 5,000 m² site in East London. It consisted of brick walls, concrete and steel floors, with an asphalt on concrete roof. At the time of the fire it was stocked with a large quantity of paper files.

The first call to the fire brigade was received at 1431. A fire alarm had originally activated on the premises at 1423. An initial response of two pumpers and an aerial were despatched and the first firefighters arrived on scene at 1436 and 1437. At this stage, there was nothing visible from the building's exterior but during a search of the premises, firefighters located smoke on the 2nd floor mezzanine level. At 1441 four firefighters were ordered to rig in CABA and were sent to investigate. A line of hose was eventually laid into the fire compartment but the severity of the heat and smoke prevented firefighters from advancing more than 2 m into the area. From this position they were unable to mount an attack on the fire.

As the firefighters withdrew to lay in a larger hose line the conditions on the fire floor worsened. A second team of four tried to advance on the fire but were unable to gain further ground and they too were forced to withdraw.

Firefighting efforts progressed throughout the afternoon while battling against an intense build-up of heat and smoke that prevented an effective interior attack being made for some time. Despite the stringent safety procedures (including a detailed accountability system) that were in operation at this incident, two firefighters became lost in the smoke as their air supplies ran out, and died.

Comment:

A report on the incident was made following an investigation by Britain's Fire Brigade's Union. Therein it stated:

"When it is safe to do so, firefighters should commence ventilation as soon as possible – *Manual of Firemanship (Book 12)* – Chapter 10, paragraphs 2 and 3). Many members reported the intense build-up of smoke which hampered both operations and the rescue attempts, yet it was apparently a considerable time before ventilation was started." The report recognised that the failure to organise ventilation is a major failing in command and control.

Case No. 19: Prior Park College, Bath, Avon, 1991

At 1607 on Friday, 16th August, 1991, the County of Avon Fire Brigade (England) were called to a fire at the Mansion House, Prior Park College, Bath. The first two fire vehicles were on scene six minutes later, followed at 1614 by an aerial ladder.

On their arrival they were confronted by a building of five storeys, measuring 60×30 m. Constructed in 1730, the building consisted of stone walls, timber floors, a slate and tile (on timber) roof, with internal walls made up from lath and plaster. A fire was reported in a bedroom on the top floor and faint smoke was percolating from the roof above this area.

A two-man team rigged in CABA mounted an attack on the fire, utilising a high-pressure hosereel. A severe fire was in progress within the room and it was immediately noted that fire had travelled into the stud-partition wall. It was obvious that there was also fire involvement of the roof void above their heads and the floor void below them, at this stage – smoke conditions were light.

Although a further pumper arrived at 1617, manpower resources were immediately stretched with the report of a student missing in the area of the fire. Further teams in CABA were sent to search the fire floor and at 1632 a request for an additional engine was sent ('make pumps four'). Just four minutes later (1636) fire was showing at roof level and an extra two engines were requested as the aerial ladder was pitched to the roof to investigate.

From this point it became obvious that a serious fire situation was developing, with fire spreading horizontally both above and below firefighting crews, vertically to the roof, and down to lower floors. A further request for additional appliances, including an aerial platform, was sent at 1712 and at 1729 a partial collapse of the roof occurred, some one hour 16 minutes after arrival.

The second aerial arrived on scene at 1744 and by 1821 the fire was reported as 'spreading through the roof space'. At this stage, firefighters were evacuated from the area as a further partial collapse of the roof occurred. Firefighting efforts were now being directed from the roof but further collapses of the roof structure occurred at 1923 and 1950. By 2108 all personnel were withdrawn from the structure.

The incident was closed at 1530 on Sunday, 18 August. By this time the structure had suffered severe damage as follows:

Building of 60×30 m, consisting of four floors and basement. 100 per cent of roof, 100 per cent of third floor, 75 per cent of second floor, 50 per cent of first floor all severely damaged by fire. Remainder of building severely damaged by water.

Comment:

This was a 'void' fire of some major proportion. Not only was the internal wall partitioning involved, but so too was the large expanse of common roof space. The initial response was stretched with reports of a missing occupant and resources were diverted to searching the fire floor.

The fire originated at one end of the building and the prevailing wind was 'pushing' the fire further along the roof void. The only possible strategy would be a 'trench', cut at an early stage and sited some distance from the area the fire originated in. However, this was never certain to be effective for: (a) there was a shortage of cutting equipment, and (b) there was extensive horizontal fire spread on the floors below which may have broken into the roof beyond the trench.

The application of 'high-pressure' streams (or sprays) into structural voids are never likely to 'chase' a fire. Moreover, they willl 'push' the fire into more remote sections of the building. However, it is not suggested that such an occurrence took place at this fire, but it is a worthy point to bear in mind.

Structure Venting – The 'Golden Rules'

Before I enter into a discussion concerning the various techniques involved in venting a fire involved structure, it is worth mentioning some 'golden rules' that are applicable to most situations:

(a) Any attempt to ventilate a building must be co-ordinated with the interior attack, and then, only on the express instructions of the incident commander. To ensure such co-ordination, all crews must maintain an effective communications link with each other, and with the incident commander. Any lack of control over such operations is likely to reduce the effectiveness of the overall fire attack and place firefighters in danger.

(b) Prior to ventilation openings being made in the structure, the incident commander is to assess the occupancy life hazard. Where an escalation of the fire is likely to place occupants in immediate danger the 'opening up' process must be delayed. However, depending on reports from crews working on the interior, he may have to take a gamble if conditions within the structure are slowing the progress of firefighters involved in search and rescue.

(c) It is important that an escalation of the fire is anticipated and planned for, where venting is to take place. This means laying out and tactically placing additional hoselines to cover any spread of fire as it occurs. Being one step ahead of the fire is sound planning. Such lines may be required both externally and internally, or on the roof.

(d) Ventilation openings should be made at the *highest* point. This may refer to the highest point in a roof, a floor level, or an individual window, depending on the location of the fire. To ignore this rule could be disastrous. I once saw a firefighter engulfed in flames as he vented a shopfront window at low level instead of taking out the top section first.

(e) Openings made at low level within a structure will feed the fire with oxygen. The potential for a backdraft is always great under these conditions, although low-level entry points will often precede any ventilation operations.

(f) Where smoke 'sucks' back into a ventilation opening, or a 'pulsing' effect is noted, initiate an *immediate* evacuation of the structure, for these are sure signs of an impending backdraft. If such signs are noted before any openings are made, *do not ventilate* until the incident commander is aware of the situation.

(g) Where 'cover-lines' are sited adjacent to ventilation openings, ensure that the stream is not directed in to the opening itself for this will negate any venting effect.

Ventilation Techniques

These are:

(1) Top or vertical
(2) Cross or horizontal
(3) Water fog assisted
(4) Negative pressure fans (NPV)
(5) Positive pressure fans (PPV)

(1) Top or Vertical

Where a fire, or its combustion products, are mushrooming, throughout the upper portions of a structure, the situation is prompting some form of topside ventilation. Large single-storey buildings – possibly devoid of partitions – such as warehouses, supermarkets, bowling alleys, industrial shops, enclosed sheds or other commercial enterprises, under certain conditions, present an extremely hazardous environment for a fire to propagate. Such fires may occur 'after hours' when the building is unoccupied or during weekends, where the fire may continue to burn undetected for long periods of time.

At its inception, the abundance of oxygen assists in the generation of tremendous heat under a condition of relatively free burning. Ultimately the condition becomes one of relative incomplete combustion with the development of super-heated gases with a high carbon monoxide content. These gases tend to ignite other combustible contents not already involved in the fire. The entire area becomes a seething mass

associated with volumes of heat, smoke and gases (including carbon monoxide) – all lighter than air – seeking to escape at the roof level where there are no existing openings.

Teams of firefighters attempting to 'move-in' on the fire below will often experience a wall of thick smoke, possibly down to floor level. There will be surges of heat as the fire swirls around above their heads. The structure will begin to creak and groan as the upper portion comes under severe attack. In an attempt to find the fire they may direct their hose streams into the darkness ahead of them. Unable to find the searing heat, their confidence begins to fail as they start to back-out of the structure.

The building is crying out for topside ventilation. . . .

The correct action, under these circumstances, would be to open the roof at its highest point. However, before firefighters are committed onto the roof an assessement should be made of its construction – and stability – during this stage of the fire. Such a decision will require the fire officer to bring to bear all of his knowledge, training and experience. Quite simply, if the roof is too unstable for firefighters to work upon, then it is also dangerous for firefighters to work *under* it, and crews should be withdrawn from the area.

Many modern roofs are designed and constructed to the latest lightweight specifications. They are often formed of factory-built lightweight trusses and will not stand up to the stresses of a fire in similar fashion to traditional timber and joist construction. These modern roofs – often designed to span large areas – will collapse early in a fire. All depending on the level of fire involvement, the safety rule of 'ten minutes to collapse' should be borne in mind at all times. In effect, this means such roofs should never be trusted when severely stressed by fire. Taking attendance times into account, this type of construction is ready for collapse just on, or after, the fire department's arrival!

Under such circumstances, and depending on access, the possibility of firefighters working to vent such a roof from the cage of a hydraulic platform might be considered.

Another European-based argument against roof ventilation operations is that tiled and slated roofs, and other heavy forms of construction, are not ideally suited to such a strategy. That, I believe, is rubbish! Such roofs, unless formed upon trusses connected by lightweight metal gusset plates, are generally perfectly safe to work upon, and easily openable. The two main problems with working such roofs are: (a) steep inclines situated high above the ground are difficult to reach safely; and (b) the depth of the void beneath the roof may be too far to breach the ceiling below.

When opening a pitched roof, a team of two firefighters can work safely, and effectively, utilising safety lines in conjunction with a roof ladder. The breaching of a roof will require a selection of tools such as axes, hooks, and portable petrol-driven power saws (rotary and chain) with a selection of cutting blades, able to cut through gravel, tar, concrete or steel.

There are, very basically, three types of roof cut: *(Figures 4:3, 4:4 and 4:5).*

(a) **Inspection holes** – Triangular cuts, all sides being equal at about 9 ins, made to observe conditions below, also noting the roof's construction.

(b) **Main roof cut** – A cut made over the main body of fire to release the heat, smoke and gases from the structure. It is essential for this opening to be co-ordinated with the interior fire attack, and effected on instructions from the incident commander. There are mixed feelings on the minimum size a 'maincut' should be, although one

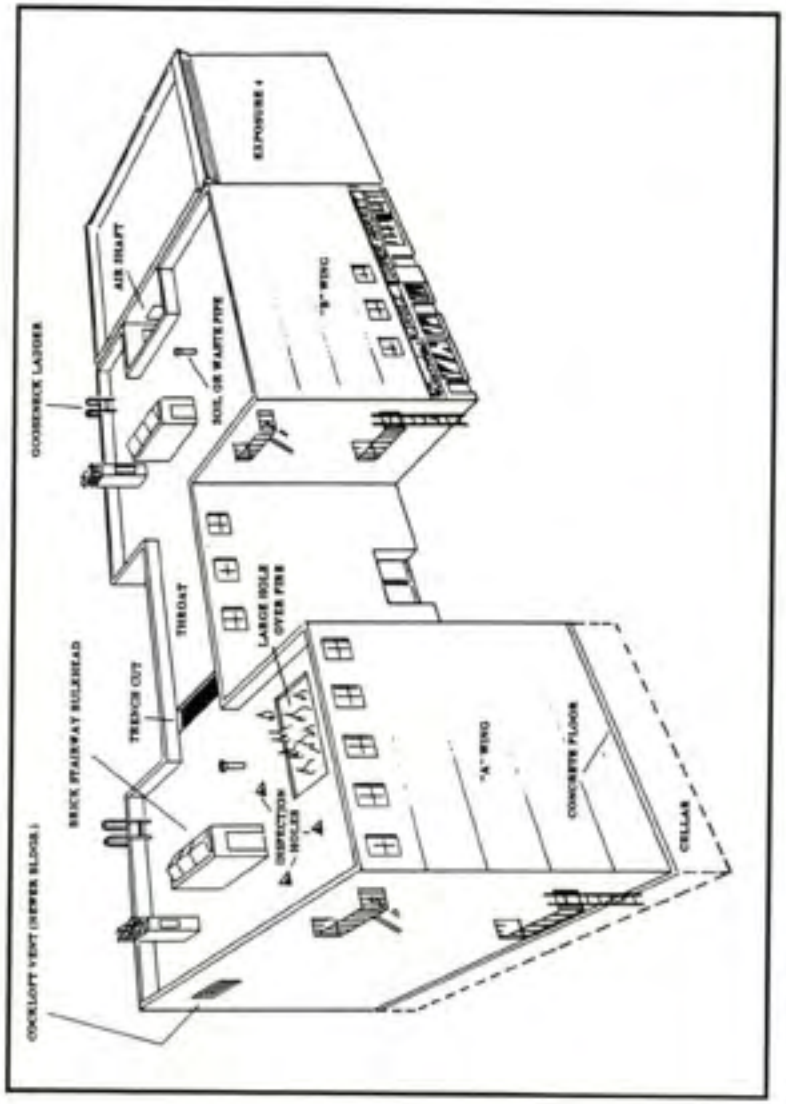


Figure 4:3 – Three types of roof ventilation cut.

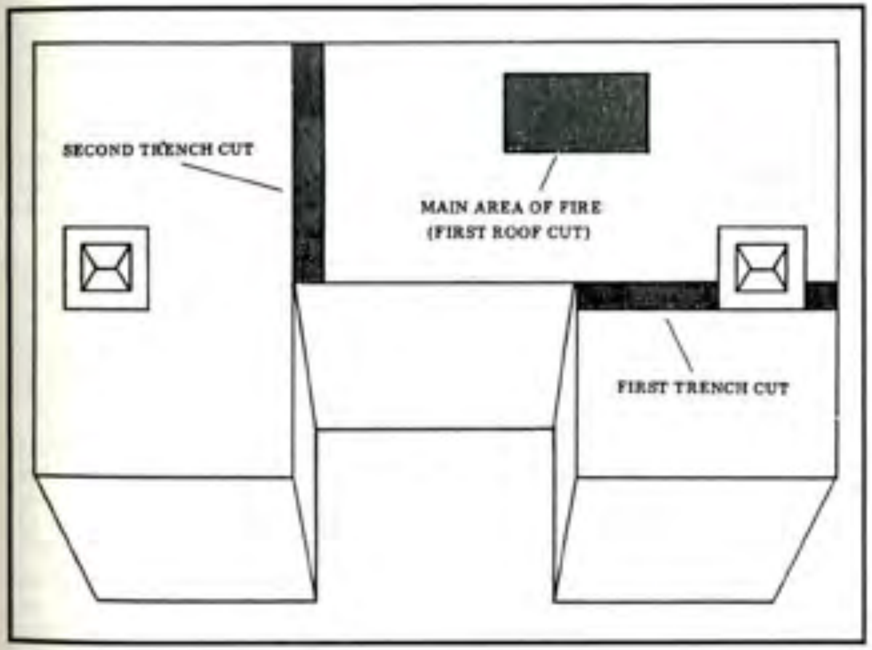


Figure 4:4 – Three types of roof ventilation cuts.

square metre is a good base-mark. While fixed venting systems are often designed on a six per cent area, authoritative recommendations suggest areas of 1 to 10 per cent of the floor area to be vented should be opened-up by firefighters on the roof. In a building 30 m×15 m (450 sq m) using a 10 per cent venting factor would require 45 sq m of roof area to be opened up. As several smaller openings are more effective (and safer) than one large hole, two openings of 3 m×7.5 m would probably suffice. Mr. John Mittendorf, a Battalion Chief with the City of Los Angeles Fire Department, and an accepted authority on ventilation tactics, suggests a roof should be opened until smoke stops venting under *pressure*.

Mr. Mittendorf explains, in his book *Ventilation Methods and Techniques* (Fire Technology Services, Ca., USA), that the important factors when working under such conditions are to **read, sound,** and **test** the roof *before* cutting (his terminology)! He goes on to describe how it is important to evaluate the safety of a roof before embarking on such operations. He also emphasises the importance of not cutting major supports, trusses, or rafters, which might affect the 'keying-in' of the structure. His concerns over firefighter safety are highlighted by the sound advice of keeping your escape route open, working towards the sited ladder, with the wind at your back, and *never* placing your weight on the section being cut!

(c) **Trench cut** – Also referred to as a 'strip-cut', or 'stripping', a trench

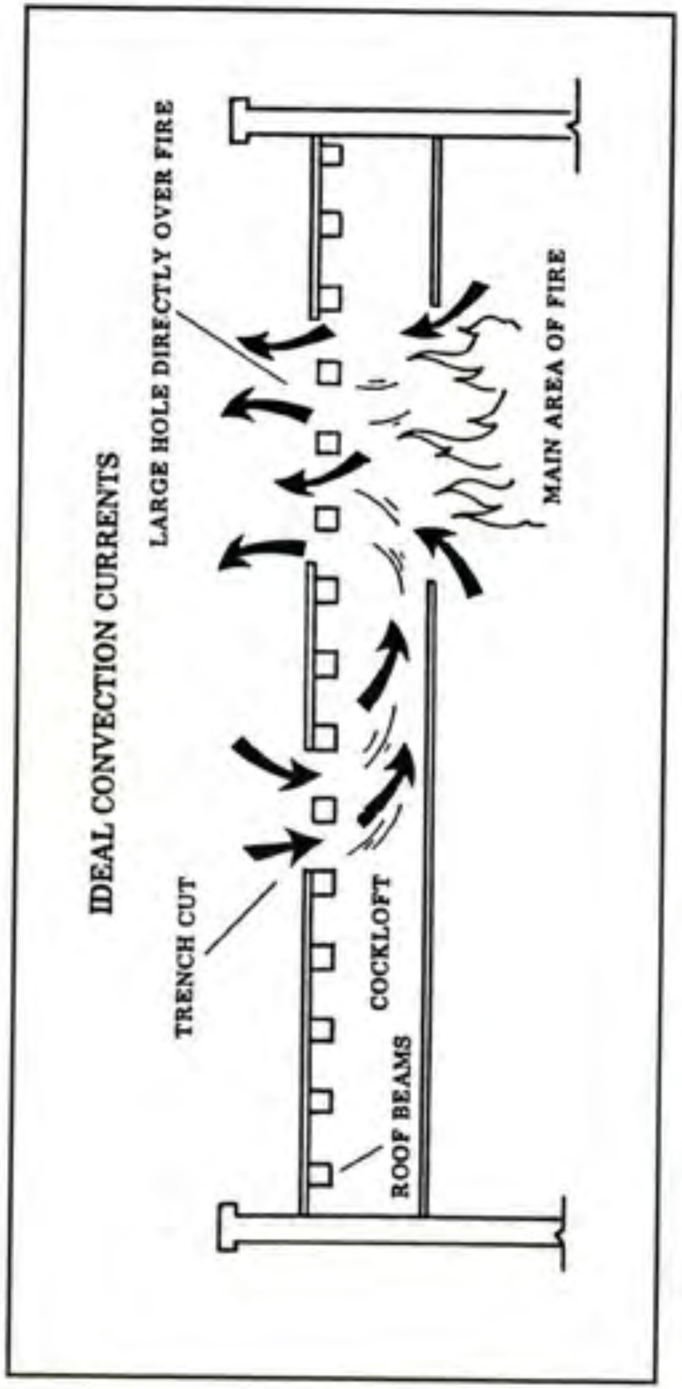


Figure 4:5 – Convection currents to aim for.

cut is an opening made across the full distance of a roof, between its outer edges, or exterior walls or other fire stops. The width of a trench is generally recognised as one metre wide. It is a defensive measure, often made to supplement main cuts.

A trench must be made well ahead of the fire, and as it is intended as a final stop, it is important to cover the opening with strategically-placed hoselines. The technique of trenching will also set up ideal local convection air-flows to prevent flames extending into an attic, or void, where a main cut is made.

Arguably, a trench cut is the most effective opening that can be made at a fire for it acts upon the same principle as a firebreak in a forest fire. It is particularly effective on roofs of great length, or large areas. To test the effect of trenching, one fire department in Illinois, USA, carried out a test burn in a derelict horse-barn, 225 ft long. Prior to starting any fires, a 1 m-wide trench was cut into the roof at the midpoint of the structure. They did not cut the ridge-board although some fire departments do recommend this.

During the test burn, ignition of the roof rafters (at 0.5 m spacing) was occurring at the rate of one every four seconds. As heated gases mushroomed across the underside of the roof, they reached the trench, and the natural convection currents moved the heat upward through the trench and out of the building, thus stopping the horizontal spread of fire.

The fire was attacked from the opposite end of the trench, pushing the flames towards the roof cut. However, even under this adverse condition, the trench still cut off the fire spread. During two later burns a deluge gun, delivering over 1,400 LPM (370 GPM US) was set up underneath the trench, at ground level.

This was used to push heat and smoke up and out of the trench successfully. On one occasion, when the fire was allowed to burn right up to the trench, the flames actually moved past the trench for a short time. The deluge gun quickly pushed the fire back, and though flames extended down to near head height briefly, the position was not abandoned.

In retrospect, this department suggests a wider trench of 2 m would be more likely to restrict the spread of fire, although the 1 m trench still did the job admirably.

A particular form of flat roof construction common in the USA is that of the 'metal deck roof'. This roof is based upon a corrugated steel deck topped with an insulation panel and layers of asphalt-saturated felt and pitch roofing material. Between the insulation and steel deck lies a quantity of tar. This type of construction is suited to lightweight commercial buildings, its advantage being easy and cheap installation.

When a metal deck roof becomes involved in fire, the action of propagation is self-sustaining. As the steel is heated, the tar gives off flammable gases that ignite on the underside of the deck. The continuing chain reaction will eventually lead to a complete collapse of the roof. The trench cut is recomended as the most suitable way of dealing with such a fire, although some will prefer to cool the deck from below by an application of water spray.

Finally, when venting a roof, consider the possibility of fixed installations, such as sprinkler systems or smoke reservoirs, that will ultimately affect the benefits to be derived from such an operation.

(2) Cross or Horizontal

Where a fire is confined to a particular area, and the products of combustion are not being carried to the upper reaches of a structure on the convection currents, another form of forced ventilation is necessary to gain relief on the fire floor. This is achieved by cross, or horizontal, ventilation, generally through the opening or breaking of windows.

Weather conditions are always a primary consideration in determining the correct ventilation procedure, particularly where cross ventilation is concerned. Under certain circumstances, where there is no wind, cross ventilation is generally less effective since the force which removes the smoke is absent. It is extremely important to assess the wind direction before venting a floor, or roof. This is particularly important in high-rise buildings where wind direction can change at varying heights above the ground. Before windows on the fire floor are vented at upper levels it is good practice to test the effect by opening a window on the floor below.

High humidity and rain will lower the buoyancy of smoke and gases and slow up air currents, perhaps making more openings necessary to achieve effective ventilation. Firefighters should, therefore, not undertake ventilation from the side without considering: (a) the direction and force of the wind; (b) which is the windward side of the building (open leeward windows first); and (c) the humidity and temperature.

A situation that is often faced by firefighters is the large shopfronted glass opening. Where a fire has burned within the compartment to a stage of incomplete combustion, the build-up of heat and flammable gas is just waiting to mix with the outside air. The strength of shopfront glass may prevent any self-venting at an early stage and the firefighter is faced with the predicament of forcing an entry through the glass facade. In this situation it is essential to vent the shopfront at the highest level before an entry is forced lower down *(Figure 4:6)*. It may be the case that a smaller panel exists above the main sheet. Under these circumstances the smaller panel should be breached first. The firefighter should also make use of any cover, ie, standing to the side of the shopfront while breaking the glass with a long hook – for he is literally standing in the barrel of a loaded shotgun!

(3) Water Fog Assisted

The technique of utilising water fog to extinguish fires in compartments has been studied for many years. The principle of indirect attack is generally well known, although more modern applications of the technique are not widely appreciated. During the early days of evaluating fog stream effectiveness, it was noted that a pressure wave would move ahead of the fog stream and force the fire to travel away from the advancing firefighters.

The ability to push a fire had both advantages and disadvantages. It was believed that combustion products could actually be directed out of a structure by forcing them with a fog stream. While there may be some truth in this, a far more effective technique of utilising fog streams to vent smoke from a building was waiting to be discovered. . . .

The principle of creating a negative pressure in a compartment by placing portable extraction fans at points of exit had been used with success for some time. It was noted that the negative pressure that occurred at the base of a fog cone could also serve to suck smoke out of an opening and tests to confirm this effect were established. The Fire Service Extension Department of the University of Maryland, USA, with technical assistance from the Mechanical Engineering Department, conducted a test to determine the relative effectiveness of fog streams as a ventilation tool, using two smoke ejector fans – 5,000 and 10,000 nominal cu ft – as a basis for comparison.

All openings in the test building were closed off except one window for the placement of smoke ejectors and fog nozzles, and a second window, 5.25 sq ft in area, for air intake. Air flow measurements were taken at the point of intake.

Figure 4:6 – Before ventilating a compartment it is important to ensure that the attack team is ready with a charged hoseline and the added protection of CABA – with masks in place. The correct method of venting a glass shop-front is shown above. A 'cover-line' should be sited to the side of the opening.

allowing the ejection rate to be computed into **cubic feet of air** figures. It should be noted that, due to the small intake area, both ejector fans and fog nozzles were unable to reach their full rated capacities. The size of intake was restricted to facilitate air-flow measurements.

The first tests were run using smoke ejector fans. The results were as follows (NB: CFM=cu ft per minute):

Unit	*Ft per sec*	*CFM air moved*
5,000 CFM fan	430	2,257.5
10,000 CFM fan	896	4,704.0

Before conducting the tests with fog nozzles, tests were run to determine the most efficient position for a fog nozzle used to eject smoke. The tests showed that the best nozzle position is a few feet inside the room, near enough to the opening so that a fog pattern of about 55 to 60 degrees covers about 85 to 90 per cent of the opening *(Figure 4:7)*.

With a fog nozzle flowing 60 GPM (227 LPM) at 100 psi (7 bars) on a 1½ ins (38 cm) line, the following amounts of air were moved out of the compartment:

Nozzle position	*Air velocity*	*Air moved (CFM)*
2 ft o/side window	370 ft/sec	1,961
At window	680 ft/sec	3,604
Inside window	1,020 ft/sec	5,406

Subsequent tests using fog streams were made with the nozzles positioned inside the window, in the most efficient position. Test results were as follows:

Hose	*GPM (LPM)*	*Air velocity*	*Air moved (CFM)*
1½ ins (38 cm)	60 (227)	1,020 ft/sec	5,406
1½ ins (38 cm)	95 (360)	1,270 ft/sec	6,731
1½ ins (38 cm)	125 (473)	1,260 ft/sec	6,678
2½ ins (65 cm)	125 (473)	1,340 ft/sec	7,102
2½ ins (65 cm)	175 (660)	1,400 ft/sec	7,420
2½ ins (65 cm)	250 (945)	1,660 ft/sec	8,798

It was noted (at 125 GPM) during the tests that performance varied among nozzles produced by different manufacturers where nozzle design influenced exit velocities from the tip.

These tests demonstrated that fog nozzles may be up to four times as effective

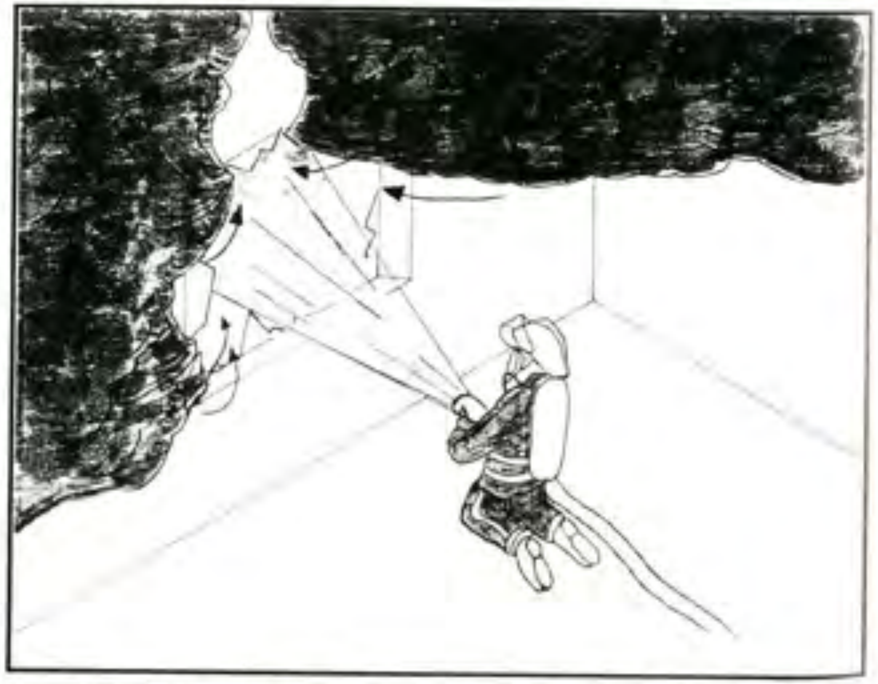


Figure 4:7 – With a nozzle position located a few feet from the window, and a fog cone of 55-60 degrees, the Venturi effect in the stream will assist in displacing the smoke from the compartment.

when compared to smoke ejector fans, although there may be a minor amount of water damage at the application site.

(4) Negative Pressure Ventilation (NPV)

The technique of creating a negative pressure within a compartment, by use of extraction fans (smoke ejectors) sited at points of exit, has already been mentioned. The negative pressure creates an outward flow of air (and combustion products) from the affected compartment.

It is a method that has been used by fire departments around the world for many years, usually after the fire has been extinguished. It requires the placement of portable fans – usually electric driven – in the upper portion of exit points. Alternatively, a fan may be sited deep within a compartment, directing smoke out through lengths of polythene ducting leading to the exterior.

(5) Positive Pressure Ventilation (PPV)

Another form of pressurised ventilation utilises the reversed effect of smoke ejectors, by creating a positive pressure within a compartment, or structure, to force air out through natural openings. It is a technique that in the early 1990s was gaining in popularity across the USA, although, surprisingly, it has been around for some time. It has been described as "the wave of the future" for firefighting, and "the greatest aid to firefighters since the introduction of breathing apparatus"!

It is unique in the fact that firefighters are utilising this method not only after the fire has been extinguished but also in actual fire attack. It is said that PPV directs the heat away from firefighters advancing into a fire with a fan operating at their rear. If quantified by air movement alone, it is far superior to negative pressure ventilation. Its full merits are discussed in the next chapter.

Fires in Atriums and Tall Buildings

Smoke movement in tall buildings and atriums is affected by a number of factors. It is important for firefighters to have an understanding of such aspects that may directly affect their ability to rid the structure of combustion products.

All enclosed tall structures will effect a naturally rising airflow within, termed the 'stack effect'. This vertical movement of air through the building is caused by the differences in temperatures and densities between the inside and outside air. As warm air rises within the natural shafts of the structure, to exit through natural openings in the upper levels, cool air is drawn into the lower levels to replace it. This movement of air can often be heard within lift-shafts, or open stairways, serving such buildings, its speed being reliant upon the difference between the two temperatures.

Stack effect is most significant in very cold climates where the difference between the inside and outside temperatures creates a very fast air flow. This is termed 'winter stack' and its effect is of great interest to firefighters because of its natural convecting speed. In very warm climates the difference between inside and outside temperatures is not so pronounced and air movement is much slower. However, a condition may arise where the outside temperature is warmer than that found on the inside of the structure. This effect is termed 'summer stack' and is of interest to firefighters for a reversed air-flow can occur within the building moving in a downwards direction. It is important to understand that stack effect air-flows are not caused by a fire within the structure, they are present at all times, and a fire in a tall structure is unlikely to affect the rate, or direction, of normal flow.

Somewhere between 35 to 52 per cent of the building's height above ground level lies an area termed the Neutral Pressure Plane (NPP). Its exact position will depend upon ambient conditions in and around the structure at any one time. At this 'midpoint' the flow of air in to, or out of, the structure will be neutral, ie, will not take place. Below the NPP the flow of air is inwards and above the NPP the flow is outwards, the magnitude of these forces increasing proportionally as to the distance from the NPP.

To test this effect of stack movement, feel the intensity and direction of air-flow under doors at different levels in a tall building. Find the NPP for yourself and note its position within the structure.

When a fire occurs within a tall structure, the combustion products will ride the convection currents created by the stack effect. It is generally accepted that such products will rise in a building, the greater the stack effect, the further, and faster, they will rise. However, the effects of summer stack are not so well documented.

When a fire broke out on the 20th floor of the 44-storey Westvaco building in New York City, in June 1980, because the fire occurred on a hot day, and because the interior of the building was cool from the air-conditioning system, the smoke banked down to the 17th floor, thereby making it necessary for firefighters to use the 16th floor as the staging area from which to mount their attack. This phenomenon of downwards smoke travel is to be expected where a summer stack exists, with a fire *below* the NPP.

A knowledge of stack effects is not only of interest to the firefighter, it is essential if he is to utilise such air-flow to his advantage. If a fire occurs some distance below the NPP in a tall building, the natural flow of air at the floors near the fire floor (and perhaps the fire floor itself) will be into the building. Therefore, the opening of windows at this level may drive smoke further into the structure. Another situation may arise where smoke-logging affects floors just above the NPP. At this point the natural air-flow is outwards and suits a cross-ventilation operation. However, if the structure was vented at its highest point as well, this would have the effect of *raising* the NPP by several floors and the outwards flow on the vented lower floors would now be reversed as those levels were brought below the NPP.

When a fire occurred in 1946 on the third floor of the Hotel Winecoff, a 15-storey building in Atlanta, Georgia, USA, the building was not vented at roof level. This caused the NPP (Neutral Pressure Plane) to remain around the midpoint of the structure, somewhere between levels six and seven. Guests on upper floors opened windows to gain relief from the smoke that was statifying at levels six to 12. At these levels the natural air-flow was outwards and pressure was from stair-shaft to room areas. This had the effect of pulling the smoke, and fire, towards the hallways and guest-rooms and, as door transoms failed, 119 guests perished.

Had the building been vented at its highest point at an early stage, the NPP would have been raised above the 11th floor. This may have prevented smoke stratifying at such low levels as air-flows below the 12th floor reversed to an inwards direction. The resulting pressure wave from guest-rooms, to halls, to stairway may have assisted the spread of fire up the stairs but might have reduced the eventual life loss.

The air-flows, as predicted through normal stack action, are indicated *(Figure 4:8)* for a structure without roof ventilation (left) and with roof ventilation (right). such predictions can only remain as theory and are not able, in any way, to take full account of the conditions on upper floors of the Winecoff Hotel during the actual fire. They do, however, represent a good example of influencing smoke movement through raising the NPP.

It becomes apparent that the firefighter is able to influence air-flow, and ventilation of lower floors, in a multi-storey building by his actions at roof level. To ensure that any roof opening is working to his advantage, a sound knowledge

of stack effect and NPP is essential.

While the natural stack action will assist the rising smoke plume in a multi-storey building, or other tall structure (such as an atrium), in practice there are other influential factors that affect smoke movement. One such factor is the buoyancy of smoke as it rises.

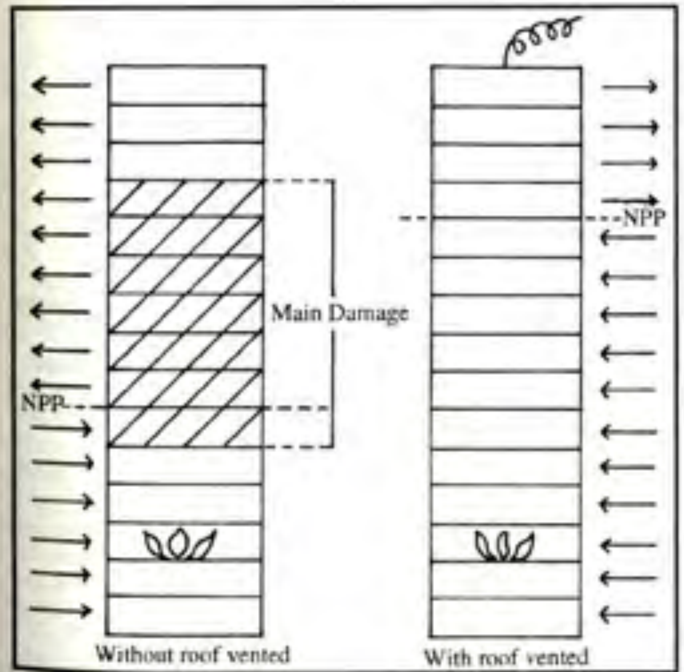


Figure 4:8 – The Winecoff Hotel fire: stack effects.

As smoke moves away from the fire – either vertically or horizontally – large quantities of air are entrained into it. This will have the effect of increasing its volume and cooling it. The heat output of a 10 MW fire will register a smoke temperature of 460 deg C at 4 m, rising to 98 deg C at 12 m, 25 deg C at 24 m, and 16 deg C at 36 m. At this height the smoke will have hardly any buoyancy force available to move it out of an open vent. Therefore, it would be inappropriate to try to vent smoke from a fire on the ninth floor, via a skylight opening at the roof level of a 30-storey building. It would be likely that such smoke, venting up a shaft or stairway, would 'stratify' around the 15th to 19th floors.

If we imagine an original NPP at level 12, without a roof opening the air-flow on the smoke-logged floors would be favourable for a cross-ventilation operation. However, by opening the roof we have raised the NPP and created unfavourable air-flows on levels 15 to 19 (air-flow towards shafts). With the roof opened we would need some assistance to raise the smoke up the stairway, in the form of pressurised fans. Some stairways in high-rise buildings, and some atriums, are designed with smoke-ejectors built-in at the head. These are generally automatic in operation and their effect on the NPP may need evaluating in 'real' fire conditions.

It can be seen in *(Figure 4:9)* how smoke stratified at levels 15 to 19 from the fire on level nine. The effect of opening the skylight raises the NPP and creates unfavourable air-flows for ventilation.

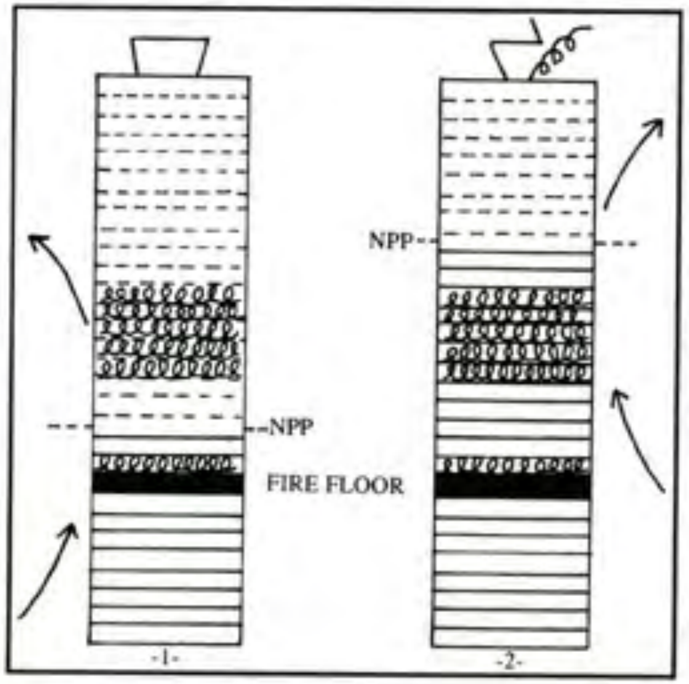


Figure 4:9 – Vertical ventilation in this case raises the NPP and creates unfavourable air flows on the upper levels.

Of course, most modern multi-storey buildings are designed as sealed enclosures with self-contained air conditioning, and smoke control systems, built in. There are many different types of system and it is important for the fire officer to understand the basic principles upon which they function. The opportunity should be taken, at structure familiarisation visits, to discuss a particular system with the building's chief engineer. As well as the other factors I have discussed (stack effects, NPP, smoke stratification, and wind speed/direction), the system that is designed into the structure to control air movement will probably have the greatest effect of all when it comes to ridding floors of combustion products.

The system of air movement within a structure may – depending on its particular function at the time – assist or even hinder firefighting efforts. In modern high-rise construction, with steel deck floors and fire resistant compartments, the biggest enemy to the firefighter is heat build-up. Basically, the variable effects of an air-movement system will create one of the following situations.

(a) The system continues to function on the fire floor, forcing air (and oxygen) into the fire zone, creating an extremely intense fire.

(b) The system is shut-off, either automatically or by manual method, causing the lack of oxygen on the fire floor to create a level of incomplete combustion, leading to smoke-logging. The fire may be giving off great heat and becomes hard to find.

(c) The system may be automatically triggered into a smoke exhaustion mode, drawing combustion products (and possibly the fire itself) into the ceiling plenum, from where it is directed at the core of the structure, and into a smoke shaft leading to the outside of the building. This situation may encourage fire to travel within the plenum. It may also draw heat towards the core of the structure, directly at the advancing fire attack teams! Shutting the system down may relieve heat at the core, but will create a smoky fire floor. This sytem also relies on automatic dampers and extraction fans to function correctly. Failure to do so could lead to the recirculation of contaminated air throughout the building. This could prove extremely hazardous to occupants on unaffected floors, particularly where high air-exchange rates exist. The problems discussed in this paragraph (c) were all present at the New York Plaza fire in 1970 and hindered the fire attack in many ways. Such systems may be perfect at the design stage, but real fire conditions are the ultimate test!

Again, it becomes apparent why a basic understanding of air movement systems is of such great importance to the fire officer. Without this knowledge, he will be unable to optimise air-flows within the structure to his advantage.

Fires in Voids

The tragic fire in Syracuse, USA, discussed earlier in this chapter, demonstrated the problems faced by firefighters when dealing with a fire that has involved structural voids. The extent of a void fire rarely makes itself obvious until it is too late for preventive action and it is generally only in the aftermath of such incidents that the full extent of fire involvement is appreciated.

In March 1987, London firefighters were stretched when a fire occurred in one of a group of buildings (all similar in construction) under the control of Crown Estates.

On the fire brigade's arrival a fire engulfing the ground floor kitchen was quickly extinguished by firefighters wearing CABA. During the subsequent cutting away and overhaul operations, smoke began to percolate from the central-heating warm air vents on the upper floors of the six-storey structure. Teams of firefighters were investigating the situation when conditions deteriorated rapidly on both the first and third floors, as fire erupted from within the walls. Subsequent investigation revealed the existence of a void between the outer front wall and inner partitions. This void was approximately 6 m in length and up to 300 mm in depth. It extended the full height of the building housing various utilities – pipes, cables, central heating ductwork etc – and lacked any form of fire-stoping at various floor levels (including the roof space).

The inner partitions that cleverly disguised, and separated, the void from the accommodation consisted of: (a) plaster on wire-mesh backing; or (b) plaster board panels; or (c) plywood panels.

The ductwork from the gas-fired warm air central heating system extended from the void at various levels into the floor/ceiling space to provide outlets in the rooms.

The initial fire in the kitchen had breached the fibreboard panel suspended ceiling and entered the void at this level, burning undetected and involving the roof void before burning down and into the accommodation.

Another fire in London's busy West End district presented firefighters with a typical basement operation in a brick and timber-joisted multi-storey building, which was promptly extinguished utilising an aggressive attack down into the fire. However, subsequent ventilation operations at all floor levels caused the smoke-logging of upper floors to increase. It was eventually apparent that the fire had spread to voids throughout the structure and fire eventually showed itself at all levels as the building came under severe attack.

A further example of a structural void fire occurred in England when Surrey County firefighters were faced with a serious blaze at an eighteenth century mansion, in use at the time of the fire as a school. More than 75 firefighters battled to control the blaze that kept the fire force on scene for three days following.

While the initial fire appeared to have started on the ground floor, it had gained a considerable hold prior to the arrival of the brigade. Although the initial action of firefighters appeared successful in attacking the fire; due to the nature, and construction, of the building, fire had penetrated undetected into the many wall and floor voids. Throughout the years the building had been put to various uses and undergone a number of modifications, both internally and externally. Vertical shafts and ducts had been created to carry services, and dumb-waiters and a lift shaft had been boarded over. The space between floor and ceiling was measured in excess of 18 ins (450 mm) and the floor was covered with a copper/zinc lining, which was then timber boarded. All these factors contributed to the fire travelling undetected to the affected areas of the building. The fire spread at an alarming rate from one floor to another; indeed, it was considered possible that the roof was involved before the arrival of the fire brigade. The lateral spread of fire was concealed and greatly assisted by the unusual floor construction. The metal linings hampered 'cutting in' operations to the point where the fire had travelled past the point where firefighters were working and in cases, did not show until it broke through into other areas, affecting rooms well away from the main fire.

Such problems are common to structural void fires. From an operational viewpoint, a well-advanced structural void fire is an extremely difficult situation to handle. It is generally the case that, on arrival, firefighters are faced with a heavily smoke-logged building of substantial size. Teams wearing full CABA will enter the thick smoke in an attempt to locate the fire but progress in such conditions is inevitably slow and it may be quite some time before they become aware that the source is hidden behind walls, ceilings and floors. Subsequently, they will face immense problems in accurately locating, and gaining access, to the main areas of fire spread. The dangers of void fires are not generally recognised until it is too late and the relatively minor fire is escalating into a major conflagration. Initial strategy by first-arriving firefighters is the key to success and *every* building should be suspected, whatever the conditions dictate on arrival.

The first sign to look for is light smoke issuing from under the eaves. This may not be immediately obvious from ground level and demonstrates the importance of having a roof team in position as soon as possible. If there is a smoke condition from within the roof void, and the main fire is several floors below, suspect the possibility of fire extension into voids. If the building is so heavily smoke-logged that firefighters are unable to make any progress, it may be necessary to ventilate the structure first before an entry is made. If smoke is lighter, 'hold' on the ventilation and utilise thermal image cameras to assist firefighters in locating the extent of void involvement. It is essential that *all* crews are equipped with CABA, hoselines, and forcible entry tools. Additional lines may be required on several floors in anticipation of a rapid escalation of the fire. Where any amount of fire is detected, 'cutting in' should be undertaken and portable power saws are essential if the operation is to be completed effectively, and with speed. Try to anticipate the fire's direction of travel and work ahead of it. Cutting small holes with axes, and applying hose streams or water fog in through the openings, is more likely to spread the fire than extinguish it. Large cuts are necessary if the spread of fire is to be checked.

The ventilation of a structure under attack by a void fire presents the incident commander with a difficult decision. By opening the roof, a fire laying dormant within voids is likely to escalate beyond control. The time taken to locate, and open, voids will enable the fire to escalate out of all proportion. However, if the fire is already advancing into the roof space a ventilation opening is necessary to prevent downward spread, as occurred in Syracuse and London.

The complexities of forcibly opening a structure to ventilate any products of combustion within, that may hinder the advancement of firefighters, are apparent.

This chapter is not, by any means, a complete guide to tactical ventilation techniques. Perhaps John Mittendorf's book is closest to the existence of such a text. It is, perhaps, more of a critical approach to a highly controversial strategy that is most certainly over-used by some, and under-used by many more.

I have attempted to describe, in some detail, the basis of the strategy in its application to a multitude of varied situations, so the reader may realise its potential for himself.

Historical Views of Tactical Venting of a Structure

During my research into tactical ventilation I began to wonder how firefighters of the nineteenth and early twentieth centuries were able to enter, and remain in, a severely smoke-logged building to search out victims without the protection of self-contained breathing apparatus. Surely they must have been experts in the art of structure venting?

During the early part of the nineteenth century, James Braidwood was at the centre of much controversy when he encouraged his Edinburgh firefighters to enter buildings involved in fire, to mount an effective attack at close quarters. Prior to this it had been generally accepted that an exterior attack was the normal approach. He brought his new found strategy to London when he became their chief and the capital's firefighters found themselves crawling on their bellies, searching for the six to 12 ins of air, at floor level, which Braidwood had promised was there. Any attempt to ventilate the building would not, it seems, have pleased London's first chief fire officer!

> 'The men of the fire brigade were taught to prevent, as much as possible, the access of air to the burning materials. What the open door of the ash-pit is to the furnace of a steam-boiler the open street door is to the house on fire. In both cases the door gives vital air to the flames.'

This statement of Braidwood's opinion appeared in a book published some years after his death, following the tragic Tooley Street wall collapse, called *Fire Prevention and Fire Extinction* (1866) – a collection of papers and memoirs from his early years.

Several years later, Braidwood's successor, Sir Eyre Massey Shaw, documented several declarations that clearly established his viewpoint on tactical venting operations:

> 'I am strongly of the opinion that many heavy losses, in past times, may be traced to the injudicious breaking of windows, for the purpose

of entering by means of ladders, when it might have been quite possible to pass up and down the stairs, and at the same time to exclude from the rooms in danger all air except the small quantity unavoidably admitted during the momentary opening of the door for the purpose of looking around.'

'When circumstances admit, it is advisable to commence a search of this kind at the top and work downwards, as the entering of each room necessarily involves the momentary opening of the door, and consequently the escape of a certain amount of heat and smoke; and if it be commenced at the bottom, the accumulation of smoke about the stairs and top landings may become so great as to smother persons in the upper rooms, or, even when this is not the case, to prevent the fireman reaching them.'

'It is most dangerous for any persons who happen to be in the other rooms of the house, particularly those above and at the back, into which, after once a front window has been cut through (broken), it is probable, if not almost certain, that the fire will penetrate before the firemen can reach them' . . . The firemen 'must not forget that in doing so (breaking windows) he consigns the house to almost certain immediate destruction, and that, if there happen to be other persons inside, he cuts off from these latter very nearly every hope of escape'.
Fire Protection (1876)

It was clear that Sir Eyre was expressing some abhorrence in the act of breaking windows to enter structures. However, did this extend to the art of tactically venting a building? In an earlier paper he had presented *(Instructions Concerning Air and Water* – 1869) he recorded his approval of such a strategy:

'It is not necessary that every fireman should be profoundly versed in the higher branches of the study of the atmosphere known as 'pneumatics' (or that of water known as 'hydraulics'); but, as he has to deal constantly with those substances, it is absolutely indispensible that he should thoroughly understand their nature and properties, and the general working of certain principles by means of which he is enabled to control them to his use'.

Sir Eyre went on to say:

'. . . the air from the scene of a fire, after travelling upwards to a point at which it, and the surrounding atmosphere are of the same specific gravity, loses its motion and, when it does so, it allows the charred particles to descend, and they accordingly return to the earth again by their own gravitation. In other words, hot smoke ascends, and cold smoke goes downwards, and on this account we invariably endeavour, when working in smoky places, to make an opening at the top for its exit and at the bottom for a supply of pure air to replace it, and at the same time, when it is possible, we light the gas and keep up the heat in every available way until the whole of the particles have been removed by the current thus formed.

'If we neglect or are unable to do this while the smoke is hot, much inconvenience and danger may ensue, and goods of certain kinds, such as silks and other wearing apparel, groceries, spices, and almost all articles of food, besides many other substances with which we have to deal, are liable to be deteriorated in value almost as much as if they were consumed by fire.

'It, of course, requires a considerable amount of discretion to determine the proper time for performing this important act of replacing a substance, in which fire cannot exist, by a supporter of combustion, but it is to be presumed that those entrusted with the important duty of extinguishing fires understand their business sufficiently to judge of the proportion between the end to be attained and the means at their disposal, and will not admit air to increase the fury of the flames until they have first satisfied themselves that, either by being enabled to approach the flames or in some other way, they are likely to gain an advantage by doing so.

'In very large rooms in which the foul air has to rise to a great height, it is likely to lose its heat before reaching the point of discharge; the best mode of obviating this is to add some artificial heat, such as that of a gas jet, to assist the upward current. These are points which it is of special importance to all persons of our profession to understand thoroughly, as without a sound practical knowledge of them fatal errors may constantly be committed.'

Another of London's former chief fire officers, Sir Aylmer Firebrace, CBE, approved of the strategy in the early part of the twentieth century. He wrote in his book, *Fire Service Memoirs*:

'In fighting a fire, careful attention must be paid to "ventilating" it. Put simply, the art of ventilating is the art of providing a way of escape for heat and smoke in order to prevent them being bottled up, or from mushrooming into parts of the building not yet affected by the fire. Ventilating may be achieved by opening, or if necessary breaking, windows, either on staircases or in rooms; by smashing pavement lights over basements; or skylights in roofs. Often slates have to be removed and a hole cut in the roof timbers before an attic space can be cleared of heat and smoke.'

Sir Aylmer continued . . .

'An American Fire Chief told me that he rubbed in the principle of ventilating by making his recruits extinguish a fire in a "drill" building with all ventilation shut off; they had a gruelling time of it. Then he gave them a similar fire with the building vented. They never forgot the lesson. Ventilating must be done at the right time; air must not be encouraged to flow into a burning building until lines of hose are laid out and water is available. So important is ventilation that in all London theatres, and in many of the provinces, a portion of the roof over the stage opens automatically in the event of fire, so that the heated gases may escape into the air, rather than be drawn towards the audience.'

I find the entire study of tactical ventilation operations fascinating. It is obvious that the strategy was recognised and well practised by firefighters in days gone by but it seems that many modern firefighters fail to understand the principles involved, or refuse to accept the strategy for whatever reasons.

I strongly recommend the reader to consider his own views on the strategy, in the light of personal experiences as they occur. After *every* fire ask yourself this question: Would a tactical venting operation have improved or worsened the situation? ie would it have affected fire spread? improved search times? improved visibility and lowered temperatures within for advancing firefighters? Might it have saved a life? In my experience, tactical ventilation of a structure will achieve a success rate of 95 per cent and possibly save many lives if employed *promptly* on arrival. But remember, it is the firefighters inside who say when!

Although the strategy is effected almost entirely throughout the USA and Canada, it finds little support elsewhere. Here is a review on the feelings of several fire departments around the world:

Cape Town (South Africa) – While Cape Town firefighters are aware of the techniques used to ventilate buildings during the attack phase, they are somewhat reluctant to utilise such a strategy, particularly where a fog attack is underway. It is felt that the low-flow nozzle would be unable to contain any rapid build-up of fire that may result from a ventilation operation.

Pretoria (South Africa) – It is felt that any venting should normally be done after the fire has been extinguished. There is a 70 per cent chance that the fire will spread if venting is carried out too early, although the decision to vent is very much left to the incident commander's initiative.

Singapore – It is believed that venting during the attack phase is a good strategy, particularly to aid rescue operations. It is also considered that Positive Pressure Ventilation (PPV) may be a useful strategy for some basement fires, or confined fires where heat has built up to untenable levels. However, the PPV technique is not yet utilised by Singapore firefighters.

Tokyo (Japan) – In Tokyo, over 50 per cent of the buildings are of timber-frame design (mostly private houses) and fires in such structures are quick to self-vent. Therefore, in the past little attention was made to such techniques. However, as modern construction has increased within the city over the years, the fire department has reviewed the situation. Tokyo firefighters will now ventilate windows (in modern construction) during the attack phase but are reluctant to break roofs. They also believe that high-pressure fog applications can be utilised to assist venting.

Hong Kong – Construction is different in Hong Kong, when compared to the USA. There are few large wooden structures in Hong Kong, so American venting techniques of cutting into the roof – or breaking windows – is not practiced there. They are not familiar with the PPV strategy.

Oslo (Norway) – Oslo firefighters will ventilate whenever possible. During the mid-1950s the PPV strategy was introduced by a fire officer in Finland. The system, termed 'Fenno-Vent', utilised a powerful fan that was able to create both positive or negative pressures within a structure. Today, they are aware of the importance of such techniques, and believe that fires can be fought more efficiently, and safely, by using ventilation fans.

Oulu (Finland) – Oulu firefighters will only resort to venting a structure *after* the fog attack has been successful.

Milan (Italy) – While not an official quote from the Milan Fire Brigade, this statement by an experienced Milan firefighter interested me(!): "The job of the firefighter is to prevent damage. That is what we do in Milan, and we do it well. To cut holes in the roof, and to break windows will create damage – this is unnecessary. . . ."

London (UK) – The firefighters of the London Fire Brigade are guided, in their ventilation operations, by the British *Manuals of Firemanship*, a collection of books that give brief guidance to British firefighters on a host of firefighting practices. The section on ventilating buildings appears in *Book 12;* it states . . .

> 'Ventilation generally has little effect on the rate of burning of a fire in a large building in its initial stages, though it would eventually cause an unattended fire to burn more rapidly than it would otherwise do. If unwisely or incorrectly performed, however, ventilation can lead to the rapid spread of the fire within the building and endanger people present. Releasing the fire can also put neighbouring structures and combustible roof coverings at risk. Accordingly, firemen should not start ventilation until they are sure it is safe and have branches (nozzles) in position to guard against the risk of fire spread. Subject to the necessary precautions, however, it is important that they should start ventilation as soon as possible.'

It goes on to say:

> 'If it is essential to ventilate from outside, men should get to the roof via adjacent buildings or ladders. . . Actual cutting into the roof should only be undertaken as the last resort'.

This UK Government's Home Office Fire Department publication gives further advice to the British firefighter on the topic of ventilation, and it may appear that fireground strategy closely follows North American guidelines. However, in real terms, structure ventilation is rarely carried out until the fire has been extinguished. The role of the 'roof team' is not normally effected by the initial attendance, and firefighters are not naturally positioned to complete such tasks unless directed. Other assignments achieve greater priority on the fireground as ventilation is held back for varying reasons. Again, the decision to ventilate is left to the incident commander's initiative. Case histories 6, 7, 8, 9 and 16 presented earlier in this chapter reflect the true situation.

John Craig, Chief Fire Officer of **Wiltshire** (at the time of writing) was the first in Great Britain to issue 'Standard Operating Procedures (SOPs) based on US fire ventilation strategy, to his firefighters. The Wiltshire Fire Brigade's SOPs clearly describe ventilation operations utilising roof cuts, PPV, NPV, and give instructions on stack effect and NPP.

Further still, Wiltshire's fire appliances are equipped with portable power saws and ventilation fans, and firefighters receive specialised training in the techniques involved. The strategy has been used on several occasions with a great amount of success and Wiltshire firefighters can take pride in acting as innovators for the British Fire Service.

A warehouse fire in Swindon kept Wiltshire firefighters occupied for 9½ hours before being brought under control, although the force remained on scene for three days.

The building was of steel-frame construction with outer cladding and a thermo-liner. Smoke and heat build-up within the structure caused firefighters to back-out on several occasions before the incident commander took the decision to vent the building. Working from the cages of aerial appliances, firefighters used K1200 disc

Those that do	*Those that do not*
Amsterdam	Rotterdam
Stockholm	Milan
New York	Oulu (Finland)
Boston	Cape Town
Chicago	Hong Kong
Los Angeles	London
San Francisco	Pretoria
Seattle	Paris
Las Vegas	
Phoenix	
Dallas	
Metro Dade	
Miami	
Honolulu	
Singapore	
Tokyo	
Melbourne	

Table 4:1 – The practice of 'tactical ventilation support' during firefighting operations.

cutters to cut large openings at high level on the leeward side of the structure. This did not prove particularly effective until a single opening was additionally cut on the windward side of the roof. This action relieved conditions inside the warehouse and crews were able to advance lines into the structure and extinguish the fire. Over 50 CABA sets and 100 air cylinders were used in the operation.

Melbourne (Australia) – Melbourne firefighters will only venture onto a roof, for ventilation operations, once attack hoselines are in place below. The concept of Positive Pressure Ventilation (PPV) is now becoming more popular and several CFA brigades are carrying Tempest blowers on attack pumpers.

Paris – Generally speaking, the building is kept closed during the fire attack. Paris firefighters attempt to minimise the damage . . . the damage caused by fire and water is enough!

Chapter 4 – Ventilation Support – Bibliography

4:1 **Brannigan, F.** *'Building Construction for the Fire Service'*, (USA).

5
POSITIVE PRESSURE VENTILATION

'The men of the fire brigade were taught to prevent, as much as possible, the access of air to the burning materials. What the open door of the ash-pit is to the furnace of a steam-boiler the open street door is to the house on fire. In both cases the door gives vital air to the flames.'

James Braidwood
'Fire Prevention and Fire Extinction' 1866

Described as "the wave of the future"; "a giant step forward in firefighter safety"; and "the greatest innovation since the introduction of CABA", it is certain that positive pressure ventilation (PPV) made a big impression upon firefighters in the USA during the late 1980s.

A recent readership survey published in America's *Fire Chief* magazine suggested that 57 per cent of the fire departments that responded to the survey utilise PPV. The same survey indicated that 31 per cent of the fire departments implementing PPV used it during the 'post-fire' phase of operations for removing smoke and toxic gases from the area. However, a further 67 per cent employed it for both 'post-fire' and 'pre-attack' situations.

The concept of forced ventilation to remove smoke from a building by the use of air movement fans has been practised for many years. Firefighters have adopted such equipment to encourage a negative pressure within a smoke laden compartment, enabling fresh air to be drawn in, and forcing the smoke out *(Figure 5:1)*. This technique of negative pressure ventilation (NPV) is widely accepted and practised during the post-fire phase by firefighters all over the world.

Surprisingly, PPV is not new on the scene. It was researched in both the USA and Scandinavia during the 1950s and firefighters in Los Angeles claim to have been implementing such tactics for 25 years! Even so, the concept is unfamiliar to the majority and remains untested by most.

Initial applications in the USA, back in the 1950s were aimed at controlling 'backfiring' during west coast forest fires, or projecting fire retardants and water fog across great areas of exposure during the same. In 1960 large 72 ins units were effectively used against the Rothchild Refinery fire at Santa Fe Springs, California, projecting water fog over exposed tanks through the convection column for over 300 ft. In 1961, Controlled Airstreams Inc (USA), in conjunction with the Los Angeles City Fire Department (LAFD), developed upon the theory of using the high-powered fans to eject smoke from buildings and specifications for such use were written by the LAFD. By the mid 1960s the fans were being used from outside the fire building to force clean air in, thus creating a positive pressure inside the structure and forcing the smoke out from alternative points *(Figure 5:2)*. Although the effectiveness of PPV was far superior to that of negative pressure ventilation (NPV) the concept failed to flourish and the 'staunch and steady' were slow to adapt!

Figure 5:1 – A fan is used to initiate negative pressure ventilation.

Figure 5:2 – The basic concept of positive pressure ventilation (PPV).

In Finland during the 1950s, a serving fire officer also recognised the potential of pushing smoke out of a building, as opposed to sucking it out. The Scandinavians developed upon his theory and produced a similar unit to the Americans – termed 'Fenno-Vent'. This technique became very popular throughout Finland, Sweden and Norway at the time.

During the 1980s, fire departments and fan manufacturers in the USA advanced the concept a stage further and the idea of a pre-attack application was developed. The Fire and Rescue Services Division of the North Carolina Department of Insurance completed a series of research projects focusing on the use of PPV as a tactic in structural firefighting. The study *(Bibliography 5:1)* addressed some highly relevant points, such as: can PPV be used as an attack tool in fire suppression?; does PPV decrease the carbon monoxide levels inside the structure?; should PPV be used before the interior fire attack?; does PPV create a safer environment for firefighters and victims?; and does PPV increase visibility within the structure?

The tests took place in a two-storey masonry burn building specifically designed for firefighter 'live' fire training. The structure was set up to resemble a dwelling with two rooms on each level, totalling 1,291 sq ft of floor space. Several fires were effected based upon three scenarios: (a) no PPV utilised; (b) PPV implemented before attack; and (c) PPV fan used after attack.

In each case, operations were effected two minutes after the temperature in the burn room reached 500 deg F. Carbon monoxide (CO) levels within the structure were measured at six locations, including the ground floor room adjacent to the fire room (at 30 ins above floor level) and in an upstairs room furthest from the burn area.

The test results showed:

- CO levels on the fire floor were increasing from the moment the fire was originated and peaked at three minutes.
- CO levels on the floor above the fire were not registered until almost two minutes after the fire had started. However, after four minutes the level recorded was higher than that on the fire floor.
- The effects of PPV, as implemented in the post-fire phase, in reducing CO levels was comparable to standard window ventilation (but slightly more effective).
- The ability of PPV to reduce CO levels throughout the structure, when used in the 'pre-attack' mode was outstanding, particularly in areas furthest from the fire.

General Operating Principles

As it applies to firefighting operations, the term **ventilation** is easily defined as: 'specific procedures necessary to effect the planned and systematic direction and removal of smoke, heat, and fire gases from a structure.'

Within this simplistic definition of ventilation is a phrase that requires additional emphasis – *specific procedures*. This term denotes two key characteristics when applied to ventilation:

(1) **Purpose** – Ventilation operations are most effective when based on a specific purpose or intent and should not be randomly utilised.

(2) **Pre-planned** – Ventilation considerations should be preceded by Standard Operating Procedures (SOPs) that form a foundation for effective and safe ventilation operations.

Basic Principles

In its purest sense, the implementation of PPV entails the siting of a 'fan' (also termed 'smoke ejector' or 'blower'), or multiple fans stacked or side by side, so that the air-flow is directed into the structure, creating a positive pressure therein. Important features of the technique are: (a) fan capability; (b) fan placements; (c) discharge openings; (d) wind effects; and (e) sequential ventilation. Each of which is explained over the following pages:

Fan Capability

The Tempest Technology Corporation have established themselves as front-runners in the field of PPV equipment. The Tempest 'Power Blower' comes with a choice of blade size: 12 ins, 16 ins, 21 ins, 24 ins, 27 ins and 36 ins, or a 72 ins truck-mounted model. They also offer a choice of engines, either electric or gasolene, with a range of 3, 5, 8, 10, 11, and 250 hp for the truck-mounted unit.

A fan's performance, or the amount of air that is moved by a particular blower, is measured in cu ft per minute (CFM) (or cu m per minute – CMM). The methods of obtaining such measurements may vary and, therefore, obtained ratings from different methods may fluctuate. Blowers less than 18 ins do not offer high CFM ratings due to their size and limited power choices. 18 ins blowers offer generally good CFM capabilities with power choices up to 5 hp. The 18 ins size is a popular choice, suitable for standard dwellings but limited in use for larger premises. The larger 21 ins blowers are increasing in popularity due to their size (similar to an 18 ins blower) and performance (similar to a 24 ins blower).

Gasoline powered blowers will add a small amount of carbon monoxide (CO) when air-flow is directed into a structure. This has led many fire departments to opt for the lesser-powered electric blowers. Even so, the amounts of CO are minimal – estimated at 30 ppm for two-stroke engines and 60 ppm for four-stroke engines. It should be remembered that PPV blowers are primarily intended to reduce CO levels within a structure and where levels are registering many hundreds of ppm, such a small input is immaterial, particularly when one realises that gasolene powered blowers operate at a higher RPM which can produce up to 40 per cent more CFM than a comparable electric powered blower.

Size and weight are also important considerations. A fan must suit the storage compartment available for it, and should be light enough for one or two firefighters to manhandle it into position. A Tempest 18 ins weighs 56 lbs; a 21 ins fan 65 lbs; and a 27 ins (10 hp) fan 95 lbs. Another important factor is blade design. Blades that wear out quickly and become unbalanced tend to create vibration through the unit. Where the blower is left unmanned (as is usually the case) a large amount of vibration will cause the fan to change its direction, with obvious effects.

According to Tempest, another important design function is effected by the shroud unit which surrounds the impeller. An unshrouded unit produces a stream of air, instead of a cone *(Figure 5:3)*. This makes it difficult to achieve a complete door seal and create an effective positive pressure within the structure.

Tempest positive pressure power blowers are third party tested through the AMCA Certified Ratings Programme. As examples of output (CFM), in relation to weight, the following information is given:

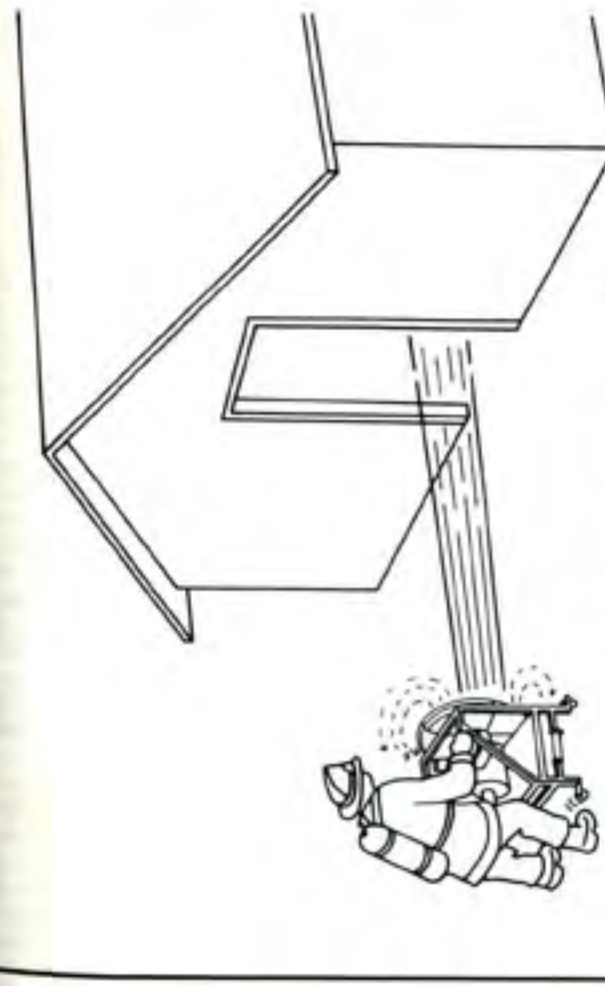
Weight	*CFM*
58 lbs	6,790
60 lbs	6,500
65 lbs	7,890
66 lbs	8,820
74 lbs	9,535
76 lbs	10,850
95 lbs	16,050

Table 5:1 – Tempest gasolene powered fans.

Fan Placements

On its own, a single blower should be positioned so the cone of pressurised air just covers the entrance opening *(Figure 5:4)*. If the blower is too close to the opening, the air-cone will not fully cover the opening and reduce the effect of the unit's operation. If the blower is too far from the opening, pressurised air will strike the area around the opening and reduce the amount of air in-flow taking place.

When trying to achieve the optimum effect of the air-cone, test the area around the opening with the hand, and feel for correct cone coverage. Factors affecting



An unshrouded fan creates the "clamshell" effect, where the air is forced out the front and circles back into the fan, creating a lot of undirected wind. The cylinder of air that this design produces cannot be focused or directed.

Figure 5:3.

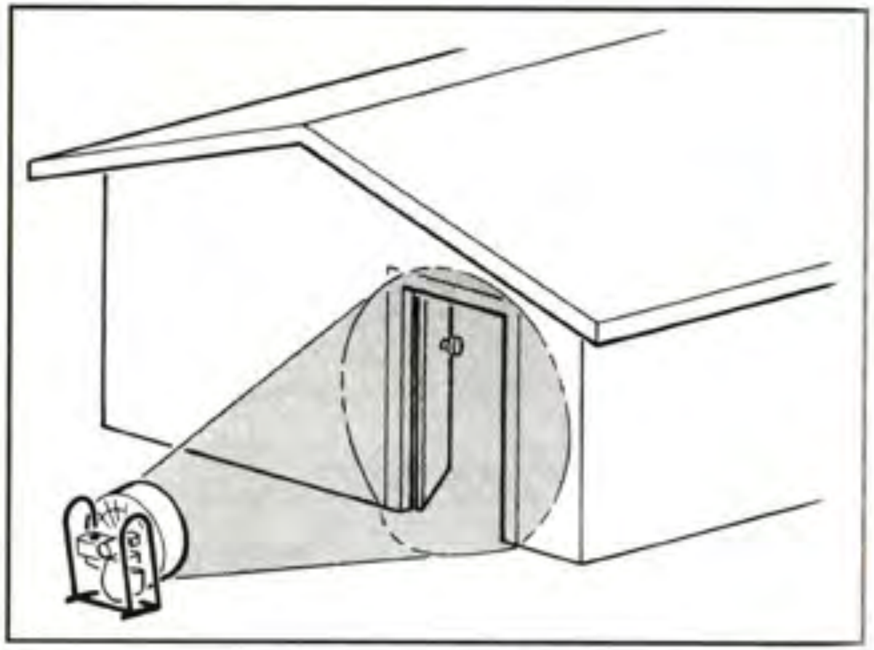


Figure 5:4 – On its own, a single blower should be positioned so the cone of pressurised air just covers the entrance opening.

placement include: size and type of fan, size of the intake opening, and number of fans in use. The larger the fan, the larger the cone of air produced and the *closer* the fan should be placed to maintain a seal. The smaller the fan, the further back placement must be. The optimum placement, for a regular sized door opening, is generally about 2 m (6 ft) away.

Most modern fan units have a 'tilt-back' feature of about 20 to 30 degrees, enabling more effective coverage.

Multiple blowers can dramatically increase air-flow (volume) and reduce the time necessary to complete a ventilation operation. The ideal 'set-up' for a regular sized door opening is to place two fans in-line as follows *(Figure 5:5)*:

Place the first fan (*A*) about 1 m (3 ft) from the opening with the second fan (*B*) ideally positioned 1 m (3 ft) behind it to create the correct cone effect around the doorway. Where fans of unequal size are used, place the larger fan nearer the door opening *(Figure 5:5 again)*.

Some training manuals suggest another way of increasing air-flow into the structure is by stacking units on top of each other. However, tests have shown this to be an ineffective technique that actually reduces the air flow into the structure *(Figure 5:6)*.

Where entrance openings are large, units can be arranged in parallel, ie, side by side *(Figure 5:7)*, although where possible, it is more effective to reduce the size of the opening. This can often be done where loading-bay doors exist. The Pittsburgh Fire Department spent time developing a cover (one sq m) that is used to reduce the size of a door opening when the fan unit has to be sited close in, for example, a narrow porch *(Figure 5:8)*.

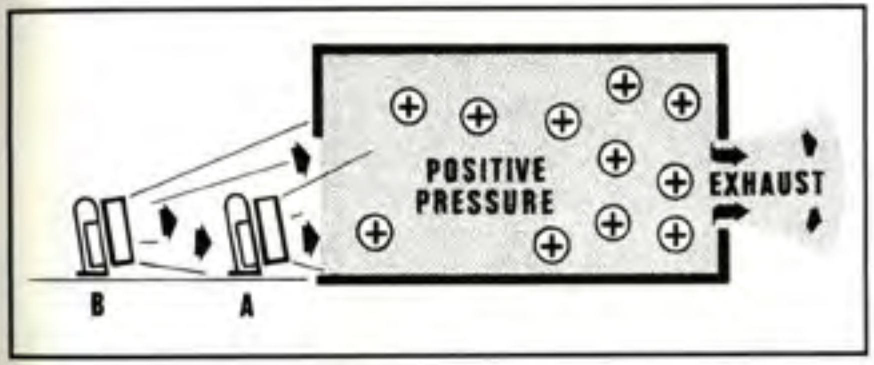


Figure 5:5 – Effective placement of twin PPV fans.

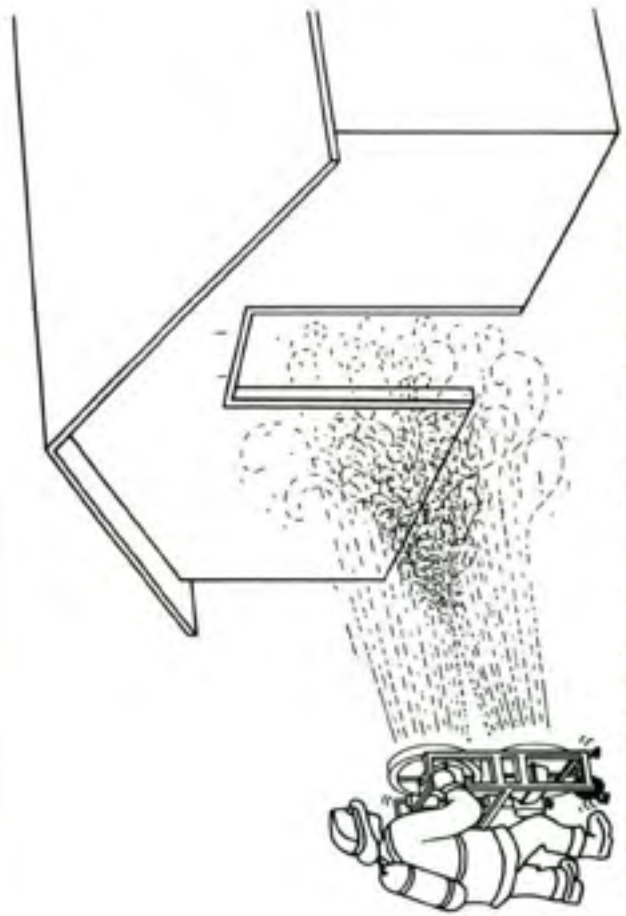
Discharge Openings

The key to effective PPV lies in the ability to control the openings within the area to be ventilated, allowing the establishment of a selected channel of air-flow. Just as it is essential to effect a suitable fan placement at the chosen intake opening, so is it equally important to locate the optimum discharge (also known as exhaust) openings. It is often the case that the location of such openings is dictated by damage to the structure, caused by the fire. However, when siting such openings, consideration should be given to: (a) the ideal location; and (b) the optimum size of such openings.

The ideal location for a discharge opening is generally on the side furthest from the intake opening. This will be influenced by the availability of natural openings – doors, windows, etc – and wind direction and force. Wind can have an adverse effect on PPV operations and, as in any ventilation operation, maximum efficiency will be achieved by utilising the prevailing wind to advantage. Where this is not possible, experience has demonstrated that PPV operations can be carried out effectively *against* wind speeds up to 25 miles per hour.

It is also important not to open-up the structure too much, in relation to PPV operations. The number, and size, of discharge openings should be in relation to the size of the intake in use and the fan's capability to move air. Where large fans, or multiple blowers, are in use the discharge openings will need to be enlarged in proportion. A distinct odour of gasolene fumes within a structure is a sign that the discharge opening is not large enough.

In general, try to keep the discharge opening/s to three quarters to one and three quarters the size of the intake. The exact size depends on the available pressure within the structure, which is dictated by fan capability, but optimum efficiency will be achieved by a combination of training and practical experience. As with any vent opening, it is important to remember that the existence of mesh curtains, or fly screens, will reduce smoke outflow by up to 30 per cent. Where possible, and where the fire has not already determined the location of discharge openings, select an opening at the highest point of the area to be vented. For example, where an 'average' sized door (2 sq m) is used for an intake air-flow from 21 ins fan, the top section of two 'average' (1.5 sq m) family home windows would work effectively as would a sliding patio door if adjusted for effect.



Stacking units does not increase their power. Stacking effectively reduces power by producing counter pressure where the two shafts of air conflict, which creates turbulence instead of forward pressure. The turbulence in turn creates more vibration, resulting in an unstable configuration.

Figure 5:6.

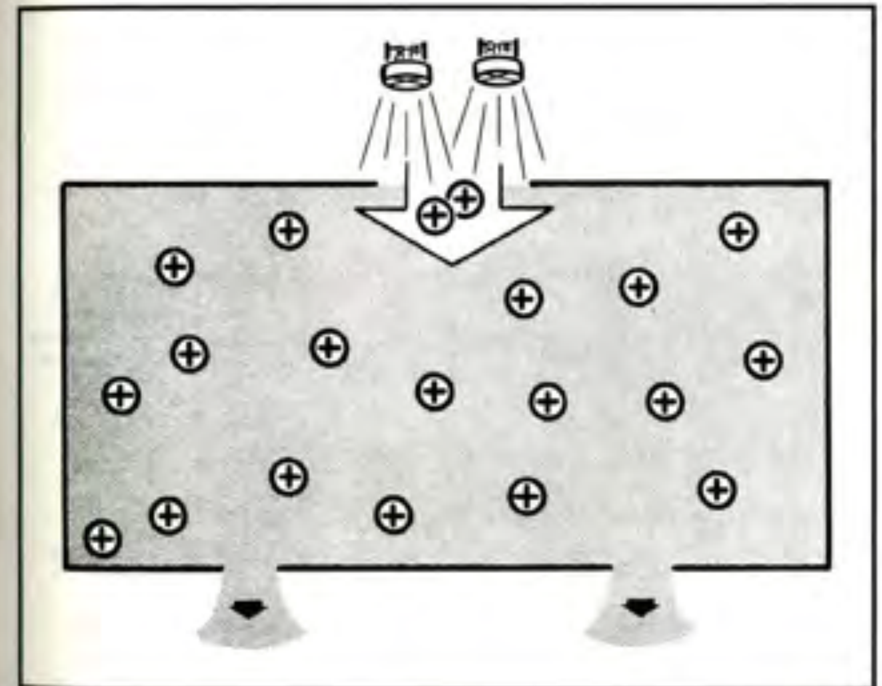


Figure 5:7 – Parallel configuration of PPV units where entrance openings are large.

Wind Effects

As mentioned, if wind speeds are in excess of 25 MPH then the siting of discharge openings must be carefully selected. The wind direction may be utilised to assist any PPV operation by placing intakes on the windward side and discharge openings on the leeward side, or at right angles to the wind to create a venturi effect.

Sequential Ventilation

Where contaminated areas requiring ventilation form definite compartments within a structure, the process of sequential ventilation will achieve the best results. This entails providing the maximum amount of pressurised air from a blower to ventilate each area in turn. Such an effect is obtained by opening and closing doors within, to direct the in-flow of air towards designated channels.

This technique is demonstrated by the clear objectives displayed in *(Figure 5:9)*, where a seven-roomed dwelling requires sequential ventilation – clearing one room at a time. Starting at the kitchen (*1*), all other doors remain closed as the full effect of PPV is channelled therein.

If a multiple-storey dwelling requires venting, the operation should be effected as in *(Figure 5:10)*, where the lowest level is vented before the upper levels. Any enclosed areas unable to provide openings that can be used for exhaust purposes may be cleared of smoke, during a PPV operation, as demonstrated in *(Figure 5:11)*.

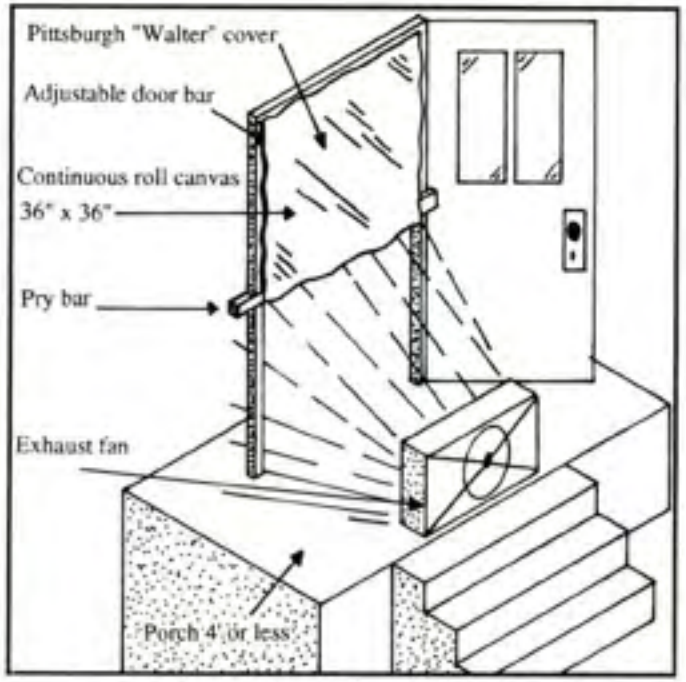


Figure 5:8 – The Pittsburg Walter cover.

PPV – Extremely Versatile

The term 'air superiority', once referred to an air force's ability to dominate the skies in time of war, has now been adopted by the fire service to reflect their own ability of controlling a fire zone. The techniques associated with PPV are becoming highly technical and are no longer restricted to simply clearing a compartment of smoke. In addition to the application discussed earlier, PPV can be used to:

(1) Reduce levels of carbon monoxide, and other toxic and irritant gases, during the 'overhaul' ('mop-up') phase of fireground operations.
(2) Create pressurised stairways in the high-rise environment to assist firefighting efforts, or persons escaping from the structure.
(3) Clear the entire facade of a structure of smoke that is hindering life or death rescue attempts. The improved visibility will allow lighting of the building to take effect, enabling prompt and accurate ladder placements to reach those in immediate peril.
(4) Control and abate certain airborne chemical vapours such as anhydrous ammonia.
(5) Confine the spread of fire in certain situations, such as 'strip shopping' units.
(6) Ease firefighting efforts when used in the 'pre-attack' mode.

(1) PPV During 'Overhaul' ('Mop-up') Operations

It is common for firefighters to discard the protection of breathing apparatus during the clearing up operations that follow the main fire suppression effort. During this

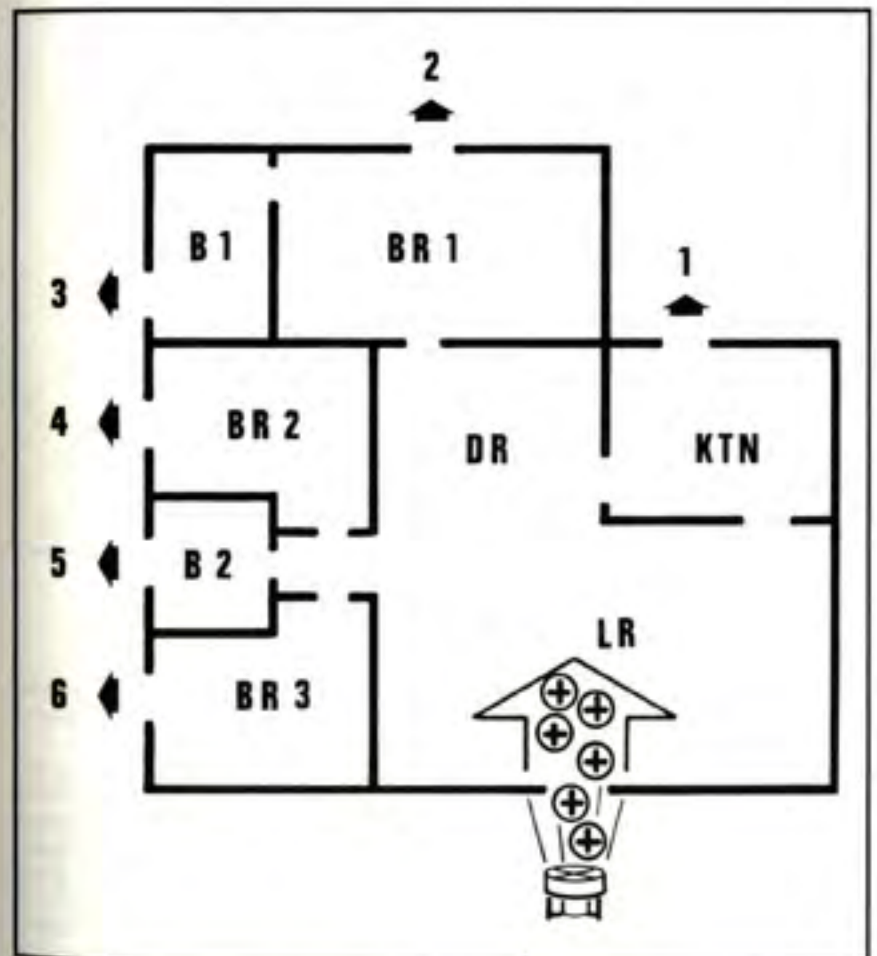


Figure 5:9 – Sequential ventilation of a seven-roomed dwelling.

phase of operations the building's contents will be torn apart or ejected from the building where embers may still exist within. To check for further fire extension the elements of structure may be cut-away and opened up. Where visibility is much improved, and an atmosphere feels comfortable to breath, the firefighters will generally forgo their 'air-pack' in an effort to ease the workload. Such an option will inevitably take its toll as minor levels of carbon monoxide (CO), and other toxic or irritant gases are inhaled over long periods. It is common, depending on the type and location of the fire, to experience CO concentrations registering hundreds of ppm and such levels can be considered as harmful.

In her book *In The Mouth of The Dragon* (Avery Publishing, NY, USA), Deborah Wallace pays scrupulous attention to these hazards and describes the symptoms so commonly apparent following such exposures. All firefighters have –

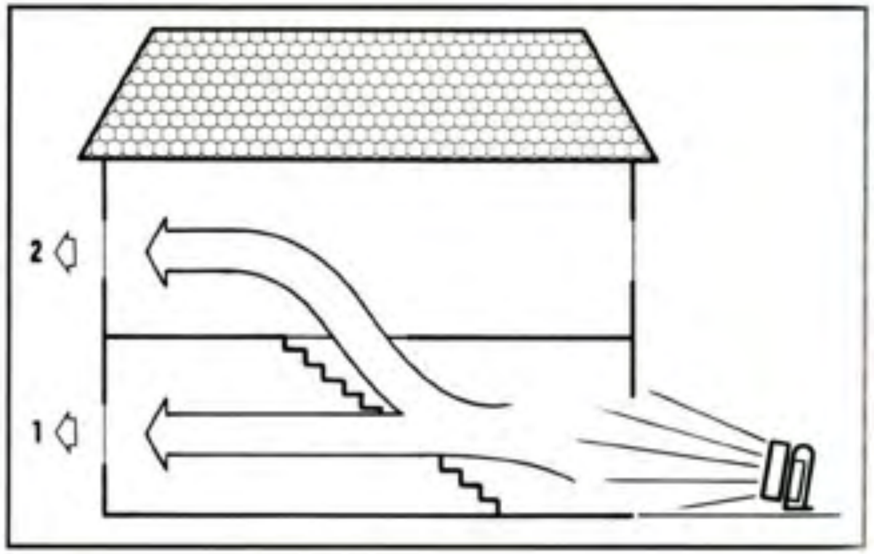


Figure 5:10 – The PPV concept utilised in a multi-storey structure.

at some time – experienced sore throats, tight chests with some pain, headaches, nausea, irritated eyes, and lung congestion following heavy 'mop-up' operations at fires – it is part of the job – but is it necessary?

Tests have proved that dangerously high concentrations of CO, and other gases, remain in the fire compartment long after the fire has been extinguished. While short exposure to such atmospheres may not lead to any appreciable effects, longer exposure can lead to an array of problems, resulting in many of these symptoms. Studies have suggested that in certain cases there may be longer term effects – even cancer and heart disease.

The potential for PPV to clear stagnating fire gases from within the structure during the 'clean-up' phase was soon harnessed *(Figure 5:12)*. It became clear that PPV was far superior to negative pressure ventilation (NPV) in reducing the gas levels, and further tests proved that a single blower (or multiples in larger premises) would lower recorded ppm levels by up to 80 per cent. The environment within was noticeably improved and the overhaul could continue under safer conditions.

The use of PPV during overhaul also served to assist firefighters by showing up hidden embers and areas of smouldering. This tended to speed up the whole operation and mop-up time was often cut in half.

It should be emphasised that such operations may require the use of Thermal Image Cameras (TIC) to help locate hidden areas of burning. The introduction of large quantities of air into the structure will increase the burn-rate and a fire hidden in a void, or behind a false ceiling, may accelerate rapidly. However, when used in conjunction with a TIC, the use of PPV will reduce the potential for re-ignition at a later stage.

(2) The Use of PPV in the High-rise Situation

The fire at the MGM Grand Hotel in Las Vegas (reported elsewhere) clearly

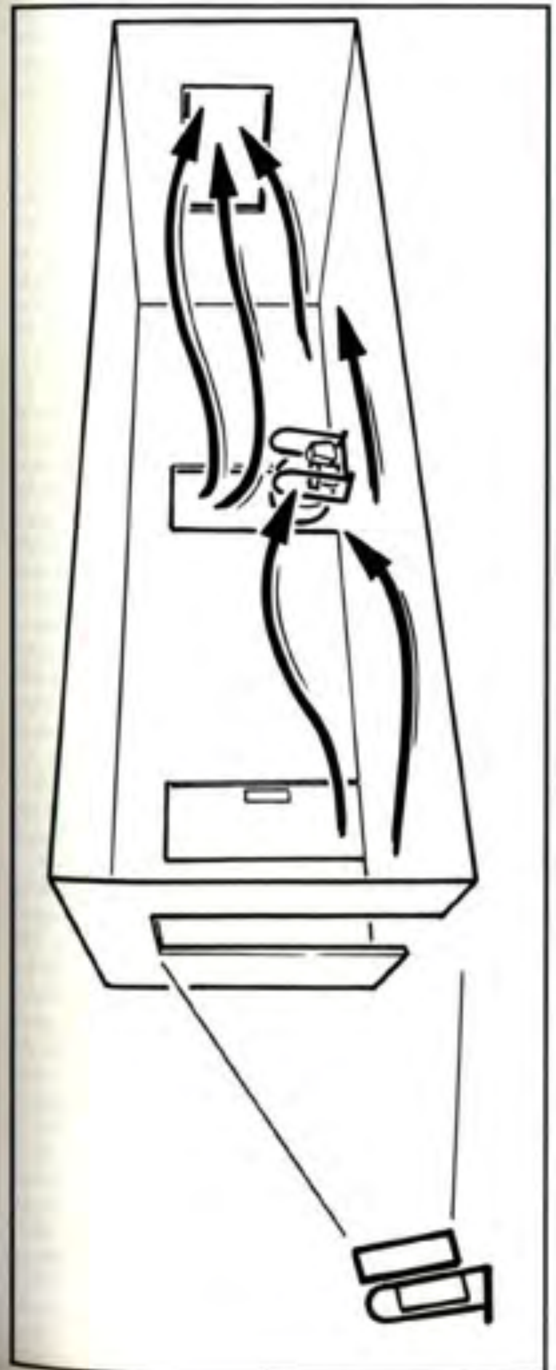


Figure 5:11 – Using PPV fans to ventilate enclosed areas with no openings.

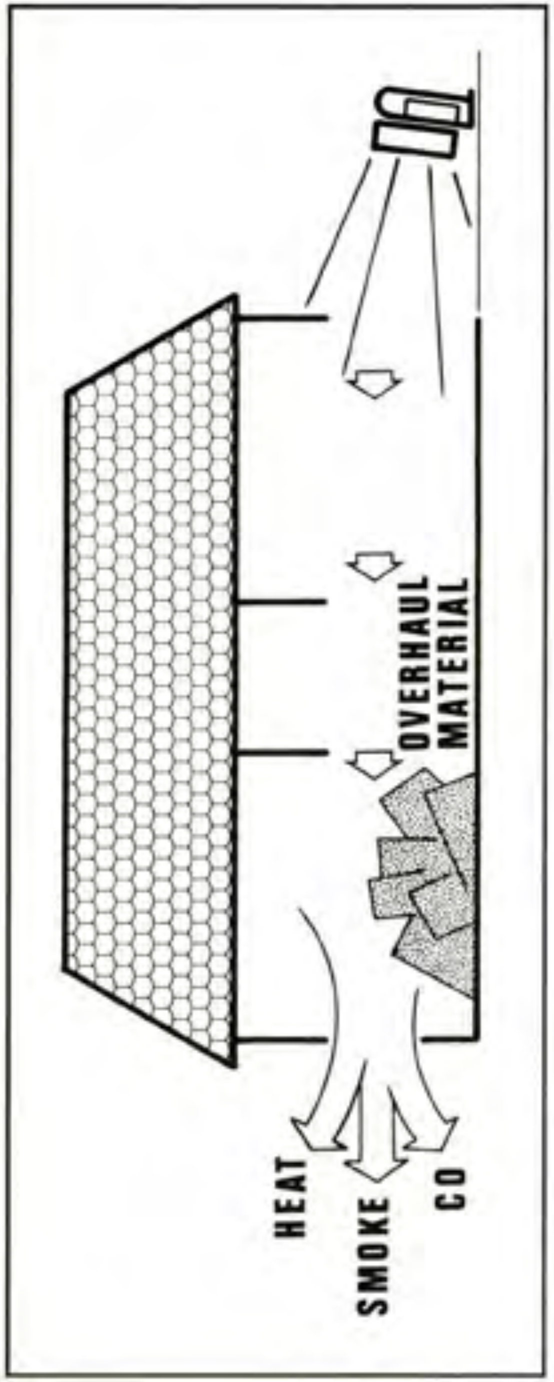


Figure 5:12 – PPV during mop-up (overhaul) operations.

demonstrated that the movement of smoke and toxic gases throughout a high-rise building may often present a greater hazard to life and firefighting efforts that the spread of fire itself. The problems associated with venting smoke from tall buildings are unique and special attention should be paid to the techniques utilised to achieve such objectives.

A symposium *(Bibliography 5:2)* held in Charlotte, North Carolina, USA, brought together PPV specialists from all over the USA to present views and share experiences. The symposium included live demonstrations of the effectiveness of PPV in a 32-storey office tower under construction. The demonstrations utilised a ground level corridor, the emergency stairwell and two unfinished floors – the 20th and 28th. By using a rooftop discharge opening it took natural air movements (stack action) 15 minutes to clear the 30 m long ground floor corridor of smoke while two PPV blowers placed in-line were able to achieve the same in seven minutes.

Further tests by the Charlotte Fire Department involved 'smoking' floor spaces, of 7,000 and 14,000 sq ft respectively. Various fan placements were evaluated to compare their effectiveness, including in-line and parallel configurations forcing air into the base of the emergency stairwell. During the course of one operation a fan was sited at an upper floor level to boost the air-flow. This arrangement led to a noticeable build-up of exhaust fumes on the involved floor. However, carbon monoxide monitors could not detect a measurable amount. The various fan placements all effected adequate smoke clearance times, forcing the smoke to leave the involved floors at an average rate of 500 sq ft per minute.

When smoke enters a stairshaft in a tall building it will generally rise to the upper levels and either 'mushroom' at the top of the shaft, where it is unable to escape from the structure *(Figure 5:13)*, or 'stratify' at a mid-point within the shaft where the smoke has cooled. This stratification *(Figure 5:14)* generally serves as a 'lid' for other products of combustion which will tend to bank down below the stratified layers. The principles of PPV may be harnessed in several ways to assist firefighters in the high-rise situation. Upper levels may be cross-ventilated by in-line configurations of blowers sited at ground level *(Figure 5:15)*. Tests have shown this set-up to be effective up to 25 storeys. Above this level additional fans will be needed to boost the air-flow on the involved floors *(Figure 5:16)*.

Vertical ventilation may also be effected within a stairshaft by an in-line fan configuration at ground level. Where the intention is to prevent contaminants from entering the stairshaft the operation will prove most effective with no openings at the top. However, where the objective is to clear a smoke-logged shaft, the head of the stairs will require an opening to exhaust the contaminants to the exterior. Many high-rise buildings already have pressurised stairshafts to maintain smoke-free escape routes. The same principles that apply to the overall effectiveness of these systems also apply to PPV operations in tall structures. The potential for success will be hindered where too many openings (eg. open doors) exist within a shaft.

Past fire experience has demonstrated just how difficult it is to keep stairshafts free of smoke where pressurised ventilation does not exist. As firefighters gain access to the fire floors and 'lay-in' from the rising main (standpipe) system, lobby doors are often forced to remain open, allowing smoke to contaminate the shaft. This creates difficulties for firefighters working on the upper floors and is even more relevant where the stairway is in use for occupant evacuation.

The Los Angeles Fire Department experienced such problems during the massive fire at the Interstate Bank in 1988 (reported elsewhere) and have since written the use of PPV under such circumstances into their Standard Operating Procedures (SOPs) covering high-rise firefighting. It is now standard practice for LAFD firefighters to resort to PPV techniques to maintain smoke-free stairshafts during the high-rise situation.

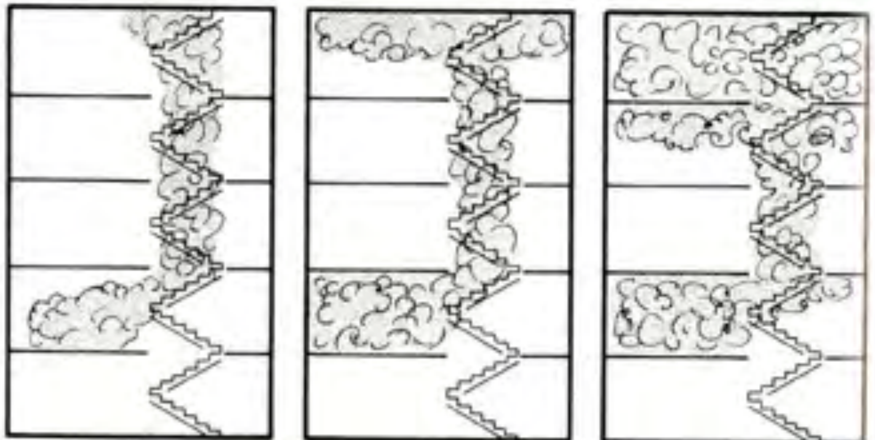


Figure 5:13 – The mushrooming effect of smoke at upper levels.

(3) The Use of PPV Blowers to Clear Smoke from the Facade
On occasions, the responding fire force is faced with large amounts of dark smoke issuing from openings on the structural facade as they arrive on scene. The true picture may be masked by the quantity of smoke as trapped occupants cling to ledges several floors above ground. Overhead power lines, street lighting and projections from the structure may not be immediately apparent to firefighters and the whole situation would be hindering prompt ladder placements to enable rescuers to reach those in immediate peril.

Under such circumstances, firefighters in the USA have utilised their PPV fans to create a false wind across the face of the building, clearing the smoke aside and enabling them to light the facade to assist priority ladder placement *(Figure 5:17)*.

(4) Control and Abatement of Airborne Chemical Vapours
The Watsonville Fire Department, in California, USA, conducted a series of tests *(Bibliography 5:3)*, using a condemned industrial refrigeration warehouse, to evaluate alternative techniques utilised to safely control an accidental release of anhydrous ammonia (NH_3) into the atmosphere. The tests focused on the use of PPV to ventilate the warehouse of dangerous vapours and also assessed various methods of dispersing such vapours as they exited from the structure.

Anhydrous ammonia is such a common chemical that every firefighter ought to be aware of its hazards. Its uses range from water purification, to refrigerant, to fertiliser, among others. When released in large uncontrolled amounts it can be very dangerous – the vapours are flammable and explosive, asphyxiant, and may cause irritation or burns to the flesh. However, the pungent odour is detectable at

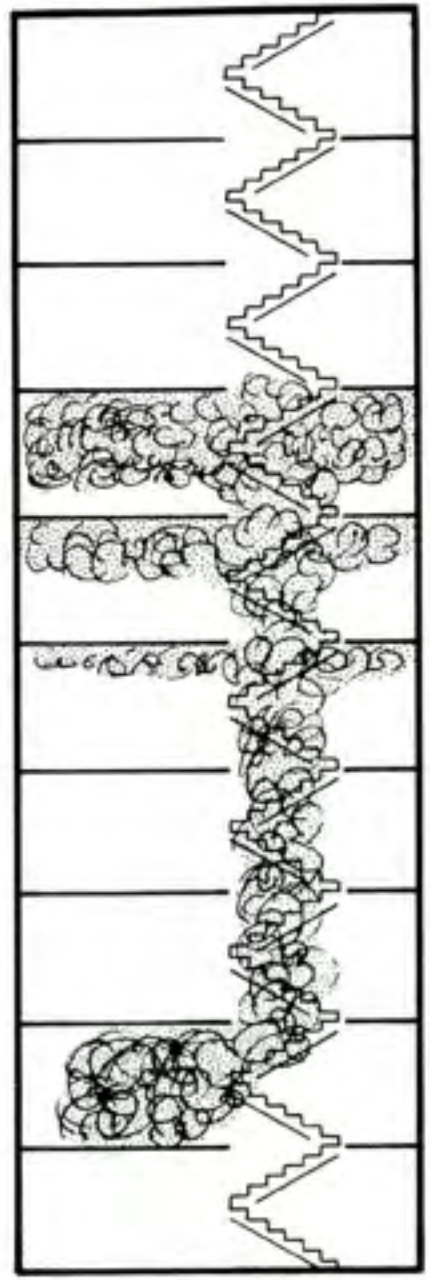


Figure 5:14 – The 'stratification' effect of smoke in tall buildings.

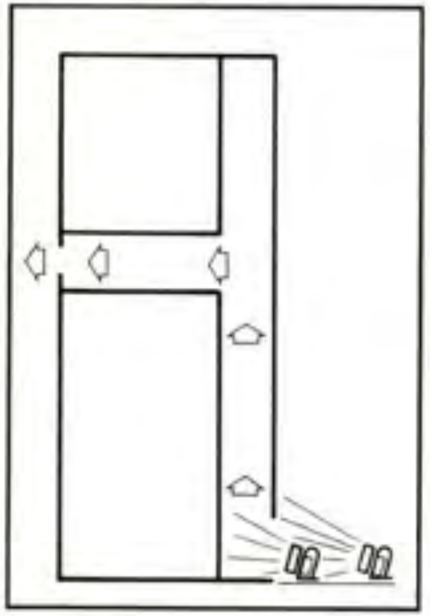


Figure 5:15 – Cross ventilation of a high-rise by in-line blowers.

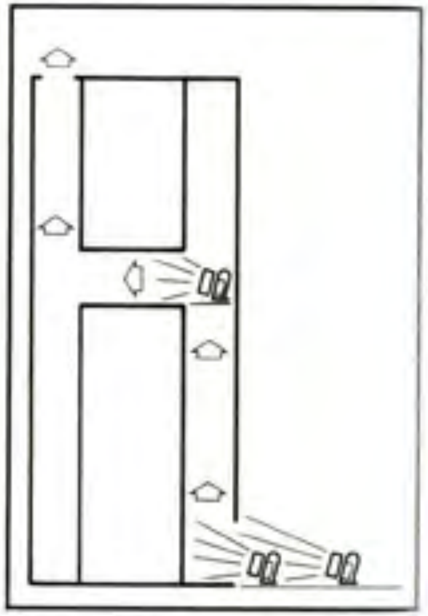


Figure 5:16 – Additional fans sited at upper levels to boost air-flow.

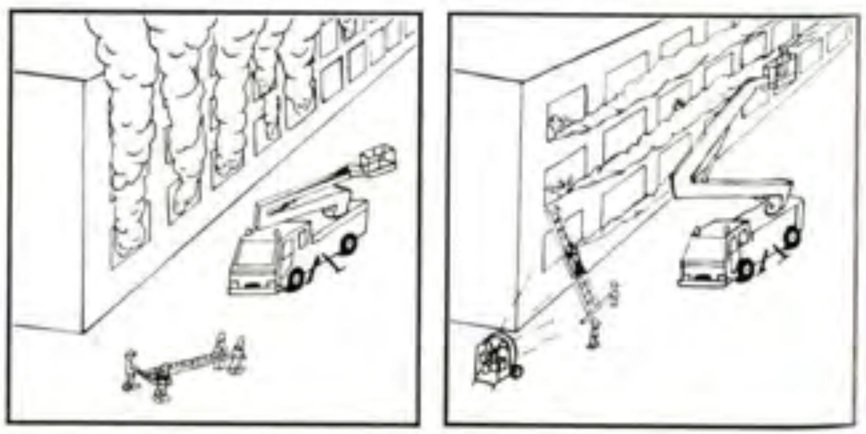


Figure 5:17 – US firefighters utilise a PPV fan to create a 'false wind' across the face of the building, enabling a better view for ladder placements and rescue operations.

The tests were conducted in a 250,000 cu ft warehouse where ammonia was discharged from a tank to attain inside readings of 10,000 to 12,000 ppm. Ammonia concentrations were monitored at various points within the structure, as well as the exit point and several hundred feet downwind. The water run-off at the exit point was also monitored for its pH factor.

TEST ONE: With the exhaust doorway some 80 ft across from the intake opening, the use of two 27 ins PPV fans reduced the vapour levels within the compartment from 12,000 ppm to 4,000 ppm in 14 minutes. At the exit point a three-quarter inch PVC pipe, with seven × 3 GPM garden spray heads, had been set up around the doorway, the objective was to evaluate the effectiveness of a low-flow spray unit on the NH_3 vapours. Readings up to 30 per cent of the IDLH (Immediately Dangerous to Life and Health) were registered just outside the exit point and strong ammonia vapours were detected 500 ft downwind. Water run-off samples indicated a pH of 10.

TEST TWO: A concentration of 9,000 ppm was reduced to 5,000 ppm in 12 minutes by using one 27 ins fan. A second fan was sited at the point of exit and proved extremely effective in directing vented vapours away from adjacent buildings. The same PVC spray-pipe was utilised in this test and the results reinforced the need for a larger water spray.

TEST THREE: A 1,000 GPM monitor was used as a fogging stream at the exit point in place of the PVC pipe. Inside the warehouse the vapours were reduced from 11,100 ppm to 3,500 ppm in nine minutes by using one 27 ins PPV fan. Air monitoring near the exit point, and downwind, still registered high levels of ammonia vapour. This seemed to suggest that a 'venturi effect' was being created from the monitor, causing a poor absorption rate by the stream.

TEST FOUR: In this test two hoselines were positioned approximately 30 yards downwind from the exhaust opening, using 45 mm (1¾ ins) lines with fog nozzles on a narrow pattern, rotating the fog streams in large circles. One 27 ins fan was able to reduce the vapour levels from 12,000 ppm to 6,000 ppm in 20 minutes within the structure and air monitoring downwind showed a significant reduction in ammonia concentration.

Based on these tests, it was concluded that PPV was a safe and effective method for ventilating ammonia vapours from a closed compartment.

(5) Confinement of a Fire

The ability of PPV to confine a fire has been noted on several occasions. This practice has proved successful when used in buildings such as 'strip' shopping centres. Where possible, a higher pressure should be applied to compartments either side of the fire *Figure 5:18* graphically describes the principles involved.

(6) Pre-attack PPV

During the 1980s the PPV concept evolved a stage beyond that related to normal smoke removal and North American firefighters are now utilising its effect to aid the fire suppression effort. Many innovative fire officers have learned to harness the force of the airflow to push dangerous smoke and flammable gases out of the way of their interior attack teams. This has aided the advancement of firefighters into a structure by cooling the environment and increasing visibility.

While the concept of 'pre-attack' PPV is very much in its infancy, the number of fire departments in the USA initiating this strategy is increasing rapidly, and as this

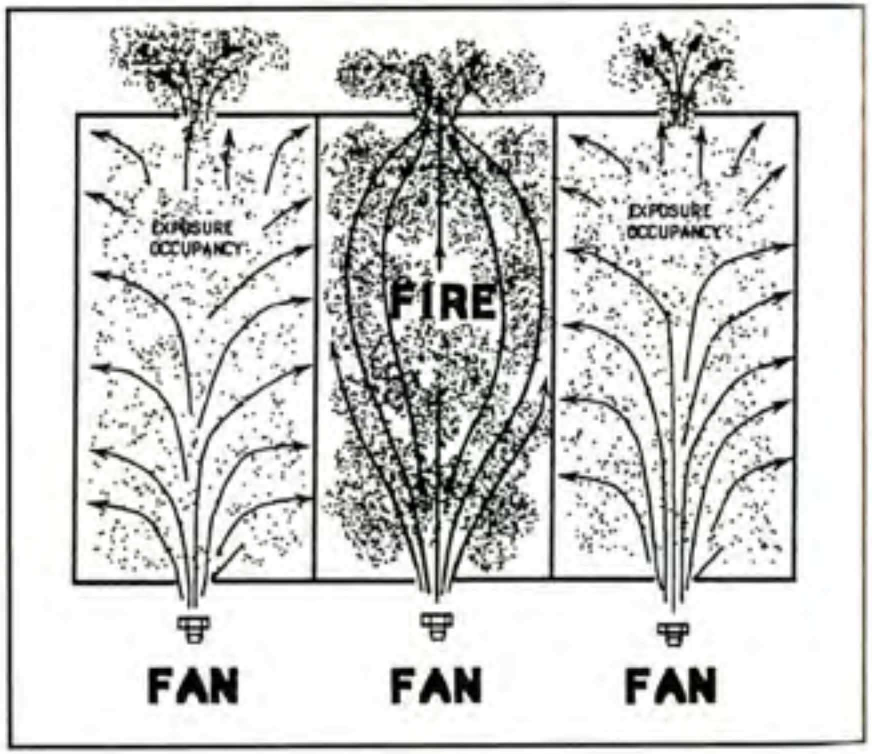


Figure 5:18 – The use of PPV fans to confine a fire.

five parts per million (ppm) when it becomes an asphixiant. The flammable range is between 16 to 25 per cent, ie 160,000 ppm to 250,000 ppm.

happens its actual use on the fireground provides us with a case-load of fire experiences. Reports of rapid interior searches resulting in prompt rescues continue to incite the imagination and test results never cease to amaze.

In one such test, Californian firefighters claimed a single 24 ins fan reduced the monitored temperature in a 9 ft×12 ft bedroom from 1,500 deg F. to 200 deg F. in 20 seconds! Even so, though all the reports and claims are impressive, the majority of stalwarts remain horrified at the thought of forcing air into a blazing building!

Pre-attack PPV – Operating Principles

The basic principles for initiating PPV to remove smoke from a structure have already been discussed. When used in the pre-attack mode the operating principles remain the same, with one or two minor adjustments. However, much emphasis should be placed upon promoting an awareness of potential hazards where an incorrect application is made. While the strategy is still in its infancy, past experience may assist to provide such an awareness.

- Some have expressed thoughts that the wave of pressurised air entering the structure will create a 'churning' effect in the fire gases, upsetting the thermally balanced layers and forcing heat and smoke down on advancing firefighters. Tests have shown that this is not normally the case and all heat and smoke is generally forced forward with no churning effect. However, a definite 'swirling' effect has been observed during actual fire operations in 'T' shaped compartments *(Figure 5:19)*. The effect is thought to have upset the thermal balance and created unfavourable conditions within the compartment.

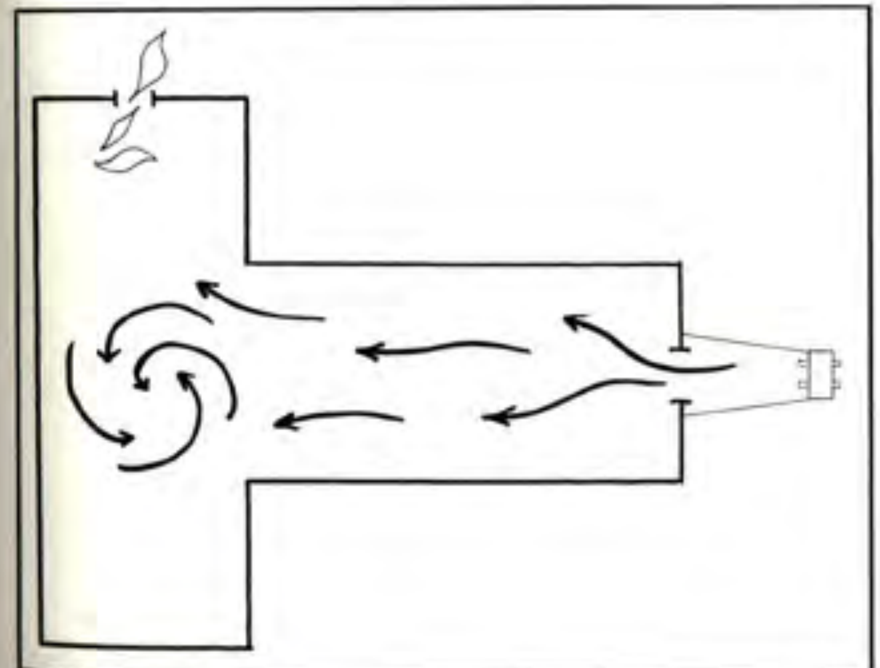


Figure 5:19 – The 'swirling' effect noted where PPV is used in 'T' shaped compartments.

- A compartment fire that has progressed beyond the flashover stage of fire development will intensify with the introduction of PPV into the structure. It will, in fact, burn hotter with temperatures increasing by up to 300 degrees F. Such an increase in intensity will have no great effect on the contents of the compartment but may cause a fire to burn through elements of structure and spread beyond the compartment itself. If the confines were already breached then PPV could possibly speed further escalation. Where a heating, ventilation and air conditioning (HVAC) system remains in operation, forcing air into a compartment, a similar effect may be experienced.
- The pressure wave that moves through the building as PPV is introduced behaves in the same way as that created by a continuous water fog application. It will push heat and smoke, and possibly fire

too, into uninvolved areas of the structure. Where the fire involves a room on the periphery of the building, and where a high fire load, such as foam filled furniture, is involved, the flames issuing from openings will intensify dramatically. Any local exposures will immediately come under threat and fire extension through the eaves and into the attic is a distinct possibility *(Figure 5:20)*.

Figure 5:20 – Fire extension into the roof space has been a common problem where PPV is concerned and the situation should be anticipated and checked before the fire is allowed to escalate beyond control.

• Where a PPV fan is placed too close to the intake opening during the pre-attack phase there is a danger that flames will be drawn *towards* the intake, exiting at the upper portion of the opening *(Figure 5:21)*.

• Where a discharge opening is sited at less than 90 degrees to the intake opening, the effects of PPV may be unfavourable rather than positive.

• The immediate siting, and operation, of a PPV fan prior to the opening being effected may disguise any indication of backdraft potential where smoke naturally sucks back into an opening or 'pulses' back and forth.

• Any attempt to move smouldering chairs or mattresses, while PPV is in operation is likely to cause an amount of flame-up. It is essential

Figure 5:21 – An incorrect placement of the PPV fan is likely to cause a 'blow-back' at the point of entry. The fan above is sited too close to the opening and the cone of air is unable to cover the upper section.

not to get caught without some extinguishing medium on hand if doing so!

• Where a fire has progressed into a smouldering phase, within a compartment, it is likely that the mixture of gases therein will surpass the upper 'rich' level. The introduction of a wave of forced air into the compartment could cause a backdraft.

In addition to these points, the following list of safety considerations should be adhered to:

(a) Before initiating pre-attack PPV, the fire must have (or must be) vented to the outside.
(b) The exact location of the fire should be known before a fan is placed in operation.
(c) The area of involvement must be close to the discharge opening/s.
(d) When selecting *any* vent opening, a prime consideration must be the need to draw smoke and heat *away* from building occupants and firefighters.
(e) As soon as a discharge opening has been made, and the PPV fan has been placed in operation at the intake site, a period of 15 seconds should pass before firefighters advance the attack line into the structure, to enable the force of air to take effect within the structure.

(f) PPV is likely to be ineffective where the total area of the discharge openings is greater than one and three-quarters the size of the intake opening(s).

When Pre-attack PPV Should *Not* be Initiated

- When the potential for a backdraft exists within the structure, particularly where warning signs are exhibited.
- Where there is any risk of disturbing loose dusts, or powders, that may cause a dust explosion.
- Where the fire's location is not established.
- Where discharge points are not ideally placed in relation to the fire's location, and the chosen intake opening.
- Where discharge points are adjacent to immediate exposures, or attic openings.
- If the fire has evolved to a smouldering phase, with large amounts of smoke and fire gases being given off.
- Where the materials involved in fire are likely to burn slowly, with deep penetration into the source, eg. cotton bales, deep-piled or high-racked storage, etc.
- In 'T'-shaped compartments where a 'swirling' effect may interfere with the thermal balance, creating unfavourable conditions within the structure.
- Where the fire is known to have spread beyond the compartment of origin, particularly if it has spread into structural voids.
- Where the known layout of internal construction, doors, openings, etc, will not suit air-flow direction.

Conclusion

Positive Pressure Ventilation (PPV) tactics most certainly have a place on the fireground and the techniques practised by firefighters in the USA throughout the 1980s have been highly innovative and imaginative. The uses of PPV are widespread and the full potential of directing forced air-flows has yet to be realised.

The effectiveness of PPV fans to rid a structure of smoke and stagnant fire gases during the clean-up phase of operations is beyond doubt. I have witnessed PPV clear smoke-logged areas, sometimes in seconds, but always within a few minutes. I believe that PPV fans should be on scene within minutes of a fire being suppressed. The versatility of such a tool should be harnessed by every fire department, and firefighters should be instructed in the correct techniques, as described in this chapter. The choice of equipment is as important as taking the decision to implement PPV strategy into department SOPs. Effective PPV operations require the most modern fan units, specifically designed with PPV in mind.

However, PPV in the pre-attack mode has proved highly controversial and while many remain convinced of its attributes and ability to improve upon firefighter safety, there are others who believe that the strategy is often unpredictable and limited in its use.

I personally feel that pre-attack PPV warrants further investigation by both scientists and firefighters alike. Under known conditions the strategy is undoubtedly effective as an attack tool, but how often are firefighters able to confirm the exact location of a fire?; or establish the type of materials involved at an early stage?; or assess the level of confinement?; and all at the outset of operations!

Even so, with 90 per cent of fires, in the UK, being held to the room of origin, it is arguable that a large percentage of fire suppression efforts would benefit from the use of such tactics and there is much to be said in support of a ventilation technique that greatly reduces search and rescue times, increasing the survival rate of trapped occupants. We should all be viewing the strategy with great interest.

Chapter 5 – Positive Pressure Ventilation – Bibliography

5:1 **Hughes, L.** *'PPV in a Test Setting'* – *Fire Engineering* (USA) (December 1989 pp 56-59).
5:2 *'Symposium on PPV'* – *Fire Chief* (USA) (August 1991).
5:3 **Brady, T. and Rackley, R.** *'Control and Abatement of Anhydrous Ammonia'* – *Firehouse* (USA) (July 1991).

•The author wishes to thank Tempest Technology Corp. for allowing him to reproduce much of their original artwork in this chapter.

On this page and over – **Backdraft: firefighters advance into the unknown, the thick black smoke hiding the danger** ... *(continued overleaf).*

... suddenly the temperature soars as an in-flow of oxygen mixes with the igniting gas layer and a ball of flame heads in their direction – *see Chapter 4.*

Firefighters in Nassau, New York, struggle with a rapidly escalating fire involving lightweight construction – *see Chapter 4.*

Tempest power blowers – *see Chapter 5.* *(Photo by manufacturer)*

Las Vegas firefighters utilising PPV tactics in the pre-attack mode – *see Chapter 5.*

Correct applications of the PPV concept utilise equipment specifically designed for the purpose – *see Chapter 5.* (*Photo by Tempest*).

6 SMOKE EXPLOSIONS

'. . . the power of getting close and the habitual exercise of this power are infallible symptoms of efficiency.'

Sir Eyre Massey Shaw, KCB
'Fires and Fire Brigades' 1889

A fire occurring in a compartment (or a room) will develop – providing there is sufficient air (oxygen) and fuel – to a stage where all combustible surfaces will quickly become involved and the fire will progress to its maximum intensity. This action will occur in three distinct stages, or 'periods': (a) the growth period; (b) the fully developed period; and (c) the decay period.

Their relationship are displayed on the time/temperature fire profile *(Figure 6:1)*.

The term 'flashover' is commonly applied to the brief transitional period between the growth and fully developed stages of a fire, during which it develops very rapidly to involve the build-up of flammable gases within the compartment. This phenomenon occurs almost instantaneously and temperatures soar within the compartment to levels that will not generally support life.

A fire in its growth period is totally reliant on an adequate fuel supply and a sufficient level of oxygen to enable its progression to the next stage. If either is used up, the fire will extinguish itself. If the level of oxygen is reduced drastically the fire may smoulder for quite some time – awaiting a fresh supply that could come from a window breaking, or a door opening.

The fire loading – ie the flammability of contents in the modern structure – is far in excess of those encountered 20 or 30 years ago, and fires burn 'hotter' than they used to. Also, modern structural design is biased towards energy conservation, providing an internal environment more tightly sealed from the elements outside.

These facts, coupled with the modern protective clothing that enables the firefighter to move deeper into blazing buildings to approach the fire, or search for victims, mean that they are more likely to be subjected to the searing heat of a 'smoke explosion'. When fire propagates so rapidly to raise the surrounding air temperature to over 550 deg C. (1,022 deg F), the firefighter's chances of survival are slim – he literally has seconds to live!

In March 1989, the British government-funded Fire Experimental Unit (FEU) based at the Fire Service College, Moreton-in-Marsh, Gloucestershire, undertook a project that went some way in predicting a firefighter's ability to tolerate conditions in a fire. Temperature measurements were obtained during realistic exercises at the Breathing Apparatus School when firefighters were subjected to conditions that may similarly be experienced in the 'average' fire.

The FEU had previously recorded temperatures experienced at the 'National Bank Exercise' at the college, following a request from the BA School in 1985. The

National Bank Exercise was designed to simulate a fire in the vaults of a bank and is considered a severe test of stamina and endurance because it requires crews to move downwards through heat barriers. Temperatures in excess of 450 deg C (842 deg F) were recorded in the ground floor fire room at a height of 5 ft.

Two firefighters wearing full CABA and fire protective clothing of Nomex, but without flash-hoods, were wired up with thermocouples on the outside of their fire coats that recorded on a portable datalogger worn inside the coat. Then they proceeded on a 30 minute simulation in the school's 'ship' structure where various extremes of temperature were encountered.

The concluding results demonstrated that the firefighters so equipped were able to tolerate conditions up to 200 deg C (392 deg F) for a short time (7½ minutes during the test) but with some discomfort to exposed skin. Temperatures of 235 deg F (455 deg F) were considered too hot, even for a short period, and the firefighters felt the need to move to a cooler area. The tests also demonstrated that sudden blasts of hot air will deceive the firefighter into thinking that the conditions are intolerable. For example, a blast that suddenly raised the temperature to 135 deg C (275 deg F) caused the firefighters to vacate the compartment they were occupying in an attempt to find a cooler environment.

While the FEU tests were representative to a degree, they acknowledged that the ability to tolerate conditions in a fire cannot be dependent on temperature alone. Factors such as humidity/moisture content, working conditions, level of protective clothing, rate of change of temperature, area of exposed skin, physchological state and physical condition must also have an influence. Even so, it is awesome when one actually realises that the modern-day firefighter is entering into fire-involved structures and working in literally 'oven-like' conditions where the temperature is in excess of that recommended for cooking the Christmas turkey!

Explosions

In general, an explosion may be defined as 'the sudden conversion of potential chemical energy to kinetic physical energy in the form of pressure, heat and light'.

Explosions range in violence from the diffused rolling type of progressive flame resulting from the combustion of a mixture of flammable gases or vapours and air, to the violent, almost instantanenous, detonation of condensed-phase explosives. The destructive effects of these explosions vary widely ranging from broken windows, to complete dislodgement of brick walls, columns and beams.

The term 'explosion' is most often used in its widest sense, ie to describe an oxidation reaction of varying levels. These oxidations can be defined at four levels:

(a) **Combustion** – Exothermic reation of a combustible substance with an oxidiser, usually accompanied by flames, and/or emission of smoke.

(b) **Deflagration** – An explosion propagating at subsonic velocity.

(c) **Explosion** – An abrupt or decomposition reaction producing an increase in temperature, pressure, or in both simultaneously.

(d) **Detonation** – An explosion propagating at supersonic velocity, characterised by a shock wave.

One can see from these definitions that each category increases in its reaction rate, from the slow to the ultra-fast. There are a number of conditions experienced by firefighters while tackling a fire that will fall into the above categories. It is important for the firefighter to have a basic understanding of the various phenomena that may be linked to the word 'explosion'. Such a knowledge will provide him with an awareness of fire behaviour in a real fire, enabling him to predict the fire's progression during the critical, early stages.

Explosive combustion

As a fire develops within an enclosure, the process of combustion will lead to a build up of fire gases within the compartment. Initially, these gases will form a mixture with air that is too lean to ignite. However, as the fire progresses the fire gas mixture will eventually reach its optimum limits and, providing sufficient heat is available, the gases will ignite almost instantaneously.

This is the transitional stage of the fire's development termed 'flashover'. If the fire was slow to progress during the intial stages and smouldered for some time, the build up of fire gases will become too rich to support ignition of the gas layer. However, they may simply require the addition of some air, which will dilute the gas layer, bringing it back to the optimum limits. Fire gases that ignite in this way are causing a 'backdraft' of air into the compartment.

Flashover

Defined by *British Standard 4422* as: 'the sudden transition to a state of total surface involvement in a fire of combustible materials within a compartment'. As stated, a flashover is a transitional period between two stages of fire development. It is generally an extremely rapid reaction that produces a low-intensity pressure wave. In fact, there is no precise definition of the term 'flashover', probably because it is not an event, like ignition. The attainment, or onset, of this transition has been defined by scientists in three stages: (a) flames emerging from ventilation openings; (b) a temperature of 600 deg C below the ceiling; and (c) a radiant heat flux of 20 kW/m² at floor level.

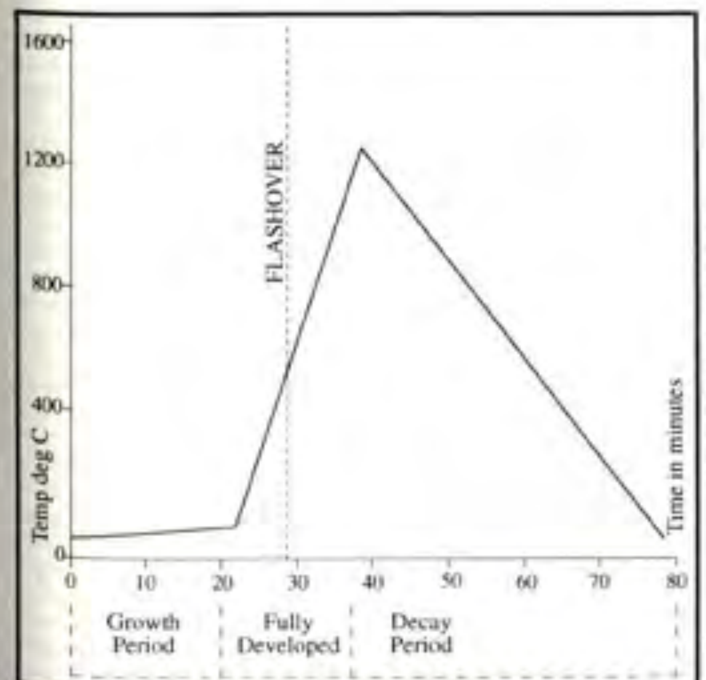


Figure 6:1 – The time/temperature fire profile: the curve represents the average temperature of a compartment fire determined under test conditions.

A further definition of the more widespread use of the term 'flashover' is offered by scientists at the Fire Research Station (FRS) in England:

(1) Ignition of the flammable volatiles beneath a horizontal barrier (usually a ceiling) which have collected as a result of pyrolysis mechanisms from overheated materials.
(2) Downward radiation from flames beneath a ceiling causing rapid decomposition of 'fuel' beneath, and acceleration of fire spread.
(3) 'Explosive' burning of flammable volatiles within an enclosure when the compartment is ventilated by the opening (or breakage) of a door or window.
(4) 'Explosive' burning of some special types of 'cold' smoke from the smouldering of foams.

It is worth noting that the definition given under (2) is the preferred (scientific) explanation of a 'flashover' whilst that at (1) is more commonly termed 'rollover' (or 'flameover') and (3) and (4) are closely linked to the term 'backdraft'.

Large expanses of combustible materials – such as wall and ceiling linings – will contribute significantly to the rapid growth of a fire. The radiation from large areas of burning surfaces, exponential rate of flame spread over vertical surfaces and relatively low ceilings, interact to promote the rapid development of fire within a compartment. If the walls and ceiling are lined with insulating material the thermal radiation feedback into the compartment is increased and the time scale to flashover is reduced.

Few items on their own can produce flashover in a 'standard' room (3 m×4 m×2.5 m high) – exceptions include large items, such as foam-filled chairs. Otherwise, the fire must spread to adjacent items to produce a cumulative rate of heat release necessary for the fire's progression.

The duration of the pre-flashover fire is very difficult to establish. Analysis of the results of a large number of small-scale tests suggest that the onset of flashover will be enhanced by the following factors: (a) the combustible items are tall; (b) the item first ignited is in a corner; and (c) fire spread over the items within the enclosure is rapid.

All three factors ensure that the time taken for flames to reach the ceiling of the compartment is reduced.

WARNING SIGNS – 'FLASHOVER'

It is important for the firefighter to anticipate the onset of flashover so that he may take remedial action.

The following signs are reliable indicators that a flashover is imminent:

(1) A build-up of heat within a compartment that forces the firefighter to crouch low.
(2) The classic sign of 'rollover' (or 'flameover'), where tongues of flame can be seen snaking through the fire gas layer at ceiling level.
(3) The smoke is rapidly banking down to about one metre from the floor and the fire is beginning to 'run' along the ceiling.

At this stage the firefighter should be backing out of the compartment, or applying an offensive fog attack to quench the burning gas layer.

Backdraft

A term that has often become confused with flashover is that of 'backdraft' (or 'back-draught' as it it is spelled in the UK). However, there is no reason for this, as they are two separate phenomena. It is rather surprising that the term has received little attention in recent times and is rarely documented in British circles. There is a brief, but rather undescriptive, mention in the *Manual of Firemanship Book 6* Part C (page 146) although perhaps a better description of a 'backdraft' appears in *Book 12* (page 159) where the term 'smoke explosion' is used in its place. There is also an entry under the English spelling in the *IFE Dictionary of Fire Technology*.

One of the earliest known UK references was made by Sidney Gompertz Gamble, a former deputy chief fire officer of London Fire Brigade, in his 1931 book *Outbreaks of Fire, Their Causes and Means of Prevention*, where on page 423 he states: 'Backdraught is the sudden ignition of inflammable dust in the air caused by organic substances that have become heated by the fire. Owing to lack of oxygen, combustion is delayed until a window is broken or a door opened. When the inrush of cold air containing its oxygen causes the sudden ignition of the heated air and an outburst of flame with such force as to give the effect of an explosion . . . a dense mass of black smoke is usually seen issuing from the building a few moments before an outburst of this kind occurs'. Interestingly, further references to backdraft in books by two ex-chief fire officers of London Fire Brigade appear in the following books:

•*Fire* by Major C. C. B. Morris (page 102) where he describes the firefighting operations at the massive Crystal Palace fire in 1936: 'As the wind veered round to the west the fire began to spread into the north transept. Two crews manning nozzles were sited therein in an attempt to halt the fire at this point. However, there was a grave risk of collapse and a back draught of flame might occur' . . . Just as it seemed the tactics were working, 'in a flash, a huge sheet of flame travelled along under the roof over their heads' – causing a rapid evacuation of the transept that eventually fell to the fire.

•In Sir Aylmer Firebrace's book *Fire Service Memories*, he describes a backdraft on page 66: 'A fire in a large unoccupied house in Upper Grosvenor Street once gave firemen a surprise. On the arrival of the first appliance, smoke was seen eddying from under a closed window; no fire was visible. On entry being made the whole house burst into flame, providing a highly spectacular sight. After the fire was extinguished, a police constable on the beat revealed very honestly that he had passed down the street at 2 a.m. and smelt smoke. He had conscientiously searched the neighbourhood but failed to find a fire. Two hours later he again passed that way and once more he smelt smoke. On this occasion it was nearing daylight and a wisp of smoke was seen coming from under a closed window on the top floor. He pulled a fire alarm. Here was clear proof of what is often believed to happen. A slow-burning smouldering fire occurs and eats up the oxygen in the building in incomplete combustion; the house fills with smoke and, with well fitting windows nothing is seen from the outside. When the Fire Service is eventually called and breaks in, oxygen is admitted, and the whole house instantly becomes a mass of flames.

In his NFPA fellowship paper in 1987, Chief Fire Officer John Craig (Wiltshire, England), described one fire in a major European city where a backdraft killed 15 firefighters back in the 1960s. A still active fire officer explained to CFO Craig that a 'low temperature smoke explosion' had been responsible for the terrible tragedy, however, when the term backdraft was put to this firefighter he said it meant little to him.

In effect, a backdraft may result in a high-order explosion that produces a shock-wave capable of causing structural collapse. It is *not* a stage of fire development, as is a flashover. The conditions that may lead to a backdraft are those where a fire is contained in a tightly sealed compartment. As the fire develops the supply of air (oxygen) is depleted and the process of flaming begins to die until a state of smouldering exists. At this stage the fire may even extinguish itself. If, however, a supply of air is introduced into the compartment – say for example where a window breaks or a door is opened – a backdraft may occur. The phenomenon may occur with tremendous speed, the sound of the air-flow being likened to an express train in a tunnel!

The effect can be devastating causing entire structures to collapse within seconds. The likelihood of a backdraft depends upon the type of material burning, and the level of containment of the fire.

Although the term backdraft is generally linked with smouldering fires, another situation may arise where a developing fire causes combustible gases to be dispersed into structural voids or concealed ceiling space. These gases will build up and may eventually ignite, often with explosive force.

WARNING SIGNS – 'BACKDRAFT'

The warning signs for backdraft are different to those for flashover, and are as follows:

(1) Thick black smoke may be seen to issue from the compartment moments before a backdraft occurs.
(2) Smoke, or tongues of flame, may pulse intermittently from openings.
(3) Smoke may be forcing its way out from around closed windows and doors.
(4) Windows may be rattling and may be too hot to touch.
(5) Smoke may 'suck' back into the structure.
(6) The appearance of blue flames at any stage in a fire is a good indicator.
(7) Fires in basements, or other confined areas, are more likely to initiate a backdraft.
(8) A sensation of air rushing past your ears, heading towards the fire, creating swirling patterns in the smoke.

The difference between the two phenomena is graphically explained by the diagrams opposite *(Figure 6:2)*. On the left a fire, supported by a plentiful supply of air through the open window, has been able to develop freely. The gas layer that formed at ceiling level was initially too lean to ignite. However, it has now reached its Lower Explosive Limit (LEL) and as the gases start to burn the thermal feedback is radiating down to other items in the room, causing them to give off further amounts of gas. Within seconds, this situation will reach the flashover stage as the total amount of gas suddenly ignites.

The situation on the right has not been able to progress to the free burning stage due to lack of ventilation. The partially quenched flames are forming unburned gases within the compartment (smoke) that are actually above their Upper Explosive Limit (UEL) and too rich to burn. However, should a sudden inrush of air take place, as the window is breached for example, the gases will be rapidly

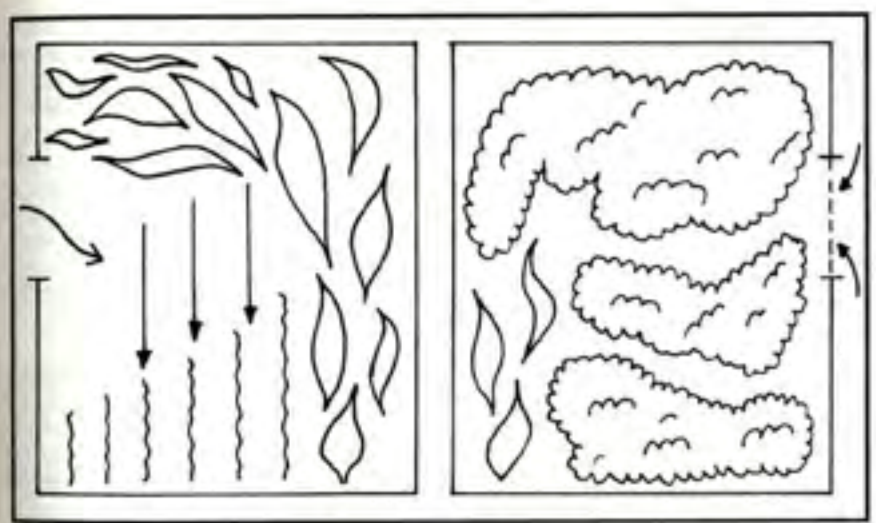


Figure 6:2 – Radiation induced (left) and ventilation induced (right).

diluted and brought back within their explosive limits. This backdraft of air causes the gases to ignite, possibly with some explosive force.

Explosive Combustion – Further Forms

There are other types of explosive combustion that the firefighter may encounter during the course of his work (not including pressurised containers, etc):

Blowtorch – The 'blowtorch' effect, experienced mainly in tall buildings when a high wind enters the structure as the windows fail, is a situation that is often described by firefighters as a flashover. The sudden rise in temperature and the rapid escalation of the flame-front often misleads firefighters into believing a flashover has occurred, when this is not the case. While there are a number of warning signs that may indicate the potential for a flashover, a blowtorch effect is totally unpredictable. It is a condition that must be in the back of every firefighter's mind when tackling fires in high-rise buildings – particularly on a windy day!

Dust Explosion – The potential for various dusts that are combustible in nature to cause an explosion exists. While it is necessary for the dust to be suspended in air for the effect to occur, the possibility of such a condition arising is quite likely in a fire situation. Dusts such as chocolate, flour, sugar, and starch are all examples and are likely to ignite in explosive fashion if in a confined space.

Gas or Vapour Explosions – The potential for a natural gas explosion is always a major concern during the early stages of most fires in occupied structures. Firefighters should be on the look out for the characteristic blue or yellow 'flame-thrower' effect of burning gas mains inside the building and must avoid extinguishing the flame until the main can be shut down or effectively sealed.

The explosive potential of any gases leaking into a structure creates a highly hazardous environment where a fire exists within. Likewise, the possibility of flammable vapours being given off in any industrial situation is equally as hazardous and efforts must be directed at reducing any such risk.

Trench Effect – The fire at London's King's Cross Underground Railway Station in November 1987, demonstrated a previously unrecorded form of 'explosive combustion' that became known as the 'trench effect'. The fire, which originated underneath a moving stairway (escalator) in a shaft that transported passengers from the lower track levels to the ticketing hall (and street exits) above, killed 31 people, including a fire officer. The fire's rapid escalation took the responding fire force totally by surprise as it roared upwards with the speed of a flashover. The original investigation by forensic scientists concluded that it was either a flashover or a blowtorch effect caused by the piston action on air-flows created by trains entering the station below, that led to such a rapid escalation of the fire. However, following extensive research that included 'test-burns' on scaled-down models, and a computer simulation, the phenomenon that had been noted in the past by fire engineers – such as Dr. Dougal Drysdale of Edinburgh University, Scotland – but not recognised as having an important role in 'real' fires, was discovered.

Whereas flames normally burn vertically upwards, entraining the air necessary for the combustion process from the perimeter of the flames, if the flames are burning on an inclined plane, a pressure differential is produced that causes the flames to be deflected towards the inclined surface. It was found that this effect was particularly marked when the surface was sloping greater than about 20 degrees to the horizontal and was restricted in the form of a trench.

In the case of the escalator in question, the fire would have initially been burning at one side and would have burned in a normal manner. Once the flame front extended across the full width of the escalator steps, however, the flames would have been deflected towards the steps of the escalator. The deflected flames then heated the wooden steps and risers much more rapidly than would otherwise have been the case, causing a rapid acceleration of the burning, until the flames billowed out of the ticketing hall as if they were produced by a flame-thrower.

It is likely that this behaviour is not unique to escalators and may be observed in other inclined combustible surfaces with an appropriate degree of confinement.

Case Histories

The British government's Building Research Establishment (BRE) facility at the Fire Research Station in Borehamwood, Hertfordshire, presented an informative study *(Bibliography 6:1)* in 1980 on fires involving explosions. A search of some 2,700 fire journals – mainly of British and American origin – covering the period 1907-1976, revealed reports of 127 fires where firefighters were subjected to explosion effects. The study provides an invaluable source of reference for firefighters and should be examined closely to grasp the experience.

The BRE report showed that 70 people (including some firefighters) died in the 127 fires reviewed, and 302 were seriously injured. The work examines in detail the types of fire that caused the explosion – ie: 'smouldering' or 'developing' – and discusses at great length the materials involved that contributed towards the explosive effects.

The report reached a number of conclusions. The most enlightening of these were:

(a) A substantially higher proportion of firefighters were killed by explosions occurring in warehouses, than in any other occupancy.

(b) Although more explosions were associated with 'developing' fires as opposed to 'smouldering', the difference was minimal, 45 per cent versus 41 per cent. The remaining 14 per cent was linked to 'developing fires with secondary explosions'.

(c) The materials most commonly found to have assisted the explosions were: varnished, painted and polished woodwork, and combustible Fibre Insulation Board (FIB).

The following are some case histories I feel merit attention:

Stardust Discotheque fire – Dublin, Ireland – 1981

Forty-eight young people were killed when fire destroyed a discotheque in Dublin on St Valentine's night 1981. To a large extent it was the very rapid spread of the fire that prevented the safe evacuation of the occupants. The fire began in an alcove hidden from view by a roller blind (cause never established). It originated in a seat unit at the back of the alcove. Although the seat was upholstered with PU foam and covered by PVC, subsequent tests showed that these particular seats were difficult to ignite with a small ignition source unless the covering had been damaged before. The tests also showed that a seat on its own would not be sufficient fuel to create the fire conditions that existed in the disco hall that night. However, the combustible carpet tiles that had been used as a wall lining provided the fuel that led to the production of large quantities of smoke, containing toxic gases (particularly carbon monoxide). The layer of black smoke and heat made its way across the ceiling of the dance floor. Many survivors gave witness to 'blue flames' dancing up the walls and 'floating' yellow flames creeping across the ceiling in the smoke. The low ceiling made of mineral fibre tiles suspended on a metal framework created a high thermal radiation feedback to the dance floor below and a massive flashover occurred.

Carpet warehouse – Sheffield, England – 1982

A 'small' fire was noted by a passing police patrol in a front office of the 30×20 m two-storey structure. The fire, which originated in a desk, spread to fibre insulation board (FIB) supported on timber studding and heat flowed into the main storage and working areas of the warehouse.

The first-arriving firefighters were faced with smoke billowing out of the windows and openings at the upper storey and roof level. However, the premises were so well secured that the fire crews were forced to smash their way in by breaking a large panel of glass in one of the main doors. Almost immediately a backdraft occurred throughout the ground floor.

Hochelaga school – Montreal, Canada – 1907

One of the earliest references to the effects of a smoke explosion is that of the Hochelaga school fire in 1907. The fire appeared to have been burning for some time in the concealed spaces between the ceiling and the upper floor of the two-storey building. As the fire was discovered, occupants within the school became trapped by smoke and opened windows to gain relief. The resulting inflow of oxygen caused a backdraft that took the lives of nine children and a teacher.

Derelict House – London

A small rubbish fire was burning in the corner of an unfurnished room facing the street at ground floor level. A moderate breeze was blowing into the window of the room that had no glass remaining. It was a 'routine' fire and the 'stop' message was being transmitted to fire control over the radio. Suddenly, an explosion that was heard over the radio in fire control, ripped the room apart and engulfed the building in flames. There was no gas supply to the premises and the fire load was insufficient to cause a flashover. The only explanation was a backdraft, caused by an inflow of air mixing with carbon monoxide accumulating in the upper portions of the room.

Public House (Bar) – London
On Christmas Day 1991, West End crews were faced with a difficult fire involving the ground floor (bar area) of a two-storey public house, measuring 10×15 m. On arrival, the entire building was heavily charged with smoke and although all window glass was intact, a severe fire was apparent within. A forced entry was made at ground floor level and heavy brown smoke began to 'pulse' from the opening before being drawn back into the structure. The signs were indicating backdraft conditions and firefighters hesitated on making any advance into the building. Within seconds a 'transom' window vented itself at the side of the building and blue flames were briefly seen to issue from this point. Eventually, smoke flows reverted to normal and no backdraft ensued, as the fire was extinguished. If the 'transom' had remained intact, the outcome may have been completely different.

Shopping centre – Phoenix, Arizona
As Phoenix firefighters approached the Bayless Shopping Centre, engine 20 reported considerable smoke issuing from a roof vent and requested a second alarm assignment. The fire, which originated in one of the central shop units, had spread into the common roof void and smoke was 'pulsing' intermittently from several roof vents minutes after arrival. Within seven minutes of the fire department arriving, a backdraft occurred in the roof space that caused ceilings to collapse trapping several firefighters. Plate glass windows were blown across the street.

Wensley Lodge hostel fire – England – Multi-fatal
A fire originated in room 11 on the first floor of the hostel and spread throughout the structure to kill several occupants. Alcoves in room 11 were faced with fibre insulation board (FIB) on timber studding. These alcoves were used as service ducts to the upper floors and roof space. When the door to room 11 was opened by an occupant a backdraft occurred in the ducts, spreading the fire upwards.

Drug store – Chicago, USA – 1951
A fire that occurred in the basement of a Chicago drugstore had apparently been extinguished by firefighters. Although the main fire had been knocked down, a smouldering fire continued in the basement with very little heat output. A large explosion, presumably a backdraft, occurred without warning, injuring 27 firefighters in the process.

Warehouse – Glasgow, Scotland – 1960
A warehouse containing 19,400 casks of whisky, and an adjoining warehouse containing 1,300 tonnes of tobacco became involved in a fire in 1960. Glasgow firefighters were faced with heavy smoke-logging and difficulty in gaining access to the fire during the initial stages. Fire crews on one side of the building had seen a 'bluish' flame beneath the ground floor ceiling and so they entered and found themselves in the tobacco warehouse. As they were trying to force entry into the bonded sections of the whisky warehouse an explosion occurred that demolished the front and rear walls of the building killing 19 firefighters. It is believed that alcohol vapours may have caused the explosion – or was it a backdraft?

Mattress store – Kent, England – 1975
An incident, that was to become known as the Chatham Dockyard Fire, caused the death of two Kent County firefighters in 1975. A storeroom containing foamed rubber latex mattresses was sited on the ground floor of a three- and four-storey building used as stores, offices and sleeping accommodation. When the fire brigade arrived the ground floor was found to be smoke-logged. Two firefighters wearing CABA entered the store where no particular build-up of heat, or fire, could be found. To assist locating the fire they opened several windows, which caused a backdraft and an intense fire followed.

Bowling complex – Oklahoma, USA – 1944
A massive explosion occurred when fire involved a ceiling made up of fibre-board panels.

Electronics store – Chicago, USA – 1985
Three Chicago firefighters were killed and four others injured when the roof of the electronics store they were operating on suddenly collapsed during an early-morning three alarm fire. On arrival, firefighters were directed onto the roof to carry out ventilation operations. The building was heavily smokelogged and crews were finding it difficult to advance hoselines on the fire. The roof was laden with ice and snow as fire crews began to cut into the surface. One firefighter was instructed to 'punch-out' some windows on the side of the two storey structure, and as he did so his observations were that the smoke was "sucking" back into the structure. He immediately attempted to warn members who were working on the roof of the conditions within the structure, but was too late. A backdraft is thought to have caused the collapse.

Two-storey brick warehouse – Baltimore, USA – 1986
A fire in the basement of this two-storey house caused problems when Baltimore firefighters responded. The design of the structure allowed the upper portion of the basement to rise above ground level at the rear, providing the opportunity for some small windows to provide natural light to the basement. As firefighters made their approach to the fire from the ground floor stairs leading into the basement, a window failed at the rear allowing a massive in-flow of air. The effect was so pronounced that one of the firefighters was actually sucked down the stairs and into the ensuing backdraft.

Basement areas have always provided a grave potential for backdraft conditions. The absence of ventilation and the general use for storage creates a slow smouldering fire with large amounts of CO given off.

Four-storey house – London, England – 1987
When London firefighters responded to a fire in this house, it all seemed routine. The house, of four floors and basement, measured 20×15 m and was constructed of substantial brick and timber joist under a pitched slated roof. It was heated throughout by gas-fired warm air central heating.

The fire occurred during the evening and was initially confined to the kitchen area on the ground floor. While the fire had involved a substantial part of this room it had not warranted the attendance of further crews and was dealt with by the first response. However, the walls and suspended ceiling of fibreboard panels had cleverely disguised the existence of a large service void that transported the fire into both the roof space, and the many floor and ceiling voids that existed on the upper levels. The progress of this fire extension was initially slow, and went unnoticed. However, the smoke on upper floors was not clearing, it was in fact worsening, and firefighters began to cut into the walls and floors to uncover the hidden smouldering.

As one firefighter opened a window to vent the increasing haze of smoke he immediately noticed the smoke suck back into the structure. Almost simultaneously, firefighters on the upper floors were caught as the backdraft exploded from within the walls and floors of the structure. Rooms burst instantaneously into flames and firefighters reported "blue flames" torching up out of the floor voids. One firefighter at the head of an aerial ladder was engulfed in a ball of flame as the fire erupted from the fourth storey windows. Incredibly, there were no serious injuries.

Leningrad Hotel – Russia – 1991

Leningrad is one of the largest cities in Russia, with a population in excess of 5.5 million. There are 3,000 firefighters serving the city (1,200 on duty) from 100 fire stations. The Hotel Leningrad is a modern purpose-built structure of 10 storeys, constructed in 1970.

On the morning of Saturday, 28 February, 1991, at 0745, guests on the 7th floor had noted a strong smell of smoke, however no action was taken at this stage. At 0755 a passing motorist observed flames in a 7th floor window of the hotel. He immediately informed a police officer in the street outside the hotel who went into the building to investigate. He arrived at the 7th floor by elevator at about 0800 and shortly after this the building fire alarm actuated. The corridor was filled with smoke and the door to room 773 was open. There was a severe fire in the room and the police officer broke a window in the corridor to relieve the smoke condition.

The Leningrad Fire Brigade received the first call at 0804 and despatched 36 firefighters, manning 12 pieces of equipment, to the scene. The first of these units arrived at 0809. Firefighters noted much confusion among escaping guests who had blocked their path up the stairways. A team of four firefighters, rigged in CABA, travelled up to the fire floor using an elevator. They were followed almost immediately by a further team of two firefighters in a second elevator. As the first elevator arrived at the 7th floor the fire had spread into the corridor and was just reaching its flashover stage. The four firefighters were engulfed in fire as they

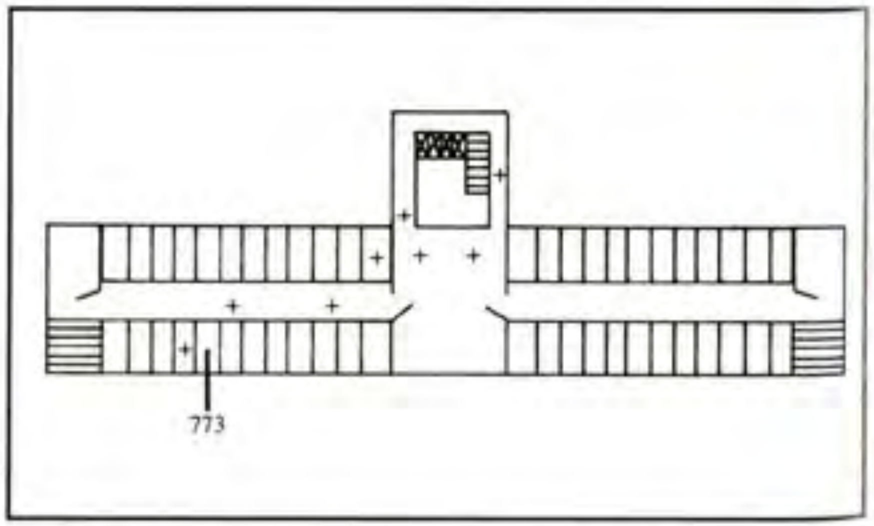


Figure 6:3 – 7th floor of Hotel Leningrad (not to scale) with approx. location of bodies.

emerged from the elevator car. As the second team arrived on the floor, they too were blasted with super-heated air as the doors opened into the inferno. Their colleagues were seen on the floor outside, crawling around with their clothing alight. One firefighter from the second elevator crawled out into the corridor, trying to locate the exit stairway.

At 0812 the second wave of firefighters arrived on scene and a team of four made their way to the 6th level, from where they mounted an attack, utilising the rising water main. On reaching the fire floor they immediately located a firefighter (with 50 per cent burns) crouching low in an elevator car. Following his rescue the four firefighters progressed an attack on the fire. Then, as the building's booster pump failed, they lost their water supply on the nozzle and were forced to retreat. Being in a corridor, the fire regained a hold and travelled faster than they could run. Unable to make the stairway, they were forced to take refuge in a staffroom. Eventually, after some minutes, they jumped from the 7th floor onto a flat roof five levels below; only one survived.

At 0815 there were three aerial ladders and two 30 metre Bronto Skylifts on scene but their access was restricted at the rear. During the following 35 minutes, 20 people were rescued from floors 7 to 9 by these ladders. Firefighters used hook ladders to reach the 8th floor to search for further occupants. One person fell trying to climb down knotted bed sheets. In total, over 80 people were rescued by firefighters while three guests, the policeman, and eight firefighters died as a result of the fire.

Hardware Supermarket – North Stockholm – 1986

In October 1986 the Taby Fire Brigade, situated in North Stockholm, Sweden, responded to a fire in a hardware supermarket that measured 90×60 m. As firefighters entered the structure they noted the high ceiling but were unable to locate the fire due to heavy smoke conditions. Approximately 25 minutes after arrival, firefighters inside the structure noted a sudden increase in the temperature and tried to make their escape. However, fire gases had been accumulating above their heads and as they ignited, the fire blew out into the street like a giant gas burner. Two firefighters were killed in the backdraft.

Common Factors

Among this collection of case histories there are many common factors related to explosive combustion. As the UK governmental BRE (Building Research Establishment) report so rightly stated, the linkage of fibre insulation board (FIB) with the phenomenon of backdraft is widespread. Its uses within a structure may range from wall partitioning to ceiling tiles, or insulating linings. FIB is not easily ignitable but all types are combustible and it is renowned for its ability to decompose, producing large amounts of flammable fire gases in the process.

Fibre building boards can be manufactured from most softwoods and hardwoods either by the traditional 'wet' process, or by the following newer 'dry' process that is becoming more widely used. Wood chips are defibrated into bundles of wood fibres. To these are added various chemicals, bitumen, or resin adhesive, before the final process that forms the impregnated fibres into compressed finished boards.

Examples of fibre building boards:

Standard hardboard
Tempered hardboards
Medium density fibreboards
Softboards
Bitumen-impregnated insulating boards.
Medium boards

Common uses:
Architectural mouldings
Box and I beams
Ceilings
External cladding
Flat roof insulation overlay
Formwork
Internal wall lining
Movement joint fillers
Overlay to structural floors
Roof sarking
Sheathing
Soffits and fascias
Staircases
Window boards.

The firefighter should seek out any structures in his locality where fibre boards are utilised to any great extent within the construction and make a mental note of the backdraft potential.

An interesting aspect that may warrant further investigation is the many reports of blue flames, often seen to precede a backdraft. At a large hotel blaze some years back in the USA, firefighters observed blue flames issuing from a sidewalk entrance into the basement, although in this instance there was no backdraft. The reasons for the existence of blue flames were not immediately obvious in this case. However, subsequent investigation concluded that the effect had been caused by the ignition of a build-up of carbon monoxide gas (which burns blue). This was considered a good theory, for the intervening space between the sub-basement where the main fire was, and the basement where the blue flames were seen, had no actual fire involvement.

The preceding case histories cite several instances where blue flames were observed. Survivors of the Stardust Disco fire, and firefighters in Glasgow and London were among those to have witnessed the effect.

Small-scale experiments by Rasbash and Stark *(Bibliography 6:2)* (FRS note 614) to find the effect of fire load and ventilation on the composition of fire gases within a compartment showed that a reduction in the concentration of oxygen was accompanied by an increase in the concentration of carbon monoxide and carbon dioxide. They also found that when the composition of the fuel and its method of ignition allowed deep seated smouldering to become established, then with very small amounts of ventilation, the fire continued to burn slowly, producing substantial concentrations of carbon monoxide.

Their experiments went on to demonstrate the pulsing effect of smoke and flames as they emitted from venting points. This effect is well documented as a warning sign for a backdraft. Some later experiments by Tewarson *(Bibliography 6:3)* (1972) investigated fire behaviour in enclosures with minimal ventilation. He noted changes in flame colour as gas levels varied and different burning regimes progressed. As 'floating' blue flames became apparent they were followed by minor explosions, reflecting conditions of extreme danger at this boundary of the fire's progression.

While it remains uncertain as to what actually caused the appearance of blue flames in most of the instances discussed, there are certain factors worth considering:

(1) When a fire burns with limited ventilation, the reduction in oxygen levels causes an incomplete form of combustion. This will increase

the levels of carbon monoxide collecting within the compartment. This gas is highly flammable, explosive and burns with a blue flame.

(2) Where air enters the base of a normal diffusion flame at great speed, a pre-mixed flame will appear below the diffusion flame. This effect is similar to a backdraft, where air is rushing into the base of the fire at great speed. A pre-mixed flame burns blue in colour.

(3) Although there are other possible explanations for blue flame sightings eg: pyrotechnics, vapours, gas etc, it is sensible to consider this effect as a potential backdraft indicator in all situations.

Training Beyond the Limits in Sweden's 'Tunnel of Fire'

As you move in on the fire the searing heat can be felt through the facemask of the CABA. The glow up ahead becomes intense as the gas layers above your head start to ignite. The fire begins to roll across the ceiling and all of a sudden the temperature soars as the fire reaches flashover. It may seem that this is the firefighter's worst nightmare, but Swedish firefighters experience this situation four times every year through their innovative 'container' training system.

In 1986, the Swedish national government's Fire and Rescue Services Board Training Academy developed a system for training firefighters to recognise, anticipate and deal with the flashover phenomenon, based upon an idea initiated by a Stockholm fire officer Anders Lauren. Nicknamed the 'Tunnel of Fire', the programme developed around the use of redundant steel shipping containers, modified in their design to include side doors and ventilation hatches. An end section of the 7.5 m long container forms a podium, upon which a fire compartment is constructed prior to each 'burn'. In this section the walls and ceiling are lined with fibre board and a small fire is begun involving broken wood pallets. As the heat builds up within this section the fibre boards decompose to emit large quantities of flammable fire gases that collect in a ceiling reservoir.

The firefighters are able to watch the growth of the fire, as it develops through various stages, from an observation chamber just two metres away. They witness the fire's behavioural aspects and learn how a neutral plane is created as air flows into the base of the fire.

As the fire progresses, the instructor directs firefighters to look up and observe the tongues of flame that begin to snake their way through the layer of fire gases. This is the 'rollover' stage and it is warning that the risk of flashover is imminent. Even though fully protected by flash-hoods, the sudden increase in temperature within the compartment is immediately obvious to firefighters, who are now crouching below the burning gas layers as the flames start to merge. Its all there, the warning signs that you read about in books are actually clear to see.

The first student takes his position at the podium where the wood pallets are burning, and grips the nozzle in readiness. Suddenly, the gas layer begins to move rapidly down towards the crouching firefighters. This is it . . . the fire has reached its flashover stage and its actually happening in front of your eyes! Only the man on the nozzle can stop it now. "Push, push, push" shouts the instructor and several quick bursts, or 'pulsations', from the fog nozzle aimed at the burning layer of gas seem to quench the process as all flames instantly disappear. The effect is extremely impressive, giving the firefighter at the nozzle a complete sense of control over the situation.

The concept of a flashover, or room fire, simulator has fuelled much debate and the training programme has become extremely popular throughout Sweden, Finland and the USA. The Essex County Fire and Rescue Service is one of the first in the

UK to use the simulator to train firefighters and it seems that the whole programme is about to boom in the 1990s. Until recently, flashover simulators have been designed and developed mainly by fire brigades, based on their own experiences and practical knowledge. Phenomena influencing their operation have neither been systematically investigated, nor have physical parameters in this context been measured. Thus the total understanding of the simulator has been far from satisfactory.

To remedy this shortcoming an investigation into the operation and safe use of a flashover simulator was carried out at the Fire Technology Laboratory *(Bibliography 6:4)* of the Technical Research Centre of Finland (VTT). The safe operating range of the simulator has been determined through practical tests and based upon this, a proposal for a suitable instructor's guide has been drawn up.

In June 1990 a manufactured simulator was acquired by the Finish laboratory. The construction was as follows *(Figure 6:4)*:

- Height 2.5 m 8.3 ft
- Width 2.3 m 7.6 ft
- FC length 3.0 m 10.0 ft
- OR length 4.4 m 14.6 ft

(FC = Fire Compartment)
(OR = Observation Room)

The floor of the fire compartment was 400 mm above the floor level of the observation room. This formed the podium. The observation room had a side door, an end door, and a 500 mm square (20×20 ins) roof ventilation hatch. In the ceiling of the observation room there was a 1,000 mm high hinged protective shield at the door post of the side door next to the fire compartment.

The fire compartment of the simulator was insulated on the inside with 10 mm thick calcium silicate boards lined with a 0.6 mm thick corrugated steel sheet. The ceiling and upper parts of the walls of the observation room were also insulated with 10 mm thick calcium silicate boards.

The simulator was almost gas tight, and in practice the fire gases escaped only through the door openings or the roof hatch. Various techniques were used to measure gas temperatures at varying levels in the simulator during a live 'burn'. The purpose of the tests were to determine the temperature distribution and the thermal radiation inside the simulator in order to evaluate the limits of the fire load, and ventilation, under which the equipment can be safely used and its operation controlled.

In total, 23 tests were carried out in the simulator. It was generally noted that when the burning gas layer was restricted to the fire compartment, the temperatures recorded in the observation room ranged from 70 deg C at a level of 1.4 m to 350 deg C near the ceiling. However, when the burning gas layer was allowed to spread to the protective shield the temperature soared in the observation room to 650 deg C at shoulder height, as the layer approached the floor. At the same time, the temperature at 0.8 m was only about 250 deg C *(Figure 6:5)*.

During the tests, sharp transient peaks occurred in the heat fluxes and irradiances up to 35 kW/m^2 were recorded, although levels of 20 kW/m^2 were only registered for less than 10 seconds. During the test burns the CO concentration in the simulator was lethal, making the use of breathing apparatus essential. In comparison, floor level irradiances at the Stardust Disco fire in Dublin were estimated in the region of 60 kW/m^2.

The Fire Technololgy Laboratory investigation concluded that the external dimensions of the simulator proved to be practical. A suitable number of persons

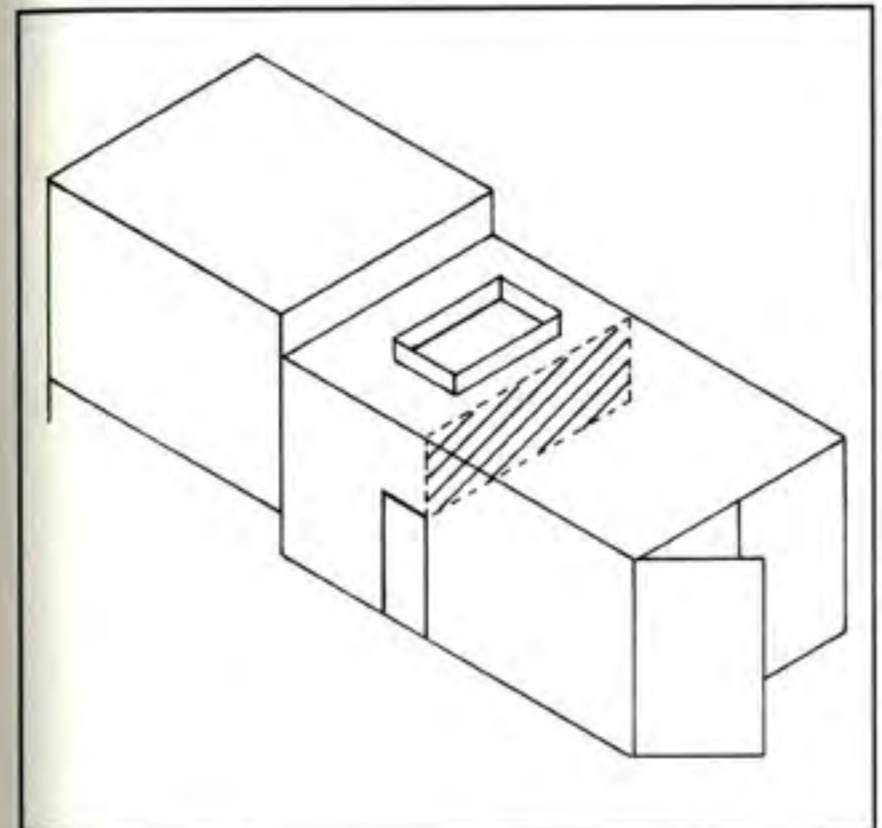


Figure 6:4 – Room fire simulator – manufactured container design.

for each exercise is four firefighters plus one instructor. A fire load of four to six particle boards, and an ignition source of wood sticks soaked in paraffin proved to be suitable.

The extinguishing of the burning gas layer can be carried out either before it spreads into the observation room, or when the burning gas layer reaches the protective shield in the observation room. With the burning gas layer in the observation room conditions are considered more realistic. The extinguishing must be timed correctly as the burning gas layer, once merged, flows quickly down towards the floor during a few tens of seconds. The optimum time to start extinguishing is when the flames reach the protective shield, *ie* before the thickness of the burning gas layer begins to grow.

During the drills, at least one door must be kept open throughout the test. If the door is closed the fire is quenched, but the pyrolysis process continues in the particle boards. It is possible, that a mixture beyond the upper flammability limit is formed within the compartment. When the door is opened an uncontrollable backdraft could possibly occur. As far as is known, this has never happened in a container and the likelihood is, perhaps, extremely remote. However, it should be the intention not to quench the fire in any way, either by direct extinguishing during the course of a drill, or by the closing of doors.

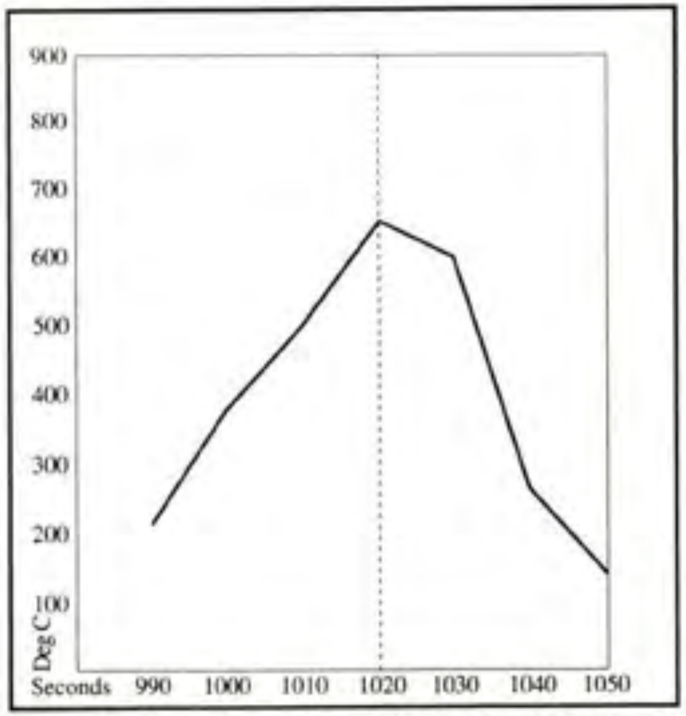


Figure 6:5 – Temperatures at 1.6 m from the floor during an extinguishing cycle in a fire simulator (extinguishing of the gas layer begins at 1,020 seconds).

Objectives of the container training system:

(a) To teach firefighters important aspects of fire behaviour and fire science through classroom discussion.
(b) To teach firefighters the concept of 'neutral plane' enabling them to observe air flows within a fire compartment.
(c) To teach firefighters to 'read' a fire situation by direct observation, so that they may understand a fire's development and growth stages.
(d) To teach firefighters to recognise warning signs, enabling them to anticipate when a fire is reaching its flashover stage.
(e) To teach firefighters a method of preventing a fire reaching its flashover stage.
(f) To teach firefighters how to deal with a situation where the fire has developed into a full flashover.
(g) To enable firefighters to practise compartmental 'opening' and 'entry' techniques.
(h) To enable firefighters to practise various 'offensive fog applications'.
(i) To teach firefighters, through simulations, the difference between 'radiation induced (lean-mix) flashovers' and 'ventilation induced (rich-mix) flashovers (backdrafts).

Safety in the container

The container training system is not dangerous, providing certain safety procedures are followed:

(1) All firefighters should be fully hydrated *before* entering the container and re-hydrated at the end of the drill.
(2) Protective clothing should be of a high standard and should include flash-hood, ensuring that all exposed skin is fully covered before entering the container. Coats, in particular, should be loosely fitted to maintain an air gap between undergarments. Undergarments should cover the entire arms and legs and consist of natural non-melting fibres.
(3) A second hoseline with fog nozzle, supplied by a separate pump, should be manned by a two-man crew fully rigged in CABA, standing by outside the container.
(4) All firefighters inside the container, including the instructor, should be in radio contact with a safety officer situated outside.
(5) An exit doorway should be located in the observation room, adjacent to where the firefighters are working.
(6) Damp clothing should *not* be worn at the outset of a container drill as it may lead to burns.
(7) Where polycarbonate visors are fitted to fire helmets, these should be removed from the helmet before entering the container. There is every likelihood that these may melt down across the CABA facemask vision panel restricting the wearer's view, and possibly interfering with the exhalation valve.
(8) When simulating a 'ventilation induced' flashover (backdraft) within a container, a fuel-rich gas layer is allowed to accumulate by closing the doors. This has the effect of quenching the flames and producing a large amount of unburned gases. As the doors are opened, a sudden in-flow of air occurs as the gas layer begins to ignite from the rich-mix side. Swedish scientists recommend that firefighters do not occupy the container whilst this in-flow of air takes place. While an 'explosive' backdraft is unlikely, the potential for such an occurrence does exist. Rather, they should take the opportunity to practise 'opening' and 'entry' techniques, utilising 'offensive fog applications', while taking advantage of the realistic effects of a typical closed room fire simulation.

Further 'offensive-fog' applications

The Swedish technique of 'offensive-fog' application, described in Chapter 3, is extensively practised during container training. The student spends much time familiarising himself with the TA Fogfighter nozzle and practising nozzle technique before even entering the container. The knob on the spray control is set at 11 o'clock, giving a 60 degree cone spread. With a nozzle pressure of 6 bars, the student aims up at a 45 degree angle to the horizontal and learns to discharge several short, sharp, 'pulsations' of fog into the air. Only a very small amount of water is actually dispersed from the nozzle as the droplets are extremely fine.

The student is taught correct 'door procedure' and learns to inert the environment outside a door before entering the container, by discharging a fine mist into the air to prevent an outflow of burning fire gases from the compartment *(Figure 6:6)*.

On entering the compartment the student is taught how to apply the 'water test'

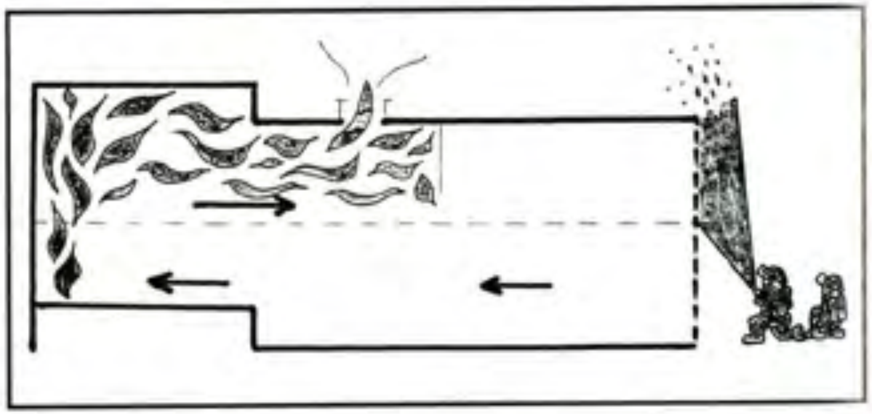


Figure 6:6 – A 'neutal plane' can be seen about one metre from the floor. Below this level the flow of air (and smoke) is towards the fire, while above it the flow is reversed. Before firefighters open the door to a free compartment they should inert the air outside it with a burst of fog. (Note: only the finely divided particles of a water fog are able to suspend in air – the droplets from a 'spray' nozzle may be to heavy to create this effect.)

by 'pulsing' the fog directly above the head *(Figure 6:7)* and assessing the amount of 'drop-back' (ie, the amount of water, if any, that falls from the ceiling). If no water drops back down then the gas layer at ceiling level is super-heated and has evaporated the fog. The student is then taught to give a few quick 'pulses' into the upper strata of fire gases and then to utilise the air flow below the neutral plane by discharging a quick two-second burst of fog low into the compartment *(Figure 6:8)*, in the hope that the fine water droplets wil be drawn in with the air heading towards the fire.

While inside the container, students can follow the development of a fire from its initial stages, through to a full-scale fire, finally experiencing a flashover. During this time they are able to observe changes in temperature and smoke composition. They can also see the boundary layer between the hot gases at high pressure and the vacuum caused by the fire. They can observe how to influence the level of this boundary layer and gain extensive practise in applying water fog safely, and effectively, by producing the fine 'pulsations' which make use of the vacuum caused by the fire, cooling the gases produced *(Figure 6:9)*.

False sense of security

While it is essential that firefighters are equipped with flash-hoods while taking part in container training, there are mixed feelings as to whether such hoods should be worn into 'real' fires. In both the USA and Sweden the flash-hood is becoming a popular issue among firefighters who value the skin around their necks and ears! However, much opposition to the use of hoods in 'real' fires is based upon the commonly held views that:

- A firefighter should retain some amount of exposed skin that will enable him to assess the severity of a fire. He literally needs to 'feel' the environment to ensure that he receives a reliable indication of when to leave the area.
- 'Over-protected' firefighters are likely to advance too far into a fire involved structure, placing themselves rather unwittingly into potentially lethal situations.

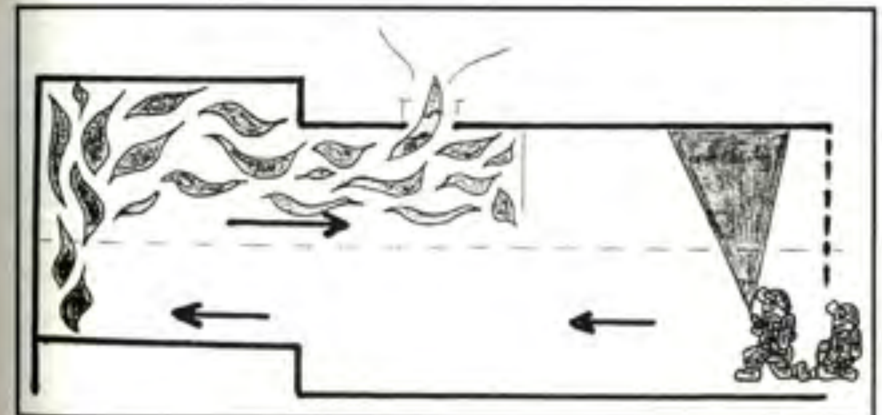


Figure 6:7 – On entering a fire compartment, firefighters apply the 'water test' by directing brief 'pulses' of fog immediately above their heads. This will determine the temperature in the fire gas layer above them. If it is cool, the water will fall back on them.

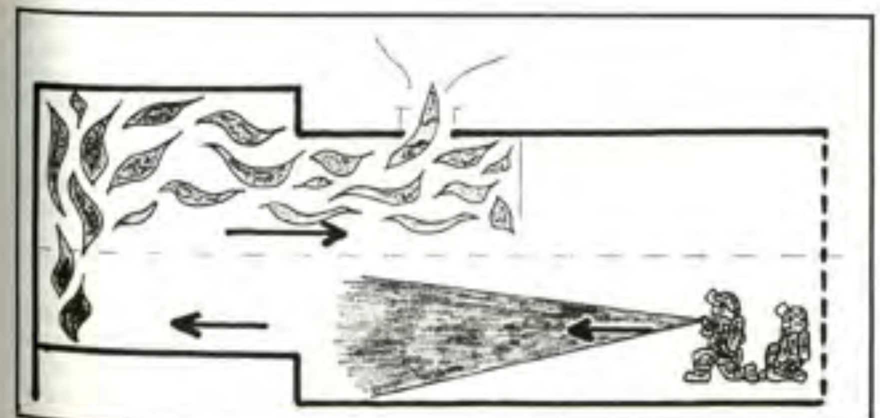


Figure 6:8 – Before firefighters advance into the compartment, full use is made of the air-flow below the neutral plane. A brief burst of fog is applied at low level into the compartment, enabling the water droplets to be drawn in towards the seat of the fire. While this is a good tactic in a real fire it should be avoided in a container simulation, where it should be the intention *not* to extinguish the fire's seat.

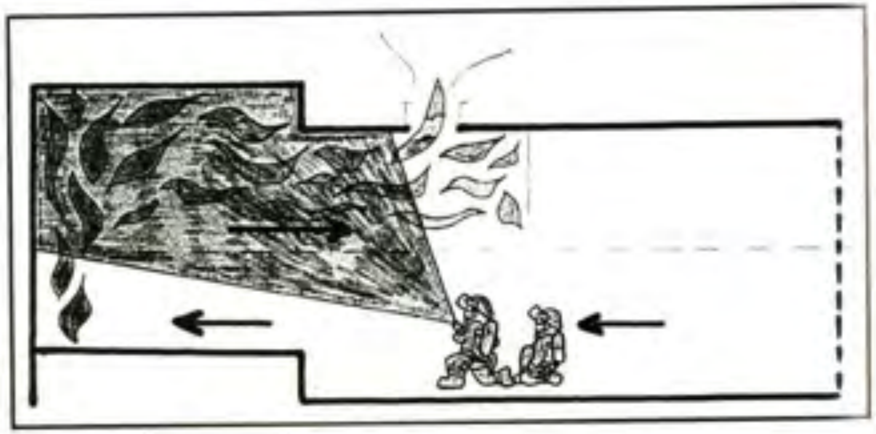


Figure 6:9 – Where a super-heated, or burning, gas layer is located, firefighters proceed with an 'offensive' application of fog.

Most firefighters who have worn a flash-hood during container simulations will testify to the fact that a firefighter wearing a hood is perfectly capable of assessing the severity of temperature within a fire compartment, particularly where sudden changes take place. Try it for yourself – place a flash-hood over your hand and blow through the material onto your skin . . . you'll feel the warm air for sure.

It is the nature of a firefighter's work to occasionally place himself into a compartment that may be bordering on the stage of flashover, particularly in a situation where persons are believed trapped therein. Container simulations will teach him to 'read' a fire as opposed to 'feeling' it (although he will still be able to do so – even with a flash-hood). It is imperative that a firefighter is adequately protected and equipped to work in such an environment. Just as he wears gloves for protection, so too must he wear a hood. When a flashover occurs, the temperature within the compartment will soar above 600 deg C with an immediate irradiance at floor level in excess of 20 kW/m^2. Where firefighters are subjected to such levels of thermal radiation it is estimated that the time to severe burning is around 100 seconds where the level of protective clothing is adequate.

However, under the same circumstances, exposed skin will receive burns within five seconds.

It is also important that a firefighter should be effectively trained to operate under such conditions and he should not have to rely on past experience to get him through. This is why container training is so valuable. There is no other known method for creating such realistic conditions, other than a 'real' fire, and this makes the programme unique.

Even so, it is important to realise that a container simulation is not wholly representative of the average room fire. There is no real smoke production that restricts the firefighter's view on entering the compartment and the fire develops quite openly within full view. Also, the firefighter is working in a known environment, an area that contains a limited fire load placed directly in front of

him. Basically, it is an effect of limited dimensions where 'thermal feed back' into the compartment plays no part in the development of the fire and it may be easy for an inexperienced firefighter to be misled into gaining a false sense of security, possibly even becoming over confident in a 'real' fire situation. As with the over-protected firefighter advancing dangerously beyond safe limits into a fire, the answer lies in a high standard of *training*. It is extremely important to place a great deal of emphasis upon the limitations of equipment, technique and procedure. What may work in practice is never certain to be as effective when applied for real.

Nevertheless, the manufactured fire simulator is as close as a firefighter can get to practising technique, and learning certain aspects of fire behaviour in safety, and with correct training the programme will most certainly advance him as a professional and improve safety standards on the fireground.

Chapter 6 – Smoke Explosions – Bibliography

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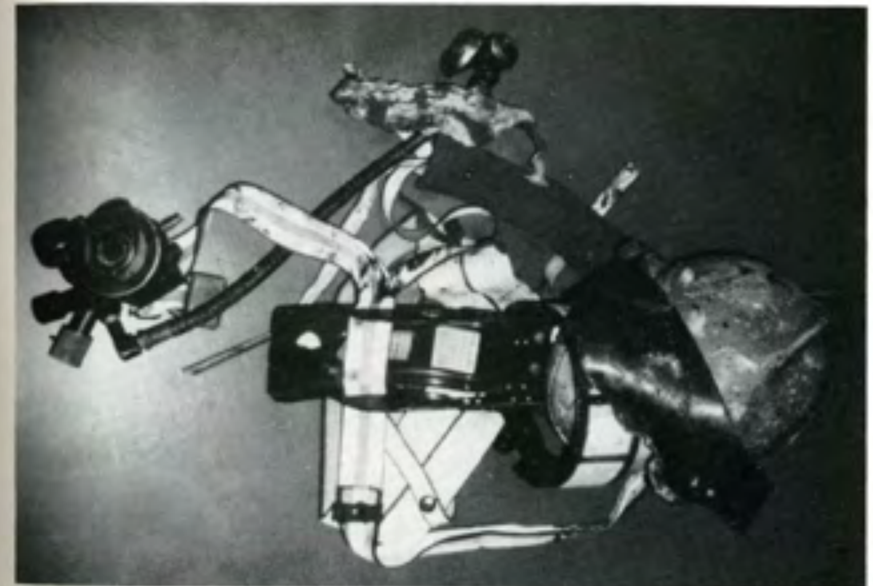
In this sequence of photographs *(which continue overleaf)* we see London firefighters taken by surprise, in the early hours, by a flashover. Sound tactics might question a forced entry without the protection of a 'charged' line?

Sequence continued from previous page – see Chapter 6. *(Whole set taken by Martin Lloyd-Elliot).*

Firefighters in Oxford Street, London, narrowly avoided injury as a backdraft blew the shop front out *(see next page)* after gases had collected in the ceiling space seconds before they were able to make an entry – see *Chapter 6.* *(Photo by London Fire Brigade).*



It is essential that a firefighter's protective clothing meets the highest standards. This is the damage incurred after a Phoenix, USA, firefighter was exposed to temperatures of over 1,000°C for seven seconds! He was injured – *see Chapter 6*).

The colour of smoke is almost entirely determined by the character and type of fuel involved and the availability of oxygen for complete combustion. The presence of dense black smoke *(see photo above, by Carolyn Garcia, Dallas Fire Dept)* may indicate the involvement of carbonaceous material, or that the fire is 'searching' for oxygen. This is a true backdraft indicator and great care should be taken. Wood, and most organic building materials produce a white, or light grey, smoke *(see photo left, by Erik Crichton, London Fire Brigade)* when burning with a plentiful supply of oxygen – *Chapter 6.*

Top – The fire compartment, lined with fibre-board, allows the fire involving broken wood pallets to create a highly flammable gas layer within the container. *Bottom* – London firefighters are given a final briefing during a flashover training programme in Sweden – *Chapter 6.*

A scaled-down model of the container is used to teach firefighters some important aspects of fire behaviour, in relation to flashovers and backdrafts, prior to taking part in container training – *Chapter 6.*

The severity of conditions encountered inside the Swedish flashover simulator places all items of protective equipment under great stress – *Chapter 6.*

The Las Vegas Fire Department is one of many around the world that insist their firefighters wear flashoods, in conjunction with CABA, at every fire – *Chapter 6.*

The use of flashhoods inside the flashover container is essential. However, these London firefighters are not issued with such items of protective clothing for use in real fire situations – unless gas cylinders are known to be involved – *Chapter 6*. *(Photo by Stefan Carlzon, Sweden).*

The Hotel Leningrad, following the fire that killed 12 people, including eight firefighters, some of whom died in the flashover. *(Photo by Kaare Brandsjo, Sweden)* – ***Chapter 6.***

7
SEARCH AND RESCUE

'It cannot be too generally known, or too often impressed on those who undertake the responsible duty of saving life from fire, that if they have been thoroughly instructed in the duties of their profession, and are personally and otherwise competent to do the work, their success will be on almost all occasions in exact proportion to the risk they run.'

Sir Eyre Massey Shaw, KCB
'Fire Protection' 1876

While such advice was handed down to firefighters a century ago, much of it holds true today and the reader should question his own ability of carrying out such deeds, for in Captain Shaw's own words: 'his whole success depends on his getting in and remaining there'.

Such aptitude requires extensive and regular training, a disciplined mind and a capacity to learn from experience, coupled with such personal qualities as courage and determination. Personal attributes such as these are rarely on display for an audience to see, however a typical example of such heroism was described in Sir Aylmer Firebrace's book *(Bibliography 7:1)*:

> 'A phenomenally brave deed, was that carried out by Fireman Frederick Davies at a house in Harlesden [London] in August 1945. On the arrival of the escape [pumper], the crew were told that there were children in a room on the second floor, from the window of which flames were already coming. Even before the ladder was pitched to the building, Davies was half-way up it. At the top he was met by intense heat and fierce flame. Only one man in ten thousand would have attempted to enter the room. Turning away from the flames, he stepped backwards into the room. Groping round, he found a child, and was seen to be trying to tear his tunic off in order to wrap the child in it, but by now his hands were too burned to have any feeling left in them. He flung himself onto the escape (ladder) with the child in his arms; his clothes were alight from head to foot, and he was screaming with the intense pain of his burns. Neither rescuer nor child survived. Davies was posthumously awarded the George Cross; it is impossible to imagine a finer example of self sacrifice.'

Since the days of Massey Shaw, many other deeds of daring have resulted in the rescue of building occupants trapped by fire. However, the improvements in structural fire protection, and a change in material content, has made such events rare. The majority of trapped occupants are now usually overcome by the highly toxic gases given off by modern-day fires and this fact, coupled with the added protection of SCBA, demands that the firefighter must now penetrate the inner depths of the fire building to locate any victims. To attain such objectives with any element of success demands a high standard of training and where structures are large, with high occupancy loads, a systematic search and rescue plan is required.

Deborah Wallace detailed a number of case histories in her book *(Bibliography 7:2)* and developed the notion that modern plastics play a far bigger part in causing fire fatalities than is currently realised. A close study of fires in New York, Dallas, and Las Vegas (among several others) also suggested that short exposures to modern fire gases resulted in long-term effects for survivors, in both a physical and physcological sense. It was somewhat of a coincidence that I had read her graphic account of how firefighters had suffered at the New York Telephone Exchange fire (1975), just four hours before my fire station responded to a 'working' fire involving an electrical transformer station in London's West End district. As we approached the incident, thick black smoke was pouring from a room situated underneath a high-rise tower. The reports of burning PVC cables giving off such highly toxic emissions as hydrogen chloride, phthalates, carbon monoxide, benzene, and organics, leading to throat cancers and other fatal conditions, were still fresh in my mind as we climbed down from the pumpers. A team of firefighters had attempted a closer look ahead of us (without CABA) and I immediately turned to colleagues, warning them of the dangers. Seconds later the advance team came coughing and spluttering into the street. They complained of chest pains for days afterwards!

Ms Wallace clearly states her case, believing that we are constantly surrounded by modern-day plastics, decompose to give off toxic gases, corrosive irritants, asphyxiants, and organic chemicals. Those that survive exposure to such emmissions may suffer damage to organs such as the heart, brain, kidney and the liver. They may also experience amounts of respiratory tissue death, lung edema and haemorrhage, chemical pneumonia and bronchitis, susceptibility to respiratory infections, permanent abnormal lung functions, skin scarring and sensitisation, eye damage, and neurological and vascular reactions. Organic chemicals usually affect the nervous system. Phthalates are also heart poisons. Benzene causes blood cell abnormalities, including leukemia. Many organics poison the liver and cause cancer . . . the list is endless!

These gases have a distinct effect on the immediate survivability rate of trapped occupants, as well as a long term effect relating to the quality of life for survivors. The firefighter of today should pay heed to such evidence and don CABA at *every* fire. Such equipment should form part of his protection, as does his turnouts, helmet and gloves.

The Dallas Fire Department were involved with a research project that evaluated the survivability rates of rats placed at different locations during a series of full scale test burns in a derelict split-level dwelling. (It should be noted that this was not the prime purpose of the study.) Temperatures up to 1,990 deg F and CO concentrations up to 20,000 ppm were registered inside the structure during the tests. It was clear that a direct correlation existed between performance time and the observed survivability rate. In general there was a 46.6 per cent survival rate when rescue occurred between 12 and 15½ minutes, but the survival rate dropped to 5.5 per cent when rescue occurred between 15 and 17½ minutes. In one test a bedroom window failed due to a build-up of heat. An increase in available oxygen immediately registered and the survival rate in this instance was high.

Of course, such research findings involving animals can do no more than provide approximations as to 'real' survivability rates which are liable to fluctuate, depending on fire gas analysis, age and levels of fitness of victims etc. However, it is certain that from the moment a fire originates within an occupied building, the countdown has begun and firefighters should make it their objective to complete search and rescue (S&R) operations within five to 10 minutes of their arrival on scene, depending on the size of the structure.

Where victims remain within the confinement of a smoke logged structure for any longer, their chances of survival are almost zero. To complete such effective S&R times will require a well trained firefighter who is used to 'blind-search' procedures. It will also necessitate the correct, and safe, use of ventilation support

tactics (including positive pressure ventilation – where practised).

Gaining Roof Access

It is often the case that the location of trapped occupants is unknown. Reports of persons thought to be in the structure may be vague and unconfirmed. Even so, the fire chief must assume that victims may be in the building and a S&R operation should be mounted at the outset of operations. Without confirmed reports it may be difficult to justify placing firefighters at risk, both on the fire floors, and above. However, the time of day, and the type of building, will yield clues as to victim potential and where any doubt exists, a search should be made.

Many fire training manuals suggest that a systematic search of the fire building should begin at the point of greatest danger, working away towards safety. On arrival at an incident it may not be possible to immediately define where the point of greatest danger exists, particularly in a multi-storey building. The exact location of the fire may remain unknown at this stage and one could argue that either the fire floor, the floor immediately above, or the top floor itself are the most likely places that victims will be found.

In the USA, firefighters are specifically assigned to fulfil certain roles on arrival at an incident. Such procedure is clearly defined through individual department standard operating procedures (SOPs). The basic concept of engine company firefighters effecting the water supply and attacking the fire, while ladder company firefighters adopt the roles of forcible entry, ventilation and rescue, is generally practised throughout the USA. Where multi-storey buildings are concerned (not high-rise) the standard operating principles will place a 'roof team' in position at a very early stage in the operation, usually within two minutes of arriving on scene. The size of this team is variable and depends on an individual department's manning levels. However, anywhere from two to five firefighters will make up the initial roof team in metropolitan areas. Their primary function is to:

(a) Visibly check the rear (and sides, where necessary) of the building for trapped occupants; some may already have reached the roof.
(b) Make a visible assessment of internal lightwells for potential rescues.
(c) Report their position, and status of such areas, to the incident commander.

To effect such rescues they are likely to be equipped, and trained, for abseiling the building. Their secondary function will be to ventilate the roof, on the orders of the incident commander. This may be a simple operation, requiring the opening of a door or roof hatch. However, they will be prepared to 'cut-in' where necessary and the relevant equipment will be on hand. The team may be further occupied by making entry to the structure through the roof, to complete a downwards search of the upper floors. The employment of such a tactic may be extremely productive at many fires in terms of rescue and ventilation. The key to its success lies in an *early* placement of the roof team, ensuring they are well trained and equipped to carry out their functions effectively.

The possibility of persons becoming trapped within an elevator (lift) car during a fire must always be anticipated by the fire force and the roof team will be ideally situated to check shafts from the top, to determine their status and location. They will also be in an immediate position to effect rescues under such circumstances.

Access to the roof is generally effected by one of several means:

(1) An early siting of a suitable aerial appliance, turntable ladder, hydraulic platform etc.
(2) By use of stairways in adjoining structures, using available means to cross on to the involved building.

(3) The use of hook, scaling or Venetian ladders, where provided.
(4) By utilising a stairway within the fire building that may be passable to firefighters, but not occupants.

Moving in Smoke

I do not intend to discuss in any great detail the various search 'patterns' and techniques used to complete a 'blind' search in thick smoke and darkness. The reader will already be (I presume) well practised in such procedures and one needs only to refer to a basic training manual to glean such information. However, I wish to touch upon one or two points that are occasionally seen to hamper search and rescue operations.

In general, a 'walking' search pattern is considered most effective where visibility and smoke conditions are light to moderate; where there is no possibility of overlooking an incapacitated occupant; and the crew is able to advance in safety. Under such circumstances it is perfectly feasible to expect open areas to be searched with extreme speed and research findings have indicated that a 'search-rate' of 4,000 sq ft/min. (368 sq m/min.) is possible.

To simulate search and rescue (S&R) operations under more severe conditions the Dallas Fire Department carried out some research where firefighters, with sanded CABA visors to obscure vision, adopted a 'crawling' search pattern. In an open area, under simulated conditions of moderate to heavy smoke, the crawling firefighters were able to complete their search at a rate of 227 sq ft/min. (21 sq m/min). However, under the same conditions, the search-rate was reduced further still when working in a compartmented area, where a rate of 163 sq ft/min. (15 sq m/min.) was indicated.

These are interesting findings and through 'real' fire experience I can relate to them directly. It is most certain that 'real' fire search-rates will decrease even further and I would suggest that for compartmented areas a more reliable estimate would be 100 sq ft/min. (rounded to 10 sq m/min. for ease of calculation).

Having reached this stage we are now in a position to create a reliable formula that can be used to estimate the manpower requirements for any particular S&R operation.

For example: If a hotel, consisting of five storeys, measured 100×30 ft (totalling 3,000 sq ft on each floor level) and a fire at the second level had led to severe smoke logging of the 3rd, 4th and 5th levels, how many firefighters would be required to complete a search of these upper levels within a ten minute time scale?

Solution: By totalling the floor area to be searched (9,000 sq ft) and dividing this by the standard 'search-rate' of 100 sq m/min., we are left with 90. This means it would take one search team 90 minutes to search the three levels, if heavily smoke-logged.

Now, by dividing 90 by the 'target time' (in this case the target time is 10 minutes) we are left with the figure nine. This tells us that it will take nine search teams about 10 minutes to complete the search of upper floors (3, 4 and 5) in the hotel. *NB: Where this method is used under metrication, to simplify matters for fireground purposes a rough estimate of manpower requirements can be achieved by using a standard 'search-rate' figure of 10 sq m/min., although a figure of 9 sq m/min. would yield a more exact answer.*

The ideal size for search teams under such circumstances would consist of two firefighters. Where large open areas are to be traversed for search purposes, or where teams are advancing a hoseline into a structure, additional firefighters may be required to form a team. However, the case in question places a demand for 18 firefighters to be assigned in nine units to complete the task within the time-scale allotted.

Such a demand for manpower, on the initial response, would place a heavy burden on the fire force and stretch their capability to the limit. Indeed, as I explained in Chapter 1, many forces would be unable to cope with such a demand and S&R times would have to be increased, reducing the survival chances of trapped occupants. It is here that the 'Expanded Response System', as practised in Phoenix and Seattle, USA, would achieve its greatest effect.

It should be noted that S&R times (10 minutes in this case) do not actually start until search teams reach the affected floors.

$$\frac{\text{Area (A)}}{\text{Search Rate (SR)}} = \text{Minutes (Mins)}$$

$$\frac{\text{Minutes (Mins)}}{\text{Target Time (TT)}} = \text{Search Teams (ST)}$$

Where:

A	– Total area to be searched (sq ft or sq m).
SR	– Standard search Rate – 100 sq ft/min or 10 sq m/min (9 sq m/min) is exact).
Mins	– The time required for one search team to complete the task.
TT	– The target time is the time allotted to complete the task.
ST	– The number of search teams required to complete the task within the time-scale allotted.

Table 7:1 – S&R target rate formula.

Case History:
Hotel Fire – West London, UK

Prior to the mid-1970s, when the UK's stringent life safety codes for hotels began to take effect, this area of London was renowned for its particularly bad fire record concerning such occupancies. However, even with current legislation enforcing the provision of fire alarms, adequate escape routes for occupants, and restricting the materials used for internal finish, a major hotel blaze is still not totally impossible.

The particular incident in question was typical of the modern day fire that serves to demonstrate the effectiveness of an in-built fire protection factor. However, when elements of workmanship deteriorate, or fire doors are left open, the fire force is faced with an immense problem in this type of structure, particularly if the fire occurs during the early hours.

As firefighters arrived on scene at this particular incident just after midnight the hotel of six floors, measuring 50×30 ft, was partially alight at the second level. The upper levels (3 to 6) were charged with variable amounts of moderate to heavy smoke, and an unknown number of occupants were believed involved. It was fortunate that a second stairway remained passable throughout the fire and the entire building occupancy had been able to use this to escape to safety, prior to the firefighters arriving on scene. However, the incident commander could not be aware of this at the outset and a massive S&R operation ensued.

Several important lessons were learned, and reinforced during these operations:

(a) The S&R teams consisted of three firefighters. In total, three teams (9 firefighters) were despatched to the upper levels to complete the task.
(b) On entering the structure, the teams had not been properly briefed as to their objectives. They had simply been told that persons were believed trapped at upper levels and a search was to be made.
(c) There was no method in use of indicating areas/rooms that had been searched to firefighters on the upper levels.
(d) In effect, what resulted was a totally inefficient search pattern that wasted resources and stretched the target time. The entire operation took nine firefighters over 30 minutes to complete.

Initially, the teams would have been better deployed in two-man units. The S&R formula tells us that the 6,000 sq ft area (four floors) would have taken four two-man teams about 15 minutes to complete the task. Ideally, each team could have taken a floor to themselves. However, without adequate instructions, the three-man units found themselves wasting valuable time, searching areas that had already been checked by other teams. If a door marking system had been utilised this would not have happened. Additionally, firefighters experienced great difficulty in keeping together as teams passed each other and searched rooms off of the confined corridors.

Ladder Placements

As firefighters approach the fire building, the opportunity should be taken of making a quick visual check of the structure from different angles. If the existence of fire within is obvious, the structure may be shrouded in a layer of smoke, preventing such scrutiny. A primary action is for a firefighter to circle the building, where possible, to report on the location of smoke, flames, or trapped occupants. This function should be fulfilled at *every* incident, even for the routine call to 'Fire alarm actuating'.

It is absolutely essential for an *immediate* ladder placement to take place where occupants are located at windows within a fire building. While the situation may not appear to be particularly urgent, one should never underestimate a fire's ability to wreak havoc within a structure and the opportunity for rescue should be grasped while it is still possible.

I once attended a fire during the latter stages that endorsed this lesson: The initial response arrived within five minutes of the first emergency call placed to the fire brigade, but it brought just one pumper with five firefighters to the scene (additional engines were responding from some distance). First arriving firefighters were faced with heavy smoke issuing from an apartment on the second level of a modern, purpose-built block. A man was seen outside on a balcony that served the apartment and even though smoke was pushing from the open glass doors behind him, he was not particularly distressed. An attempt was then made to gain entrance to the apartment via the main doorway situated off the interior stairway at 2nd floor level.

However, efforts were hampered by security locks and the strategy reverted to an approach from the street. As firefighters were siting the ladder to rescue the man the fire flashed over and he was forced to leap from the balcony, some 25 ft from the ground. His injuries were not severe – at the worst, a broken ankle.

However, the situation could easily have resulted in disaster and the firefighters should have sited the ladder immediately on arrival. *If you see someone at a window on an upper level of the fire building, and if you think you can reach them with a ladder, GO FOR IT!*

The rear of a fire building is so often forgotten during the early stages of a fire; particularly where there is a major work-load on offer at the front! It is extremely important that a firefighter is assigned to check the rear, immediately on arrival. If the building forms part of a long terrace, and access is not obvious, utlise an adjoining building to reach the back.

A major hotel fire occurred in Amsterdam, Holland, where many people were throwing themselves from the upper floors, into the back courtyard. Fortunately, firefighters were quick in reaching the rear of the structure and sited some jumping nets that saved the lives of many people.

Another major fire in Paris, France, involved a large number of people hanging off the rear of a blazing apartment block. Again, a rapid response to the back of the building brought firefighters with scaling ladders (also known as 'hook' or '*pompier*' ladders), and they climbed the face of the building to reach those in peril.

Milan, Italy, firefighters are frequently in action from rear courtyards, or side alleys, slotting their 'Venetian' ladders on top of one another to reach those trapped on the upper floors. It is certain that some of the most dramatic rescues are carried out to the rear of many buildings. *The next time you arrive at a fire building – CHECK THE REAR. . . .*

Another area of a multi-storey structure that is often forgotten is a lightwell (an open shaft in the centre of a building, used to provide natural light to the floor areas). It is not surprising that lightwells are so often missed by firefighters during the early stages of a fire, for they are hardly obvious from an exterior position.

At one fire in San Francisco, USA, firefighters discovered a large number of bodies at the base of one such lightwell during the later stages of a fire. The occupants had been leaping to their deaths, unknown to the fire force on scene.

The quickest way to locate such a feature is by the prompt siting of the roof team. Where occupants are trapped at windows facing into the well, the roof team is, perhaps, their only chance of rescue. Firefighters working inside the structure must also be on the lookout for lightwells at an early stage and a check should be made at the base for victims.

Whenever ladders are sited over window areas below, a covering jet *must* be provided to protect personnel climbing the face, should smoke, heat or flame suddenly erupt in their path. It should be second nature to firefighters to effect such a precaution, not necessarily waiting to be given instructions to do such a thing. *If you see a firefighter working on a ladder, near or over windows, without such protection – run out a length and COVER THE RISK!*

Finally, at the earliest opportunity under darkness, utilise a lighting unit to light the structure. The façade will benefit from an early lighting operation, assisting in occupant location and ladder siting. Also main-beam portable lighting should be provided *inside* the search area to speed any rescue operations.

Chapter 7 – Search & Rescue – Bibliography

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8
FIRE ATTACK

'A fireman, to be successful, must enter buildings; he must get in below, above, on every side, from opposite houses, over back walls, over side walls, through panels of doors, through windows, through loopholes, through skylights, through holes cut by himself in the gates, the walls, the roof; he must know how to reach the attic from the basement by ladders placed on half burned stairs, and the basement from the attic by rope made fast on a chimney. His whole success depends on his getting in and remaining there and he must always carry his appliances with him, as without them he is of no use.'

Sir Eyre Massey Shaw, KCB
'Fire Protection' 1876

As the fire vehicles turn into the street smoke can be seen banking down across their path ahead. People are running in the roadway frantically waving at the responding fire force and pointing up in the air. The adrenaline flow peaks as firefighters make a grab for their equipment in the cab, straining their eyes through the haze ahead for the first glimpse of the fire. Suddenly, a flicker of flame lights up the frontage of a building where thick black smoke can be seen pouring from three windows on the third storey of a ten-floor brick and joist office structure.

The primary actions of the fire force are dependent on the life hazard to occupants and the fire spread to internal and external exposures. However, no aspect of fire control is more important or influential on the final outcome of the overall situation than that of 'Initial Attack Strategy'. The old maxim of 'putting the blue stuff on the red stuff' becomes intolerably simplistic as advances are made in the techniques utilised to suppress fire. The complexities of extinguishing fires have never been more detailed and as each further experience is documented, we learn new lessons.

How one particular fire department responds to, and attacks, the fire described above does not create a precedent for others to follow and it is extremely interesting that there can be so many views on how to lay hose and advance lines into a 'standard' fire situation. Such contrasts in technique may prompt us all to review our own individual attack strategy with an overall intent to improve.

Siting the Initial Response

One of the most pressing decisions a fire force has to make involves the siting of the initial response apparatus. Of all primary actions, this surely is the most influential for it sets in motion the whole strategic plan and fireground tactical options are dependent on such positioning from the start.

It is generally a strategic decision that forms part of a pre-plan, although certain department policies allow the company officer to decide *en route*, or on approach to the incident. Should the first arriving pumper site itself adjacent to the hydrant or in front of the fire building? or should the frontage be left completely clear for incoming aerial apparatus?; on initial assessment, does the fire warrant an attack utilising straight streams or water fog? or would the initial response be better employed protecting exposures?; what type of hose placement would best suit this fire and, even more important, is the first alarm response sufficient to handle the situation or should the attendance be increased?

These may be standard questions but on a global basis opinions vary widely as to the answers. While structure design and construction may influence tactics to some extent, the way London or Tokyo firefighters handle a 'standard' fire is totally different from, say, firefighters in Chicago or Los Angeles.

Factors that will affect the siting of fire vehicles on the initial response include: water supply, aerial access, visible rescues, 'master streams', 'line pumping', fire involvement, structural stability, and style of attack.

Water supply: The location and capability of fire hydrants and other water supplies are of obvious importance. The hydrant grids in the USA are generally more modern than those found in most parts of Europe and will flow substantially larger amounts of water. In certain parts of Europe it is more effective to draft water onto the fireground than utilise the low-pressure hydrants. In Amsterdam, for example, the plentiful supply of water in the canal system throughout the city ensures that the major demands of a large fire are always met.

The tactical options concerning water supply for the initial response relate to the pro's and con's of siting the first arriving pumper (a) adjacent to the fire hydrant; or, (b) in front of the fire building.

Aerial access: Many American fire departments believe it essential to leave access to the frontage of the building completely clear for aerial apparatus. This tactic is rooted in the priority of early roof operations where teams of firefighters will position themselves almost immediately in anticipation of ventilation or rescue operations.

Visible rescues: On approach to the structure it may become obvious that visible rescues on the building façade are to take priority. In this case a major laddering operation is called for. European firefighters will position their 'quads' (attack pumpers that carry lengthy portable ladders) adjacent to the façade to facilitate prompt siting of ladders. The 'quad' is becoming a popular concept in the USA where its versatility is found to appeal and gain respect.

Master streams: A common feature of US fire pumpers is the top-mounted multiversal deluge gun. This may or may not be portable, but is most commonly employed by the initial attack pumper utilising the tank supply. Such a technique will empty the tank in seconds but may be invaluable in certain circumstances. The attack pumper will get priority when positioning at a fire. Uses of a deluge gun include:

(a) Mounting an immediate 'BLITZ' attack against an escalating fire front.
(b) Providing a 'COVER' line to protect firefighters involved in exterior rescue operations.
(c) Creating immediate protection for external exposures from radiated heat.
(d) Developing a 'RUN-DOWN' effect on the façade of a curtain wall structure to prevent auto-exposure where fire is threatening to lap upwards into the floors above.

The ability to provide a master stream immediately on arrival can be extremely advantageous and few European fire brigades are able to achieve this capability with such speed.

Line pumping: The wide range of line-pumping techniques used to transport water on the fireground dictate the exact positioning of the supply pumpers. (Discussed further in Chapter 2).

Fire involvement: Obviously, the level of fire involvement will dictate to great effect the available access for responding fire apparatus. A major firefront may prevent any pre-planned approach to either the structure, or the most suitably sited water supply.

Structural stability: The increasing use of lightweight construction makes it even more essential to make an accurate evaluation of structural stability and collapse potential when siting fire vehicles.

Style of attack: The varying styles of attack, as adopted by fire departments worldwide, will place individual demands on first response apparatus, directly enforcing a pre-planned location on the fireground. The low-flow fog attacks as practised in most parts of Europe and Scandinavia place the attack pumpers (quads) in a position close to the fire, water supply being a secondary consideration. In complete contrast, the high-flow straight stream/spray attacks adopted by North American firefighters demands that water supply must be an early consideration and the initial pumpers usually site adjacent to hydrants.

Modes of Attack

It is common practice in the USA to evaluate and determine the 'mode of attack' a fire force is functioning in at any particular time. The mode will be either *offensive* or *defensive* and the strategy employed on the fireground will reflect the particular mode the fire force is in.

In order to determine the most effective deployment of firefighters on scene, the incident commander must balance the level of fire involvement with the capability of his force to deliver water onto the fire. An appraisal of manpower, equipment and resources on scene will provide an estimate of 'resource capability'. As an example of this, the 'standard' fire described earlier would attract a central downtown response in the city of London of three pumpers (quads) and an aerial appliance. A fourth pumper may be automatically dispatched on receipt of further calls. Such an attendance would deliver about 15 firefighters on site who would have the initial capability of flowing over 2,000 LPM (530 GPM US) through twin attack lines, supported by an aerial stream. Such a capability would easily place this fire force in command of the situation and put them in an offensive mode. However, if it were the case that two entire floors of the structure were fully involved on their arrival then this would be deemed to be beyond the capability of the initial response and they would immediately assume a defensive strategy until additional engines arrived to assist. In reality, the former situation would probably be handled by one or two high-pressure hosereels (booster lines), acting well within their actual capability prediction.

Somewhat in comparison, if the same fire occured in the city of Miami, USA, an initial response of two pumpers and an aerial appliance would bring 12 firefighters on scene. Such a reduction in attendance may be expected to present a lower resource capability prediction when compared with that in London. However, Miami's firefighters are, I believe, seen to be more 'capable', supported by a more effective hydrant grid that is optimised by advanced line pumping techniques. In effect, less firefighters are able to flow more water and more are free to function in offensive roles, as opposed to London firefighters who must lay their supply lines by hand.

Based on figures provided and an assessment of various hydrant grids, *Table 8:1* gives an estimation of resource capabilities of various fire department's first alarm assignments around the world:

City	*Engines*	*Aerials*	*F/fts*	*LPM*	*GPM US*
Seattle	5	2	40	5780	1530
Phoenix	4	2	30	5024	1330
Dallas	4	2	24	5024	1330
Tokyo	7	2	36	4850	1283
New York	3	2	27	4268	1130
Chicago	3	2	25	4268	1130
Los Angeles	3	2	24	4268	1130
San Francisco	3	2	22	4268	1130
Las Vegas	3	2	20	4268	1130
Boston	2	1	12	3512	930
Oslo	2	1	9	3512	930
Miami	2	1	12	3512	930
Metro Dade, Fl	3	1	16	3512	930
Cape Town S.A.	3	1	20	2650	700
Hong Kong	2	2	24	2650	700
London	3	1	15	2100	555
Amsterdam	2	1	16	2100	555
Pretoria S.A.	2	2	19	2100	555
Singapore	2	0	16	1110	290

Table 8:1 – Global resource capability on first alarms

In order to assess an individual 'first alarm assignment's' resource capability one must accept that there are always variables at any fire that are not always predictable. The manpower requirements needed to secure the water supply, gain entry to the structure, and carry out rescues may drain the initial resource capability, thus reducing their effectiveness in an offensive mode. The flow capability of the hydrant grid must also be taken into account. However, for every fire a certain amount of water is required to extinguish the flames. It is interesting to note individual capabilities so one can effectively predict the tactical options that are open to us at any one time.

Offensive Tactical Options:

Straight streams: The concept of structure fire suppression in the USA has developed around mid or large diameter high-flow attack lines. Such equipment is designed to flow between 100 to 250 GPM US (378 to 945 LPM) through highly manoeuvrable boselines, ranging in size from 1½ to 2½ ins (40 to 65 mm) diameter. This type of attack line can be easily laid and handled by two firefighters advancing on a fire. To improve the effectiveness of water used in firefighting or overhaul operations a wetting agent may be induced into the stream.

The technique used to extinguish fires is that of 'direct' attack where the nozzle is advanced to within reach of the burning material/fuel and a direct hit is attempted at the base of the flames. In practice the technique is fairly successful but necessitates a large amount of water to be discharged into the structure. For example, an average two-roomed fire may receive in excess of 500 gallons before the fire is extinguished. This will exceed the initial tank supply of the fireground

OFFENSIVE: An *offensive* strategy is one that employs firefighters in a direct attempt to control and extinguish the fire. Providing that resource capability is adequate and primary factors such as rescue, excessive fire load, structural stability, and ease of access etc, are not hindering the effort, then an offensive strategy is naturally progressed.

DEFENSIVE: A *defensive* strategy is required where resource capability is inadequate; for example, where water supplies are insufficient or manpower is in great demand. For example, where there is a grave risk of structural collapse or hazardous chemicals are preventing an aggressive approach on a 'minor' fire. In these cases the priority is to contain the fire in an attempt at preventing its communication to exposures. A defensive strategy may entail an attempt at 'holding' the fire to a floor by placing two or three small attack lines at strategic points, or the setting up of master streams to prevent the rapid escalation until reinforcements arrive to boost an interior attack. A defensive strategy may result following an unsuccessful offensive approach.

Table 8:2 – Modes of attack

pumper and helps to explain the unpopularity of the 'quick-water' style of attack in the USA.

Blitz attack – Nearly all fire suppression training stresses the importance of getting inside a burning building to mount the most effective attack. The 'get in and get it' concept certainly is the way to go at most fires. However, the popularity and widespread use of timber construction in the USA has led to the development of the 'blitz attack' to make an initial 'hit' on an escalating firefront during the first few vital moments of arrival.

The speed a fire can spread in these timber structures is awesome and additional factors such as high winds can create a fire storm, a situation rarely experienced in Europe since the Second World War! However, the blitz is not solely reserved for escalating fires in timber properties. Heavy fire loads in modern fire resistive or brick and joist structures can present a major conflagration to first arriving crews and a 30 to 60 second high flow application via a deluge gun, or 70 mm preconnected attack line, may empty the pumper's tank but under certain circumstances the initial hit will be just enough to bring the fire within reach of the first alarm assignment. The aim is not to extinguish the fire but reduce it to a manageable level.

A straight stream should be utilised as opposed to a fog application for it will be less likely to push a fire further into the structure or out into a rear alley creating a possibe exposure problem. Even with a straight stream there is a likelihood that the fire, and steam, may 'blowtorch' in the opposite direction. Try to anticipate any extension of fire from the rear and cover this possibility if an exposure exists. This 'wave of pressure' that moves ahead of a fog stream (discussed in Chapter 3) is of major concern, particularly where used in blitz style from a large nozzle.

At one fire in New York the rear of the structure had no openings. With a major fire escalating rapidly throughout the structure a blitz attack, using a major fog stream, was effected from the front. The resulting pressure wave had no natural escape from the structure and suddenly blew the entire roof off, spewing flames high into the air with the ferocity of a giant blowtorch. The effect was awesome and clearly demonstrated the dangers of blitzing with fog sprays.

The blitz should never be used where there is any possibility that persons remain trapped inside a structure. If used at all, any success will be obvious within the first 15 seconds of application. If, at this stage, there is little indication that the blitz is having any effect the stream should be shut down and the position (or tactics) should be changed.

Recent research into the technique of blitzing has suggested that a high-powered burst of water is likely to reduce application rates, when compared with many fires controlled in a conventional manner using medium-flow handlines. A series of 'burns' in derelict buildings demonstrated the effect *(Bibliography 8:1)*:

	Fire Zone	*Blitz rate*	*Applied*	*R/N*	*V/2*
1.	43,750 cu ft	720 GPM	300 galls	875 GPM	162 GPM
2.	30,000 cu ft	680 GPM	1,075 galls	600 GPM	111 GPM
3.	30,000 cu ft	750 GPM	500 galls	600 GPM	111 GPM
4.	24,000 cu ft	264 GPM	110 galls	480 GPM	89 GPM
1.	1,225 cu m	2,721 LPM	1,134 litres	3,307 LPM	612 LPM
2.	840 cu m	2,570 LPM	4,063 litres	2,268 LPM	420 LPM
3.	840 cu m	2,835 LPM	1,890 litres	2,268 LPM	420 LPM
4.	672 cu m	998 LPM	416 litres	1,814 LPM	336 LPM

Table 8:2 – Blitz chart.

The first structure to be burned was an old two-storey farmhouse measuring 50×70 ft. A fire was allowed to build up in the upper level and burn through the roof. The four rooms upstairs, and one at ground level, became fully involved. A pumper with a 500 gallon tank was used to supply two 2½ ins, and one 1½ ins handlines. The entire attack was made from outside the structure and a total of 300 gallons was discharged into the fire area in a 25 second application. The fire was knocked down almost entirely. When applied to this situation, the Royer/Nelson (R/N) fire flow calculation (see Chapter 3) anticipated a necessary flow requirement of 875 GPM, while the V/2 calculation suggested the fire might be controlled with a flow of 162 GPM *(Table 8:2)*.

The second and third tests involved a two storey house, measuring 50×60 ft. Again, the entire upper level was alight as the roof burned off and five rooms upstairs, along with a room at ground level, became fully involved. Two 250 GPM handlines were supported by a further two 95 GPM lines in an exterior attack. Water was applied for one minute 35 seconds to achieve a knock-down. It was considered that this attempt to blitz the fire failed as the amount of water required was well in excess of that available from the pumper's tank. The fire was re-ignited and allowed to burn up to its original intensity before hitting the flames with three 250 GPM handlines for a total of 40 seconds. This effort proved more effective although it emptied the pumper's tank.

The final test took place in another house, measuring 60×40 ft. There were three rooms and two large closets upstairs and a fire was set in each room, and allowed to reach the flashover stage, before the suppression effort commenced. An interior attack was made using one 250 GPM handline that was advanced upstairs and applied in a fog pattern, using a rapid circular motion. The fire was knocked down in 25 seconds, requiring a total of 110 gallons.

The tests demonstrated some impressive knock-down times, and the amounts of water generally required to complete the operation were equally inspiring. The concept of blitzing would generally promote a flow-rate in excess of 400 GPM (1,500 LPM) and such a capability is not available from normal handlines, unless two or three are grouped, as happened in these tests.

In my experience, I have observed several situations where a blitz attack would have changed the course of events. A particular fire in Sweden comes to mind, where a large pile of builder's rubbish was alight, adjacent to a four-storey building under reconstruction. The rubbish was sited just a few feet from the rear of the structure and as the firefighters arrived the heat from the flames was just beginning to radiate in through the window openings. A 38 mm line was taken to the rear to deal with the rubbish fire but the escalation of the flames soon out-paced the hose stream. The fire eventually spread into the building to damage most of the floors and burn the roof off! The fire could have been knocked down by a promptly sited pumper with roof mounted deluge-gun, operating a blitz attack at the blazing rubbish.

Water fog attack – A technique originally developed in the USA has flourished throughout Europe, Scandinavia, Japan and Hong Kong, among others, while losing some ground in North America. Water fog may be applied in both low or high pressure modes via rubber hosereel (booster) tubings or large diameter attack hose. Its appeal lies in the fact that water damage is kept to a minimum and the low flow-rates ensure that maximum use is made of pumper tank supply, enabling the attack pumper to site near to the fire building. The technique requires experienced operators and depends on correct applications to prevent steam injuries occurring to firefighters.

Defensive Tactical Options:

Exposure protection – If the fire has escalated beyond the first assignment's resource capability on arrival, they will attempt to confine the fire and protect exposures. If a massive flame front is building up, threatening surrounding properties, then the effort should be directed solely at exposure protection. 'Water curtains' are not the most effective way to protect property at risk. Direct cooling of exposures by playing hose streams onto exposed openings will provide the optimum level of protection.

The degree of efficiency, when related to exposure protection, has been estimated at 5 to 15 per cent. This means that up to 95 per cent of the water used in exposure protection serves no purpose whatsoever! Even so, it is often an essential action and from the cooling requirement viewpoint, the exposed surfaces should receive a constant delivery rate of 1 LPM/sq m (1 GPM/45 sq ft) where subjected to radiated heat. This level of protection should be increased to 10 LPM/sq m (10 GPM/45 sq ft) where direct flame contact is taking place.

During the Fort Dodge fire in Iowa, USA, firefighters rigged up a metal shield to cover themselves as they moved into the fire zone to protect exposures. In a great many instances one of the most effective means of reducing the exposure hazards is by reducing the rate at which heat is being generated. This means a full frontal attack to knock-down the fire front.

Often, glass may be turned brown and show cracks from heat and yet remain intact. It is important not to strike heated glass directly with hose streams or the glass is likely to fail. Rather, it would be better to let the water run down the outside surface of the glass, helping to keep it cooled.

Buildings that are taller than the fire structure may present the most serious exposure risks as the radiated heat tends to rise out and up. Elevated protection streams from aerials may be necessary.

Cover lines – An important technique that is often neglected during rescues on the building's exterior is the provision of a 'cover line' to protect firefighters working on the structure's façade. Often, such rescues will involve firefighters working on fire escapes or ladders sited above suspect windows or openings. If a fire were to suddenly erupt from the opening, both the firefighters and the rescued may be engulfed in flames. A cover line should be set-up and manned in advance to protect people on the façade *every* time such operations dictate the need.

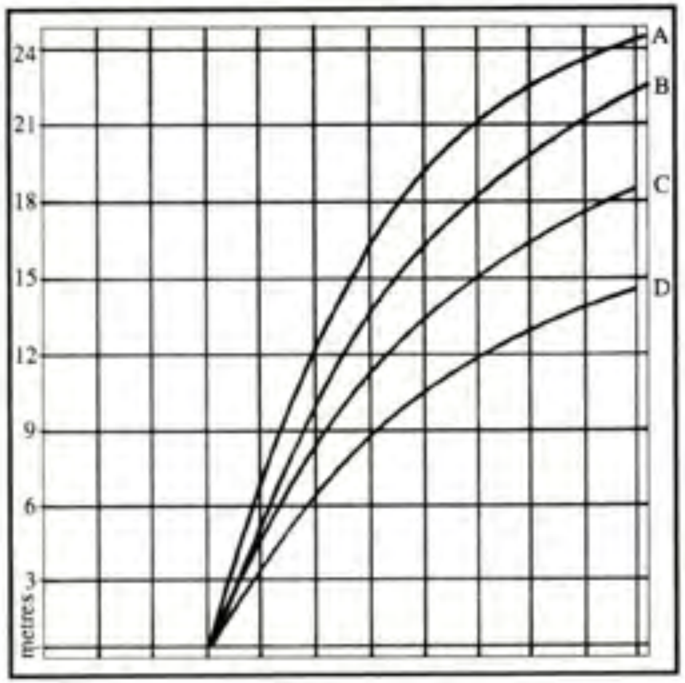


Figure 8:1 – The ideal 'cover line'.

The purpose of a cover line is to protect firefighters working above window openings on the façade of a building, particularly where involved in ladder rescues. It requires one firefighter to effect this action and therefore, the pressure supplied to the nozzle must be within the realms of control. As it is often the case that the pumper may not be receiving a supply, having just arrived on scene, it is equally important that the flow-rate is not excessive to maintain the tank's supply.

The above diagram shows examples *(Figure 8:1)*, presuming a single line (continuous flow) is operating from a 1,360 l (350 gallon) tank.

'A' An 'automatic' (fogfighter) nozzle will flow 250 LPM (65 GPM) at 5 bars (75 psi) NP, reaching an effective stream height of 25 m (85 ft), for a duration of 5.4 minutes.

'B' A 20 mm (¾ ins) nozzle will flow 570 LPM (150 GPM) at 4.5 bars (65 psi) NP, reaching an effective stream height of 22.5 m (75 ft), for a duration of 2.3 minutes.

'C' A 12.5 mm (½ ins) nozzle will flow 250 LPM (65 GPM) at 5.5 bars (80 psi) NP, reaching an effective stream height of 18.5 m (60 ft), for a duration of 5.4 minutes.

'D' A 25 mm (1 ins) nozzle will flow 650 LPM (170 GPM) at 2.4 bars (35 psi) NP, reaching an effective stream height of 14.3 m (50 ft), for a duration of two minutes.

Run-down effect – At large fires in modern structures where a high fire load threatens to create an auto-exposure hazard, where fire laps the exterior of the structure placing upper floors at risk, a heavy stream directed into the face of the building above the fire will create a 'run-down' effect that will act as a water curtain, preventing the possibility of fire spreading in to involve the floors above. This risk is likely where a fire occurs in a modern 'curtain-wall' structure. The fire department's in both New York and Chicago have utilised this tactic on several occasions with great success.

Large Calibre (Master) Streams – the use of large calibre streams (LCS) – as the Americans call them – can be considered a defensive tactic as they are normally used as a last resort to 'surround and drown' a fire that has totally engulfed a building. However, the LCS can also be used to protect exposures from radiated heat, or to initiate a quick blitz attack at the outset of operations.

All fire streams are subject to certain limitations, where the concentrated jet of water begins to break up as such limits are reached. Nozzle size, design, and pressure will all affect a stream's reach, as will the effects of wind and stream angle. Where the LCS is utilised as a cover line, or for a run-down effect, the maximum operative height will be reached with a stream angle of 60 to 75 degrees to the ground. This will require a nozzle placement to be one-third of the desired height from the building *(Figure 8:2)*. However, where a stream's main purpose is to achieve the optimum horizontal reach, an angle of 35 degrees is recommended. *(Figure 8:2)*, although a 20 degree stream will also give good results. Where the angle is reduced further, the decrease in air pressure under the stream forces it down and the effective reach is drastically impaired. Similarly, stream angles above 35 degrees will progressively reduce the horizontal reach. A faint tail breeze may increase horizontal distances by up to 10 per cent while a strong tail wind will, while carrying the water forward, break it up into spray. Head winds will generally have the effect of increasing the vertical reach while reducing the horizontal reach.

For optimum horizontal reach, Stream A *(Figure 8:2)* is sited one-and-a-half times of the working height from the base of the building, at a 35 degree angle to the ground. To achieve maximum operative height, Stream B is placed a third of the working height from the building, operating at a 70 degree angle.

It is worth referring back to the method of rating an individual hydrant's output, as described in Chapter 2. The effect of running large calibre streams from a pumper that is being supplied by poor hydrants is clearly apparent in *Figure 8:3*.

Hydrant Class System:

Class 'A'	Over 1,500 LPM	Green
Class 'B'	900-1,500 LPM	Blue
Class 'C'	below 900 LPM	Red

In *Figure 8:3*:

Stream # 1 represents a single 25 mm nozzle, receiving its supply from a class 'A' hydrant. At a nozzle pressure (NP) of 11 bars it will easily penetrate the eighth storey (37 m). However, if an additional 25 mm nozzle is got to work from the

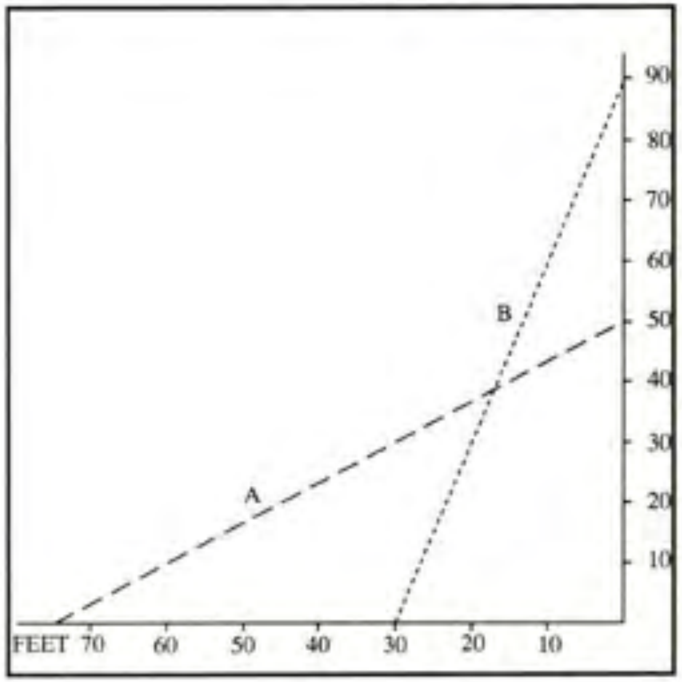


Figure 8:2 – Optimum stream effect – (A) horizontal (B) vertical.

same supply, the total output from the hydrant (say 1,700 LPM) would have to be shared. This would mean that the maximum height reached by the two streams would be around 22 m, just reaching the fifth level.

Stream #2 represents a single 25 mm nozzle, receiving its supply from a poor class 'B' hydrant. It just reaches the 5th storey (22 m), flowing just under 900 LPM at 4 bars NP. It can be seen at (a) that by reducing the nozzle size to 20 mm, and increasing the NP to 10 bars, the same amount of water can be flowed into the 7th level (29 m).

Stream #3 shows a 25 mm nozzle working off a class 'C' hydrant, flowing 400 LPM at a NP of 1 bar. Such a stream will only reach the 2nd storey. However, a reduction in nozzle size to 12.5 mm, at a nozzle pressure of 5.5 bars, will enable the stream to reach the 4th level (as at 'b').

Attack Hose Placements and Advancement Techniques

Where fire threatens the upper portions of a large building, a primary objective will be to place attack hoselines in position as quickly as possible, enabling firefighters to advance rapidly – but safely – into the fire zone. Where possible, full use will be made of internal rising water mains to assist this cause. However, where buildings are not equipped with such systems, firefighters will adopt varying techniques of hauling these lines up to the fire floors.

• **USA:** Lines of attack hose are carried, in a 'flake pattern', on the hose-bed at the rear of the pumper. The larger (63 mm) lines will generally lay to the rear, while the mid-flow (40 mm) lines will be pre-connected in a crosslay (side exit)

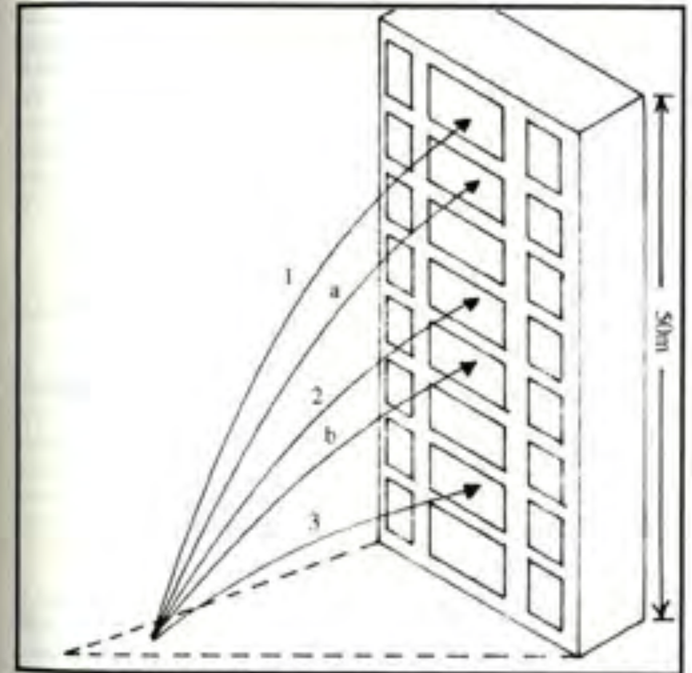


Figure 8:3 – Effect of hydrant grid classification on stream reaches.

position. As firefighters prepare to transport the hose to the upper levels, several folds will be pulled from the pumper and draped across a shoulder, before being carried up to the fire floor. Others will follow and drop folds on the stairs as they go, laying up the interior of the structure.

• **Sweden:** The Swedes have developed a neat little hose-carrier where a couple of lengths are flaked into an open-frame, one handed, carrier. As the firefighter moves towards the fire floor, the hose automatically drops out of the carrier behind him.

• **Great Britain:** The techniques used by British firefighters are representative of those used generally throughout Europe. While there may be provision for flaking a couple of 'quick response' 45 mm lengths, the majority of hose is stored on the pumper in (a) coils, or, (b) 'Dutch rolls'. The London Fire Brigade prefers the Dutch roll technique, which enables hoselines to be laid rapidly by the minimum number of firefighters, in hydrant runs or attack runs. The portable pre-packed hose can be carried into the fire building and laid on the fire floors, or it can be rapidly thrown out in the street, ready for placement.

One particular method of placing attack lines on the fire floors that is becoming increasingly popular throughout Europe, but gains little support in the USA, is the technique of 'hauling hose aloft' up the exterior of a building. As they arrive on scene, the attack team of two to four firefighters enters the structure equipped with CABA, forcible entry tools, and a 30 m (100 ft) rope (line). On reaching a location adjacent to the fire they will, from a safe position, throw one end of the rope-line to the street and haul the attached hoseline into position, from where they will advance towards the fire. The use of this technique is restricted to the length of the rope and window access at upper levels. It is extremely effective and 95 per cent of the time will enable a rapid advance to be made on the fire. Where hoselines should burst, for any reason, while placed out of reach on the structure's exterior, firefighters are practised in techniques that will maintain a water supply to the nozzle. Additionally, with less hose and less bends the friction loss is reduced and advancement into the building is made easier.

One disadvantage of working with hose 'coils' or 'rolls' is the difficulty associated with laying such hose in a confined space, such as a high-rise stair lobby. A pre-packed flake pattern is far more suited to such a situation.

Hose Advancement

There are several methods used to advance hoselines into varying situations that are worthy of note here:

Twin-Line HP Fog Attack: This technique was discussed further in Chapter 3, where the initial attack line makes an offensive approach to knock-down the main fire. A second line follows immediately behind to complete the suppression effort with a direct attack at any minor pockets of fire still remaining. This twin-line method is ever-popular when working with low-flow hosereel tubings and promotes an extremely rapid advancement into the structure that may prove critical where occupants remain trapped.

Twin-Line 'Water Wall' Attack: The method where a line is advanced with a wide (120 degrees or more) spray cone to push heat away from the attack team. This line can be backed up by a straight stream that penetrates the 'water wall' to reach the fire on the other side. Such a technique can be used in tunnels, confined corridors, or aircraft etc. It may also be used to assist entries into open basements, or ships holds, enabling firefighters to get in below the thermal barrier. However, it should be noted that a continuous spray of this type is likely to push a fire and must be used with caution.

Safety (Support) Line: A second line may be placed to support the main attack line. This technique is always used by Swedish firefighters who lay either a 63 mm, or 76 mm, line to a divider sited just below the fire floor. From here they run two 38 mm lines off the divider. One is advanced into the fire by a two-man CABA team, while the second line remains as a back-up, manned by an officer sited for assessment and safety purposes. Personally, I like to see a second line laid in support of the initial attack line whenever possible, but particularly where basements are involved, or where smoke conditions are heavy. It is an excellent safety procedure and promotes confidence in firefighters manning the main line.

Cut-Off Lines: A tactic that is commonly practised in the USA is the siting of an additional line above the fire floor, to prevent (or 'cut-off') any possibility of the fire extending through the floor, structural voids, or by auto-exposure. The line is placed early in anticipation of such events occurring, particularly in balloon-frame construction.

'Wrap-around' Effect: Where firefighters are advancing a line into an open floor area of a 'central core' design high-rise building, a danger known as 'wrap-around' can occur, particularly where continuous fog or spray patterns are used *(Figure 8:4)*. The resulting steam, or heat, may come around from behind the advancing firefighters and chase them from the floor! In this case, it is good practice to position

a second line on the floor to prevent this from happening, protecting the firefighters operating on the main line. This particular situation is also referred to as the 'doughnut effect'.

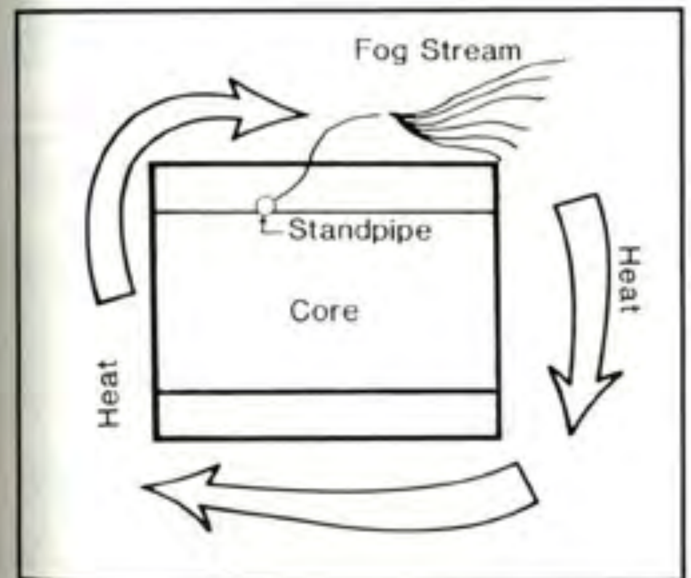


Figure 8:4 – The doughnut effect.

Hose Diameter

Hose diameters, in general use, have remained constant for many years. The mid-flow range included diameters of 38 mm (1½ ins), and 45 mm (1¾ ins), where flows were restricted to about 100 GPM (400 LPM), particularly in Europe where the pumps were not designed to cope with the high pressures necessary to overcome friction losses, as were the north American pumpers. The high-flow range of 63 mm (2½ ins) and 70 mm (2¾ ins) diameters were able to discharge far greater amounts onto the fire and also found great use in transporting water between source of supply, and fireground pumpers.

However, the popularity of large diameter hose (LDH) in the USA has led to a gradual decline in the use of 63 mm lines being twinned between supply and pumper. Modern hose design has also led to the introduction of 50 mm (2 ins) attack hose which, in conjunction with superior nozzle designs, is able to flow similar amounts of water as the larger 63 mm lines. This new hose is able to handle higher pressures and firefighters are enjoying the benefits of a wide range of flow-rates that can be selected by nozzle-control coupled with increased manoeuvrability. The 50 mm attack line is rapidly increasing in popularity across the USA and Japan.

The future, I believe, will see fire departments operating with a reduced hose complement – single line LDH (100 mm or 125 mm) for supply to pumper, or relay runs; and 50 mm attack lines that, in conjunction with 'automatic' nozzles providing operator control, will flow anything from 190 LPM to 1,323 LPM (50 to 350 GPM).

While the larger hoselines currently in use may provide higher flow-rates and increased stream penetration properties, the sheer size and weight of the fully charged lines generally hinder any rapid advance upon a fire, particularly within a compartmented area. Where the 63 mm or 70 mm line may be ideal for exterior firefighting or interior operations involving large open floor areas, the advancement of such lines within confined zones requires a large number of personnel. Additionally, the high nozzle reactions ('kick-back') associated with the larger attack lines severely restrict manoeuvrability at the nozzle and prevent efficient stream direction.

It never ceases to amaze me how some firefighters insist on laying a 70 mm line into a structure when one or two smaller lines will easily out-perform the larger version. I believe the dependence on large attack lines stems from tradition, where firefighters before us have handed down the notion that heavy streams are necessary to knock a major firefront down.

This was most certainly the case in days gone by, when London firefighters were regularly locked into battle with the flames as they consumed massive river-front warehouses containing rubber bales, and other highly flammable materials. Major C. C. B. Morris, a former chief fire officer of the London Fire Brigade, wrote in his book *(Bibliography 8:2)* about some of these conflagrations. Such fires were known to burn with extreme ferocity, causing buildings over 90 m (300 ft) away to burst into flames through radiated heat. Hand-lines, supplied from the river, were able to discharge over 1,100 LPM (300 GPM) each upon the fire, and on one occasion (1931), a warehouse situated at Butlers Wharf burned for four days. During this time 16 million gallons of water were discharged into the building – enough to fill it by volume five times over!

However, current design incorporates much compartmentation into modern construction and firefighters should adapt themselves to place a greater reliance upon the capabilities of mid-flow (45 mm) attack lines, leaving the heavier 70 mm lines for exterior operations, or open-floor space work.

Nozzle Reaction

One of the basic laws of physics, Newton's Third Law, states that for every action there is an equal and opposite reaction. To the firefighter, this means that as water flows out of the nozzle under pressure, a backward reaction, or 'kick-back' will be experienced. Actual tests with various sized nozzles have demonstrated the maximum nozzle reaction NR that is manageable by crews of varying numbers:

Size of Crew	Maximum NR
Three	6.5 bars (95 lbs psi)
Two	5.0 bars (75 lbs psi)
One	4.0 bars (60 lbs psi)

It can be seen, from the figures above, that two firefighters are capable of handling 80 per cent of the nozzle reaction that is managed by three, and one firefighter on his own is only able to handle 60 per cent of the NR managed by three. By resorting to various formulae relating to nozzle reaction, we are able to evaluate the various flows that can be managed by attack teams varying in size. For example, the formula for assessing nozzle reaction for straight-tipped solid stream nozzles is:

$$NR = 1.57 \times d^2 \times P$$

where:

NR = nozzle reaction in lbs psi
d= nozzle diameter in inches
P= nozzle (tip) pressure in lbs psi

Using this formula, we are able to ascertain the *maximum* nozzle pressures that may be handled effectively by attack teams:

Nozzle	One-Man	Two-Man	Three-Man
12.5 mm	9.6 bars 324 LPM	12.8 bars 375 LPM	16.0 bars 419 LPM
20 mm	4.5 bars 568 LPM	6.0 bars 656 LPM	7.5 bars 734 LPM
25 mm	2.4 bars 650 LPM	3.2 bars 750 LPM	4.0 bars 838 LPM
½ ins	140 psi 85 GPM	188 psi 100 GPM	235 psi 111 GPM
¾ ins	66 psi 150 GPM	88 psi 175 GPM	110 psi 195 GPM
1 in	35 psi 172 GPM	47 psi 200 GPM	58 psi 222 GPM

It can generally be said that for every proportional increase in flow (LPM), the increase in nozzle reaction will be doubled, ie a 15 per cent increase in LPM will result in a 30 per cent increase in nozzle reaction!

The nozzle reaction for conventional fog nozzles that operate with a variable-pattern cannot be based on the standard formula, and a specific formula has been developed for such application:

$$NR = 0.0505 \times Q \times NP$$

where:
NR = nozzle reaction in lbs psi
Q = flow (GPM)
NP = nozzle pressure (psi)

Similarly, as flow is increased through conventional fog nozzles, so too will the nozzle reaction double in proportion (approximately).

Automatic Nozzles: The automatic nozzle – also referred to as a pressure regulating or a constant pressure nozzle – is able to give a higher flow than conventional nozzles with less nozzle reaction at the tip. The nozzle uses a principle very similar to that of a pumper relief valve. The pressure control mechanism senses the pressure at the base of the nozzle *(Figure 8:5)*. Slight adjustments are made automatically to maintain the optimum nozzle pressure for the flow that is being delivered. The primary baffle, attached to the pressure control unit, varies the discharge opening of the nozzle *(Figure 8:6)*. In effect the nozzle of an 'automatic' is constantly changing 'tip-size' to match the water being delivered. This allows the flow being supplied to be delivered at the correct nozzle pressure and velocity.

This unique design enables the automatic nozzle to increase its flow in direct proportion to an increase in nozzle reaction, where a 20 per cent increase in LPM will correspond to a 20 per cent increase in NR psi etc. These reduced effects at the nozzle enable firefighters to deliver higher quantities of water, where required, while still maintaining control of the hose-line. Past research by Task Force Tips (USA) suggests that flows of up to 250 GPM (945 LPM) are workable volumes for TFT 'automatics' on lines handled by just two firefighters!

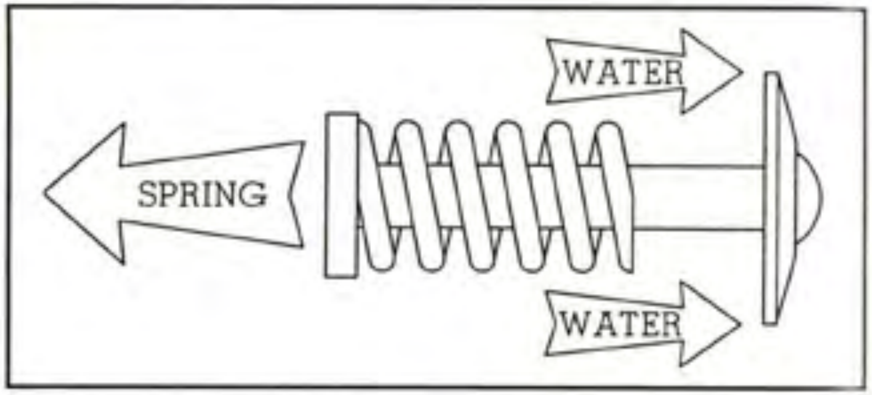


Figure 8:5 – Automatic nozzle – pressure control mechanism.

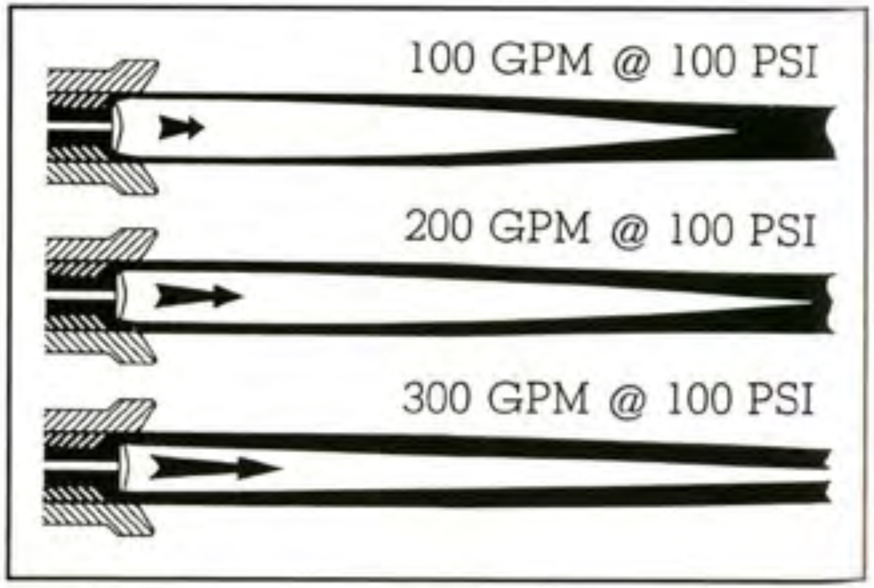


Figure 8:6 – Automatic nozzle – primary baffle varies the discharge at a constant nozzle pressure.

Hose for the High-rise Situation

As will be seen in Chapter 9, there is some controversy over which hose size is best suited to the high-rise situation. Some fire departments prefer the initial line to consist of lightweight 38 mm, while others opt for larger 45 mm lines that combine manoeuvrability with an increased flow-rate. However, the New York Fire Department is one, among several, who insist that first line should be 63 mm hose, while several brigades stick with high-flow 70 mm. With the introduction of the

50 mm attack line, the Los Angeles Fire Department was one of the originators of the versatile pre-pack that brings this innovation onto the fire floors of a high-rise. So what is best?

Much time has been devoted elsewhere to fire flow calculations, partially based upon actual fire flows at real high-rise fires. It was clear that office fires were effectively suppressed with fairly low flow-rates, provided there were no sudden escalations, or flashovers, to deal with. When located hundreds of feet above the ground the true limiting factor will be the reliability of the fixed water supply in the rising main system.

It is essential for the firefighter to obtain optimum flows from this restricted supply and his choice of hose will be a key factor in achieving this objective.

Mid-flow (38-45 mm): The mid-flow line is light and easy to manoeuver in confined spaces, such as small rooms and corridors. Where the fire floor is compartmented into small units the firefighter may be grateful he is advancing a mid-flow line. However, this type of hose does have a high friction factor and much needed pressure may be prevented from reaching the nozzle. This factor may prove critical where a low standpipe pressure is encountered on the fire floors and it is common to operate with pressures around 3 bars (45 psi) as building systems falter. This would provide a flow of about 150 LPM at the nozzle with the stream reaching around 9 m (30 ft) on the horizontal.

Large-flow (63-70 mm): The heavier hose lacks manoeuvrability in confined spaces and is more suited where floor space is open-plan. However, firefighters in the city of New York insist that the larger hose should be first onto the fire floor because of its low friction factor. This ensures that maximum use is made of the available water supply with greater flows and more effective streams. Under the same situation, larger hose, with a 12.5 mm nozzle, will achieve a 20 per cent increase in flow (LPM) and a 25 per cent increase in stream capability (throw), over the mid-flow lines.

50 mm Attack-hose with 'automatic' nozzle: Some will say that this is the 'ideal' choice for the high-rise situation, combining the benefits of low friction loss, high flow-rate, excellent manoeuvrability and lightweight feel. The automatic nozzle is designed to make the best of the available water supply, keeping nozzle reaction to a minimum and optimising stream projection. There are others who state that such nozzles are specifically designed to function at set pressures and to drop below these levels will seriously impede stream capability. However, this will depend upon individual design and automatic nozzles will generally out-perform straight tips on larger lines, even at low supply pressures. For example, where a flow of 180 LPM (50 GPM) is discharging through a 12.5 mm straight tip on a 63 mm line, an effective stream projection of about 11.5 m (38 ft) may be achieved on the horizontal. One particular 'automatic' can double this projection for the same flow!

Wet Rising (Standpipe) Main Failure

You are in the lift-car, on the way up to the 22nd floor. As you reach 22 you can smell the fire, three floors above. You don your CABA face-mask and haul the hosepacks up to 24. As you lay the hoseline onto the fire floor you crouch low, waiting for the rush of water that will allow you to hit this fire. However, seconds turn to minutes . . . there is no water in the rising main! If you are not able to connect a fire pumper at the base of the main to flow water and pressure to the upper levels, you have got problems!

This is a firefighter's nightmare, *but it happens,* and past experience shows us that we should expect it, and plan for it. So what is the solution? – 25 storeys up with a raging fire, and no water! If you are able to complete a 'back to back' connection at an outlet to the main, on a lower level, you may be able to connect a collecting breeching (siamese) to feed water into the system. However, where this is not possible, it is likely that the only alternative will be to lay a large diameter hose (LDH) main to the affected floors. This will take time and full use should be made of lift-cars, to transport hose to the upper floors in an effort to lay the main *down* the stairway. Even when the main becomes operative, to achieve adequate flows to the upper levels may require exceedingly high pressures at the pump. It may be necessary to site lightweight portable pumps at intermediate levels to boost the pressure in the main. Where there is a problem with carbon monoxide build-up, the enclosure will need venting, possibly with PPV fans. In this situation, it will be necessary to position at least two portable pumps on the stairway to achieve an effective flow at the 25th level. (See the Clarence Street, Sydney, fire in Chapter 9).

Fire departments should plan ahead and anticipate the possibility of a standpipe shut-down during firefighting operations in a tall building. This entails the need for a contingency plan to be written into department SOPs, ensuring that personnel will understand what is expected of them should the sitution arise.

Fireground Action Plan

The fireground action plan forms the base-frame of 'fire attack' operations. Although most firefighters are familiar with the various elements that make-up such a plan, I consider it necessary to discuss such procedure in some detail, for it is my experience that certain tasks continually fail to get 'actioned' at all, while other roles are not fulfilled until the later stages of a fire.

Primary Action Tactics

The first five minutes in any fire attack are critical and the primary actions of firefighters are likely to dictate the course of events during the later phase of operations. Both resource and manpower placements, and technique, will influence the levels of achievement gained by a force of firefighters at any particular incident.

Assistant Chief Robert Ramirez, of the Los Angeles Fire Department, theorises that the primary actions of a fire force can be summed up in a word – *'REVAS'*.

Rescue: The priority is obviously to locate victims within the building and effect their rescue in the shortest possible time scale.

Exposure: Ensure that the fire is surrounded and confined, preventing extension to nearby risks (exposures). This may entail directing the initial efforts into setting up water curtains or attempting a blitz attack on the fire.

Ventilation: The fire building must be made immediately habitable, for both firefighters and occupants. This will entail an early ventilation operation, allowing smoke, heat and fire gases to escape from the structure.

Attack: An effective attack must be directed at the fire at the earliest possible opportunity, timed to coincide with the venting operation.

Salvage: In this respect, damage control is the key function, and every effort must be made at limiting the damage to the structure, and its contents, caused through fire, smoke, heat and water etc.

'Tune-in and Observe'

The firefighter who has a sense of self discipline, and an element of experience in his work, will begin functioning to great effect as he approaches the fire building. It is sometimes difficult to motivate firefighters to work with such zest on every call, particularly where it is the sixteenth false fire-alarm call that night! However, the importance of not getting caught off guard should be emphasised. I remember arriving on scene at one particular incident – another alarm! We stood and chatted as two firefighters checked it out. The building was a major risk – a hospital. We did not feel the need to go through the routine of checking the rear of the structure. In fact, I am sure none of us even took the time to look upwards at the face of the building. It was unprofessional, I do not mind admitting, for deep in the heart of the structure a fire was blazing away! If one of us had taken the time to check the rear we would have noticed the smoke issuing from a second floor window. For all we knew there could have been people waving to us for help on the upper floors! I will never get caught like that again.

It is important for the firefighter to train his mind to 'tune-in and observe' essential features as he responds to *every* fire call. As the fire vehicle turns into the street start looking for that hydrant, read the crowd phsycology up ahead – are they trying to tell you something?, perhaps the fire is at the rear, are they panicking? Get an early glimpse of the structure from a distance, where possible, and scan all visible faces on approach for signs of fire. What is the roof access like? What type of structure is it? Is the construction likely to present any unusual hazards? Is there a 'haze' in the air that may suggest smoke is issuing out of view? Your nose will soon tell you!

As you step from the pumper you should know where the nearest hydrant is, and even if the fire is not making itself obvious, your senses are finely tuning themselves, ready for action. Now observe – a quick glance up at the structure, looking for smoke from the eaves, or roof. Even the slightest whisp is a good indicator of a potential *void* or *attic* fire. Scan the windows and make eye contact with visible occupants. Are they just curious or are they in need of rescue? A serious fire within the confines of a large structure may not be showing itself at this stage.

Survey any possible restrictions to ladder access – overhead wires, cables, structural projections etc, are you in a slip road? What about trees, or garden walls, and so forth? The more information you can absorb at this stage, the more effective you will be when it comes to taking any necessary rapid action. Then, as you move towards the building, take note of any fixed installations that may assist – pavement venting lights, rising main or foam inlet points etc. As you enter, take a look back – have the engines positioned themselves correctly, leaving access for aerial apparatus?

All this should be taken in during the time it takes to step off the pumper and walk into the building. The firefighter should do all of these things without thinking. They should be second nature.

Fireground Actions Checklist

The following tactics are based on a compilation of several important functions, as fulfilled by various fire departments on arrival at the fire building. The overall plan is based on the US approach to firefighting.

ESSENTIAL (PRIMARY) ACTIONS:

(1) Position apparatus
(2) Visible rescues on face and sides of structure
(3) Water supply
(4) Cover lines
(5) Exterior lighting
(6) Forcible entry (exterior)
(7) Fire attack

(8) Access to rear and rescue (may need 3 and 4)
(9) Exposures.

SECONDARY ACTIONS:
(1) Interior search plan
(2) Ventilation
(3) Additional water supply
(4) Interior lighting
(5) Master streams
(6) Fixed installations.

IMPORTANT CONSIDERATIONS:
(1) Smoke explosion potential
(2) Structural stability
(3) Hazardous contents
(4) Firefighter accountability.

The plan is comprehensive, but by no means complete. Many aspects are not necessarily listed in order; for example, many fire chiefs will insist that ventilation and fire attack operations coincide with each other, the former occurring just prior to the latter. However, as ventilation tactics are not readily acceptable in Europe, prior to the fire attack occurring, it is listed here as a secondary action.

The 'Fireground Action Plan' is based upon a modular approach where the manpower resources are organised into one of four specific units: (1) attack team; (2) support team; (3) peripheral team; and (4) roof team.

Manpower for these units should be organised at the change of each shift, in line with department Standard Operating Procedures (SOPs). They are functional on the fireground to fulfill a specific role, although their actual deployment can be varied to suit changing conditions. The 'teams' have no particular relation to the type of company a firefighter is assigned to; for example, ladder company members will carry out certain actions, designated under 'support', 'roof', and 'peripheral' roles, as routine operations. Moreover, the activities listed under each unit represent a grouping of roles that may be handled from a specific *position* on the fireground, ie; (a) at the fire, (b) near the fire, (c) on the roof, (d) outside the structure.

A review of the various tasks allocated to each particular unit is listed, as follows:

Attack team:
(1) Advance initial attack line to fire floor and attack the fire.
(2) Report on status to Incident, or Group, Commander.
(3) Report on interior construction hazards to same.

Support team:
(1) Assist advancement of first attack line.
(2) Lay-in secondary (support) hoseline to fire floor, or floor above to prevent fire extension.
(3) Provide interior support lighting.
(4) Interior search and rescue operation.
(5) Interior forcible entry.
(6) Provide ladders where interior stairs collapsed.

Peripheral team:
(1) Exterior ladder rescue, and operations.
(2) Placement of cover lines.
(3) Preparation of hose, and equipment, for hauling aloft outside the building.
(4) Exposure protection.
(5) Effect water supply.
(6) Locate, and operate (where required), fixed installations, pavement vent lights, sprinkler valves, rising main inlet etc.
(7) Check rear of building for trapped occupants and exposures.
(8) Provide exterior lighting.
(9) Provide master streams.
(10) Responsible for firefighter accountability system.
(11) Effect exterior forcible entry where necessary.
(12) Initiate PPV (where practised).

Roof team:
(1) Gain access to roof area, where possible, at earliest possible moment.
(2) Check possibility of fire spread into roof space, using TIC where available. (Possible voided building?)
(3) Check rear of structure (and light-wells) for trapped occupants, or jumpers.
(4) Report status to incident commander.
(5) Prepare for topside ventilation operation.
(6) Gain access into top floor and initiate a downwards search pattern.
(7) Check status of lift-cars and report to the Incident Commander. Where occupants may be trapped within, effect a direct rescue or locate the motor-room, depending on the car's position.

Evaluate and Apply

Possibly, one of the best learning processes is through the post incident debrief sessions, that should take place after *every* fire. It is then that various strategies may be analysed as to their effectiveness. The most searching question that a firefighter can ask himself after an incident is: "Would a different approach have resulted in a more effective operation?"

The entire operation should be evaluated – from arrival to completion – and an assessment of roles should be made to ensure that vital actions were carried out at the earliest possible moments: "Who checked the rear first?" "Was the roof checked?" "What about lift-cars and light-wells?" "Did the attack lines advance and function effectively?" "Was the support lighting effective?" etc, etc.

Use the Fireground Action Plan as a checklist for such questions and search out the answers. Evaluate the overall fireground operation and apply the new-found knowledge next time. It is by this learning process that we can all advance ourselves to become even more professional in our work.

Chapter 8 – Fire Attack – Bibliography
8:1 **Goodwin, M.**, *'Blitz attack really works – test fires in buildings show' – Fire Engineering* (April 1977).
8:2 **Morris, C. C. B.**, – 'Fire' – Blackie & Son Ltd. (London).

Above – Firefighters in Stockholm make full use of their CABA at every opportunity. _Below left_ – The 'aerial' fulfils a vital role in the fireground action plan. In addition to its rescue capability, its main purposes are for large calibre stream (LCS) penetration, or the siting of a roof team. This London firefighter demonstrates exemplary skill in siting the cage of his aerial platform through the branches of a tree to rescue persons trapped on the upper floors of a house in multiple occupation (HMO) – _see Chapter 7._

Above **– Boston firefighters make brave attempts to gain access into a blazing 'triple-decker'. This fire in the Roslindale section of the city claimed the lives of six persons, including three children, and the emotion is clear to see on the faces of the crew at the incident, *left* (Deputy Chief White is in the foreground) – *see Chapter 7*.**

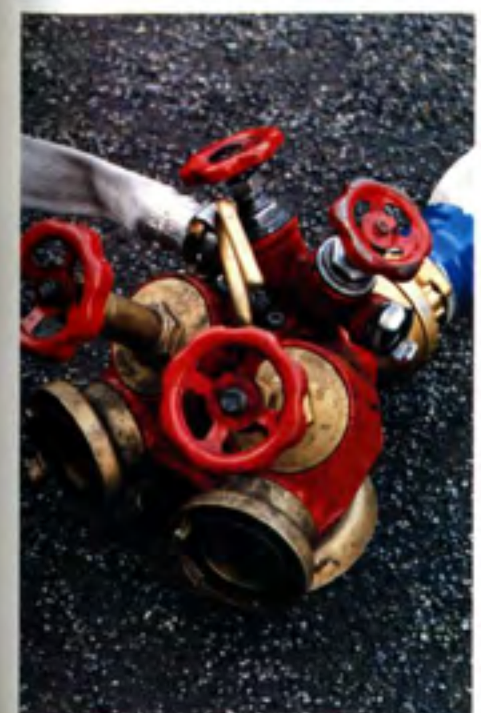
A prompt arrival, and optimum siting, of an aerial platform enabled a 'blitz' style attack to meet with resounding success in this situation – *see Chapter 8*. *(Photo by London Fire Brigade).*

Modern timber frame 'stick' construction is responsible for excessively rapid fire escalation and early collapse – *see Chapter 8.*

While operating as part of the attack on this fire, the line in the foreground is also ideally suited to function as a 'cover-line' for the crew working in the cage of the aerial platform – *see Chapter 8* . *(Photo by London Fire Brigade).*

This major blaze in east London created a severe exposure problem. Primary firefighting efforts were directed at reducing the level of radiated heat that was igniting buildings over 100 ft away – *see Chapter 8. (Photo by London Fire Brigade).*

Above and left*, the Swedish way of stowing, and laying hose – *see Chapter 8.



Above* – These Australian (CFA) firefighters advance on a fire behind the protection of a waterwall** *(Photo by Peter Baker, CFA Australia).* ***Left* – A Swedish hose divider, fed by a single 76 mm line, enables up to two 38 mm lines, and two 63 mm lines to be run from the outlets for attack purposes – *Chapter 8.

This exercise in Stockholm demonstrates the Swedish attack procedure where a three-man team runs two lines, from a divider, to the fire floor. A two-man CABA team advances the first line into the compartment while the third man (an officer) mans the second line at the entrance. This safety-support line is only brought into operation when the attack team get into trouble. The attack team remains in radio contact with the safety man on the support line – ***Chapter 8.***

Left **– Tokyo firefighters bring their 50 mm attack lines into operation to protect exposures to the rear of this single-storey structure.** *(Photo by Tokyo Fire Department).* ***Below*** **– Full protection includes CABA for these Tokyo firefighters –** ***Chapter 8.*** *(Photo by Tokyo Fire Department)*

Left **– It is important for firefighters to 'tune in and observe' the moment they turn out from the fire station. These firefighters in Frankfurt answer yet another emergency call.** *(Photo by Iveco Magirus).* ***Below*** **– Chicago firefighters in action during the initial stages of a multi-alarm fire –** ***Chapter 8.***

9
FIRES IN HIGH-RISE BUILDINGS

'The importance which I attach to a sound system of training will probably be understood when I state my conviction, founded on what appears to me the clearest and most positive evidence, that some of the greatest losses by fire which the world has ever experienced, have been owing to want of skill on the part of firemen. . . . It may perhpas be said that great numerical strength will make up for deficiency of skill and knowledge; and this may, no doubt, be to some extent correct; at least it appears to be the theory established in many places; but I am inclined to believe that, for dealing with great emergencies, no amount of numerical strength, even when combined with discipline, can compensate for the absence of skill and knowledge, and on this account I consider a proper system of training, before attending fires, the only true method for making men real firemen.'

Sir Eyre Massey Shaw, KCB
'Fire Protection' 1876

The time that elapses from the moment an initial response of firefighters leaves the fire station to the instance when an extinguishing media is applied to the fire is termed the 'Reaction time'. Where fires occur either on the upper floors of a very tall building or in the depth of several sub basements, 'reaction time' is a most vital factor that contributes to the effectiveness of the overall attack. It is often the case that the logistics and difficulty of the situation combine with the urgency to test firefighters to their fullest extent.

As London firefighters approached a 22-storey structure that towered over the surrounding city skyline there was no sign of fire from the building's exterior. However, deep within the infra-structure a life and death situation was beginning to develop. The building's two lifts shared a common shaft that discharged to all floor levels. One of the lift cars had become involved in fire and stalled with its doors shut on the eighth floor. Fortunately, this car had no occupants at the time of the fire but the other lift, stalled on the twelfth floor with its doors jammed shut, had one desperate occupant. The smoke in the communal shaft was placing this person in immediate danger.

The arriving firefighters assessed the situation correctly and broke from normal procedures by committing the first team to the twelfth floor, four floors above the fire, to attempt a rescue. The second team assembled equipment and began the ascent to the eighth floor to attack the fire. The reaction time in this case took firefighters about nine minutes from the initial response. As they were forced to haul their heavy equipment up the stairway to reach the upper floors their condition on arrival was one of exhaustion and would have required some amount of 'recovery' time before engaging in an exerting attack. In this situation, the efforts required on upper floors were minimal and the person was rescued without suffering long term effects. However, the incident prompted firefighters to consider ways of reducing reaction times and during the following weeks a number of live drills were carried out in high-rise buildings to assess: (a) Hose-Pak carries; (b) initial response procedures; and (c) the physical stress placed upon firefighters.

The results of these simulations were interesting in the fact that there were obvious lessons to be learned. However, it is sad to discover that one is not the first to learn from the experience and that other fire departments have learned these lessons long ago and already incorporated changes into their procedures to improve effectiveness. To grasp such experience we must look to those who have suffered fires in high-rise buildings and adapted their approach as each new situation presents itself.

The following case histories of serious high-rise fires provide valuable lessons that we can all learn. They should serve to influence our own approach in the future.

High-rise fire case histories

Case	*Location*	*Date*
1	New York Plaza	1970
2	World Trade Centre N.Y.	1975
3	Occidental Tower L.A.	1976
4	MGM Grand – Las Vegas	1980
5	Cambell Centre – Dallas	1983
6	Interstate Bank L.A.	1988
7	Empire State Building N.Y.	1990
8	Meridian Plaza – Philadelphia	1991
9	Churchill Plaza – England	1991
10	Clarence Street – Sydney	1991

Case No. 1 – New York Plaza – New York, 1970

A fire started on the 33rd floor of 1 New York Plaza, a 50-storey, modern office building, and spread to the 34th level to involve a total of 3,680 sq m (40,000 sq ft) of office space. The building had not long been completed and was only partially occupied. The fire floors were being prepared for occupancy and ceiling tiles had been removed to expedite the telephone wiring installation and other work. Before the fire could be brought under control two lives were lost, over 50 people were hospitalised and there was an immense dollar loss. These results were traceable to the building design, the assemblies, systems and materials employed and – in some cases – the workmanship. The contributing elements included:

(a) Central core design.
(b) Sealed windows.
(c) Central air conditioning with common ceiling plenum.
(d) Heat, flame and smoke sensitive elevator call buttons.
(e) Exterior wall construction.
(f) Spray fireproofing of structural members.
(g) Lack of evacuation procedure.
(h) Workmanship and materials used.

A smell of burning was first noticed on the 32nd floor at about the same time a security guard on the 35th floor saw heavy black smoke rolling past the windows. Other reports from around the building at 1750 clearly demonstrated that a fire was in progress within the structure, and yet the first call to the fire department was timed at 1759 and came from an adjacent building.

On arrival, firefighters observed fire issuing from the east and south sides of the 33rd level. Shortly after their arrival the windows on the 34th level blew out as the fire rapidly escalated. Fire crews made their way to the 32nd floor using a lift operated by two civilians. After discharging the firefighters, the operator pressed the button to return to the ground floor, however, the lift did not descend but rather continued upward to the 33rd floor. When the lift car doors opened the two occupants were hit with a blast of heat and heavy black smoke before the car continued its journey up to the 36th floor where it stopped. (Both men were rescued by firefighters and recovered following long confinements in hospital.)

Other firefighters attempted to proceed to the 33rd floor to search two cars that were registered as having stalled there. They used Car 36, which was in a bank of lifts serving the 31st to the 40th floors and headed for the 31st floor, electing to walk the rest of the way. However, seconds after the lift left the ground floor it stalled. They made their own escape by rapelling to the 4th floor where they took another lift to the 30th floor. Eventually, under the cover of a hoseline, three trapped occupants were located and removed from the stalled cars on the 33rd floor (one victim survived).

During firefighting operations a period of some 20 minutes elapsed during which there were no lift cars available for use at all. Firefighting reaction time was estimated at 23 minutes, and even then only one 2½ ins handline was operating on the fire due to the necessity to concentrate on rescue operations, and the unavailability of lift cars. Several firefighters were burned while attempting to maintain this position.

Lessons learned:

(1) The primary obstacle to the firefighter in high-rise fires is heat. Modern fire-resistive construction will contain the heat and complete climate control in the tall building complicates the problem where ventilation is not easily achieved. High fire loads often found in office furniture, forced draughts, and large interconnected fire areas add to the effect.

(2) Central core design, accompanied by common ceiling plenums, present a potential for large area involvement.

(3) Central air conditioning, if allowed to continue in operation, will increase the rate of fire development.

(4) Inductance-type elevator call buttons may register unsolicited calls to the fire floor in the presence of heat, smoke or flames. Short circuits and heat flow up lift shafts may lead to lift cars becoming stalled between floors.

(5) A trained building staff and a supervised, preplanned evacuation procedure are essential elements of a successful operation.

(6) All structural fire resistance is only as effective as the workmanship with which it was installed.

(7) Effective communications throughout the structure and effective control of manpower are major factors of a successful command procedure. Rotating crews to reduce heat stress and the ability to anticipate problems in advance will ensure the commander is one step ahead of the fire.

(8) An understanding of the 'stack effect' at high-rise fires should be appreciated by all firefighters on scene.

Case No. 2 – World Trade Center – New York, 1975

The World Trade Center in New York is a complex of buildings that has twin high-rise towers that reach 110 storeys or 400 m (1,350 ft), in height. The buildings are square from ground to roof with sides measuring just over 60 m (200 ft). Each floor contains approximately 3,600 sq m (40,000 sq ft) of office space. The towers are constructed around a central core design.

On the night of 13th February, 1975, a fire was started (arson) on the 11th floor of Tower 1 and spread rapidly through a common ceiling plenum to involve one quarter of the floor area. Fortunately, the air conditioning system was not operating and the major influence of the movement of air (or gases) would be the stack action created by the elevator shafts. In this situation the flow of air would be *towards* the core, which makes life difficult for the firefighters but is favourable in the fact that it probably prevented the fire spreading throughout the floor.

Lessons learned:

(1) The dangers of fire spread through ceiling plenums can often go undetected. Firefighters advancing on the fire should check the ceiling above to ensure that the plenum is clear. The use of 'hi-ex' foam into a plenum is always a consideration.

(2) Fire spread undetected through voids. In this case, fire extended from the fire floor (11) through telephone switching closets, up to the 17th and down to the 9th levels.

Case No. 3 – Occidental Tower – Los Angeles, 1976

More than 325 Los Angeles City firefighters (LAFD) from 58 companies were required to tackle a fire in the 32-storey, 146 m (487 ft), Occidental Tower office building, that occurred in November 1976.

Shortly after 0300 a heat detector showed an unusual rate of rise on the 20th floor. The building had suffered several false alarms the previous day and it was decided that a security guard would check the floor before calling the fire department. Without delay he took the lift to the 20th floor and when the doors opened he knew there was a major fire in progress. He called out over the lift telephone for the fire department to be despatched. The LAFD received the call at 0320 and Task Forces 9 and 10 were ordered to respond. They saw the flames as they left their firehouses.

As Battalion Chief Bob Morrison arrived, Task Force 10 was connecting twin 2½ ins lines into the building's riser on 12th street. The supply pumper was in turn fed by 3½ ins lines from a hydrant. BC Morrison then established a 'lobby control' and the reported location of the fire and the integrity of the lifts were checked and double checked. Firefighters formed an attack team and carried hose packs, fittings, rotary saws and extra air bottles up in the lift to level 18. From here they began their approach to the 20th floor. Two teams of firefighters were also sent above the fire to the 21st floor to cut the fire off.

On the 21st floor the attack teams saw flames lapping over the outside windows but aggressive action kept most of the fire at bay. What fire did spread in was minimal. The simultaneous attack was a big factor in the control.

Lessons learned;

(1) Even though hose packs were taken up by the initial attack teams, there was a shortage of hose at the outset of operations. An abundance of hose is a necessity at such incidents. In this case it needed enough hose to lay 13 lines into the two involved floors.

(2) Falling glass is a major hazard. The street should be cleared below and pump engineers should protect themselves any way they can.

(3) In anticipation of lift car failure, helicopters were requested. It is easier to walk men and equipment down 12 floors than up 20! The lifts did fail but only for 25 minutes. In this case the helicopters were only used for outside lighting.

(4) While the building riser (standpipe) system was able to meet demands in this case, the system was still charged by fire department pumpers and ready for use if additional flow was required.

Case No. 4 – MGM Grand Hotel – Las Vegas, 1980

The MGM Grand Hotel, Las Vegas, was opened in 1973 and consisted of a 23-storey tower sited above a 370 m × 135 m ground level complex. The tower formed a 'T' shape that housed the many bedroom suites located therein.

The ground floor deli and casino areas were ornately furnished and fitted. Much of the linings, furniture and fittings were highly combustible. The deli, where the fire originated, was approximately 350 sq m (3,800 sq ft) in area, and contained much furniture padded with polyurethane foam covered in PVC, combustible timber columns and panelling and combustible carpeting

When an electrical fire occurred early one morning while most guests were still in their bedrooms, the fire escalated with great speed throughout the ground floor complex and travelled into the high-rise tower, trapping hundreds. The speed of its spread even caught firefighters by surprise and forced them to make a hasty retreat. The inadequate fire protection measures in the structure became clearly apparent as smoke spread throughout the building. Direct fire damage was limited almost entirely to the ground-floor casino level. The building, which had 2,076 guest rooms, was occupied by about 5,000 people on the day of the fire. Most guests in the hotel were only alerted to the fire when they heard or saw the fire department arriving, or heard people shouting or knocking on doors. No fire evacuation alarm was sounded and there was a delay in calling the fire department.

In all, 85 guests and hotel employees died and 600 were injured as a result of the fire. Five of the dead were trapped in lifts. Even though the fire was under control within an hour of the fire department's arrival, evacuation of all guests took approximately four hours. Many were air-lifted off the roof by helicopter.

Lessons learned:

There were many lessons to be learned from this fire, mostly related to fire protection measures. However, the fire departments in the area agreed that their pre-plan for a fire of this scale fell drastically short and went about improving procedures and techniques utilised in high-rise firefighting.

Case No. 5 – Campbell Centre I – Dallas, 1983

The Campbell Centre I is a 20-storey glass and steel high-rise structure that was built in 1971. The building consists mainly of office accommodation and was unsprinklered, except for the basement.

A fire was reported on the 10th floor to fire department despatch at 2149 hours. Smoke was observed issuing from the roof and the high-rise plan was implemented, requesting a second alarm be despatched immediately. A 5 ins hoseline was laid to feed the riser and firefighters began climbing the stairs as the lifts were out of action.

Just ten minutes after the first call to the fire department, fire crews reached the eighth floor level and reported heavy smoke in the stairwell. The smoke became more dense at each floor level as firefighters continued their upward search. The fire was not on the 10th floor as had been reported and the attack team eventually located it when they reached level 12. Heat and smoke build-up at this level was tremendous and a twin-line attack was mounted. However, a gasket had blown from the riser, and pressure was extremely low at the nozzles. Firefighters were forced to operate with one line until pressure could be boosted. Small amounts of fire were extinguished on the 13th and 14th floors before the fire was brought under control at 2353 hours.

Lessons learned:

(1) No reliance should be placed upon reports concerning the location of the fire, particularly if approaching the location by lift. Treat such reports as a 'guide' and find the fire before mounting an attack.
(2) Information should be sought from building engineers at an early stage relating to the functioning of building systems.
(3) All firefighters working above ground in the structure should be equipped with breathing apparatus.
(4) Portable lighting and air-movement fans would be useful on the upper floors at an early stage in the proceedings.
(5) Stairwells and risers should be marked to avoid firefighters becoming confused with their location within the structure. Such markings could also extend to floor levels.
(6) A building's fire protection features cannot always be relied upon in such instances.
(7) Where riser connections are inoperative or vandalised, an alternative method of hooking up the supply hose can be utilised via a riser *outlet* sited at low level where a collecting breeching (siamese) is connected via a back to back male coupling. Water can then be pumped *into* the system at this location.

Case No. 6 – Interstate Bank – Los Angeles, 1988

The first Interstate Bank building, located at 707 Wilshire Boulevard in the downtown business district of Los Angeles, is 260 m (858 ft) tall. The 62-storey structure was first occupied in 1973 and is home to 3,500 office workers during the day. The building is of lightweight fire-resistive construction with 'Q' deck floors supporting reinforced, low density concrete. The steel framing and the underside of the 'Q' decking is protected with sprayed-on fire retarding of cementitious material. The outside wall is glass set in aluminium mullions in curtain wall design. It is a typical modern high-rise structure designed and constructed to a very high standard. At the time of the fire the building was being retro-fitted with a sprinkler system throughout. On the night of 4th May, 1988, it was inoperable.

The first signs of a fire were detected by smoke detectors on level 12 at 2230. However, even though several activated and re-activated, they were cancelled and re-set by a security guard. At 2235 a maintenance engineer was sent to investigate and at 2236 multiple alarms registered for smoke on floors 13 through 30. At 2237 several calls were made to the fire department from occupants in neighbouring buildings and the first LAFD units arrived at 2240. Fire was issuing from the 12th floor and escalating to the 13th via auto-exposure. The LAFD were past masters of high-rise confrontations and put their pre-plan into operation. An attack team of firefighters equipped with hose-paks, fittings, forcible entry tools and breathing apparatus utilised a stairway to reach the fire floor. LAFD firefighters will *never* use the lifts until their 'safe' status is confirmed by firefighters on upper floors. First-arriving units and chiefs set up lobby control, a staging post two floors below the fire for manpower and equipment resources, and a base in the street for all newly arriving units to report to. The street below was immediately cordoned off

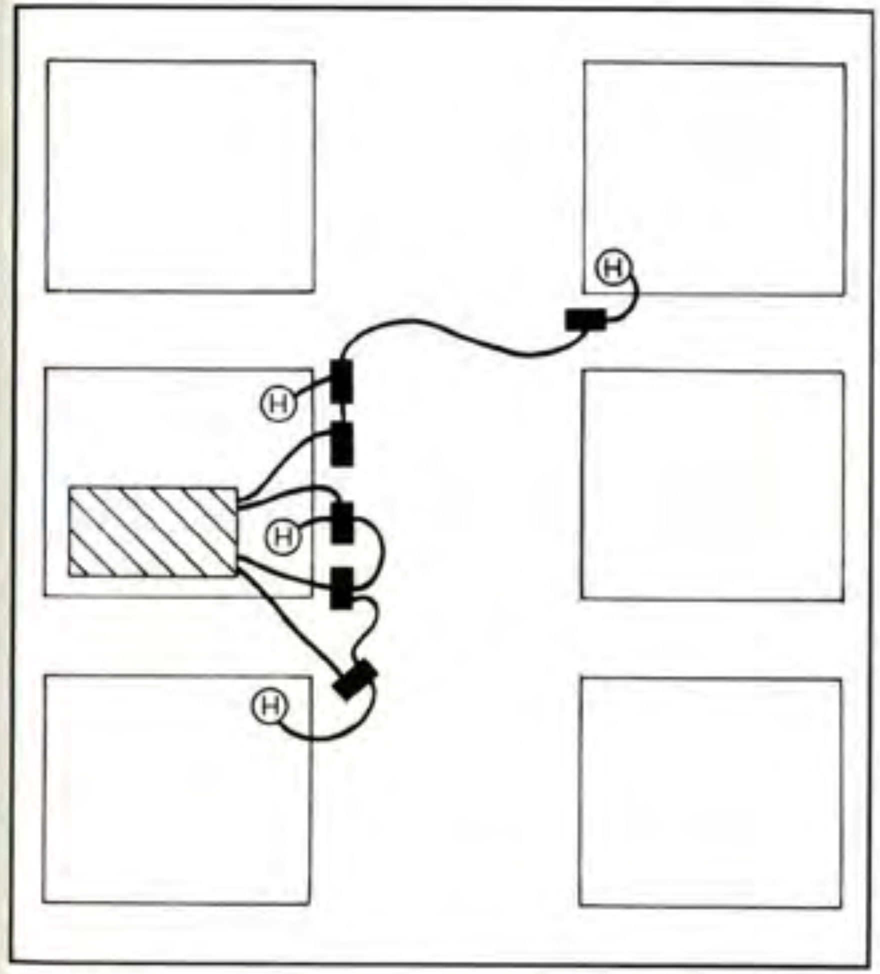


Figure 9:1 – Note the supply hose layout at the Interstate Bank fire – Los Angeles. The pumpers are sited directly on the hydrants to 'boost' the pressure, before feeding the supply into additional pumps charging the standpipes. (Fire building shaded).

and LAFD began pumping into the riser system to ensure adequate water supply to the fire floors. The LAFD incident command system was established and functioned effectively throughout the whole incident.

The fire spread upward from the 12th to the 13th, 14th and 15th floors, and was finally stopped on the 16th floor after an outstanding fire-fight that lasted over 3½ hours. The reason for the stop of fire on 16 were: (a) a decrease in the fire loading on the 16th floor; (b) the increase in compartmentation at that level; (c) fuel on the lower floors was being exhausted; (d) lines were able to move in on the fire below, and (e) this floor was selected by chiefs to 'make a stand' – a final, all out, aggressive attack on the fire in an attempt to hold it.

Lessons learned:

(1) The dangers of using lifts to approach a suspected fire floor were clearly demonstrated in this situation where the maintainence engineers went to investigate the cause of repeated detector alarms on level 12 was burned to death as the lift doors opened into an inferno.

(2) The quality of workmanship in the application of sprayed fire retardancy was unusually good and it was very effective in protecting the primary structural members. As a result, very little damage was done to such members despite the long duration and high temperatures of the fire.

(3) Fire doors rated to 1½ hours failed in minutes under such severe fire attack.

(4) Vertical fire spread in a high-rise is caused through auto-exposure as fire extends to the upper floors via the exterior. It may also travel through poke-throughs, pipe recesses, and utility shafts. In this fire, the return air shaft serving the HVAC system, constructed of ⅝ ins plaster board and serving floors 12 to 32, was responsible for allowing fire to spread vertically in the structure.

(5) Sprinkler systems are the most effective way of assuring fire safety in high-rise buildings. All such premises are now being retro-fitted in LA.

(6) The importance of establishing and adequately staffing an Incident Command System (ICS) was clearly demonstrated by the demands placed upon the fire force at this fire.

(7) Firefighters operating on the fire floors must be relieved after five to 15 minutes, depending on the heat factor. To do this efficiently, reliefs must be at the nozzle in time to take over to prevent unattended nozzles allowing the fire to gain headway. This system requires constant monitoring.

(8) First-in firefighters said, if they had to do it all again, they would take extra air bottles with them. Initially, their air supply was exhausted *before* reliefs reached them. At this time the staging post had not progressed far enough to supply them with a replacement bottle. Additional hose, portable lighting, and forcible entry tools were required urgently but again, were not immediately available.

(9) Rescue operations must be attempted from below, and the evacuation stairway must be maintained. Rescue operations must be coordinated with fire suppression operations. Rescue operations cannot wait for fire suppression to be completed before being implemented. Some trapped occupants waited five hours to be removed from the building.

(10) Reliance should not be placed upon the building's fire protection systems. Firefighters must be equipped, trained, and prepared to pump water up to the fire floors if the situation calls for it.

(11) Building personnel *must* receive selective training on their responsibilities when a fire occurs.

(12) At a fire of this scale and duration, the staging floor can be totally overwhelmed with fire personnel. It may be an idea to organise the zone over a wider area, possibly even two floors.

(13) The amount of radio traffic on the 'talkies' severely restricted the lines of communication that are so vital at such incidents.

(14) Smoke was often allowed to enter the stairways by hose-lines preventing the closure of lobby to stair fire doors.

(15) The new protective face hoods worn by LA firefighters were influential in crews being able to deal with the severe heat conditions.

(16) Helicopters must not be allowed to 'hover' the building unless for a specific use. The downdraft and noise create unfavourable conditions. A 75 m (250 ft) exclusion zone is recommended.

(17) Firefighters may become confused with their exact location within the structure if stairways and levels are not individually and clearly coded or marked.

(18) The physical stresses placed upon firefighters at this fire were immense, where heartbeats may have topped 200 beats per minute!

Case No. 7 – Empire State Building – New York, 1990

The Empire State Building towers 102 storeys above midtown Manhattan as one of the world's largest, and most famous, skyscrapers. Constructed in 1930-31 the massive structure (365,000 tons of steel and stone), survived the effects of a B25 bomber that crashed into its 78th and 79th floors in July 1945. Forty-five years later, at 1831 on 16th July, 1990, Fire Department of New York (FDNY) firefighters would be back in battle to save the building again.

As FDNY units arrived at the structure they were met by several building occupants who stated there was a fire on the 51st floor. Although there was no visible signs from street level the lieutenant in charge was confident that this was to be a 'working' fire so he requested the despatch of further fire vehicles to the scene and instigated the high-rise plan.

Immediately, firefighters made their way to level 50 using a freight lift. As they moved upwards the smell of burning became stronger – they knew they had a job! As they exited at level 50 they were directed by building personnel to stairway 'T' from where they mounted their attack, utilising the riser. The 51st floor was serviced by two stairways, one a conventional stairway (designated 'S') and the 'T' stairway the firefighters were in, which served as a 'fire tower'. The fire tower was an important feature in old high-rise construction because it improved conditions for occupants escaping from a fire. The fire tower in the Empire State Building is an interior stairway separated from the occupied areas by a vestibule that creates a space through which smoke and fire gases are vented into an adjacent air shaft. This design is excellent for evacuation purposes but, as events would show later, is a dangerous avenue of attack.

The fire had fully involved an 85 sq m (916 sq ft) office suite and firefighters had to crawl 6 m (20 ft) along a corridor, heavily laden with smoke, to reach the fire. Suddenly, the exterior windows failed and a 60 mph wind caused the fire to 'blowtorch' into the corridor, severely injuring six firefighters advancing on the fire. The effect temporarily forced firefighters off the floor and the fire started to follow the natural draught created by the air shaft in stairway 'T'. As firefighters remounted their attack the heat was being driven directly at them by the exterior wind and the effect in the air shaft behind them and while nozzlemen were continually being relieved and twin 2½ ins lines were operating along the corridor, they were making little headway against the flames.

Although it was after business hours, there were still several thousand occupants in the building at the time of the fire. The fire department despatcher began receiving numerous reports from trapped occupants and to accomplish the monumental task of searching the floors above the fire, a 'search and evacuation post' was established at level 56, five floors above the fire. This is normal FDNY high-rise procedure and four chiefs were detailed with 10 units to operate from level 56, to complete a systematic search of all the upper floors. This one operation took a third of the operating fire force over an hour to complete.

Meanwhile, firefighters on the fire floor decided to change their approach and advance another 2½ ins line towards the fire from stairway 'S'. Initially they were reluctant to do this as stairway 'S' was being utilised for evacuation purposes. However, this approach was easier as the flow of heat was away from advancing firefighters and they were able to advance on the fire to complete extinguishment.

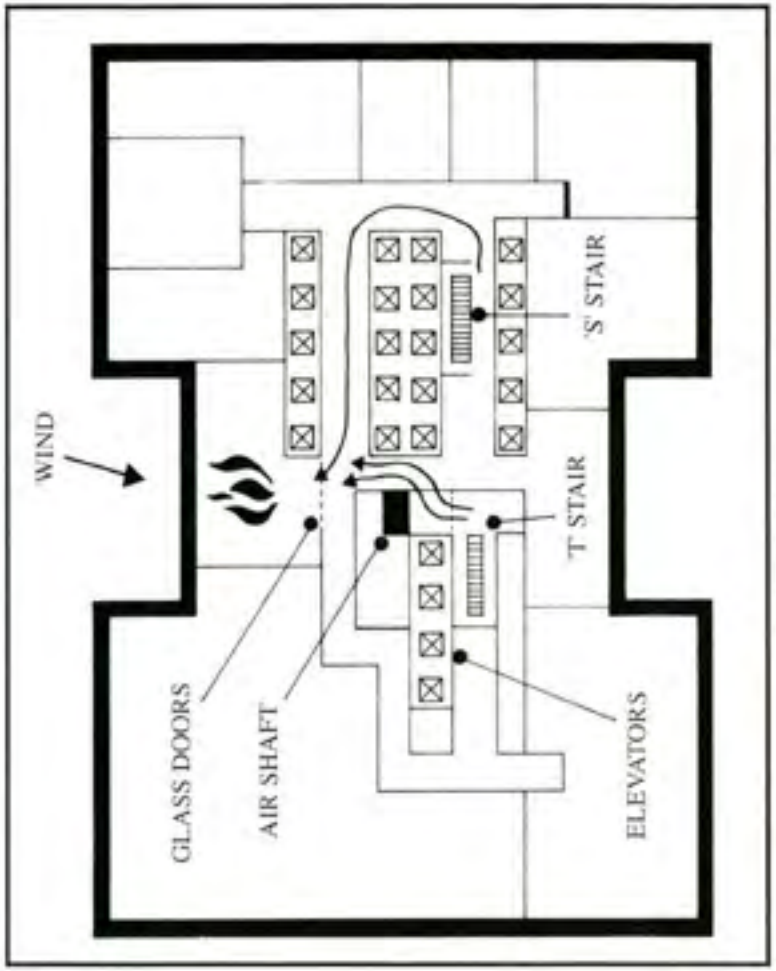


Figure 9:2 – The Empire State Building fire.

The fire had taken 18 chiefs and 34 units manned by more than 175 firefighters nearly four hours to control. Had the same amount of fire occurred in a two-storey corner block it would have been dealt with by the initial attendance! This demonstrates the difficulties that may be expected when a working fire occurs in the upper floors of a high-rise building. In this case, it was fortunate that the floor involved was compartmented and not open-plan, or the outcome might have been disastrous.

Lessons learned (and reinforced):

(1) A fire tower should not be used as an attack stair. Where a stairway is vented at the top, the negative pressure in the stairway invites a severe draft that opposes advancing forces. The main purpose of such a stairway is evacuation, and its status as such should be maintained.

(2) With fire resistive design and phased evacuation it is generally only necessary to evacuate the fire floor and the floor above the fire during the initial stages. However, a search for distressed occupants must be made on all floors above the fire with special attention given to exit stairways, window areas, roof and lift cars. This demands a systematic plan and a large force.

(3) Fire spread was minimised as the integrity of the outer walls and building facade prevented auto-exposure, and the compartmentation of level 51 prevented the fire escalating rapidly beyond control. Such features are important in high-rise construction.

(4) Each floor level in the Empire State Building has its own air handling system to control climate. There is no central HVAC system, subsequently there is less chance for a fire to spread through ducting or an air-return plenum.

(5) To effectively deal with a high-rise fire, operations must be separated into functional sectors. This fire was made more manageable by the establishment of a command post in the lobby, an operation post one floor below the fire, a staging area three floors below the fire, and a search and evacuation post five floors above the fire.

(6) Manpower relief and rotation are vital to success. Effective worktime at the temperatures encountered are from five to ten minutes. Standard FDNY high-rise procedure places two engine companies (eight to ten firefighters) on each hose-line for this purpose.

(7) At high-rise operations, fire forces are almost completely dependent on the building systems; if the systems fail, firefighters will fail unless they are prepared to utilise *contingency plans* and improvise. The ability to improvise in communications, water supply, lift car transportation, fire attack, and search and evacuation were important features of this fire.

(8) Fire safety in the skyscraper canyons of New York has a unique human element where local *Law 5* requires the provision of a full-time Fire Safety Director (FSD), who is usually an experienced ex-fire department officer. His role at a fire is to meet the incoming firefighters at the Central Alarm Control Facility (CACF) in the building lobby to ensure a reliable handover. For whatever reason, at this fire, he failed to meet them.

Case No. 8 – Meridian Plaza – Philadelphia, 1991

On the night of 23rd February, 1991, over 300 Philadephia firefighters fought the most devastating high-rise fire in the city's history. The blaze raged for almost 19 hours devouring much of the 38-storey structure before sprinklers on the 30th floor brought the fire under control the following day. Structural experts said the Meridian Plaza tower is built as solidly as any modern building. First occupied in

1972, the structure has a steel frame with concrete walls and an exterior of granite slabs. The fire, that originated on the 22nd floor, would take the lives of three Philadelphia firefighters before the night was out.

The first firefighters to arrive at the building reported smoke emanating from the 22nd floor and power failure forced them to walk the stairs to mount an attack. Crews led off with 45 mm (1¾ ins) handlines toward the fire, which began in a vacant office on the north side of the building. Although the fire was intense enough to blow out windows, raining sheets of glass on firefighters in the street below, and creating an auto-exposure problem, Battalion Chief George Yaeger believed the fire was containable at this point, until firefighters obtained streams of little more than 10 to 20 ft from their attack lines. The building's systems were failing and it appeared the pressure reduction devices in the riser system were malfunctioning to provide a totally inadequate water supply on the upper floors. This caused a major delay in operations as firefighters attempted to stretch a 5 ins hoselay up each of the three stairways. This took an hour and allowed the fire to escalate beyond control.

The situation worsened as three firefighters reported themselves trapped while running out of air on the 30th floor. A team of eight firefighters were sent to their aid but were unable to locate them and became dis-orientated and confused themselves as stairways were unmarked. The eight were eventually rescued from the roof by helicopter as other crews were committed to search for the missing three firefighters, using guide-lines to penetrate the thick smoke. They were finally located in a 28th floor office but help had come too late.

After a structural engineer advised on the safety of the building, Fire Commissioner Roger Ulshafer pulled all members out as dawn broke. The fire was still burning freely and deluge attacks were mounted from surrounding buildings in a last ditch attempt at quenching the flames. In the end, after 19 hours of raw dedication and courage nine sprinkler heads did what an army of firefighters and equipment could not do. The upper eight floors had been sprinkler protected because of the rooftop 'helipad' risk. Quite remarkably, the system came into operation as the fire reached the 30th floor and brought the fire under control.

Lessons learned:

Even with an exceptional fire force equipped and able to improvise with contingency plans, even a 'moderate' fire many levels above the ground in a high-rise structure will cause immense problems for firefighters. To contain such a fire to an acceptable level important features such as sprinklers and/or compartmentation, and separate air handling systems, are essential in the modern high-rise.

Case No. 9 – Churchill Plaza – Basingstoke, UK, 1991

As the metropolitan skyline forms, the skyscraper effect becomes more prominent. As downtown space is desperately sought after, cities around the world are reaching for the sky and a central grouping of glass towers is becoming the earmark of a busy business district.

Nowhere is such an effect more obvious than in the county town of Basingstoke, situated deep in the heart of Hampshire, UK. As the number of tall buildings increases, so does the chance of having a high-rise fire, and it came as no surprise that on the night of 16th April, 1991, Hampshire County firefighters were to get their first taste of such an experience when a fire occurred in the Churchill Plaza building – a steel framed, glass clad, curtain wall office tower block, 56 m (186 ft) and 14 storeys tall.

A smoke detector actuated the alarm and the fire brigade were immediately alerted at 2142 by the first of 35 emergency calls to a fire in the structure. The initial despatch was for three appliances and 15 firefighters. No aerial apparatus was ordered at this stage. On their arrival, firefighters observed a serious fire blazing on an upper floor but were unable to note which floor this was from the street due to the confusing design of the curtain wall. They were met by building security personnel who directed them to a lift car at the east end of the 'V' shaped structure and informed them that the fire was on level nine. An initial fire attack team of four firefighters made their way by lift to the ninth floor. They were equipped with 75 m (250 ft) of 45 mm (1¾ ins) hose, fittings, and two of the crew had donned breathing apparatus.

On arrival at the 9th floor they connected to the riser outlet situated in the fire lobby and made an entry into the smoke-filled floor area. They were soon joined by a second attack team who provided further lengths of 45 mm hose in the single line. However, they were unable to locate the fire on Level 9 having made their way right across to the west side stairway. They eventually realised that the fire was on Level 8 and made their way down the west stairs to mount the attack from the lobby there.

Although the west stairway enjoyed the protection of a pressurised air-flow there was no fire riser that could be utilised in attack. The attack team continued to advance the line they had run from the 9th level east stairway which now had some six or seven 25 m lengths of hose joined in. Even so, the stream was still able to reach the fire although the height of the office partitions and storage shelves prevented a direct hit at the base of the flames.

The fire started to spread throughout the eighth floor and extreme temperatures hampered firefighting efforts. Crews had to be relieved after 15 minutes on the fire floor to prevent the effect, of heat exhaustion. At about 2250 the windows on the south-west side of the 8th floor failed and minutes later, the strong wind conditions created a severe blowtorch effect into the floor. The fire immediately erupted and escalated up the south-east side of the structure creating an auto-exposure problem, and as the fire spread to the upper floors the lifts began to fail. Seven firefighters found themselves trapped in one of the seven lifts serving the building and required a rescue team to come to their aid. Heat and smoke entered the stairways and firefighters working in what had been 'clear' areas without breathing apparatus, became trapped in the smoke.

As the fire progressed to involve all of the eighth and ninth floors and ten per cent of the tenth floor firefighters advanced 13 hoselines in an aggressive attack on the fire. As there were insufficient outlets from the risers, and to prevent over-running their supply, many of these lines were laid up the stairs from street level. By midnight, aerial appliances were projecting heavy streams into the upper floors to reduce auto-exposure. By 0216 the fire was declared under control.

The 4½-hour long battle had taken over 200 firefighters using 240 air cylinders to the peak of exhaustion. They had stopped the fire at the tenth floor with a tremendous effort.

Lessons learned:

(1) The initial response of three fire vehicles is insufficient for a fire of this magnitude. An aerial appliance should have formed part of the original attendance.
(2) The first arriving firefighters placed too much reliance on a security guard's report on the location of the fire. To approach a fire by lift demands that a 'safe' margin should be allowed for, perhaps aiming for four to five floors below the reported location.
(3) Although the initial attack was mounted from the east end of the building, this

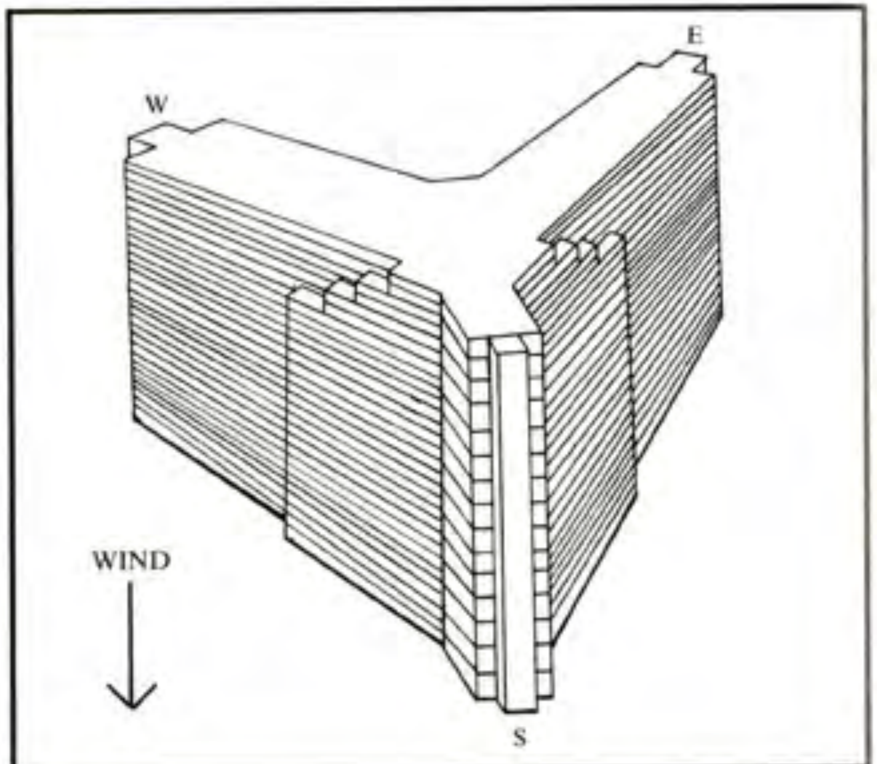


Figure 9:3 – The Churchill Plaza building that presented Hampshire firefighters with their first taste of high-rise firefighting in April 1991. A spot on the SW side of the structure marks the area where the fire originated.

switched by chance to the west end. Had the crews been advancing on the fire from the east when the wind created a blowtorch effect, several firefighters may have been severely injured. To attack from the southern (central) stairs under these conditions would be a mistake as the fire could come from the rear to trap crews on the floor.

(4) Firefighters forming part of the initial attack teams, and others working throughout the fire in 'smoke free' zones were not wearing breathing apparatus. The unexpected escalation created unfavourable conditions on stairways that trapped firefighters. All personnel should don a breathing set if going above the ground floor, even if they are not planning to start it up.

(5) The positioning of a BA control post at ground floor level when a fire exists several floors up is always a problem. In this case firefighters were required to start up their sets and walk up eight or nine floors before getting to work on the fire. This used up valuable air and placed unnecessary physical stress upon them. The absence of a staging post below the fire added to this problem and created an unfavourable time lag between orders being given and acted upon.

(6) The design of high level office partitioning, or shelving, in open-plan areas creates a major problem for firefighters trying to project hose streams at the base

of the flames.

(7) When communicating from stairways within the structure over their fireground radios, firefighters became confused as to which stairway they were in. Again, a marking system would help. This should be extended to floor levels and riser connections.

(8) Fire crews involved in operations on the fire floors must be equipped with a fireground radio, linking them with fire command. When an urgent evacuation of the fire floor is required the only effective way to achieve this is by radio link.

(9) Firefighters on the initial response said, if they had to do it all again, they would:

- (a) Not place total reliance upon fire location reports.
- (b) Set up the BA control point two floors below the fire, with at least a two man crew to handle communication links and relief responsibilities.
- (c) Ensure the attack teams were equipped with two-way radio link.
- (d) Laying *and* charging a hoseline within a fire lobby is almost impossible. It would be easier to bring the charged line up from the floor below, but then smoke will enter the stairway through the partially open lobby doors.

(10) Chief Fire Officer John Pearson later commented on the structural fire protection, saying that the flooring (Q-Deck) performed extremely well and showed little breakdown of its integrity. The gap of 125 mm (5 ins) at the curtain wall was infilled with Rockwool slab which fell out of place during the fire. The fire and smoke integrity of service ducts failed at several points. Air handling fans (both positive and negative pressure) on the stairway operated effectively throughout the fire. The fire penetrated the electrical service shaft supplying power to the fire lifts. This caused the power failure and prevented further use of the lifts. He went on to point out the valuable role a sprinkler system would have played had one been fitted.

(11) The sprayed structural steel was totally unaffected by the high temperatures and duration of the fire.

(12) The rising mains (standpipes) were only 100 mm (4 ins) in diameter. There were two risers in the building but they were unable to provide firefighters with an adequate amount of water to tackle a fire of this size. This was demonstrated by the way additional hoselines were laid up stairways to the fire floors from street level. Rising mains should be of at least 150 mm-200 mm (6 to 8 ins) in diameter. Full use should be made of dividing (siamese) connections to feed additional lines.

Case No. 10 – Clarence Street, Sydney, Australia, 1991

The responding force of firefighters is faced with a logistical nightmare when a fire occurs many hundreds of feet above the ground within the confines of a tall building. The battle ahead is likely to be arduous, even where the inbuilt fire protection measures are operative. Where such systems fail during firefighting efforts, the overall effectiveness of fire operations will suffer greatly. Possibly, one of the most difficult situations the firefighter can face is a fire on the upper levels of a high-rise that is under construction.

The first major high-rise building fire in New South Wales, Australia, tested Sydney firefighters to their limit in the early hours of April 3, 1991. The first call was received at fire control at 0110 hours to a fire at the corner of Margaret and Clarence streets and five fire appliances responded with 25 firefighters.

On their arrival it appeared from the ground that the entire top floor of the 30-storey building was well alight. Having equipped themselves with several lengths of 70 mm hose, fittings and CABA, a team of firefighters began the long haul to the upper reaches of the building, there was no internal lift installed – the building was still under construction.

As firefighters ascended the stairs they tested the rising main at the lower levels for water availability and a flow was noted. The first sign of fire was located at Level 27 where a large quantity of timber frame-work and builders scaffolding was alight. However, when the rising main was opened there was no flow at this level. In fact, the main had been capped at Level 13 and there was no water above the tenth floor.

This required a change in strategy and firefighters looked to the adjacent 20-storey Mercantile building where access existed between the two structures at the 20th level. The Mercantile building's rising main was then charged and a hoseline was taken from the top floor, into the fire building and up to the fire floor. However, the fire had now spread to involve the framework on levels 28 and 29 and as the fire attack commenced an insufficient pressure arrived at the 27th level to create a penetrating stream. A lightweight portable pump was sent to the roof of the Mercantile building to boost the pressure but this strategy failed as insufficient water was reaching this level.

Investigations revealed that an illegal fitting had been installed in the main at ground floor level, and had blown under pressure. The strategy changed, yet again, when an external builders' lift came into operation. A lightweight portable pump was transported to the 17th level in the fire building which was utilised as an in-line 'booster' where a 70 mm line was laid from the tenth floor up to the 27th Level. This enabled two 38 mm lines to advance on the fire (which had now partially involved Level 26 also) to complete extinguishment.

Lessons learned:

(1) Where a tall building is under construction, the internal fire rising main should be extended in operation in-line with the growth of the structure. In this case, the main was capped at Level 13, where it continued across the floor and up the opposite side of the building. It had yet to be joined at the crossover point.

(2) Where internal rising mains are inoperative, a contingency plan should be available (re: Chapter 8).

Standard Operating Procedures (SOPs)

The sheer complexity of approaching a fire situation many floors up in a high-rise building demands a pre-plan to ensure the fire force functions as a team from the moment they arrive. The higher the fire, the bigger the problems that may hinder the firefighters in their efforts. High-rise firefighting is a speciality. Unfortunately, many of the lessons are only learned by personal experience. This is reflected by individual fire department's pre-plans, or Standard Operating Procedures (SOPs) as they are called in the USA. There are many different approaches made by firefighters around the world to a call for help from the upper floors of a high-rise. The variance is caused by differences in opinion on how a particular situation should be handled. It is also influenced by a common refusal to accept basic facts that others have learned for themselves; while others have learned but never attempted to share their knowledge, for whatever reason.

Over the past 20 years the *Towering Inferno* syndrome has become more commonplace as many major cities, mainly in the Americas or the Far East, have suffered massive losses in high-rise fires. These incidents have clearly demonstrated failings in structural fire protection and we learn from every one as they occur, in an effort to make our own buildings 'safe'. Many of these conflagrations have occurred in countries whose regard for structural safety in a fire situation is

secondary and much of the experience related to fire control efforts can be dismissed as somewhat non-progressive. However, surely the fires that have occurred in North American structures over a period of 80 or more years can provide a worthy source of experience. These fires present a history of advances made in both structural protection and firefighting strategy and tactics. The North Americans have made continual efforts to put right what 'went wrong' last time, and while it is only within the past ten years that the fruition of this effort has become obvious, we must appreciate this history as the only source to which one can look for knowledge.

While it is clear, although still not widely accepted or practised, that sprinkler systems, compartmentation, and protected stairways with adequate rising mains, are essential features of a tall building, the provision of an effective pre-plan for firefighters, *based on experience* gained at such fires, is not so obviously apparent. Looking at SOPs around the world for high-rise firefighting makes one shudder at certain aspects therein!

At this point, it is worth considering the various uses a high-rise can be put to, or the differing occupancies it may house. This will, inevitably, affect its design and construction. This, in turn, should have a great effect on our approach to various 'types', and reflect in our pre-plans. For example, there is a great difference between fighting a fire on the 24th level of a residential tower as opposed to a modern office structure. I would suggest that our tactics should be differentiated between fighting a fire on the eighth floor of an office structure as opposed to the 28th floor of the same structure! In both cases an effective approach by the initial response would be varied. A fire within a fire resistive apartment on level 24 is rarely going to provide problems on the scale of an open-plan, glass clad, curtain walled office tower. Likewise, while a major blaze on the eighth level of the open plan office is going to keep the fire department 'on their toes', the logistical problems are nowhere near as complex as if the same fire was blazing an additional 20 storeys higher.

Most pre-plans are based upon obvious common factors. The main aim is to get water on the fire as soon as possible and this entails detailing one of the initial crews to take some hose up to the fire floor to mount an attack, while others will ensure a water supply and effect rescues. It is simple is it not?! I wish it was that easy!

High-rise firefighting is far more complex than one realises until one actually has to do it, and that is when we learn that our pre-plan falls short in certain aspects, and several points are consequently updated. Taking all this into account, a review of some fire departments' SOPs is quite revealing.

Few fire departments utilise the novel approach of Chicago firefighters who communicate over the fireground radio *en route* to the high-rise. For example, "Squad One approaching from the west side of Sears Tower – nothing showing". Other units responding will also report 'exterior status' to give an overall picture *before* arrival. This is a good strategy for it is often typical that first responders enter the lobby of a high-rise, unaware that smoke is issuing from a rear window at the 28th level. Such knowledge would enable them to call in a 'working fire' and request the despatch of additional crews that are so often needed early on in a fire of this nature.

Common to all SOPs is the provision of a 'fire attack team' on the initial response who make their way up to the fire floor to mount an attack. What is not common is their mode of approach and the equipment they should take with them. This, in turn, has some bearing on the size of the team.

Lifts or Stairs?

While nearly all European and Far Eastern firefighters will utilise the lifts to transport them to one or two floors below the reported fire floor, firefighters in the USA are far more cautious in their use. Some bad experiences where fire crews have been accidently despatched directly to the fire floor, either by malfunction of the elevator system or incorrect reporting on the fire's location, has resulted in several fatalities. It is also a common feature for lifts to fail as the building comes under severe fire attack, trapping firefighters inside. This has led many fire departments to review their approach during the initial stages of attack.

Los Angeles firefighters will not use an elevator shaft if it discharges onto the reported fire floor, unless its 'safe' status has been confirmed by other firefighters, ie the fire is not affecting the lift's protecting lobbies. This means, in effect, that LAFD fire crews will walk the stairs to reach the fire floor, even if this means 34 storeys! This procedure is followed in all instances – even a fire alarm actuating with no report of actual fire will attract the same cautious approach although greater reliance may be placed upon a security guard's word under such circumstances. Similarly, Las Vegas firefighters will not use 'unconfirmed status' lifts and the City of Miami are considering the same tact.

Somewhat in contrast, New York City firefighters will make full use of elevator banks, utilising a particular bank if it reaches within five floors of the reported fire floor (or seven, if not carrying equipment). Therefore, they are quite willing to walk five (or seven) floors to maintain a safety factor. If, however, no bank reaches that close then they will transport in a shaft that serves the fire floor but will test the lift's operation by ascending in five floor multiples, ie stopping at the 5th, 10th, 15th, etc, before discharging at least two floors below the fire floor.

The Dallas Fire Department will walk to a fire if it is within seven storeys of the ground. Previous experience certainly encourages caution when using lifts, but whether to totally disregard them during the initial stages is another thing. The effect it has on 'reaction times' and physical stresses placed upon the firefighter should be closely considered.

The 'reaction time' is the time it takes to receive a fire call on station, respond to the scene, reach the fire floor, and get water onto the fire. A study in Ohio, USA, advanced the theory that it takes a firefighter, responding from two miles away to the moment he opens the nozzle on the fire floor (using stairs as opposed to lifts) approximately one minute per floor, ie 12 minutes to reach the 12th floor:

However, there are occasions when first-arriving firefighters are not provided with an option. If the lift is inoperative at the outset then the stairs have to be walked and with this in mind, a team of London firefighters took part in assessments and simulations to review equipment and techniques. It was noted that where firefighters were required to walk more than six levels above the ground equipped with breathing apparatus (donned but not started), and other items necessary to force entry and attack a fire, their pulse rates would at least double, and in some cases treble. Variable increases in blood pressure were observed and on reaching the 12th level, all participants felt physically drained and would have required a period of recovery before mounting an aggressive attack on the fire. It was also noted that smokers suffered more than non-smokers!

When used in conjunction with the TFT nozzle they are hard to match. However, probably the most important point about taking hose aloft is the fact that there never seems to be enough on hand just when its needed, therefore take as much as you can physically carry and ensure the back-up crews do the same, if not to the fire floors, at least to a staging point nearby.

Equally as important as the provision of hose is the wearing of breathing apparatus by *all* personnel heading for the upper floors. It is a poor pre-plan that fails to emphasise this point. At a fire in a tower block in London, firefighters were

Type	*City*	*Floor*	*Mode*	*Time (mins)*
Simulated	Philadelphia	12	lift	9
Simulated	Philadelphia	12	stairs	25
Simulated	Philadelphia	25	stairs	40
Fire	Los Angeles	34	50/50	27
Fire	Los Angeles	21	stairs	36
Fire	Dallas	12	stairs	17
Simulated	London	12	stairs	10
Fire	New York	33	lift	22
Fire	Los Angeles	12	stairs	10
Simulated	Sacramento	10	lift	15
Simulated	Charlotte NC	16	stairs	22

Table 9:1 – Reaction times in high-rise

Note: In some instances there were negating effects such as the amount of equipment a firefighter had to carry, or, the amount of smoke on stairways below the fire floor that slowed the approach.

They also assessed differing styles of hose-carry. In most parts of Europe hose is rolled into a coil, ready for use. In London, hose is 'Dutch-rolled', a slightly different technique which is much faster in use than coiled hose. Even so, the utilisation of either technique for the high-rise situation is totally unsuitable. The initial hose-carry up several flights of stairs is extremely difficult and increases the physical stress suffered by the firefighter, and upon reaching the fire floor, the laying and charging of rolled hose within a confined space, such as a fire lobby or stairway, is awkward and time consuming.

The American style of a pre-packed flake was assessed and found to be much easier to carry and lay into a fire floor than the rolled hose. The 'hose-pak' consists of two preconnected lengths of hose (with branch and nozzle), laid in a 'flaked' pattern and held together by a designed, quick-release, harness with carry strap. The hose-pak can be carried by the strap, or laid across one shoulder, or draped across the top of the wearer's breathing apparatus cylinder, whichever is more comfortable.

Other styles of hose pre-packs were considered but most entailed carrying by hand and it felt the 'hose-pak' used in the simulation was more comfortable and left the hands free to carry other items if needed.

Equipment for Fire Attack:

The amount and type of equipment required at the fire floor by the initial fire attack team is based upon a minimum hose complement to enable two lines to be got to work on the fire from a rising main supply. A good case can be made for several other items to be taken that will assist this cause. But even here there is a variance in the size of hoselines to be taken up to the fire floor. Some fire departments prefer a complement of 45 mm (1½ ins) to mount the initial attack, while others never take anything less than 70 mm (or 2½ ins). Refer to Chapter 8 for 'flow considerations':

The popularity of the superior quality, high-flow, 50 mm (2 ins) attack lines that are in use in the USA is growing all the time. They combine the advantages of a high-flow LPM, effective streams, low nozzle reaction and good manoeuvrability.

Boston	70 mm
Los Angeles	50 mm
Charlotte NC	50 mm
Tokyo	50 mm
New York	70 mm
Chicago	45 and 75 mm
London	not designated
Hampshire, GB	45 mm
Dallas	45 mm

Table 9:2 – Preferred hose size on initial high-rise attack

caught without breathing apparatus above the fire when windows failed on the fire floor, allowing a 60 mph wind to create a 'blowtorch' effect, similar to conditions experienced at the Empire State Building and Churchill Plaza fires described earlier. Several firefighters were injured as the heat from the fire melted plastic fittings in the stairway *two floors* below the fire floor! Wearing of breathing apparatus is often left to option in pre-plans, and while those working on the fire will generally don sets, few others feel the need. Most SOPs in the USA *demand* the wearing of breathing apparatus above the ground level. Take a tip – the next time you go aloft, don your set. It might save your life!

Other items of equipment that should be taken aloft by the initial fire attack team are: BA control board; dividing breeching (siamese); sledgehammer (or other forcible entry tool) fireground radios; and sprinkler shut-off wedges (essential).

The Fire Attack Team should consist of *at least* six firefighters: (officer, BA control FF, and two crews each of two firefighters). A four-man team could only be expected to operate one attack line and the siamese could be dropped from the list (unless it is gated).

Additional equipment such as: portable lighting, rescue lines, spare air cylinders, ceiling hooks (pike-poles), additional hose, additional siamese breechings and forcible entry tools, will be required on the fire floor, or at a nearby staging post, *as soon as possible*.

Incident Command Systems (ICS)

The Incident Command System (ICS) is a management system that has evolved in the USA over a period of several years, and has been thoroughly tested, and refined, through its application during 'real' fires. It is designed to direct and control the resources committed to an incident so that objectives may be accomplished effectively and in order of priority. The need is identified by the first arriving officer and the system is established with the arrival of the initial attendance and the filling of the basic functions of Incident Commander (IC), fire attack, lobby control, staging, and base. The basic framework of the ICS is accepted throughout the USA with various adaptions of specific functions to suit individual needs.

It was stated after the Empire State fire, and is reiterated here that: 'To effectively deal with a high-rise fire, operations must be separated into functional sectors. This fire was made more manageable by the establishment of a command post in the lobby, an operation post one floor below the fire, a staging area three floors below the fire, and a search and evacuation post five floors above the fire.' Although fully established command and control systems are operated by most fire departments, few authorities outside the USA have adapted their own system to suit the high-rise situation. An analysis of these 'functional sectors' follows.

Actions on Arrival:

While firefighters outside the structure position apparatus and secure the water supply, the remainder report to the entrance lobby, in pre-arranged teams, equipped with breathing apparatus and other tools as relevant. The Incident Commanmder (IC) will report to the Central Alarm Control Facility (CACF) while firefighters in the lobby call all lifts to the ground floor, if this has not already been done. Usually, the first arriving fire vehicle will adopt the role of attack team. They may be reinforced with one or two firefighters from the second engine. Other units arriving on the initial response will adopt roles and responsibilities as follows:

Lobby Control:

As the fire attack team leaves for the upper floors, the second engine's crew (or remaining members) will adopt the role of lobby control. The responsibilities of the team are:

(1) Assess status of lifts at all times. (Note – a firefighter equipped with radio should be detailed to operate each lift in use.)
(2) Maintain a communications link between fire attack, operations post, staging post, search and evacuation post, base, and of course the incident commander.
(3) If controls are in the lobby area, they will be responsible for Heating, Ventilating, and Air Conditioning (HVAC) status.
(4) Control and direct movement of resources through the lobby.

The pump operator of this engine will be the water supply man and is not generally involved in lobby control. The personnel assigned to lobby control *must* don a distinctive form of identification and *all* personnel entering or leaving the structure must check-in/out with a control officer. The functions of lobby control may be taken over by officers of control units, or as designated at any stage.

Staging:

The third company, or engine, on scene will adopt the role of staging. The staging post is an essential feature of an overall high-rise operation, particularly where the fire floor is many levels from the ground. There are varying opinions of where the post should be located in relation to the fire floor. A review of fire department SOPs places the staging post anywhere between one and five floors below the fire floor, although a few department SOPs outside the USA fail to even address the function. It is important to place the post in a safe location and experience has shown that this should be at least three floors below the fire. It is almost equally as important to take into account the number of levels a firefighter in breathing apparatus could effectively ascend without suffering undue physical stress before taking over on an attack line. This will place the ideal staging post at three to four floors below the fire floor. An open-plan office area would serve as an acceptable staging post where manpower and equipment resources could be held until required.

To ensure the effectiveness of staging at a large fire it is important that the area is well organised and stockpiles of equipment and manpower are built up at an adequate pace. Past experience has shown that staging can often be overwhelmed by personnel who are either recovering or awaiting fresh cylinders that have not yet become available. The type of equipment that will be required from staging is hose, spare air cylinders, portable lighting, and forcible entry tools – make sure there is plenty of everything! Again, communication links with all sectors are vital, and staging officers must don distinctive tabards and record the flow of manpower and resources.

Operation Post:
The New York City Fire Department (FDNY) is one authority who adopt an operation post policy. Chicago, London, and San Francisco are others who place a forward command facility one or two floors below the fire. In all cases this command bridgehead functions on a different level to the staging post. While fire chiefs will want a look at the fire on all levels to gauge the effectiveness of strategy and tactics, to site such a facility so close to the fire floor is considered bad practice by many. As previously stated, the safe zone is at least three floors below the fire, ie wind effects, backdrafts or flashovers could effectively push searing heat and smoke two or three floors down stairways from the fire floor. To have anyone in that zone who is not wearing a breathing mask is bad firemanship. If a command bridgehead is felt necessary, it seems logical to site it with staging, from where individual chiefs can be assigned (in pairs or with an aide), to fire floors or sectors, enabling them to report back as necessary.

Search and Evacuation Post:
Estimates by the National Research Council of Canada shows the impracticality of evacuating an entire high-rise structure. It would take one hour and 18 minutes to evacuate occupants from a 30-storey building using one stairway (a reasonable assumption in a fire). To evacuate a 50-storey building in a similar manner would take two hours and 11 minutes. Modern design and phased evacuation plans take this factor into account. However, to think that occupants more than two floors above the fire are safe, at least for the time being, is a mistake. Many severely distressed occupants remained above several of the fires detailed in cases one to nine (earlier) until the fires were extinguished some hours after the initial outbreak. These people were trapped and on occasions, firefighters were unable to reach them. Many of them required transportation to hospital for treatment to various injuries.

Battalion Chief Glenn Dinger of the City of Los Angeles Fire Department is one man who feels very strongly that a pre-plan should ensure a team of firefighters is despatched *above* the fire on the initial response. It is somewhat surprising to discover that few fire departments (including LAFD) find a role for such firefighters on initial arrival at a high-rise incident. However, the FDNY is one who commits a two-man scout team above the fire floor on arrival. Their role is:

(1) If possible, utilise a lift in a 'blind' shaft, ie one that does not open onto the reported fire floor(s), and proceed to the top floor served. If a blind shaft lift does not exist, proceed by lift to a point two floors below the fire floor and then utilise a stairway to reach the upper levels.
(2) On reaching the roof check for occupants, smoke conditions, and wind conditions. Report status at regular intervals.
(3) Check all lift shafts for smoke conditions and car position; report and await instructions.
(4) If lift-cars are stalled between floors the scout-team are ideally positioned for motor-room work.
(5) Proceed down to check lift-cars stalled at floor levels.
(6) Report smoke conditions on upper floors and stairways, briefly assess occupant load, observe fire spread in shafts.
(7) Await instructions or report to search and evacuation post as detailed.

The Houston Fire Department operate a High-rise Evacuation and Rescue Team

(HERT) who are ready and equipped for helicopter operations. They arrive on the roof of the structure top carry out a similar role to the FDNY scout-team, but their response time is very much slower.

A FDNY search and evacuation post is usually sited five floors above the fire. From here, chiefs will detail firefighters to complete a systematic search of all upper floors. If necessary, they will supervise and direct the evacuation plan.

The floors above the fire may present a very dangerous and hostile environment. Philadelphia firefighters will be the first to emphasise this following the Meridian Plaza fire (see earlier). However, as firefighters, we have a responsibility to the occupants on upper floors and the provision of a scout team from the initial response should form part of the pre-plan.

Base:
The setting up of base is a consideration many departments incorporate into the intial stages of the plan. It is, however, a control area for additional apparatus and resources to report to when a working fire is called in. Base is usually sited at least 100 m from the building at street level; its location is transmitted over the fireground radio so that incoming apparatus can report directly. From base the manpower and resources will then be directed through lobby control, up to staging, and then on to specific locations from there.

Progressing Strategy
Having established the basic functions of a tactical approach, the working fire will present specific roles for all units called in on the second wave. In the USA, such an incident will bring a repeat attendance on the second alarm (call for assistance), doubling the initial response. Additional crews should be despatched straight into the structure, via lobby control, and on up to staging. From here, the priorities will depend on the circumstances, but an additional attack line to cover the floor above the fire should be considered, as should relief crews for initial attack teams, further scout teams, and extra hose and equipment to staging in anticipation of additional attack lines for the fire floor. To keep one step ahead of the fire, the IC many anticipate the possibility of a power failure in the structure and increase his manpower resources on scene to operate as a stairwell support force, should the need arise.

Stairwell Support
There is a strong likelihood that a serious fire may cause the lifts to malfunction. Once this vital link with the upper floors is severed the fire force are faced with a logistics problem. How to get the vital supplies of hose and air cylinders to the staging floor is the responsibility of the logistics chief. His assessment of manpower to form a stairwell support force is the key to maintaining a logistical pipeline to staging. If this link is to become weak in any way, the attacks on the fire may lose ground and become ineffective.

Previous simulations, and real fire experience, shows us what to expect from firefighters hauling equipment up stairways for long periods of time. It is suggested that the optimum arrangement is for firefighters to work in teams of two, assigned to two floor levels, alternating five minutes working with five minutes rest. It is estimated that the average team will work effectively for a period of 30 to 45 minutes before requiring a relief. Therefore, if the staging floor was at level 28, then a total of 28 firefighters would be required for 45 minutes of stairwell support. Additionally, for each five floors, a company officer should be assigned to monitor the effort. This totals to 34 firefighters overall, requiring the despatch of an additional seven companies for a 45 minute stairwell support operation.

Standpipes and Rising Mains

Fire flow calculations may suggest that rising mains in high-rise structures are somewhat inadequate. This is particularly the case in many parts of Europe and the Far East where it is common to find a standard riser that is designed to flow around 1,500 LPM (400 GPM US) to the upper floors. This main is generally of 100 mm (4 ins) in diameter, supposedly capable of supplying three good attack lines. A close analysis of fire flow calculations in Chapter 3 will demonstrate the amount of water utilised in actual fire combat in high-rise buildings. It suggests a standard flow requirement for office fire loads. If this figure is applied to any particular structure, the potential of the rising main is realised.

Example one – Telecom Tower, London: This structure has one 100 mm rising main providing 1,500 LPM flow-rate on the upper floors. Using the fire flow formula explained in Chapter 3 we are able to predict the riser's capability in a fire situation:

- Standard floor cubic capacity – 1,270 cu m.
- 1,270 divided by 2 = 635 LPM
- Riser's flow-rate = 1,500 LPM divided by 635 = 2.36.

We are therefore assessing the riser's capability would be effective providing the fire did not escalate beyond 2.36 floors.

Example two – Nat-West Tower, London:

- Standard floor cubic capacity = 2,490 cu m.
- 2,490 divided by 2 = 1,245 LPM.
- Riser's flow-rate = 3,000 LPM divided by 1,245 = 2.40.

The rising mains are effective for 2.40 floors of fire.

Example three – Canary Wharf Tower, London:

- Standard floor cubic capacity = 9,600 cu m.
- 9,600 divided by 2 = 4,800 LPM.
- Riser's flow-rate = 6,000 LPM divided by 4,800 = 1.25.

The rising mains are effective for 1.25 floors of fire.

It is clear from these examples that the rising mains installed into these structures are totally inadequate for a fire of serious proportions. The fire brigade are at a distinct disadvantage under such circumstances. Previous experience from both sides of the Atlantic tells us that a major fire blazing within the upper reaches of a tall office structure will require a minimum application rate of 0.5 LPM per cubic metre (see Chapter 3). The risers in the Churchill Plaza building in Basingstoke, UK, were unable to meet the demands of fire crews mounting their attack on the 8th and 9th levels, forcing firefighters to lay additional attack lines up the stairways from the street.

To provide an adequate flow on the upper levels of high-rise buildings the North Americans demand standpipes (rising mains) to meet high standards. In Los Angeles, for example, buildings up to 275 ft (83 m) in height must provide 6 ins (150 mm) standpipes and in buildings over this height, an 8 ins (200 mm) standpipe is the minimum acceptable, powered by two diesel, and one electric pumps. Such systems will provide far more water than the 4 to 6 ins (100-150 mm) systems found in many structures around the world.

Another feature that may affect adequate water flow to the upper storeys is a

malfunction of the supply pumps. Even though they generally have an alternative back-up system, experience has proved that a building under stress may not allow its systems to function as designed. In the USA this problem is anticipated and standpipe systems are fitted with a fire department connection to augment the supply in case of failure. This is *not* a tank-fill connection, as found in Great Britain and other parts of the world, but a direct feed into the rising main. The LAFD will automatically site a pumper at the standpipe connection and connect twin 70 mm hoselines into the system. (Hoop force makes 70 mm the automatic choice over LDH at high pressures.) The fire pumper will then pump into the system at 7 bars below the designed pressure. This will allow the system pumps to maintain control. However, if the building fire pumps falter or malfunction, the sited fire pumper will automatically start to flow water and the pump operator will take charge of supply. The LAFD have pumped up to 40 bars (600 lbs psi) utilising this technique. To do this, certain precautions must be taken: A 15 m exclusion zone is applied around the special high-pressure hoselines running into the riser. Hose connections are tied or strapped at both pumper and standpipe, and lines feed from the opposite side of the control panel in use, protecting the operator.

New York firefighters also pump into standpipes and are given guidelines of the pressures required to effectively reach the upper floors:

Floors	*Pressure*	
1 to 10	10.0 bars	150 lbs psi
11 to 20	13.5 bars	200 lbs psi
21 to 30	17.0 bars	250 lbs psi
31 to 40	20.0 bars	300 lbs psi
41 to 50	24.0 bars	350 lbs psi
51 to 60	27.0 bars	400 lbs psi

A further guide given to Boston firefighters is that a supply pressure of 27 bars will provide an effective stream from 30 m of 70 mm hose on the 62nd floor! Such pressure will, in fact, raise water to a height of 300 m.

General Tactical Considerations

Hose-run Lengths into Floors

There can be no standard length of a hose-run in a high-rise building, where floor areas will vary and compartmented zones will complicate such lays. Of the three types of fire that can be experienced in a high-rise; (a) core; (b) central; and (c) peripheral. The peripheral fire is generally the one that will require the longest lays. However, in an open-plan setting, it would have to be a substantially large floor area that could not be reached from a central core, utilising the initial hose-pak taken aloft by the attack team. If the fire involves a 'wrap-around' design, being open-plan sited around the core with no restrictions, then a twin-line attack is necessary to avoid: (a) fire at the rear of the attack team, and, (b) steam and heat chasing the initial line off the floor! Under these circumstances a third protection line may be needed.

Auto-exposure

Current practice in offices creates an abnormally higher fire load than similar risks would have several years ago. The increasing use of computer furniture has been a major contributing factor towards this trend. This, in turn, has led to an increase in vertical extension from fire through auto-exposure, where flame projection from windows laps upwards and into the floors above. This effect is more common, and likely, where the facade consists of a glass-clad curtain wall. Such spread can rapidly become progressive and create immense problems for the fire force.

The behaviour of flames emerging from windows has been the subject of several studies which conclude that:

(a) The wider the window, the greater the likelihood that flames will lap the face of the building.
(b) Auto-exposure is more likely in buildings that have combustibles close to the windows.
(c) Increasing either window height, or width, will result in greater heat radiation being applied to windows above.
(d) A 1 m high 'upstand wall' sited below windows will not contribute anything to the prevention of fire spread.

One such study, by the National Research Council in Canada *(Bibliography 9:1)* assessed the effectiveness of spandrel heights, and depths of horizontal projections, as means of protection for windows above exposing windows. The resulting data showed that a horizontal projection installed above the window offers a substantial protection to the area above the window. This protection increases with the depth of the projection, but even a 0.3 m projection provides a noticeable decrease in exposure. A 0.6 m projection reduces the exposure by approximately 60 per cent. A 1 m deep projection was seen to reduce exposure by 85 per cent, when compared with data recorded without the existence of any projection.

A spandrel wall was not found to be practical means of protection against flame 'leap-frog'. In order to achieve a 50 per cent decrease in exposure to the area above an opening, a 2.5 m high spandrel would be required. Measurements taken with projections indicate that the same level of protection as a 2.5 m spandrel was achieved at 1 m above the opening using a 0.3 m projection and at less than 0.5 m above the opening using 0.6 m projection.

The report made it clear that the use of these findings should be limited to fires producing external flames not exceeding 3 m in height. For protection against much taller flames, a projection deeper than 1 m may be required.

Wind Effects

The effects of wind are always important in a serious high-rise fire situation. A 10 mph wind at the third level can be magnified six-fold on the upper floors. As long as the structure remains sealed from the outside there is no real danger. However, if the building is vented without any consideration being given to wind speed and direction, or, if windows on the fire floor break through the heat, a severe blowtorch effect could result, forcing firefighters to leave the fire floors and causing injury in the process.

Never under-estimate the power of the wind to wreak havoc on the upper floors, and always keep it in the back of your mind! Wind eddies and gusts can cause rain to fall upwards at upper levels. Such conditions, if allowed to enter the structure, will create unpredictable flows that push the fire and smoke in all directions. A flow of wind coming in from behind advancing firefighters will ease their position and drive heat and smoke away from them. However, if the flow is strong enough it could also create a fire extension problem through voids, or auto-exposure, on the far side of the fire.

Various studies of wind effects around tall structures have demonstrated that wind speeds and direction on the exterior of a high-rise building will vary with the height of the structure, and the influence of surrounding buildings. These factors can alter, divert, or even reverse winds, and the direction is not necessarily related to the prevailing wind conditions for the general area.

Therefore, if an IC was contemplating horizontal ventilation of a fire floor, he would be well advised to check exterior conditions by opening a window one or two floors below the fire to gauge the effects at that level.

Air-flow in Tall Buildings

One important consequence of natural air-flow within a tall building, that generally receives minimal consideration by fireground officers, is that of stack action.

As the natural flow of air in a structure is in an upwards direction, the basic principle allows cool fresh air to enter at the base of the building and warmed stale air to exit at the top. In practice, this effect occurs through any natural openings in the lower and upper portions of the building and is influenced by the difference in temperature between the inside and outside of the structure. This flow of air is termed the stack action, and its effect will be greater within vertical arteries such as lift or service shafts. In a tall building the effect is quite substantial and the flow of air can often be clearly heard in the vicinity of such shafts.

A basic understanding of the principles of stack action is useful to the high-rise firefighter. With this knowledge, he will be in a position to utilise the natural effects of air-flow within a structure to his advantage, and by applying tactics that raise the Neutral Pressure Plane (NPP) in the building, he may alleviate severe conditions on the fire floor and aid firefighters advancing attack lines. (This topic was discussed further in Chapter 4.)

The Heating, Ventilating, and Air Conditioning system (HVAC) that is installed into the sealed infrastructure of a modern high-rise may also be highly influential in directing air-flows on the fire floors and its effect upon the fire itself may cause some concern. The design of such systems will vary and their objectives may conflict with the intentions of a progressive attack. The building engineer must be consulted at an early stage and an assessment of the system's effect upon the fire must be made during the initial approaches on the fire floor.

HVAC systems that continue to flow fresh air into the fire zone will intensify the fire and consideration should be given to localising the effect or shutting the entire system down. Other units that work on a central smoke extract principle will draw superheated combustion products into the ceiling plenum and create an air-flow towards the core, where the smoke-shaft is sited. This may increase fire spread throughout the floor and may lead to excessive amounts of heat being directed at the firefighters sited in the core. It is important for firefighters to check the plenum as they advance into a floor to prevent fire extending over their heads. The build-up of super-heated carbon monoxiode in the void could also lead to a smoke explosion.

Where an air-flow is naturally directed up stair-shafts, it should not be presumed that the effect will serve to relieve smoke conditions on stairs. As smoke and fire gases rise in a tall building, they will become cool and start to stratify at upper levels. A fire on the 12th level of a 50-storey building may present conditions on stairways where smoke has stratified at floors 15 to 23. Above and below these levels the stairs may remain fairly free of smoke contamination. If the problem is serious enough to distress occupants, either a cross or positive form of ventilation might relieve the situation.

'Q' Deck Flooring Creates Problems

The construction of modern high-rise buildings provides fire-tight compartments of concrete and steel. The sealed nature of the structure creates a build-up of heat on the fire floor that can be exaggerated by air-flows, as discussed above. This may give firefighters a false impression of the amount of actual fire on the floor and affect their confidence. An understanding of this effect will enable them to appreciate the situation, and prompt actions that will alleviate conditions.

The flooring system commonly found in these fire-tight compartments is termed by North Americans as the Q-deck. In this construction, a corrugated steel sheet is fastened to girders and beams for support. Concrete is then floated on the metal base and when it dries, the combination of the tensile strength of the concrete and the support of the corrugated metal serves to provide a floor of excellent stability. This method of construction is quick and economical. It is a much thinner floor than previously used, ranging between 2 and 3 ins in thickness.

When floating the concrete for the floor, it is common practice to install channels that will house electrical wiring runs when the floor is completed. When covered with wall to wall carpeting, the wiring is conveniently hidden from view. It is also easily accessible and economical to maintain.

Of concern to the firefighter is the effect of heat on the flooring from a fire below. This lighter construction is a good conductor of heat and the floor above the fire is likely to suffer to a great extent from off-gassing products of the wiring channels and carpeting. This will create a smoke-logged zone that will require searching and venting at an early stage.

Training and Simulations

The fire force that responds to a fire in a high-rise structure will function to effect as far as their pre-plan and training will allow them. If their preparation is based on tried and tested principles that have been regularly practised and updated their approach to each situation will be highly professional. As a fire officer, ask yourself these searching questions: If a fire occurred in your area today involving the 23rd level of a high-rise, would your firefighters be practised in carrying out a safe approach to the fire floor? Would they be aware of the difficulties of laying and advancing hoselines from cramped lobbies? Would your initial response be able to cope effectively with a lift failure? Would they assign personnel to check lift status, committing a scout-team above the fire floor to check lift cars? Would they take lift-keys? Would secondary responders be able to complete a systematic search of all upper floors with speed and efficiency? Could your stairwell support force maintain supplies? Think about it. . . .

High-rise *Aide-memoire*

(1) Communicate on route any exterior signs of fire.
(2) Initial pumper to position and prepare to feed/augment water supply system.
(3) Firefighters report to lobby, in teams, with associated equipment and call *lifts* to ground level.
(4) IC report to CACF (Fire Control Centre) to assess lift status, phased evacuation, HVAC, fire alarm indicator, building engineer, security report, building plans.
(5) Instigate exclusion zone at base of building as soon as working fire confirmed – Heavy pattern glass fall 30 m, minor pattern 100 m.
(6) Firefighter(s) assigned with radio link, (and CABA), to operate lifts in firefighter's shaft.
(7) Fire attack team make safe approach to reported fire floor, with pre-set equipment and CABA – BA Control report direct to staging.
(8) Scout-team sent above fire, via staging, (CABA), for reconnaissance purposes.
(9) Lobby control set-up, records to date.
(10) Staging team leave for staging post with associated equipment – donned CABA may be discarded at 'staging'.
(11) Responding chiefs assigned as detailed in ICS.
(12) Anticipate additional attack lines on fire floor and floor above, possibility of stairwell support, *evaluate strategy – assess resources.*

Chapter 8 – High-rise Fires – Bibliography

9:1 **Oleszkiewicz, I.** *'Vertical Separation of Windows Using Spandrel Walls and Horizontal Projections'*, NFPA's *'Fire Technology'* (November 1991) pp 334-340.

Left **– Tokyo firefighters in action at a residential tower block fire –** ***see Chapter 9***. *(Photo by Tokyo Fire Department)*. ***Below*** **– A flaked high-rise hose pack, as used by Los Angeles firefighters, consisting of two 50 ft lengths of 50 mm hose, with TFT automatic nozzle attached –** ***see Chapter 9***.

Left – The Churchill Plaza building, Hampshire, UK, stands blackened and scorched throughout the upper floors on the morning after the building was hit by fire, shown below *(Chapter 9)*.

Europe's tallest building, the Canary Wharf Tower, London. Are 150 mm rising mains adequate for a building of this size? North American codes would say not – *Chapter 9.*

Boston firefighters attend a routine call to 'Fire alarm actuating' in the city's downtown district. Note how many firefighters are wearing CABA – *see Chapter 10.*

The aerial power of a fire force should never be under-estimated. This fortunate resident is led to safety by Hong Kong firefighters, following a 3-alarm hotel fire where 54 others were also rescued – ***See Chapter 10.*** *(Photo by Hong Kong Fire Service).*

German firefighters in Frankfurt prefer the twin-cylinder CABA concept – ***see Chapter 10.*** *(Photo by Iveco Magirus).*

The mini-pumper is making a comeback. This particular version is run by the Metro Dade Fire Department in Florida – ***see Chapter 10.***

These fire trucks in Frankfurt are designed to run on either road wheels, or specially fitted track wheels – *see Chapter 10*. (*Photo by Iveco Magirus*).

Fire pumpers make an impressive sight against a backdrop of the Frankfurt, Germany skyline (*Photo by Iveco Magirus*).

•NB The photos in this book, unless otherwise credited, are by the author.

10 THE FUTURE

'The same reasoning may well apply to those who engage in the business of extinguishing fires, which requires much labour and patience, and an amount of constant never-ending self-sacrifice from which many other professions may be considered almost free.

'The best advice which can be given to those commencing is to go slowly, avoid enthusiasm, watch and study, labour and learn, flinch from no risk in the line of duty, be liberal and just to fellow-workers of every grade, not only the humble but those in the highest, who need liberality and justice most, take care not to wear the spurs before they are duly earned, and when they have been earned, wear them with humility, remembering that those who have the largest experience in extinguishing fires, frankly acknowledge that they fall far below their own ideal. This is not intended as the language of discouragement; it is simply that of practical caution, and if rightly read, may keep many a youthful fireman clear of the pitfalls which beset the calling – and they are many.'

Sir Eyre Massey Shaw, KCB
'Fires and Fire Brigades' 1889

It goes without saying that firefighting is a hazardous profession; statistics in the USA have established it as the most hazardous of all. Perhaps we can all relate to situations where colleagues have been critically or even fatally injured, and it is well within our interests to encourage any advancements in firefighter safety, as and when they occur.

During the past three decades there has been much progress in this area and firefighters are now able to enjoy the benefits of: (a) an increase in legislation that ensures minimum safety standards in the work-place; (b) an improvement in the levels of personal protection provided by the new generation of firefighters' clothing; and (c) a greater control of fireground operations as firefighters on scene are subjected to accountability systems.

However, there is still much that can be done to improve on standards of firefighter safety, particularly in relation to the use of CABA, communications systems, training, and hazardous materials. We must also be alert to the fact that current safety practices can, on occasions, work against the very principle for which they serve, to create unsafe situations in themselves. With this in mind, there is a necessity to constantly review various procedures to ensure that, in the light of new experience, their purpose is still fulfilled.

The Use of CABA

In many countries, and cities, it is now mandatory that firefighters don breathing apparatus as they leave the fire vehicle, unless they are specifically working in an area where smoke cannot affect them in any way, ie an MPO sited some distance from the fire. However, many fire authorities fail to endorse this golden rule and even though each firefighter is generally supplied with the protection of CABA, it is so often left in place on the engine. There are several reasons for this:

(1) In many instances, the CABA available to firefighters is too heavy and bulky to enable them to function effectively while carrying out certain tasks during the initial stages of a fire. These may involve laying hoselines, siting ladders, or carrying out difficult rescues on the building's facade. In such situations, firefighters will generally opt to forgo the wearing of CABA and as they move towards, or into, the structure they may find themselves operating under circumstances where it is not practical to immediately return outside to collect their CABA. This will often cause them to breath in smoke and fire gases.
(2) The design of the facemask of most CABAs causes a firefighter's vision to be severely restricted, sometimes affecting his field of vision by up to 50 per cent. In effect, its just like searching for victims with one eye closed!
(3) Where CABAs are not fitted with an effective speech facility, firefighters experience great difficulty in communicating with each other whilst operating inside a structure.
(4) The rigidity of some accountability systems will discourage, or even prevent, a firefighter from wearing a CABA as he dismounts from the engine. In Great Britain, the firefighter actually requires permission from the incident commander before using a CABA.

The physical demands that are sometimes placed upon firefighters have been the subject of many studies. It is generally acknowledged that the body may be subjected to varying levels of stress while fighting a fire, often causing excessive increases in a firefighter's blood pressure, heart-rate, and core temperature. The additional weight of protective clothing may total 25 kilograms (55 lbs), and this alone may reduce his physical efficiency by one-third! At long last, world standards are beginning to recognise this problem and set limits on the maximum allowable weight for CABA. However, do these limits go far enough?

The new pan-European CEN standard *EN137* stipulates a maximum of 18 kilograms (40 lbs), while Australian and US standards go even further, down to 16 kilograms (35 lbs). In the USA, the benefits of NASA space technology has led to the development of fully-wrapped composite cylinders. They are the next generation on from the light-weight hooped-wrapped versions and 12 litre (300 bar) cylinders are now available weighing just 9.6 kilograms (21 lbs). The majority of Swedish and German firefighters favour the twin-cylinder concept, where the weight is more evenly distributed across the wearer's shoulders, making this style far more comfortable on a weight for weight basis when compared to standard single-cylinder CABA. Additionally, they are not as bulky and firefighters are able to operate with a greater sense of ease and versatility.

The whole concept of firefighter accountability, at the scene of operation, is about to enter the computer age. For several decades the British system of BA control has been at the forefront of safe practice on the fireground. Other systems have evolved but none have come anywhere near matching the high standards set throughout the UK. However, on occasions the system has arguably proved somewhat inflexible in its operation and this has led to a conflict of interests. A good example of this might be in its application to incidents on the London Underground railway network where operational guidelines tend to conflict, creating much confusion among the fire force.

In many parts of the world it is unheard of for firefighters to enter fire buildings, wearing CABA, *without* a radio link to the outside. In the future, all CABA wearers will have radio contact with a control officer outside the building and point of entry control procedures will rely upon modern bar-code technology. The London Fire Brigade are looking to the future by evaluating a computerised CABA accountability system. The mobile unit, attached to the CABA facemask, has a head-up display which incorporates a series of coloured lights. Each light will illuminate to inform the wearer of cylinder contents (ie half duration, or safety margin reached), as well as a pre-set ambient temperature warning. The control PC situated outside has the facility to send all users an evacuation signal by illuminating all the lights in the wearer's head-up display in a flashing mode.

With such advances being made in breathing apparatus technology it is only a matter of time before *all* firefighters will be able to wear a CABA for protection, in the same way as a helmet and gloves are worn – at *every* incident.

As important as it is to control the entry of firefighters into a burning building, is monitoring their exit from the working environment of a super-heated structure. In the USA, it is becoming common practice for firefighters to receive a brief medical assessment immediately following their exit from a large fire, in order to evaluate their physiological state before committing them back into the operation. This programme entails a mobile medical unit responding to major incidents to ensure that firefighters are immediately able to return to the fireground. Where this is not the case, a rest and recuperation facility is on hand to allow firefighters to regain a sufficient state to continue at a later stage.

In a paper presented in 1987 *(Bibliography 10:1)* Frank Bowen, a former CABA instructor at the Fire Service College (England), described the symptoms commonly noted in firefighters who had surpassed the safe physical working limits during drills in the college's CABA training facility. The effects of heat stress were often seen to impair judgement in CABA wearers and the following principal signs were given as a guideline:

(a) Fixed stare of the eyes – eyes focused on one spot only, little or no eyelid movement.
(b) Lack of eye movement – the whole head is turned rather than the eye.
(c) Sluggish or no reaction of the iris/pupil to a local light source – the pupil may be dilated or constricted, the latter being more common.
(d) Slurred speech.
(e) Tingling in the extremities.
(f) Tremors in hands and feet.
(g) Respirations rapid and shallow.

I am aware of actual incidents where firefighters exhibited similar, or worse, signs and symptoms and were allowed to re-enter the structure in CABA without being medically assessed or advised to rest and recuperate on scene. This is a situation that cannot be allowed to develop and procedures along the American guidelines for on-site medical supervision at incidents where the working conditions are likely to lead to such events should be adopted.

Hazardous Materials

This is another area where safety standards should be a consideration of the utmost priority. It is also an area that is likely to be highly influenced by the computer age. In the USA, the fire service is recognising, often sadly with some hindsight, that

HAZMAT incidents cannot be taken lightly. It is a work load that will continue to increase for some years to come and the fire service must adapt quickly to meet the challenge. In Las Vegas, for example, the LVFD hazmat unit is equipped with all the latest high-tec equipment for dealing with a multitude of leaks or spillages. The on-board computer can evaluate, to precise detail, the potential for a chemical to create an exposure hazard in the city area and in *Figures 10:1* and *10:2* we are able to see the type of information that can be retrieved (in seconds), related to wind speed, direction, and humidity, etc.

Training

It has always been the case that a firefighter's safety on the fireground depends very much on a sound basis of training. In the past, he has also been able to rely on experience gained at fires to increase his awareness of the hazards of the profession. However, as the number of fires attended begins to decrease in future years the training aspect will become even more important.

There should be a greater emphasis, in future, on more realistic training, as experience gained through real fires reduces. The Swedish room fire simulator is a step in the right direction and there is no doubt that this concept will develop as the training potential is immense.

The entire profession will undoubtedly benefit where an exchange of views, and experiences, is encouraged. It is important to learn from the experience of others, and equally important that new experience is documented for future generations. One area of fireground experience that has failed to develop to any great extent is that of structural collapse at fires. While there have been several excellent books in the USA, and an equally informative paper *(Bibliography 10:2)* presented in the *Fire Engineers Journal* (UK) during the mid 1980s, there has been very little progression in both, training material, and pre-fire structural inspection programmes, for firefighters. The message in A. M. Grice's IFE paper on 'Structural collapse at fires' was clear: that a greater amount of information might have reduced or averted death and injury to personnel at several incidents. His research led him to realise that greater use should be made of risk-recording facilities, and such information should be available to the firefighter *on scene*. At times, his advice on structural safety appeared premonitory when, for example, several firefighters in Glasgow *(Bibliography 10:3)* narrowly avoided serious injury when a floor collapsed seconds before they were to enter the fire building. The hazard that resulted in the collapse had been clearly explained in Mr. Grice's paper just a few months before this incident but it was apparent that few were aware of his warning. His analogy of case history draws upon many important conclusions that we should *all* be made aware of. However, in the eight years that have passed since the paper appeared, there has been little, if any, progress in meeting the proposals outlined in Mr. Grice's work.

The Future

The fire service, just like any other comunity service, is expected to provide a high standard of cover that meets with economic appeal, ie it must be cost-effective. Recent advances in technological respects will necessitate an amount of re-structuring during the coming years. However, we should ensure an element of prudence where our forces are likely to be streamlined and strongly oppose any change that is likely to affect either firefighter safety, or the overall efficiency of the force.

It appears somewhat alarming that some fire authorities can allow a gradual demise in the provision of aerial power. During the past 25 years the hook *(pompiers*

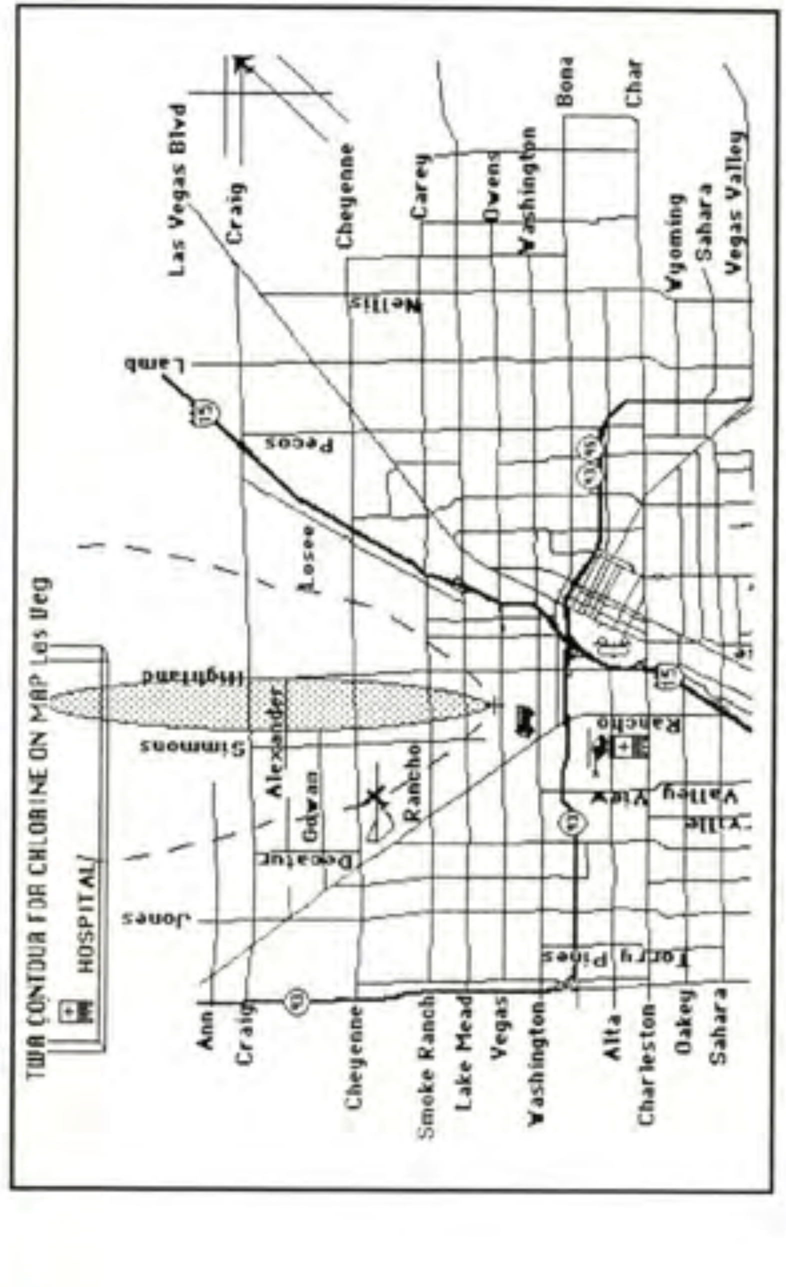


Figure 10:2 – Las Vegas HAZMAT information for a spillage of chlorine when defined on the map. It is clear to see where the 5.39 mile long vapour cloud is heading.

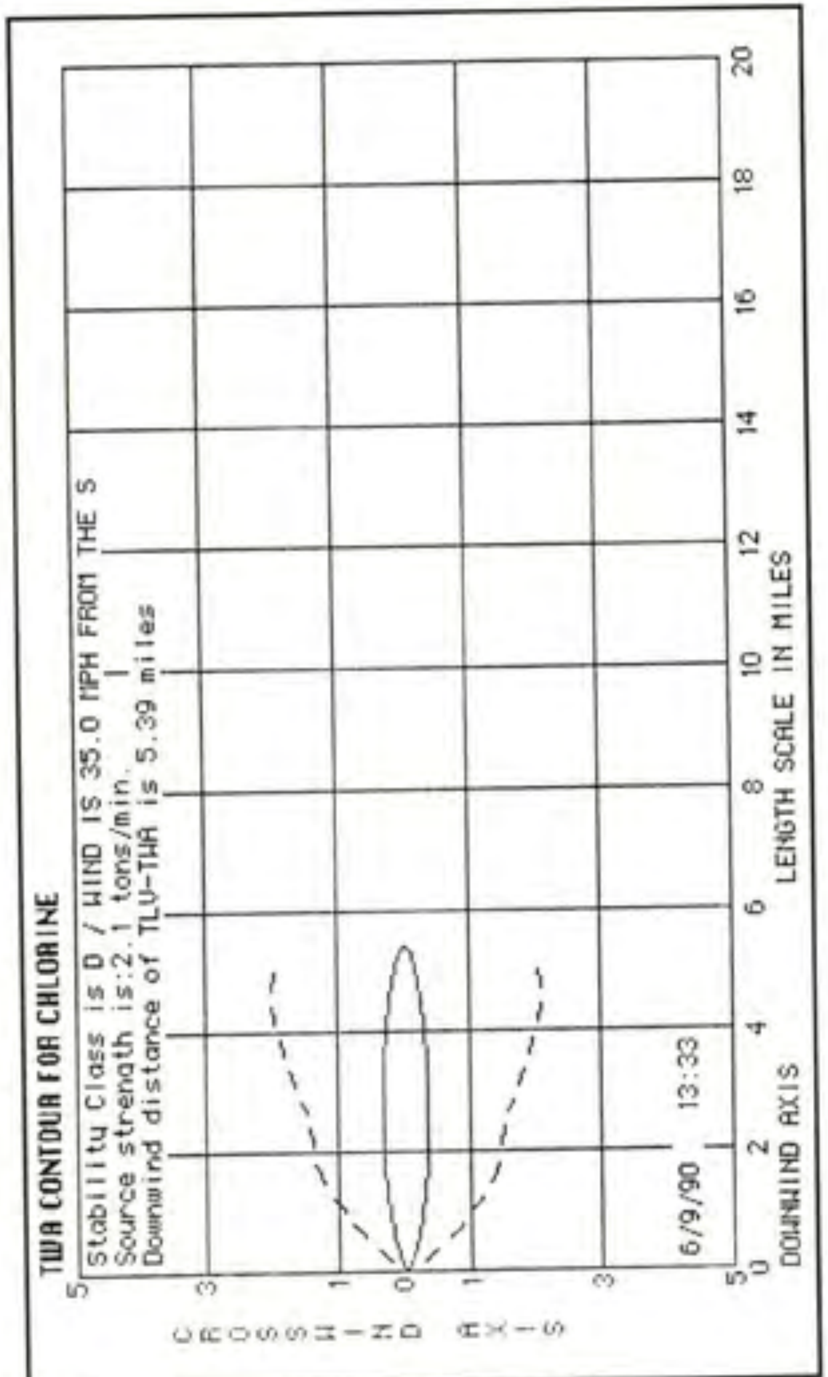


Figure 10:1 – Las Vegas HAZMAT information for a spillage of chlorine.

or scaling) ladder has begun to disappear from frontline pumpers around the world. Here was a ladder that enabled firefighters to reach those in peril on the upper floors of a building where side or rear access for conventional ladders was not possible, and yet this life-saver is now a dying breed – why? Now, it seems, there are those who are contemplating a similar reduction (in modern cities) in the aerial ladder/platform fleet. I urge such considerations to be strongly opposed for I feel that, in certain circumstances, the potential of the fleet is not being fully utilised. If one considers that the sole reason for having aerials is to rescue persons from the upper storeys of a burning building they should think again. If the aerials are not being 'worked' at incidents then this may be due to local strategy. Other than rescue, the main purpose of an aerial appliance should be for the siting of a roof team at an early stage of the operation. Such a role is discussed elsewhere in this book and I fail to see how any fire authority cannot recognise the potential of such a strategy on the fireground. I am not suggesting that *every* roof should be opened with power-saws, however, I am advocating that the provision of a roof team is an essential action at the majority of working fires in inner city buildings, for the purposes of rescue, assessment, and ventilation operations should they be urgently required. Any suggestion of drastically reducing the aerial power of a fire force clearly displays a mis-comprehension of the potential for such equipment.

However, there is a strong argument for a complete restructuring of some pumper fleets and it seems the 'mini-pumper' is about to make an appearance on the scene, following several trials over the past few decades. The concept is certainly not new but the timing appears right and the fire departments in Dallas, Metro Dade, and Paris are among several who are now using mini-pumpers as part of their fleet. It is important that the introduction of such appliances does not serve to reduce manning below 'safe' levels. The Dallas Fire Department undertook a detailed study into minimum manning levels during the mid 1980s *(Bibliography 10:4)* and their findings indicated a distinct correlation existed between staffing level and performance quality. As a general rule the study indicated that staffing below a crew size of four can overtax the operating force. In some instances, for specific tasks, a crew of five would have been more appropriate. These figures are in direct relation to the 'standard' crewing levels noted throughout the author's own research, as can be seen in Chapter 1.

The next ten years will see major changes to the structure of the fire service, both in the way it is made up, and in its approach to achieving its objectives. Let us, as firefighters, ensure we get it right, for it will be easy to structure 'down', but almost impossible to re-structure back 'up'.

Chapter 10 – The Future – Bibliography

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10:3 **Lavery, D.** – 'Build-up of Floor Layers Almost Led to Tragedy at Cafe' – *Fire* Journal (December 1984, page 21).
10:4 **McManis and O'Hagen** – 'Dallas Fire Department, Staffing Level Study' – June 1984.

'. . . to do this work properly, a fireman must be strong, active, quick, fearless and intelligent; but above all, he must be resolute.'

Sir Eyre Massey Shaw, KCB
Chief Officer, Metropolitan Fire Brigade (London)
June 1861 – October 1891

GLOSSARY

AERIAL – Either an aerial ladder or platform.
APPLICATION RATE – Defined in Chapter 3.
ATTACK LINE/HOSE – The line of hose used from the delivery side of the pump to mount an attack on the fire.
BACKFIRING – A technique used to control major brush fires, where a controlled burn of limited size is initiated ahead of the main fire to burn 'back' towards it, creating a firebreak.
BALLOON-FRAME – A form of construction, popular in the USA. It normally entails a large number of void spaces within the walls and floors of the structure that create a rapid fire spread through a lack of 'fire-stops'.
BOOSTER LINE – Also termed hosereel in many parts of the world. Normally a 19-30 mm diameter line of rubber tubing used to apply water-fog at high-pressure.
CABA – Compressed Air Breathing Apparatus.
CAVITATION – Caused where air is drawn into the pump and compressed before being discharged, causing a rattling sound at the pump and a 'popping' sound at the nozzle as the air expands again. This may be a result of over-running the hydrant supply and the condition may lead to damage in the pump casing.
DELIVERY – Discharge port.
DELIVERY RATE – Defined in Chapter 3.
DIRECT ATTACK – Defined in Chapter 3.
DISCHARGE PORT – Delivery outlet on a pump.
DOSAGE – An 'application rate' measured in l/sq m (or gallons/sq ft).
DRAFTING – An American term for creating a vacuum in the pump – to lift from open water, or occasionally to create a 'suction' effect on a hydrant.
FIRE FORCE – A group of firefighters representing their department or brigade.
FIRE-FRONT – A high level of flames merged together to create a 'wall' of fire.
FLOW-RATE – Defined in Chapter 3.
GPM – Gallons Per Minute – which, for the purposes of this text, are US GPM (all calculations relate to the US gallon).
FREEMAN'S FORMULA – Mr John R. Freeman noted that a fire stream provided its greatest horizontal range when directed at an angle of 32 degrees. A formula, derived empirically from his experiments and based on this 32 degree angle, was developed to calculate maximum horizontal ranges of various fire streams as follows:

$S = \frac{1}{2}NP + 26$

Freeman's formula is applicable where nozzle pressures are over 30 psi, using a ¾ ins nozzle where:

S = horizontal distance in ft
NP = nozzle pressure in psi

For nozzle diameters in excess of ¾ ins, add 5 to the 26 for each ⅛ ins increase in nozzle diameter.
HIGH-PRESSURE – Pump pressures in excess of 10 bars (150 lbs psi).
HOOK LADDER *Pompiers* or scaling ladder used to scale a structure from window to window, by use of the hooked end.
HOOP FORCE – The 'outwards' pushing pressure inside a charged hoseline.
INCIDENT COMMANDER (IC) – The Officer in Charge of an incident is the IC.
INDIRECT ATTACK – Defined in Chapter 3.
INTAKE – The inlet to the 'supply' side of the pump.

MAKE-UP – A major working fire requiring additional alarms.
MPO – Motor Pump Operator.
OFFENSIVE FOG ATTACK – A technique, first utilised in Sweden, of applying water fog with a pulsating effect at the nozzle. This enables the maximum cooling effect of the fog to be gained in the super-heated fire gases.
OVERHAUL – The damping down and turning over of debris stage, after the main fire has been extinguished.
PAVEMENT LIGHT – A glass window, or concrete mounted glass 'blocks', sited in, or near, the pavement (sidewalk) to give light to a basement area.
PLENUM – The void above a false ceiling, that serves as a reservoir to collect and channel air into the air movement plant of a conditioning system in a sealed structure – such as a high-rise building.
PULLING A VACUUM – An American term for creating a vacuum in the pump, generally to apply a 'suction' effect on a hydrant in an attempt to flow more water.
PUMP – European term for pumper.
PUMPER – American term for pumping appliance.
QUAD – A multi-purpose pumper, common in Europe, Australia, New Zealand, Hong Kong, etc, that carries a selection of ladders up to 15 m in length.
QUINT – A combination pumper and aerial.
QUICK WATER – A technique, popular in Europe, of siting the initial attack pumper directly adjacent to the fire building, while utilising its water tank supply to allow a prompt attack to be made on the fire.
SOPs – Standard Operating Procedures, the written strategy of a fire department.
SUPPLY LINE – The line of hose that arrives at the intake of a pumper.
TURNOUTS – The protective clothing a firefighter wears to an incident, ie helmet, coat, leggings (pants), boots, gloves, and perhaps a flash-hood.
VENETIAN LADDER – Popular in Italy – a ladder where the top is narrower than the base. The ladders have connecting braces that can be coupled together as a firefighter climbs upwards.

□ □ □

APPENDIX I

Metric conversion chart

to convert	*to*	*multiply by*	*divide by*
inches	centimetres	2.540005	0.3937
feet	centimetres	30.48006	0.0328083
feet	metres	0.3048006	3.28083
yards	metres	0.914402	1.0936109
miles	metres	1609.3419	0.0006213
miles	kilometres	1.6094319	0.6213327
square inches	sq. centimetres	6.451626	0.1549996
square feet	sq. centimetres	929.03414	0.0010764
square feet	sq. metres	0.0929034	10.76387
square yards	sq. metres	0.8361307	1.1959852
square miles	sq. kilometres	2.5899985	0.3861006
cubic inches	cu. centimetres	16.387156	0.0610234
cubic feet	cu. metres	0.028317	35.31447
cubic yards	cu. metres	0.7645559	1.307943
cubic inches	mililitres	16.387156	0.0610234
fluid ounces	mililitres	29.57	0.033818
cubic inches	litres	0.0164	60.9756
cubic yards	litres	765.00	0.001308
pints	litres	0.473167	2.113419
quarts	litres	0.946333	1.0567
gallons	litres	3.785332	0.2641776
ounces	grams	28.349527	0.0352739
pounds	grams	453.592435	0.0022046
pounds	kilograms	0.4535924	2.2046224
pounds	metric tons	0.000453	2204.6223

Bar and US Gallons

1 bar	=	14.5 lbs psi
1 bar	=	100 KPa
1 bar	=	10 mWG
Imperial Gallon	=	1.2 US Gallons

(NB: All gallons per minute (GPM) references throughout the text are in US GPM).

About the book:

FOG ATTACK offers a unique international view of firefighting strategy and tactics.

Written by a firefighter with over 20 years of fireground experience, the book explores the approaches to firefighting made by fire services in cities such as Tokyo, London, New York, Paris, Chicago, Hong Kong, Los Angeles and Singapore.

The title FOG ATTACK reflects the current advances being made throughout Europe, especially in Scandinavia, in relation to the 'new wave' of water fog equipment being utilised in structural firefighting. Author Paul Grimwood predicts an increasing awareness of this unique approach during the 1990s, and describes in great detail the developments to date.

Other chapters cover such vital aspects of firefighting as force deployment, water supplies, ventilation, search and rescue, and smoke explosions.

This book is a must for firefighting professionals throughout the English-speaking world.

About the author:

Paul Grimwood has been a firefighter since 1971, having served in the busiest areas of the West Midlands, Merseyside and London. He is currently serving at a fire station in the heart of London's West End.

In the mid 1970s he spent two years in the USA and during this period served as a firefighter in New York.

Since 1979, he has spent much of his time studying international firefighting techniques and has presented papers for the national fire journals on a regular basis. He is currently a columnist with 'Fire' magazine in Britain.

FOG ATTACK is edited by Simon Hoffman, Deputy Editor of 'Fire' magazine.