Inventing Supersonic Flight: A Historical Perspective

Richard P. Hallion

SFTE Coastal Empire Chapter
Savannah, Georgia
24 Jan 2018
Aircraft Progression: The Simple View

Kitty Hawk Through the Early Supersonic Era 1903-1956
...From Subsonic to Supersonic...

Deperdussin Monocoque

Douglas DC-1

Boeing 707

Lockheed Blackbird

Photographs courtesy The Boeing Company, NASA Dryden Flight Research Center, and the Musée de l’Air et l’Éspace, Le Bourget
...Speed by Function...

- PISTON FIGHTERS
- PISTON AIRLINERS and BOMBERS
- ROCKET AIRCRAFT
- JET FIGHTERS
- JET AIRLINERS and BOMBERS

Plateau
AN OSTESENSIBLE “PLATEAU”, BUT A REVOLUTION IN CAPABILITIES!

(JET AIRLINERS)
COMPOSITES; LARGE FANJET;
T/W = 1+; DFBW; STEALTH;
SUPERCRITICAL WING; GPS;
UAV; SENSORS; C4ISR; ETC.

(JET FIGHTERS)

AND NEXT?
Postwar High-Speed Expansion

ONLY POSSIBLE BY INTENSIVE RDT&E

FRAMED SUBSEQUENT ACCOMPLISHMENTS

FULLEST POTENTIAL NOT FULLY ATTAINED EVEN TODAY
...In the Beginning...

10:35 a.m., 17 December 1903,
Kitty Hawk, North Carolina

NMUSAF
...Europe Races Ahead...
(A 1912 Perspective)

Deperdussin
“Monocoque Racer”

Top Speed: 108 mph
Musée de l’Air et l’Éspace Photo

Wright Model D
“Speed Scout”

Top Speed: 67 mph
National Museum of the USAF Photo
1919: The Birth of the Modern Airplane...

Junkers F 13 Transport

NMUSAF
...Influences Advanced Aircraft Design...

Verville-Sperry R-3 Racer, 1923

NMUSAF
...However, Limited Performance...

Atlantic-Fokker C-2 Trimotor, 1927
...Necessitates Engine Integration Research...

Curtiss AT-5A with NACA Cowling, 1928
...Benefiting the Air Transport Revolution...
...By the Late 1930’s...

Douglas DC-3 (1936)

U.S. airliners are the world’s standard
Explosive growth in aviation industry
U.S. the leading exporter of aircraft
...Thanks to the Maturity of the Piston Engine...

P&W R-2800 radial engine
But...An Approaching Revolution
1919: Year of Transonic Discovery

Source: NACA Report 83 (1919)
1926...The Rocket Revolution...

Robert Goddard, 1926

Opel Rak-1, 1929

V-2 on Transporter, 1944
Onset of the Compressibility Crisis

Figure 25. - Wind tunnel choking Mach number.

Source: John Stack, NACA working paper, 9-16-44, NASA HD
Stack Proposed Research Airplane, 1931

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuselage diameter</td>
<td>40 in.</td>
</tr>
<tr>
<td>Wing span</td>
<td>29.1 ft.</td>
</tr>
<tr>
<td>Wing area</td>
<td>141.2 sq.ft.</td>
</tr>
<tr>
<td>Wing chord (average)</td>
<td>4.85 ft.</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>6</td>
</tr>
</tbody>
</table>

Busemann and 1935 Volta Conference: Advent of the High-Speed Sweptwing

Busemann and 1935 Volta Conference: Advent of the High-Speed Sweptwing

Abb. 5. Pfeilförmiges Tragwerk.

Denn die Dichte \( \rho \) und die Schallgeschwindigkeit \( c \) werden von der Schrägestellung des Tragflügels gegenüber der Windrichtung nicht betroffen.

2. Pfeilförmige Tragwerke.

Beid den ebenen Strömungen ergab sich, daß die besten Gleitzahlen bei bestimmten Machzahlen erreicht werden, die wenig über der Schallgeschwindigkeit liegen. Es wäre bedauerlich, wenn damit das letzte Wort über die günstigsten Gleitzahlen überhaupt gesprochen wäre. Nun zeigt die Gleichung (25), daß sich die wirksamen Machzahlen durch Schrägestellung der Tragflügel erniedrigen lassen. Es müßte daher lohnen, allgemein die pfeilförmigen Tragwerke (Abb. 5), auf ihre Gleitzahl bei Überschallgeschwindigkeit hin zu untersuchen.

Die Pfeilform der Tragwerke ist schon dadurch günstig, daß die Druckwirkungen in der Richtung des Auftriebes voll zur Geltung kommen, während sie in Richtung des Widerstandes nur mit einer Komponente in die Flugrichtung fallen (vgl. Abb. 4). Wenn man nun durch die Verringerung der wirksamen Machzahlen größere Flächenbelastungen bei gleichen Anstellwinkeln oder gleiche Flächenbelastungen mit geringeren Anstellwinkeln erreicht, wird der Einfluß der Schubspannungen der Reibungsschicht relativ geringer. Absolut kann man natürlich die Reibung durch die Pfeilform nicht beeinflussen.

Das zylindrische Strömungsfeld um den schräg angeblasenen Tragflügel (Abb. 4) kann man nach diesen Überlegungen soweit in eine ebene Strömung verwandeln, als es sich um die Berechnung der Druckkräfte auf den Tragflügel handelt. Die achsiale Geschwindigkeitskomponente fällt für die Erzeugung von Drücken völlig fort. Sie ändert jedoch die Bezugsgrößen der Strömung. Man muß bei einer Schräganblasung um den Winkel \( \varphi \) unterscheiden den wirklichen Staudruck \( q_0 \) der Strömung und den wirksamen Staudruck \( q \), der die achsiale Komponente der Anblasgeschwindigkeit nicht einhält. Zwischen beiden besteht die Beziehung:

\[
q = q_0 \cdot \cos^2 \varphi \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (24)
\]

Genau in gleicher Weise gibt es eine wirkliche Machszahl \( M_0 = \frac{v_0}{c} \) und daneben eine wirksame Machszahl \( M = \frac{v}{c} \) mit der Beziehung:

\[
M = M_0 \cos \varphi \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (25)
\]
A-4b: First Supersonic Winged Vehicle

1940 Tunnel Test of Winged A-4

A-4b, M = 4+, Jan. 24, 1945

AF AEDC Photo

NMUSAFA
Touching the Sonic Frontier

Curtiss P-36, 1937

NASA
...but not without loss...

Messerschmitt Bf 109B: Kurt Jodlbauer killed 17 July 1937
...and America was not immune...

Lockheed YP-38 Lightning: Ralph Virden killed 4 Nov. 1941

NASA
Early NACA Dive Trials

Brewster XF2A-2 Buffalo, NACA LMAL, 1940
“Normative” Subsonic Aircraft Design

North American XP-51 Apache (later Mustang)
Understanding Transonic Limitations

Source: NACA Technical Note 1190 (1944)
...Stopgap Research Methodologies...

Accelerated Wing Flow Research Model
...Stopgap Research Methodologies...

Transonic Drop Models

Fig. 3.
Representative trajectories for free-fall model.

...Stopgap Research Methodologies...

Rocket-Boosted Models

Trajectory data for a typical zero-lift type rocket-powered model.

Convair YF-102 Model, 29 Jan 1954
NACA PARD, Wallops Island

Source: John Stack, Experimental Methods for Transonic Research, 1951.
...The (Unexpected) Arrival of the Jet Age...

Heinkel He 178 (1939)

Gloster E.28/39 (1941)

Bell XP-59A (1942)

Messerschmitt Me 262 (1944)
Lockheed YP-80A, NACA Ames Aeronautical Laboratory, 1945
The Miles M.52 Project (E. 24/43)

Afterburning Turbojet

All-moving Horizontal Tail

Thin Bi-convex Wing

Cancelled Spring 1946

Cancellation was a major mistake, and resulted in a serious setback to British transonic/supersonic RDT&E
27 Sep 1946: The “Sound Barrier” bites...

de Havilland D.H. 108 Swallow
The American “X-series” Origins

• 18 Dec 1943: W. S. Farren (RAE) meets at NACA with senior US aero R&D leaders, and Bell’s Robert Wolf proposes transonic research aircraft

• 16 March 1944: NACA LMAL meeting marks origins of a two-fold approach by Navy and AAF, both relying on NACA for technical support and guidance.
The Navy-NACA Approach: Jet-Propelled

Douglas D-558 Skystreak Design Concept, 1945
The AAF Approach: Rocket-Propelled

Ezra Kotcher’s “Mach 0.999” Study, 1944
The XS-1: A Pragmatic Design

- Straight Wing (8% or 10% t-c)
- 18 g load limit
- 0.50 cal. body shape
- Adjustable horizontal tail
- 500 lb instrument package
- Intended for ground takeoff
XS-1 Inboard Profile

INBOARD PROFILE
PRESSURIZED FUEL SYSTEM
XS-1
Reaction Motors XLR 8/11 Engine

Reaction Motors Inc. XLR-11 6,000-lb Thrust 4-Chamber Rocket Engine

NMUSAFA
...A Flying Wind Tunnel & Loads Lab...
Contractor Glide and Powered Tests

Launch of XS-1 #2, 1946
XS-1 USAF-NACA Test Team

L-R: Joe Vensel, Gerald Truszynski, Chuck Yeager, Walt Williams, Jack Ridley, De Elroy Beeler
XS-1 and Supersonic Data Trace, 14 Oct 1947
The Avis Airplane...

Douglas D-558-1 Skystreak

NASA
Why Not a Sweptwing XS-1?
Initial American Sweptwing Flight Research

Bell L-39 no. 1 at LMAL, c 1946-47

Figure 1.- Three-view drawing of test airplane.
Whither the D-558 Program?

NACA Sweptwing Concept...

D-558-2 Baseline Configuration...
D-558-2 Flight Test Evolution

Douglas D-558-2 flush canopy, Jet Propulsion, Ground Take-Off, RATO Assist

Douglas D-558-2 high-speed canopy, All-rocket Propulsion Air-launch from Boeing P2B-1S
The 1st Mach 2 Piloted Flight,
A. Scott Crossfield, 20 Nov 1953, M = 2.005

Douglas D-558-2 no 2 “NACA 144” on Rogers Dry Lake, 1954

NASA
Initial US Application of the Sweptwing

North American F-86A Sabre  Boeing B-47A Stratojet
The Heirs of the XS-1

Clockwise: X-1A, D-558-1, XF-92A, X-5, D-558-2, X-4, center X-3 (1953)
The First Mach 3 Airplane

Bell X-2 no 1 (46-674) at AFFTC, 1956
...First Military Supersonic Designs...
The F-100: A Troubled Design

North American F-100A Super Sabre SN 52-2754, 1954-55
The F-100...

F-100A SN 52-5761, original short-fin

The difference in tail shape...

Final Fin, F-100A, SN 52-5778
The F-101: The Limits of the T-tail

McDonnell F-101A Voodoo SN 53-2434 c 1957
The F-102: Area Rule Pioneer

Convair F-102A Delta Dagger SN 55-3372 c 1956
Before and After…

YF-102 without Whitcomb Area Rule

After Area Ruling
The F-104: Deadly Glamour

Lockheed F-104A Starfighter SN 56-0734, AFFTC, 1960
Republic F-105: Supersonic Strike
...America’s Postwar Air Supremacy...

- Global Reach
- Global Power
- Naval Superiority
- Mach 3+ Cruise
- Hypersonics
- Stealth
Questions?

Dr Richard P Hallion
DrHypersonic1@Hotmail.com
Richard.Hallion@floridapoly.edu
Inventing Hypersonic Flight: A Historical Perspective

Richard P. Hallion

SFTE Coastal Empire Chapter
Savannah, Georgia
24 Jan 2018
Over A Half-Century of Flight Test…

The Confluence of Air and Space

Missile/Space Projects
Aeronautics R & D Projects
Hypersonic Test Projects
Hypersonic Studies

What Was Accomplished

• **We Refined Design Approaches**
  – For Aircraft, Missiles, and Aerospace Craft

• **We Mapped the High-Speed Frontier**
  – From Mach = 0.75 to Beyond Mach = 27

• **We Achieved Notable Milestones**
  – Including True “Transatmospheric” Operations
Sänger-Bredt *Silbervögel*

Source: *Über einen Raketenantrieb für Fernbomber* (1944)
The Hypersonic Transfer from Europe

H. S. Tsien Mach 10+ Hypersonic Boost-Glider (1949)

L/D = 4
96,500 lb. GLOW
(inc. 72,400 lb. fuel)
Length: 78.9 ft.
Wingspan: 18.9 ft.
Height: 16.5 ft.
“Round Two:” The X-15
X-15 Simulation and Crew Protection

X-15 Proficiency and Planning Simulator

Neil Armstrong
and Clark MC-2
Pressure Suit
The Becker Hypersonic Study, 1954

- Lower fins in folded position
- Motor accessory section
- 3 Hermes A-1 rocket motors
- Split flaps
- Aileron
- CG
- Tank
- 21.0 ft
- 5 ft dia
- 25.0 ft

Specifications:
- Weight (no fuel): 12,000 lb
- Weight (with fuel): 30,000 lb
- Wing area: 250 sq ft
- Wing aspect ratio: 3.0
- Wing taper ratio: 0.14
- Fuselage volume: 796 cu ft
- Tank volume: 410 cu ft

Sections:
- Section A-A
- Typical wing section

Dimensions:
- Total length: 47.5 ft
X-15A-2: $M = 6.70$, 3 Oct 1967

Maj. William J. Knight and the X-15A-2
It is well known that for any truly blunt body, the bow shock wave is detached and there exists a stagnation point at the nose. Consider conditions at this point and assume that the local radius of curvature of the body is $\sigma$ (see sketch).

The bow shock wave is normal to the stagnation streamline and converts the supersonic flow ahead of the shock to a low subsonic speed flow at high static temperature downstream of the shock. Thus, it is suggested that conditions near the stagnation point may be investigated by treating the nose section as if it were a segment of a sphere in a subsonic flow field.
Early Ames Blunt Body Research…

Conventional

Initial Concept

Missile Warheads

Manned Studies

NASA Photo
Eggers-Syvertson Flat Top Concept (1956)

Hypersonic L/D = 6.8

High Heat Loading

High Structural Weight

NACA-Langley *Hywards* Study (1956)

*Hywards* “flying” in the NACA LMAL Full-Size Tunnel
Ames Flat-top vs. Langley Flat-bottom

“Heavy”
TPS-driven Structural Weight versus Speed

“Light”

Graph by Peter Korycinski, from J. V. Becker, “Development of Winged Reentry Vehicles” (1983)
Eggers Syvertson Flat Top Concept (1956)
Dyna-Soar: The Lofted Boost-Glider

- Minimal Turn
- Flat Bottom
- Slender Delta
- Sloped Aft End
- Radiative Cooled
- Blended Controls
- Skid Landing Gear

NMUSAF Photo
Simulation: Claims versus Realities

“A number of fundamental problems must be solved before the SCRJ can be considered feasible. The major unknown is whether or not supersonic flow can be maintained during a combustion process. However, the trends developed herein indicate that the SCRJ will provide superior performance at higher hypersonic flight speeds.”

Republic Aviation Design Concepts

Kartveli Mach 7 Hypersonic Strategic Cruiser
...Aerospaceplane...
McDonnell ASSET

(Aerothermodynamic-Structural Systems Environmental Tests)

Winged, flat-bottom, half cone-cylinder, radiative cooling

Thor-lofted over Eastern Test Range

Mach 15.5  July 22, 1964
Martin SV-5D PRIME
(Precision Recovery Including Maneuvering Entry)

Lifting body, flat bottom, ablative cooling

Mach 27  Apr. 19, 1967

Atlas-lofted over Western Test Range
...The NASA-USAF Lifting Bodies...

X-24A 1969

X-24B 1973

M2-F1 1963

M2-F3 1970

HL-10 1966

USAF

NASA
The “X-24C”

...inspired National Hypersonic Flight Research Facility (NHFRF)
The Path to Shuttle

Dependency upon Laboratory Methodologies
STS-1

...first winged hypersonic reentry from orbit of an inhabited spacecraft

Space Shuttle Columbia
Apr. 14, 1981
John Young and Robert Crippen, NASA
...Post-Shuttle Boost-Glide Transatmospherics...

Boeing X-37B launch... ...and Recovery...
Return of the Air-Breather: NASP (X-30)

As Conceived...

- duPONT SUPPLIED GOVERNMENT BASELINE DESIGN 1983
- 50,000 POUND TOGW CLASS
- EXISTING MATERIALS
  - NICKEL ALLOYS
  - GRAPHITE COMPOSITE TANK
  - CARBON LEADING EDGES
- SCRAMJET
  - PERFORMANCE SUPPORTED BY ANALYSIS AND SHOCK TUNNEL
- RAMJET
  - PERFORMANCE SUPPORTED BY HYPERSONIC RESEARCH ENGINE TEST DATA
- ACCELERATION ENGINE
  - U.S. PATENT ISSUED TO A. duPONT
  - PERFORMANCE VERIFIED BY GASL AND PW TESTS
- DRAG LEVEL VERIFIED
  - NASA WIND TUNNEL TESTS
  - BOEING SUPPLIED MODEL
...NASP: Test Range Challenges

“Local” Ground Track...

Envelope Expansion...
X-30 NASP when Shelved...

Advanced Avionics
Cryo Tank/Structure
Slush Hydrogen
Advanced Materials
Advanced Aerodynamics
Airbreathing Propulsion
Actively Cooled Structure
Control System Integration

450,000 lbs TOGW
An Alphabet-Soup of Programs...
On 30 July 2002, the Center for Hypersonics, University of Queensland, Australia achieved the world’s first inflight scramjet ignition, at Mach 7.6, a “world’s first”…
False Starts...

X-33

X-38

X-34
...Cautionary Tales...

X-43

Blackswift

HyFly

HTV-2
X-43A: First Scramjet Validation

X-43A Checkout at DFRC

LRC Engine Test at M = 7

M ≈ 9.7, 11/16/04

M = 6.8, 03/27/04

U.S. Army IR Image

NASA Photos
The X-51: Towards Practicality

Cruiser length: 168 inches
Overall Stack length: 301 inches
Cruiser max width: 23 inches

Stack Gross Launch Weight: 3,884 lbs.
Cruiser Launch Weight: 1,426 lbs.
JP-7 Fuel Weight: 270 lbs.

$240 million
5 minute flights
1st Flight 2010

SOURCE: AFRL
X-51 Flight Test
X-51 Flight Test

May 26, 2010:

X-51-1 accel. to M = 4.87

…the “Kitty Hawk Moment”
X-51 Flight Test

May 1, 2013:

X-51-4 accel. to M = 5.10

...the “Not a Fluke” flight
A Possible Future—but Will It be Ours?

LONG-RANGE MOBILITY RATES SINCE 1800

MIGHT WE NOT ENTER THE 22ND CENTURY AT 6,000 MPH??
Questions?

Dr Richard P Hallion
DrHypersonic1@Hotmail.com
Richard.Hallion@floridapoly.edu