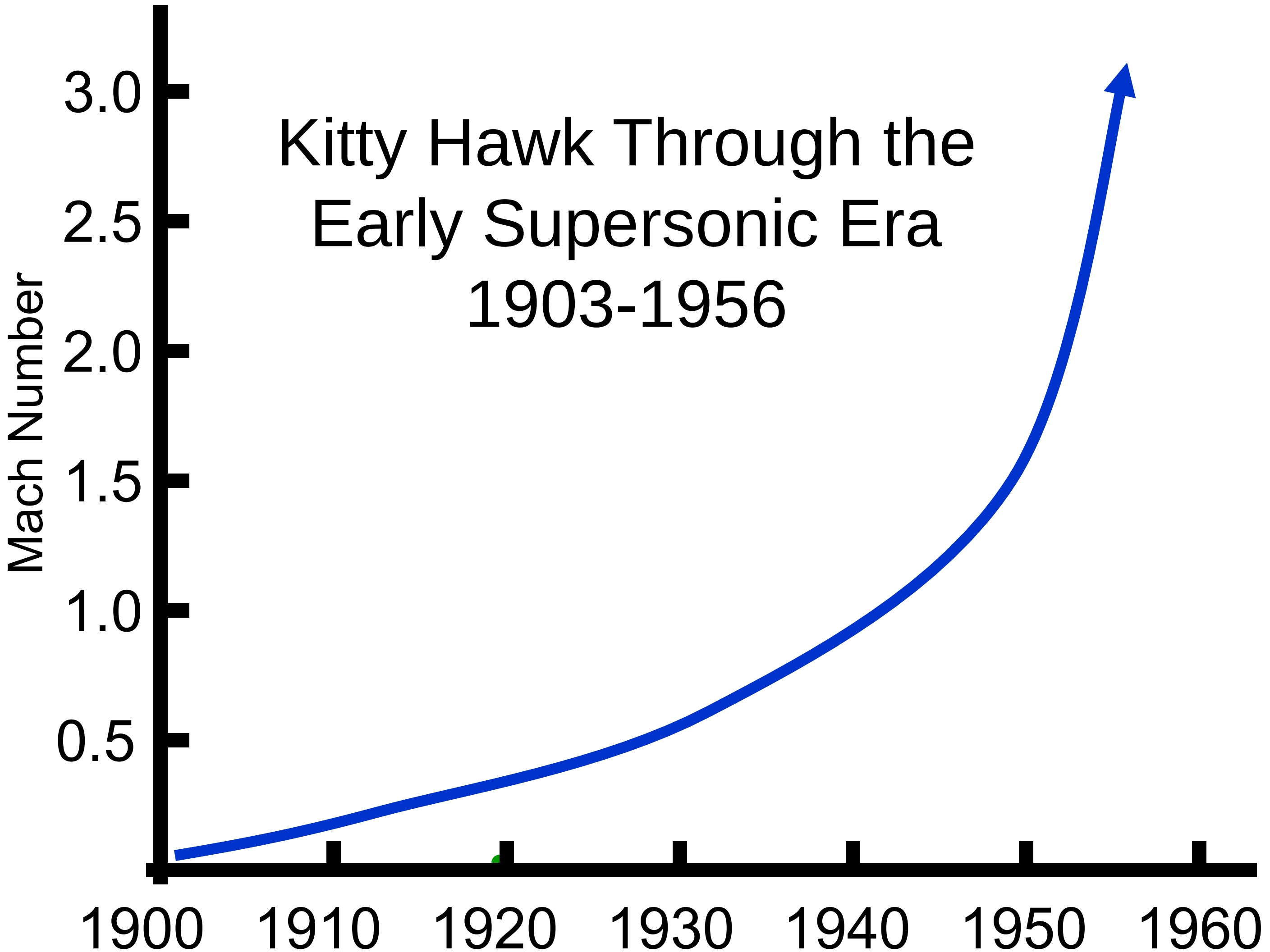
Inventing Supersonic Flight: A Historical Perspective

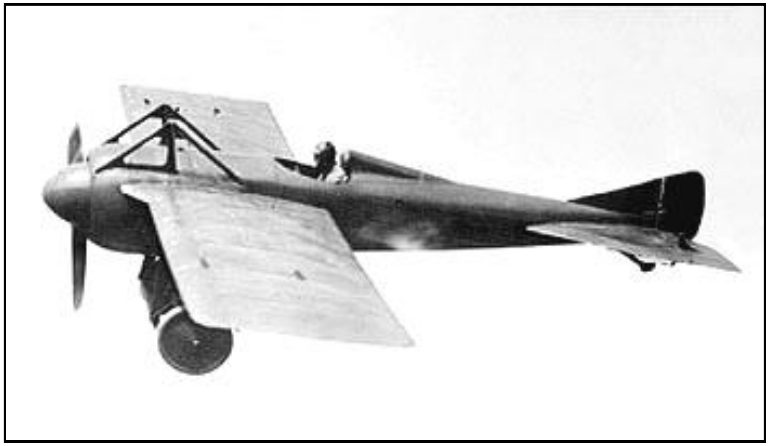
Richard P. Hallion

SFTE Coastal Empire Chapter
Savannah, Georgia
24 Jan 2018

Aircraft Progression: The Simple View



…From Subsonic to Supersonic…



Deperdussin Monocoque

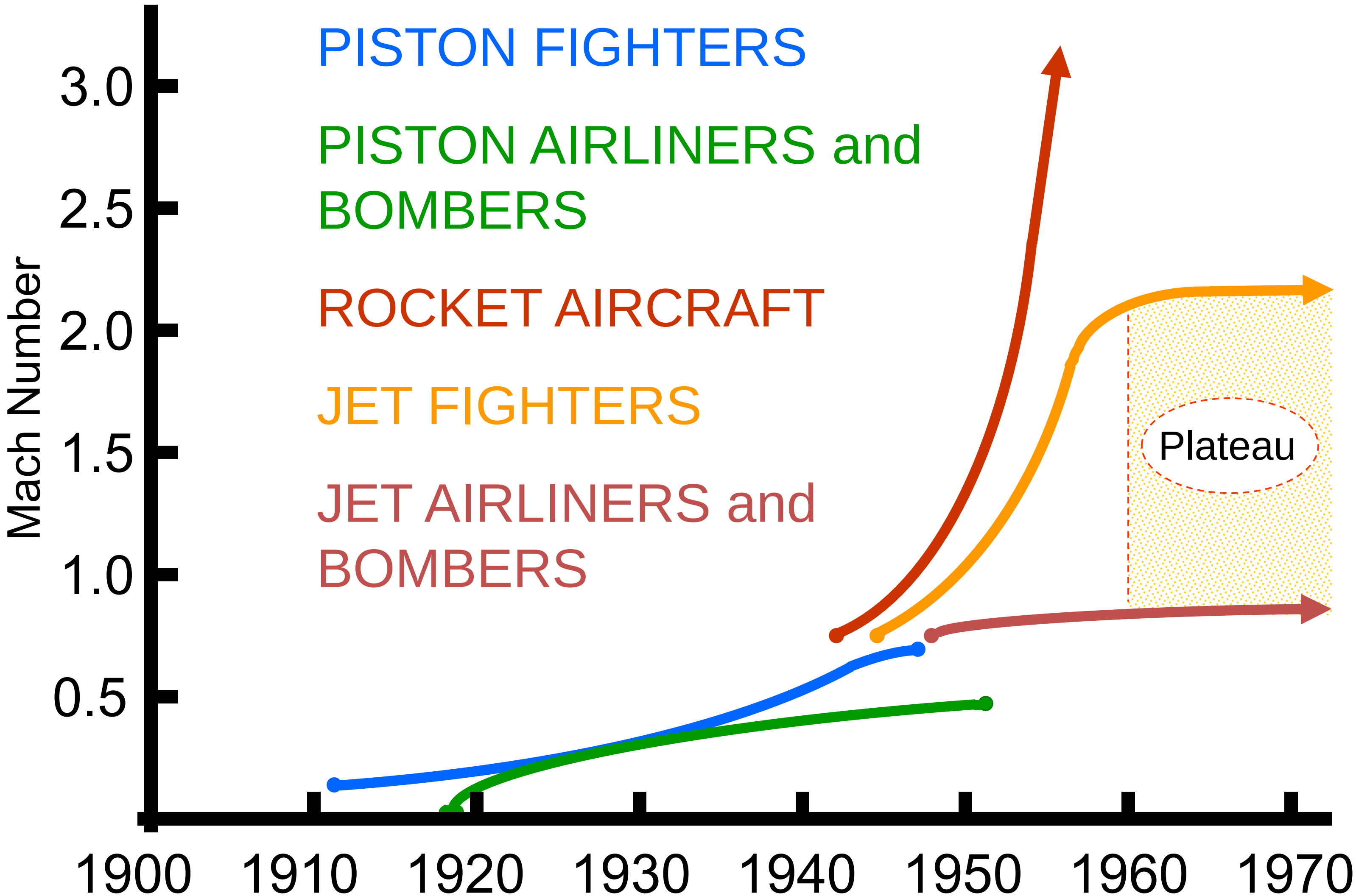
Douglas DC-1

Boeing 707

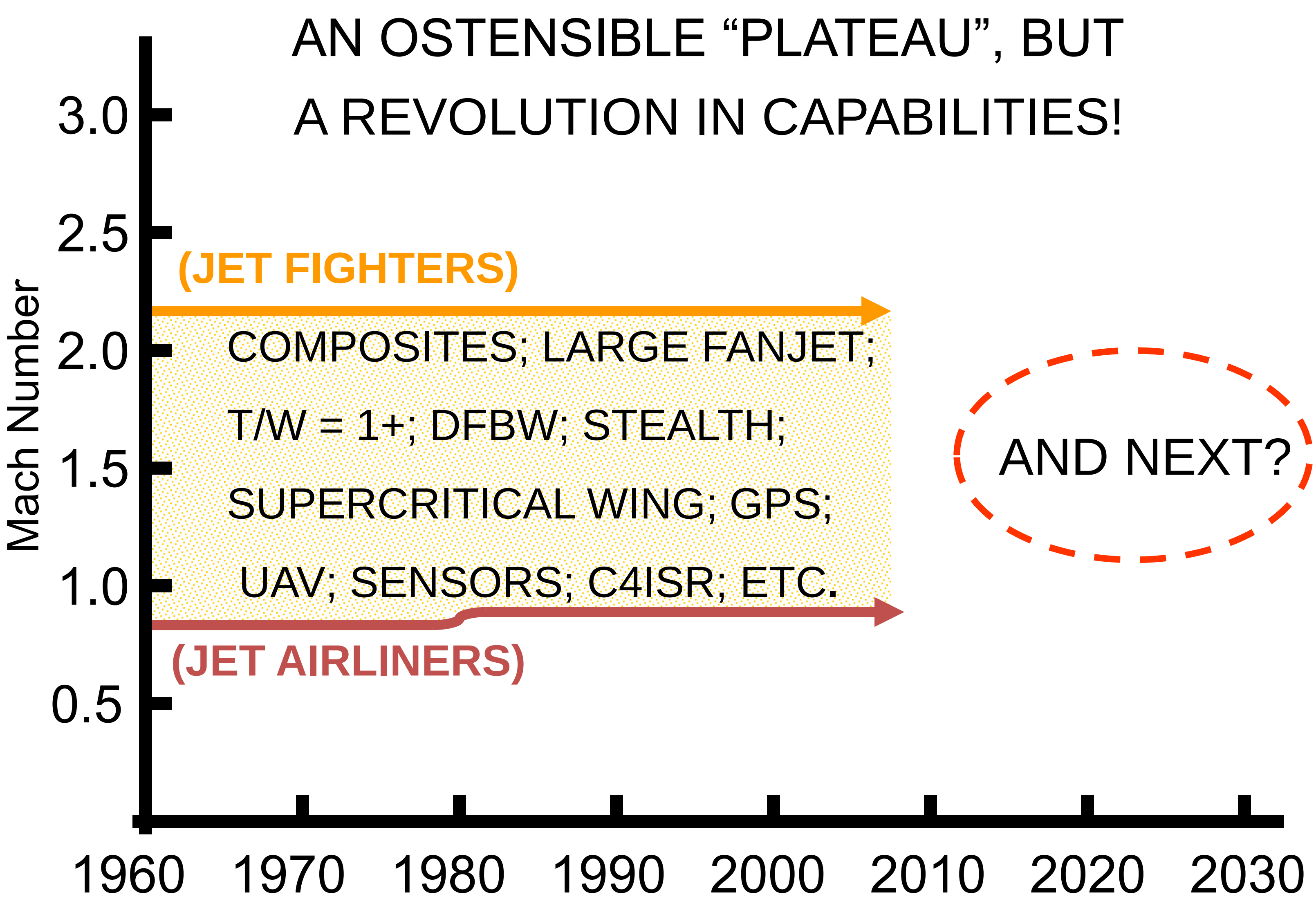
Lockheed Blackbird

Photographs courtesy The Boeing Company, NASA Dryden Flight Research Center, and the *Musée de l'Air et l'Éspace,* Le Bourget

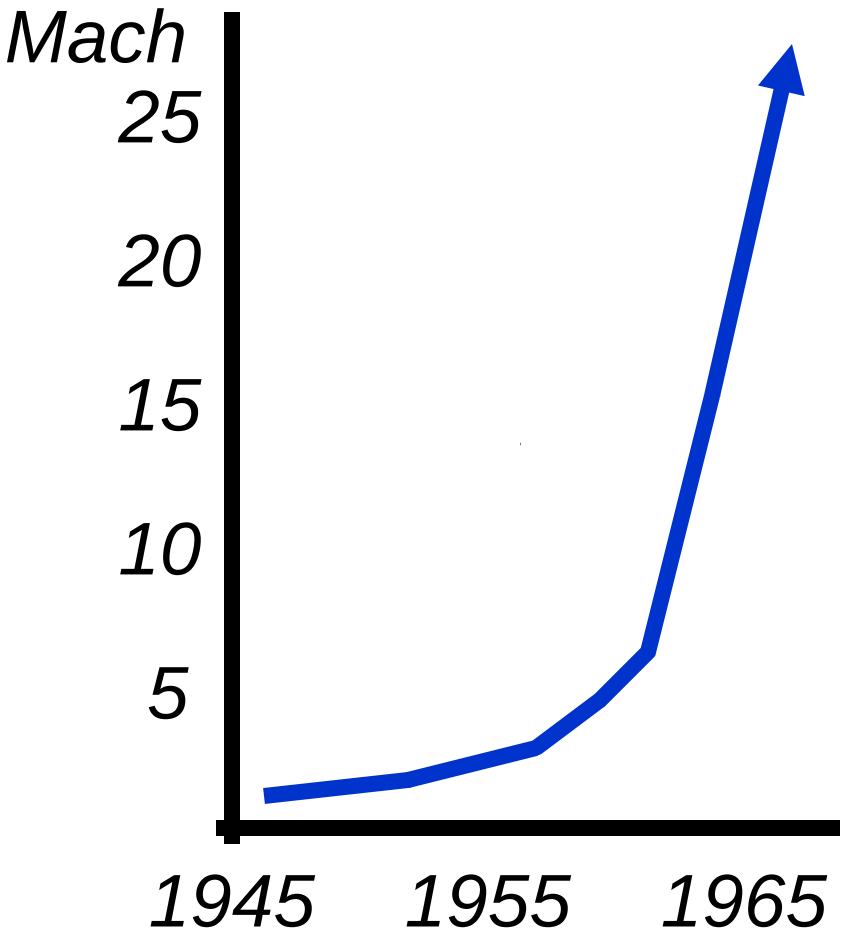
…Speed by Function…



…Aviation Progression, 1960-2010…



Postwar High-Speed Expansion



ONLY POSSIBLE BY INTENSIVE RDT&E

FRAMED SUBSEQUENT ACCOMPLISHMENTS

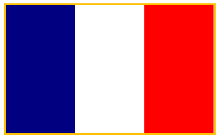
FULLEST POTENTIAL NOT FULLY ATTAINED EVEN TODAY

…In the Beginning…

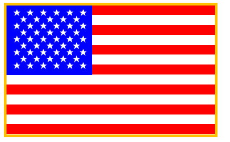
10:35 a.m., 17 December 1903,
Kitty Hawk, North Carolina

…Europe Races Ahead…

(A 1912 Perspective)



FRANCE



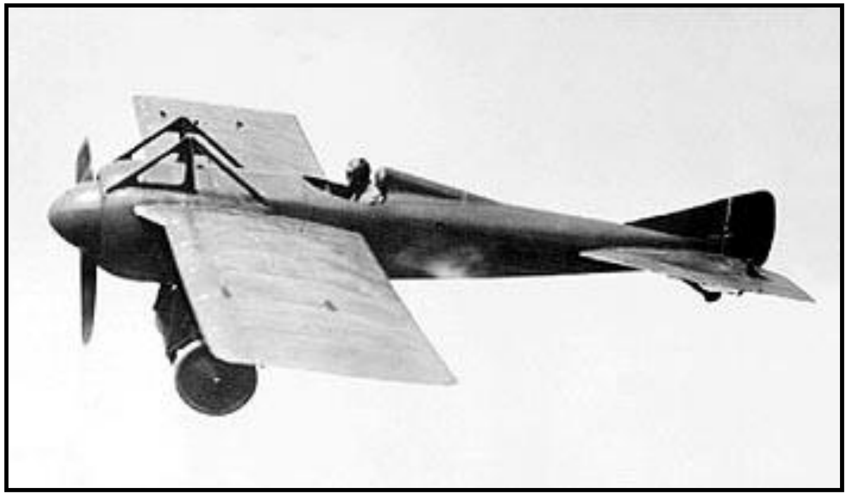
AMERICA

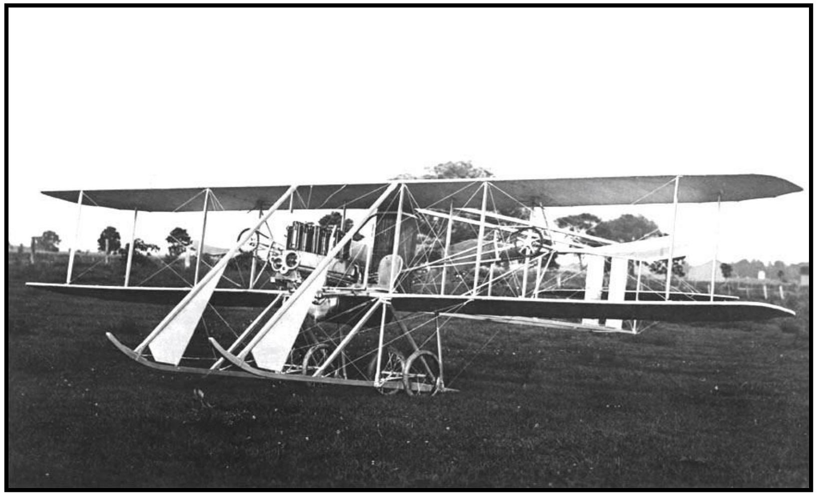
Deperdussin

“Monocoque Racer”

Wright Model D

“Speed Scout”





Top Speed: 108 mph

Top Speed: 67 mph

Musée de l’Air et l'Éspace Photo

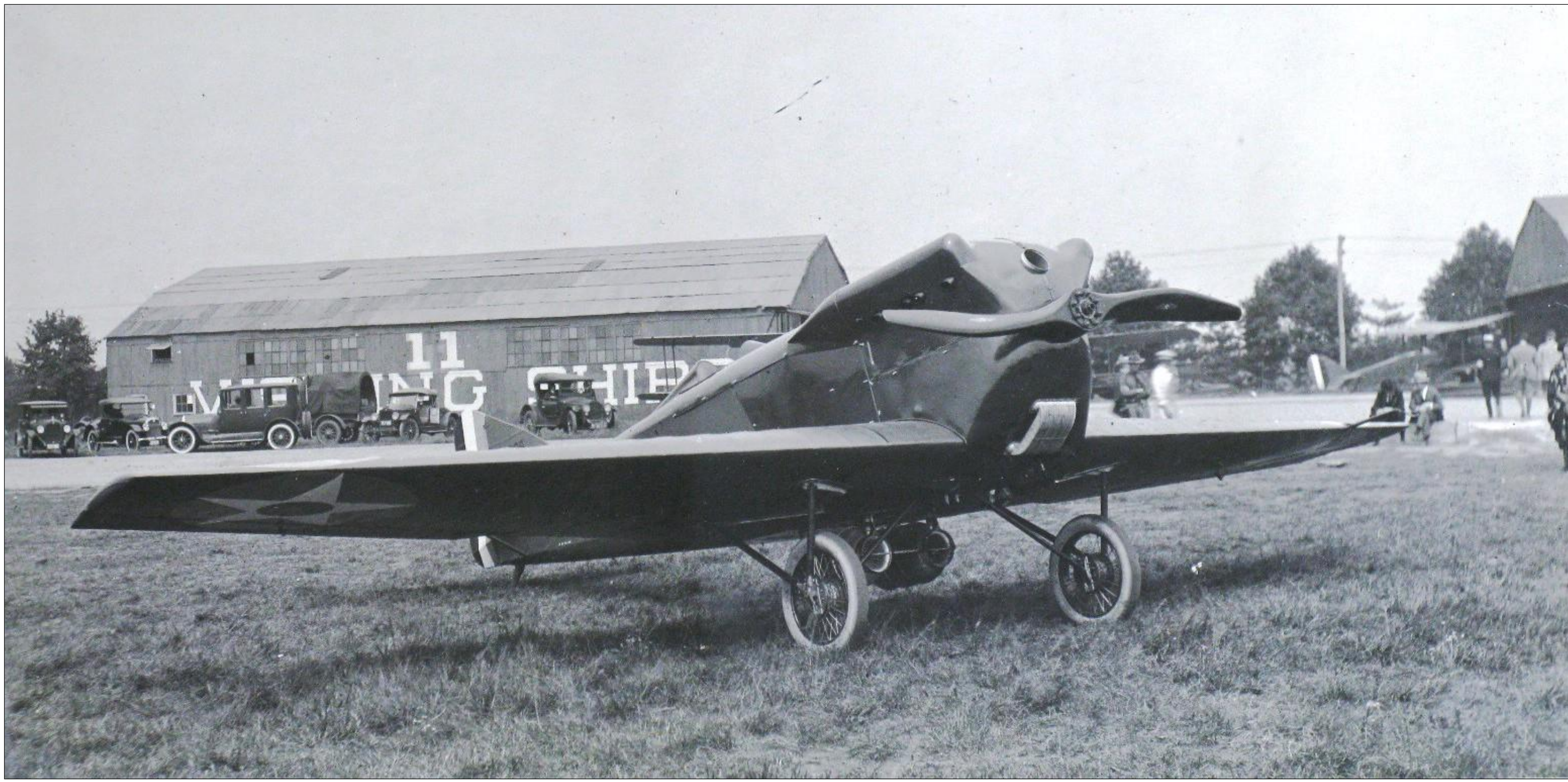
National Museum of the USAF Photo

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…

Douglas DC-1, 1933

NASM

…By the Late 1930's…

Douglas DC-3 (1936)

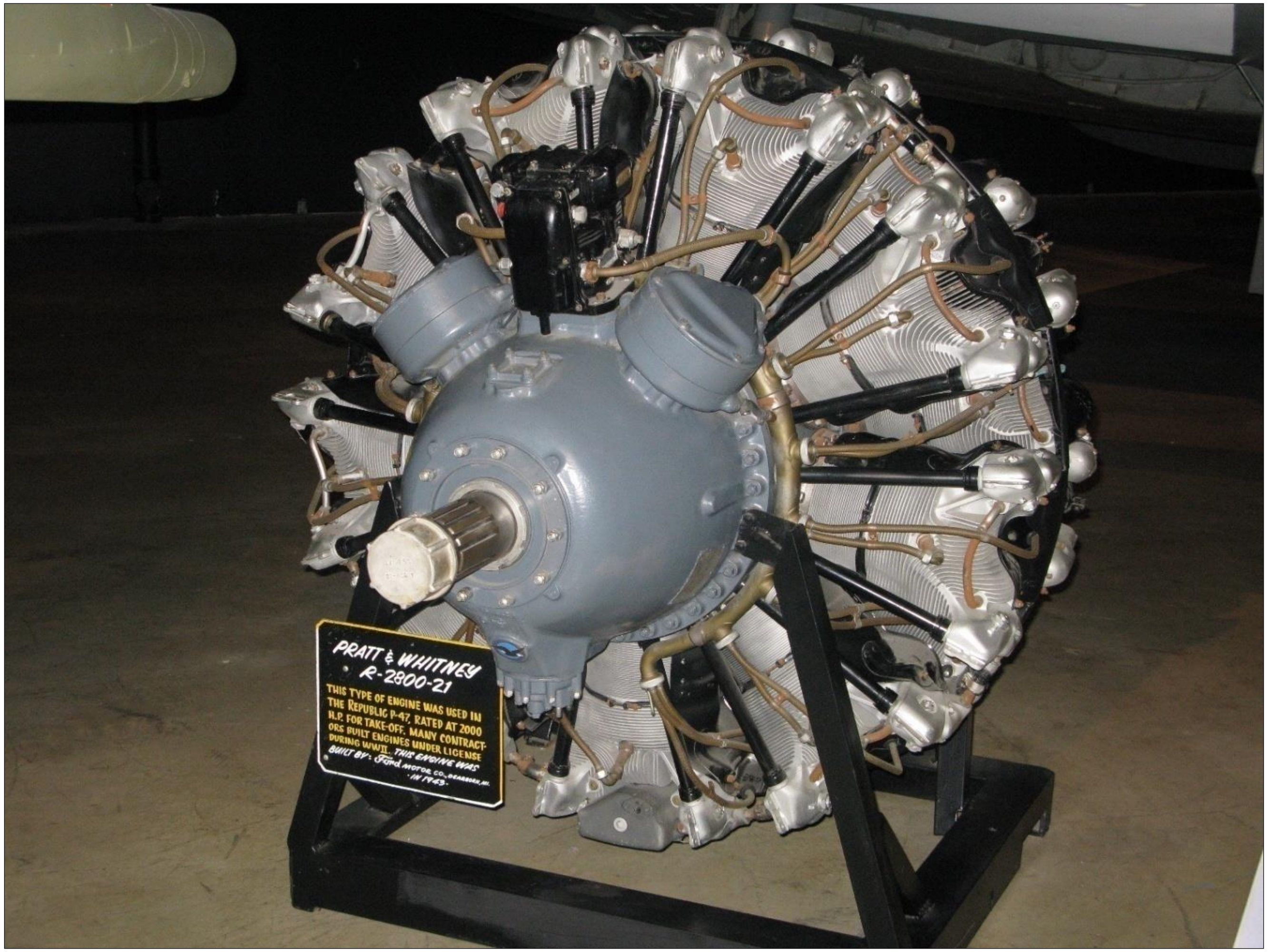
U.S. airliners are the world's standard

Explosive growth in aviation industry

U.S. the leading exporter of aircraft

USAF

…Thanks to the Maturity of the Piston Engine…

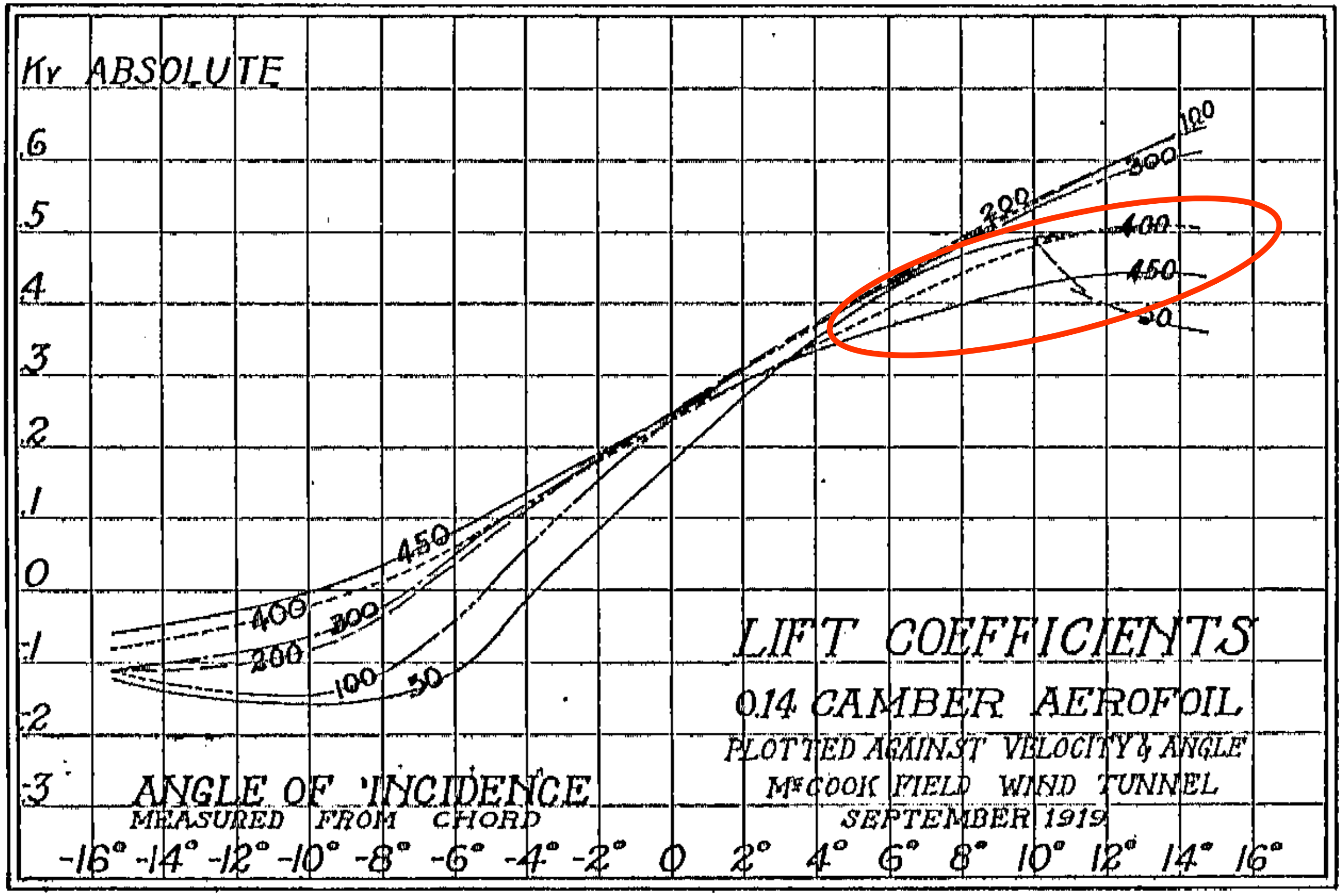


P&W R-2800 radial engine

RPH

But…An Approaching Revolution

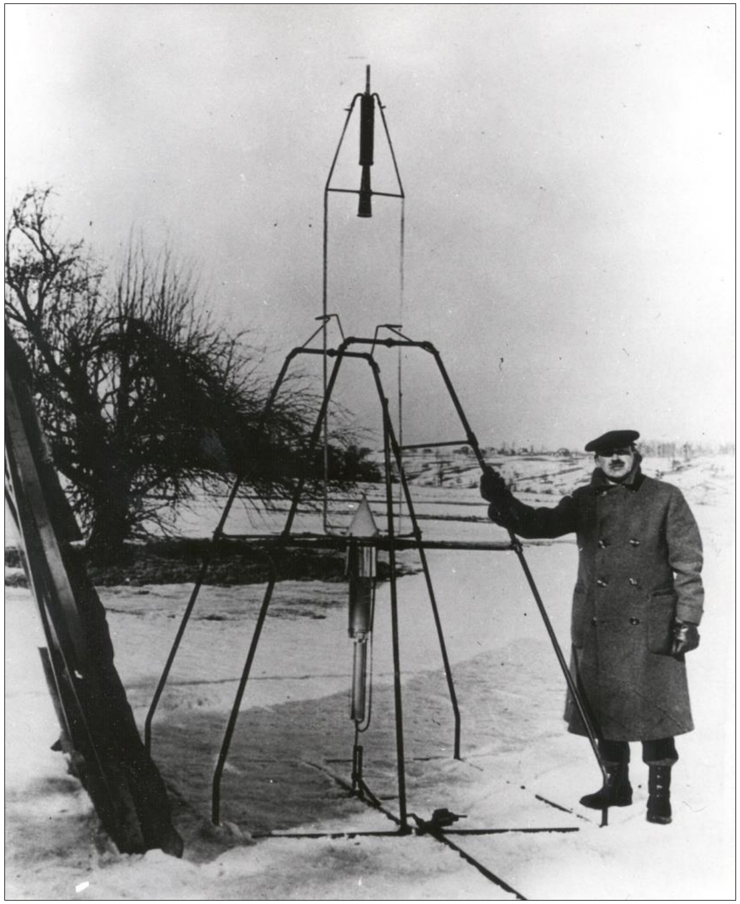
1919: Year of Transonic Discovery



Source: NACA Report 83 (1919)

NASA

1926…The Rocket Revolution…



Robert Goddard, 1926

Opel Rak-1, 1929

V-2 on Transporter, 1944

Onset of the Compressibility Crisis

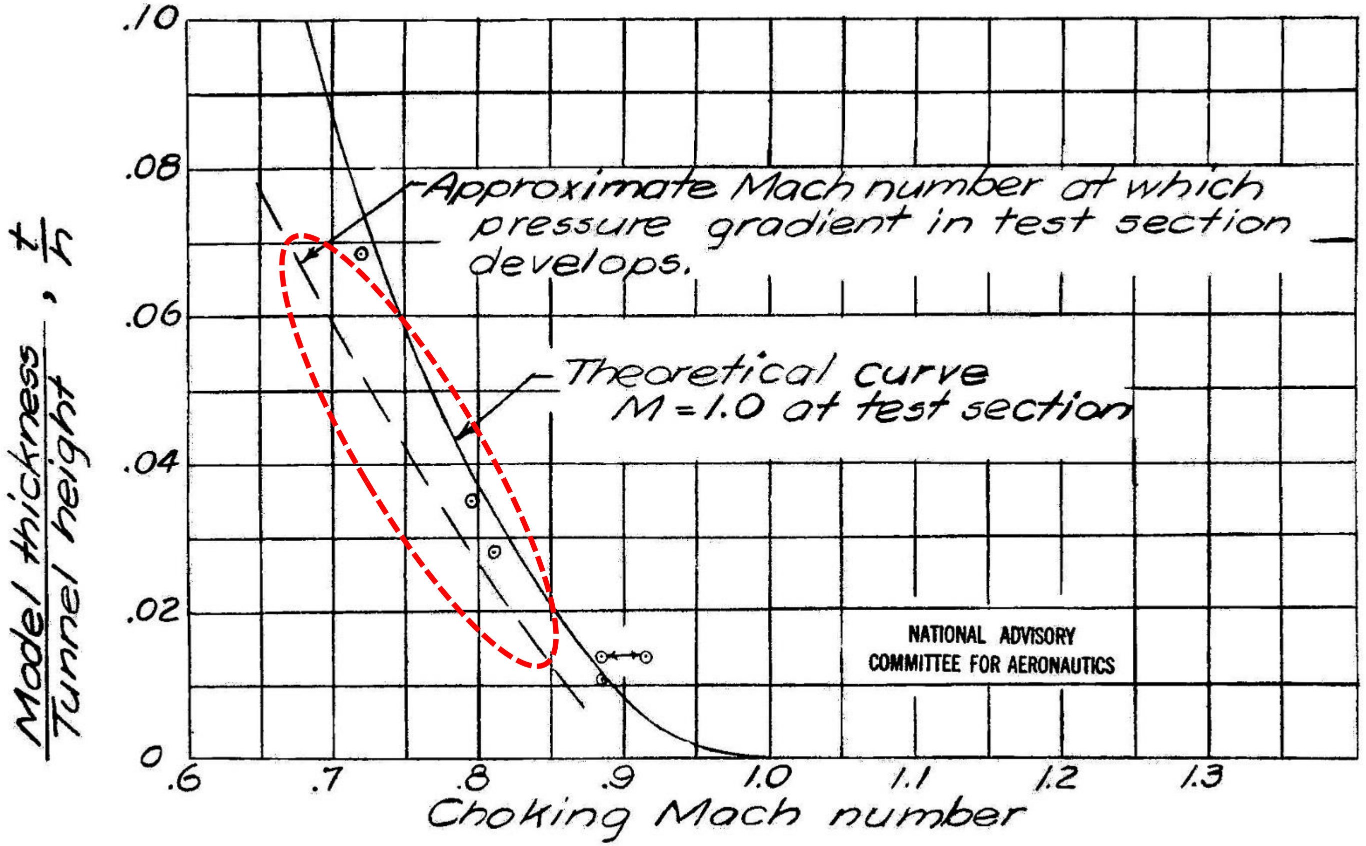
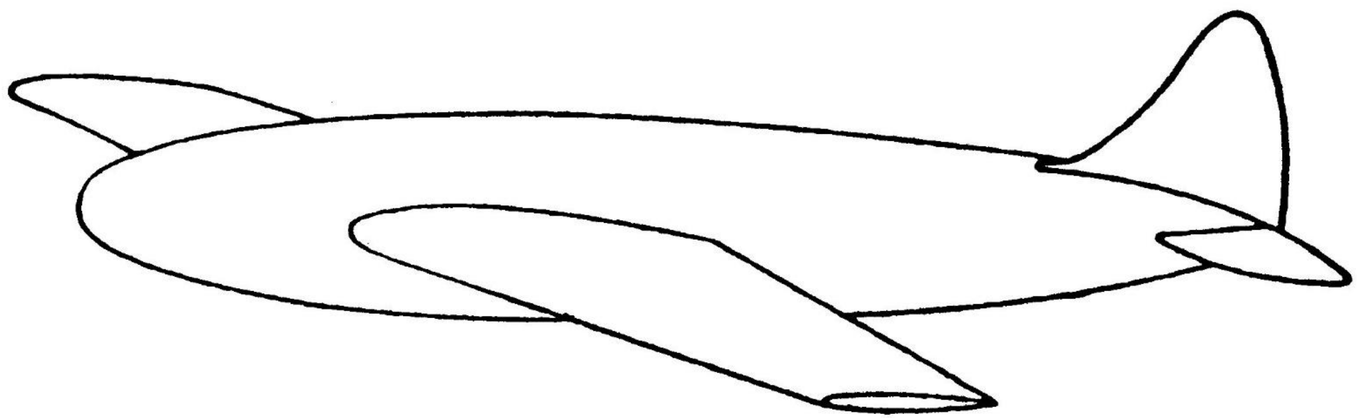


Figure 25. – Wind tunnel choking Mach number.

Source: John Stack, NACA working paper, 9-16-44, NASA HD

Stack Proposed Research Airplane, 1931

Fuselage diameter	40 in.
Wing span	29.1 ft.
Wing area	141.2 sq.ft.
Wing chord (average)	4.85 ft.
Aspect ratio	6



Source: John Stack, "Effects of Compressibility on High-Speed Flight," *Journal of the Aeronautical Sciences,* vol. 1, no. 1 (Jan. 1934).

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

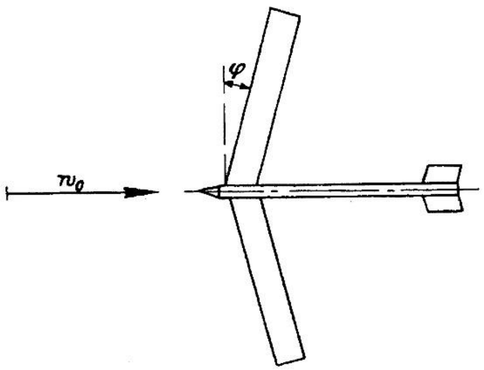


Abb. 5. Pfeilförmiges Tragwerk.

Denn die Dichte ϱ und die Schallgeschwindigkeit c werden von der Schrägstellung des Tragflügels gegenüber der Windrichtung nicht betroffen.

2. Pfeilförmige Tragwerke.

Bei den ebenen Strömungen ergab sich, daß die besten Gleitzahlen bei bestimmten Machschen Zahlen 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 Machschen Zahlen durch Schrägstellung 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 Machschen Zahl 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 φ unterscheiden den wirklichen Staudruck q_0 der Strömung und den wirksamen Staudruck q, der die achsiale Komponente der Anblasegeschwindigkeit nicht einhält. Zwischen beiden besteht die Beziehung:

$$q = q_0 \cdot \cos^2 \varphi \quad (24)$$

Genau in gleicher Weise gibt es eine wirkliche Machsche Zahl $M_0 = \frac{w_0}{c}$ und daneben eine wirksame Machsche Zahl $M = \frac{w}{c}$ mit der Beziehung:

$$M = M_0 \cos \varphi \quad (25)$$

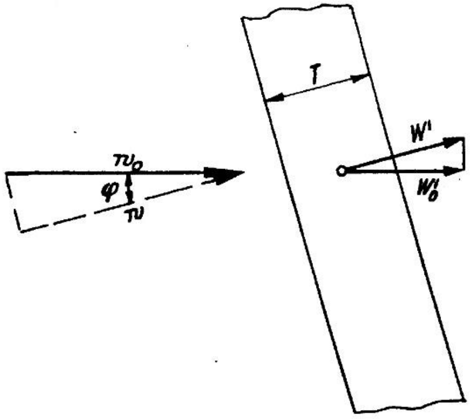
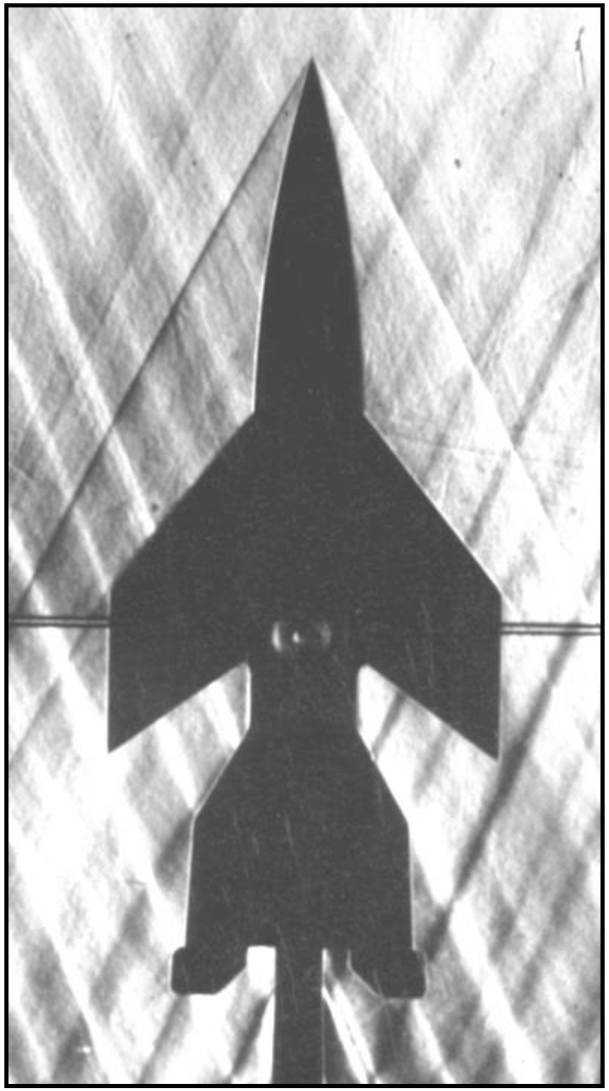
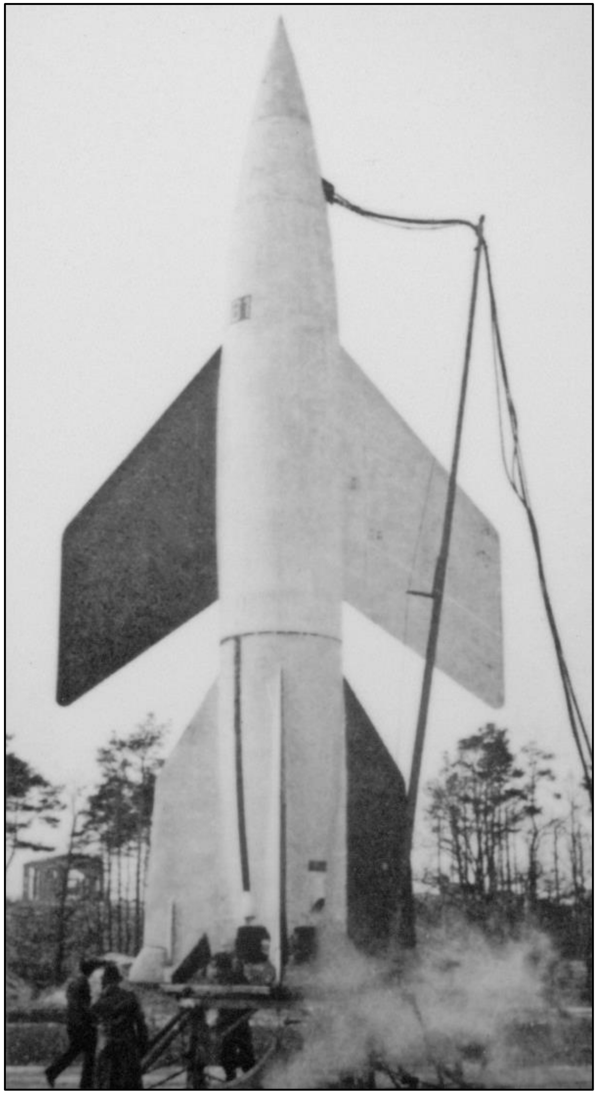


Abb. 4. Schräg angeblasener Tragflügel.

A-4b: First Supersonic Winged Vehicle



1940 Tunnel Test of Winged A-4



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

AF AEDC Photo

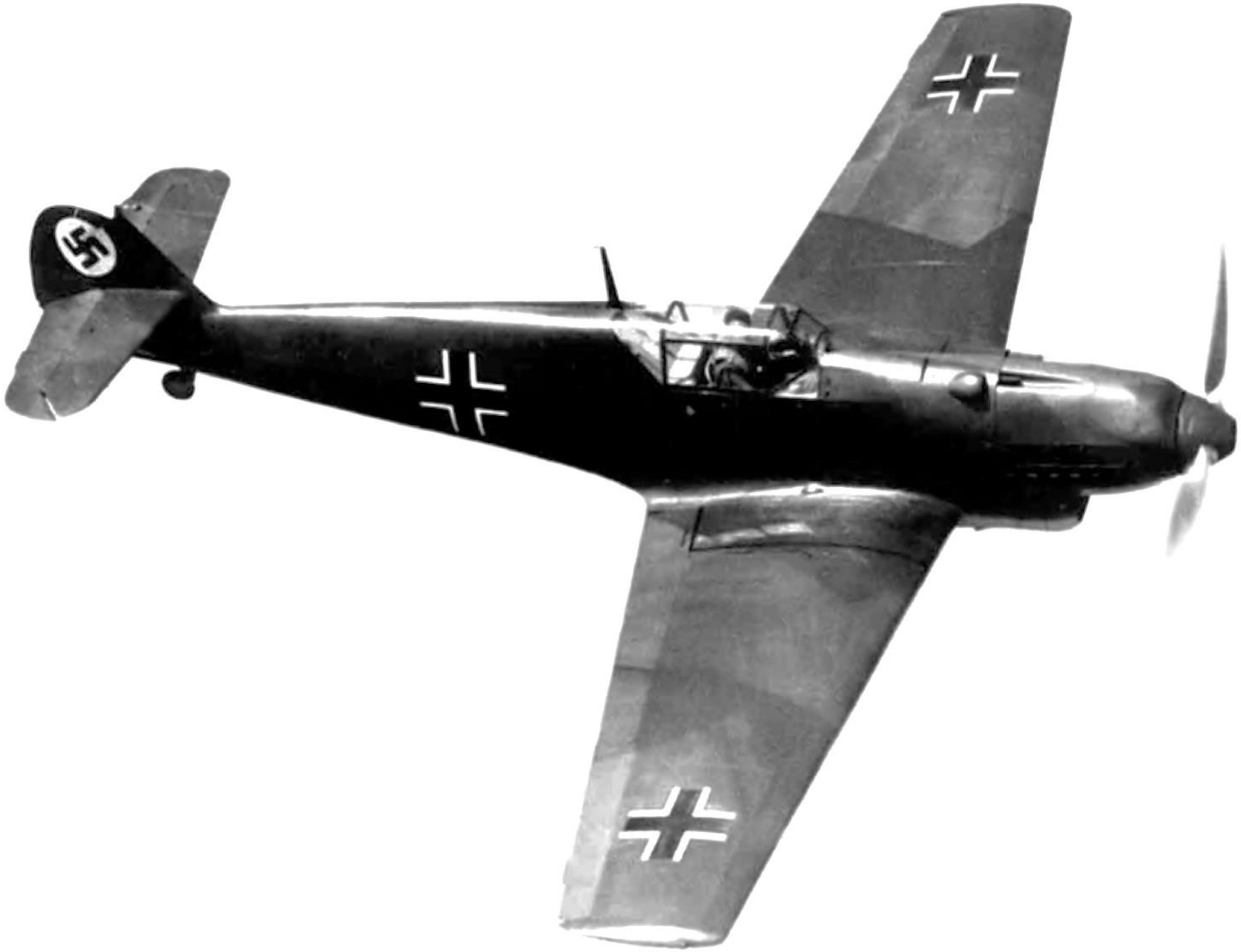
NMUSAF

Touching the Sonic Frontier

Curtiss P-36, 1937

NASA

…but not without loss…



Messerschmitt Bf 109B: Kurt Jodlbauer killed 17 July 1937

AFHRA

…and America was not immune…

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

NASA

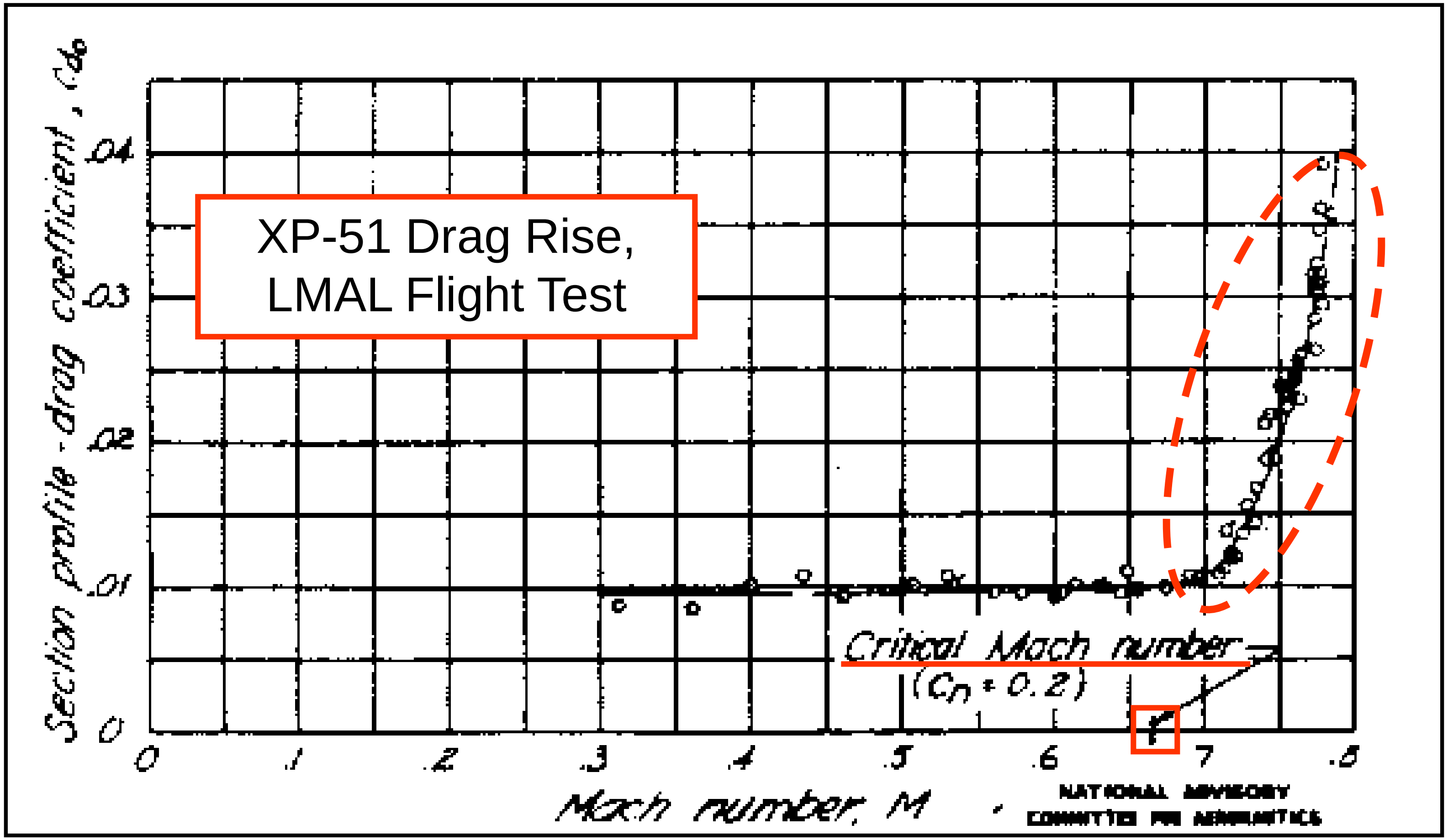
Early NACA Dive Trials

Brewster XF2A-2 Buffalo, NACA LMAL, 1940

“Normative” Subsonic Aircraft Design

North American XP-51 Apache (later Mustang)

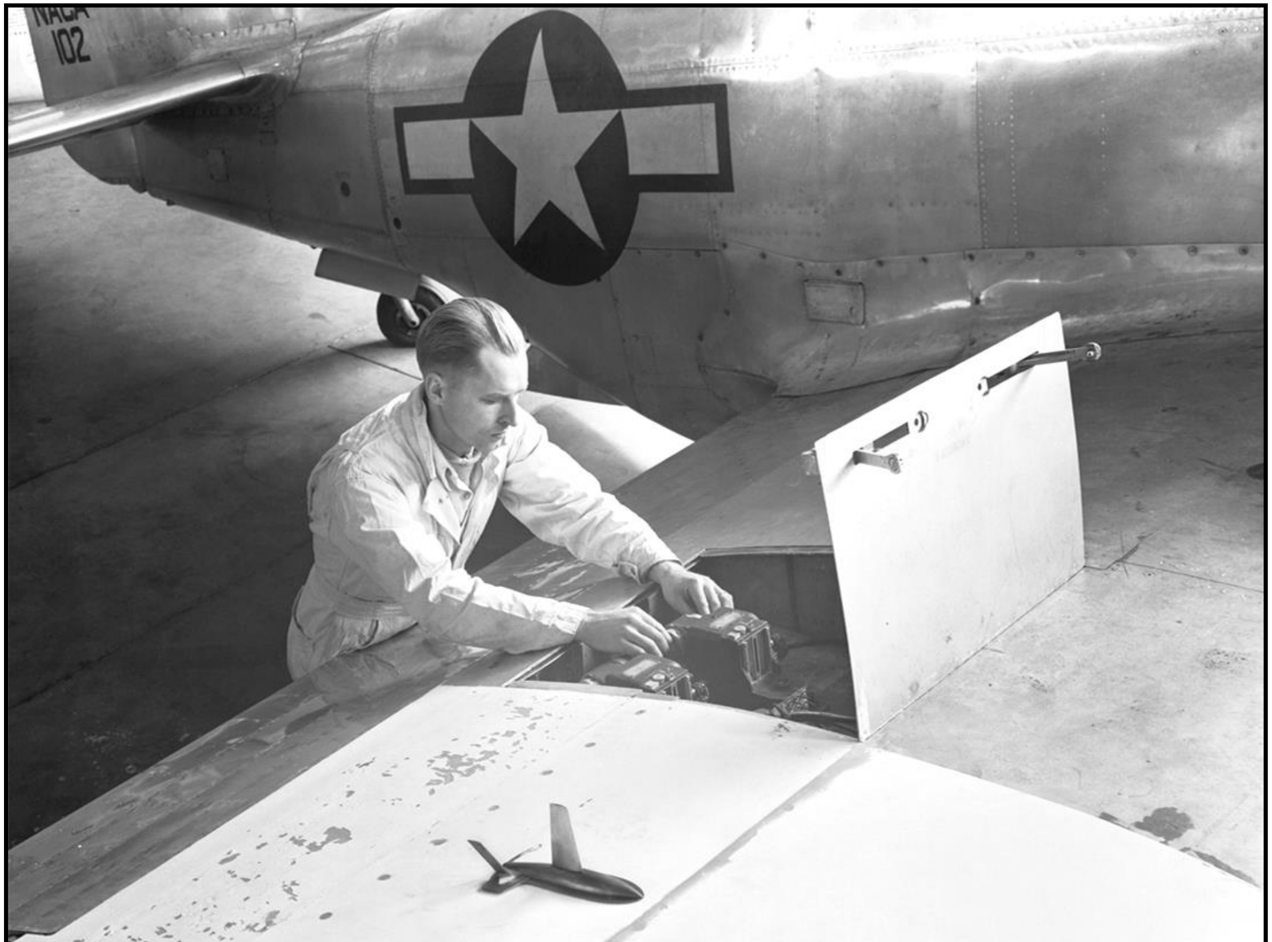
Understanding Transonic Limitations



Source: NACA Technical Note 1190 (1944)

…Stopgap Research Methodologies…

Accelerated Wing Flow Research Model



NASA

…Stopgap Research Methodologies…

Transonic Drop Models

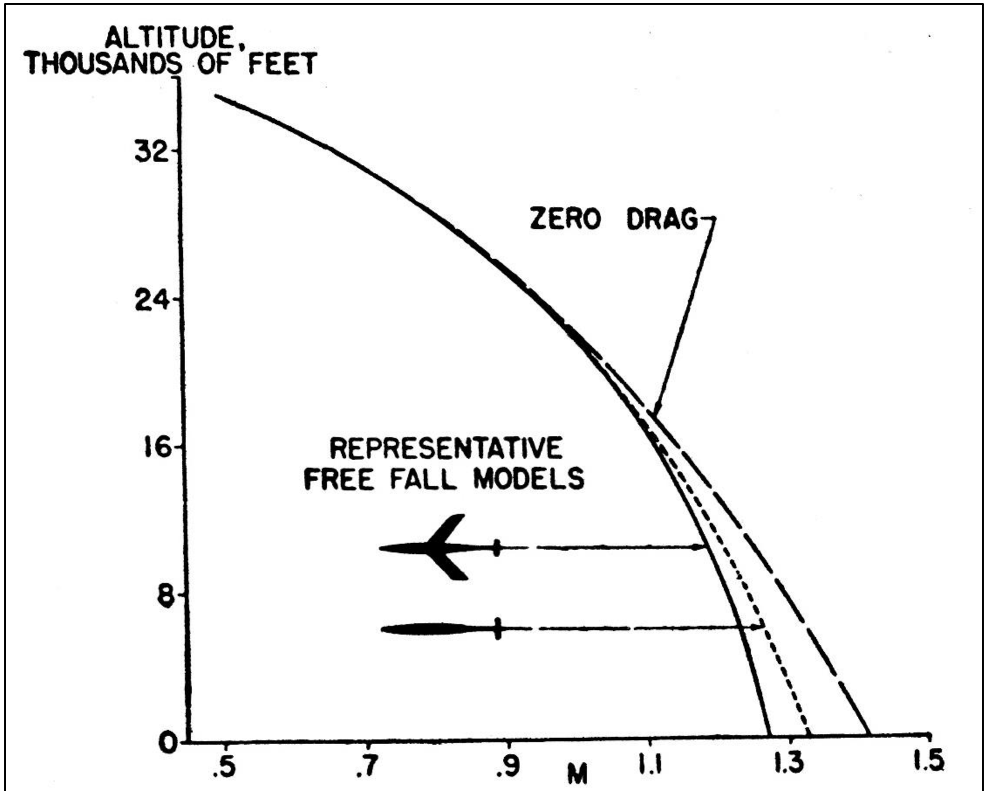
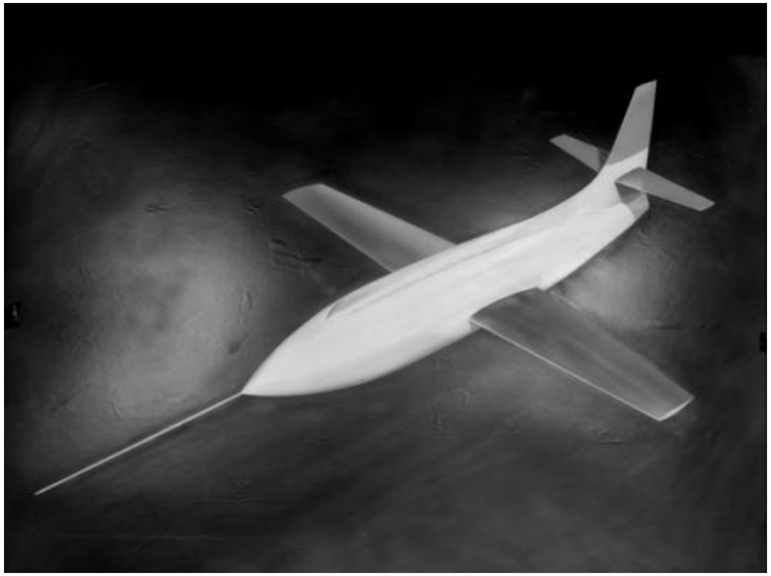


Fig. 3.
Representative trajectories for free-fall model.

Source: John Stack, *Experimental Methods for Transonic Research,* 1951.



NACA XS-1 Drop Model

NASA

…Stopgap Research Methodologies…

Rocket-Boosted Models

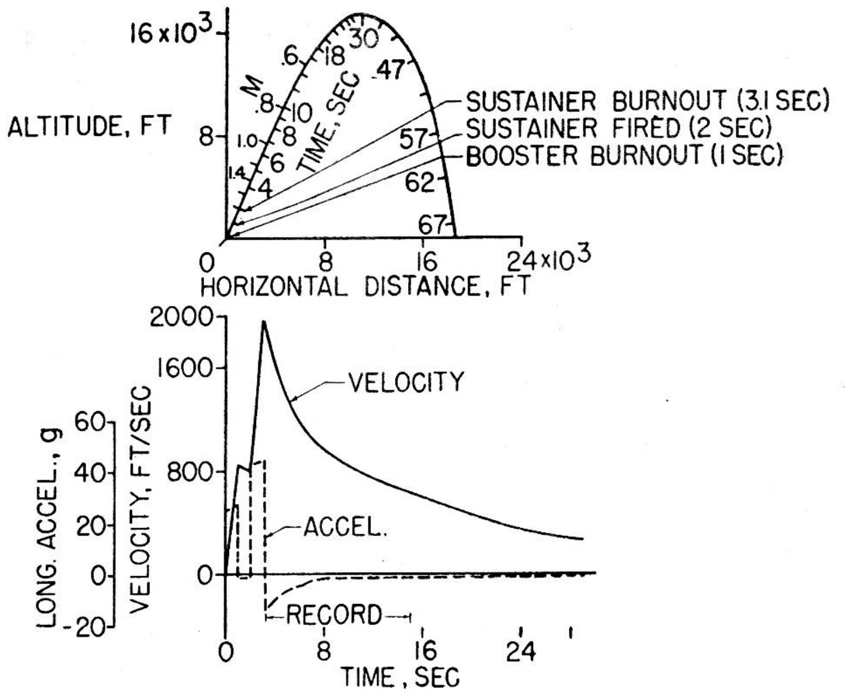


Fig. 6.

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

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

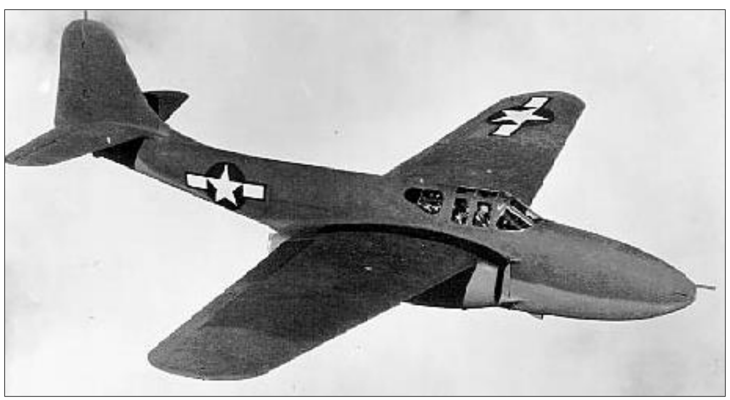
Source: John Stack, *Experimental Methods for Transonic Research,* 1951.

NASA

…The (Unexpected) Arrival of the Jet Age…

Heinkel He 178 (1939)

Gloster E.28/39 (1941)



Bell XP-59A (1942)

Messerschmitt Me 262 (1944)

USN-USAF-RAF

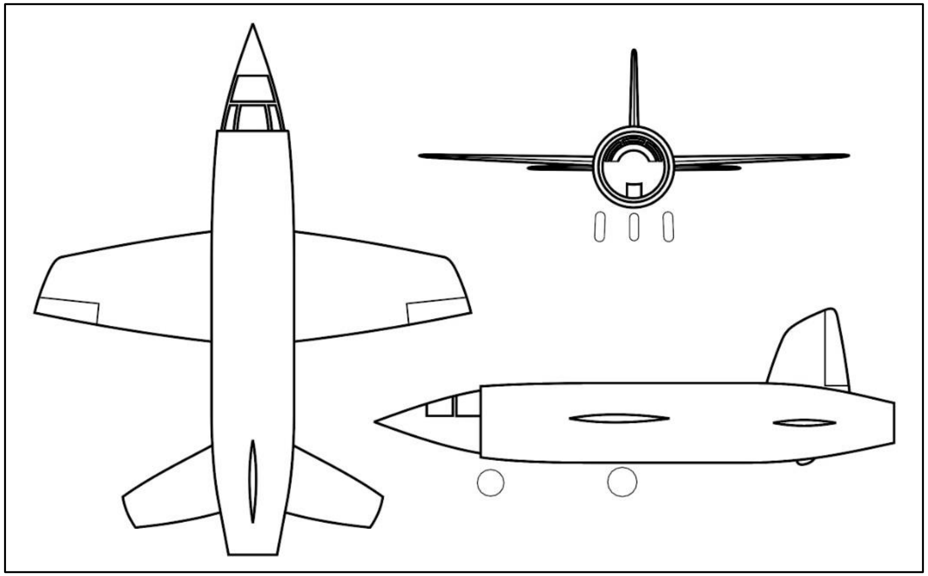
…and Interim Testbeds…

Lockheed YP-80A, NACA Ames Aeronautical Laboratory, 1945

NASA

The Miles M.52 Project (E. 24/43)

Photo courtesy Jim Pratt



Drawing courtesy M L Watts

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

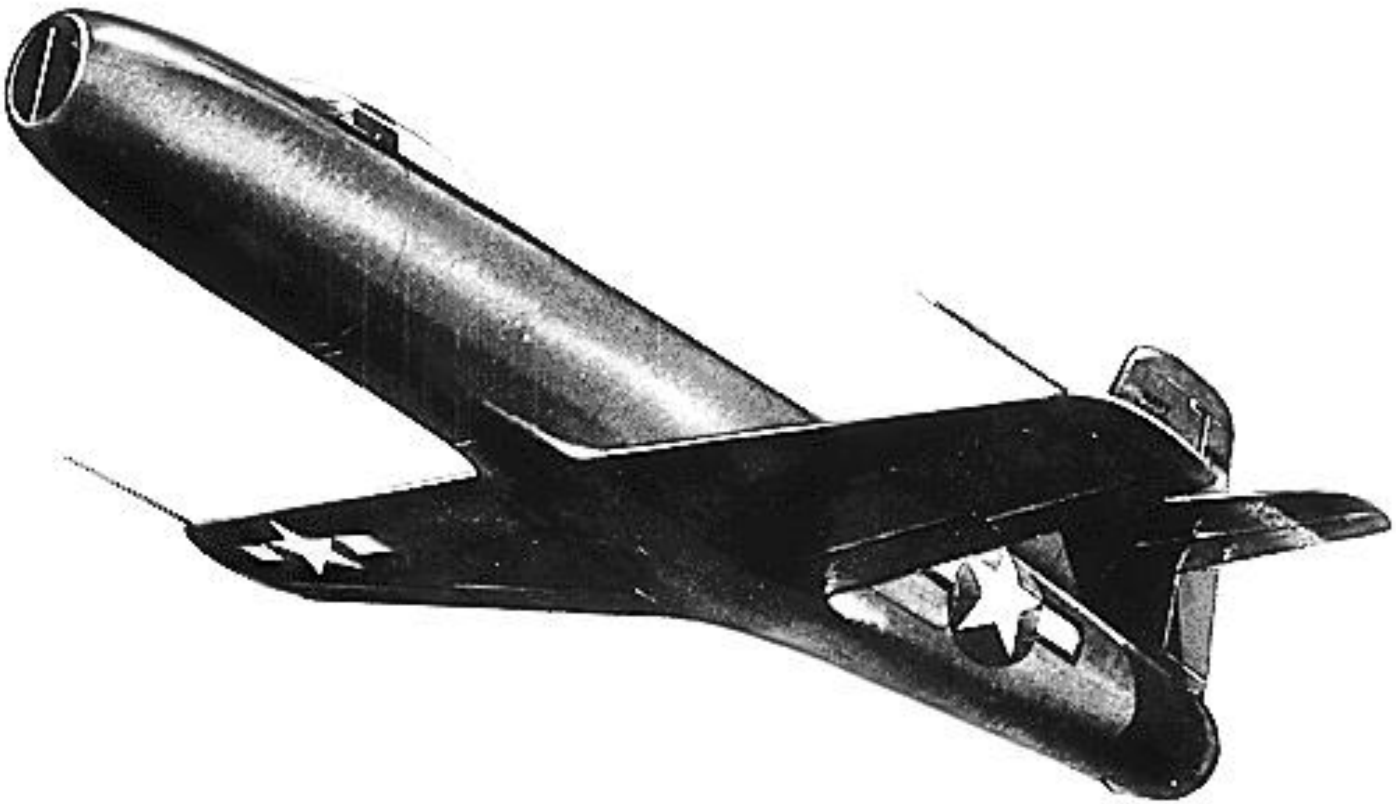
BAe

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.

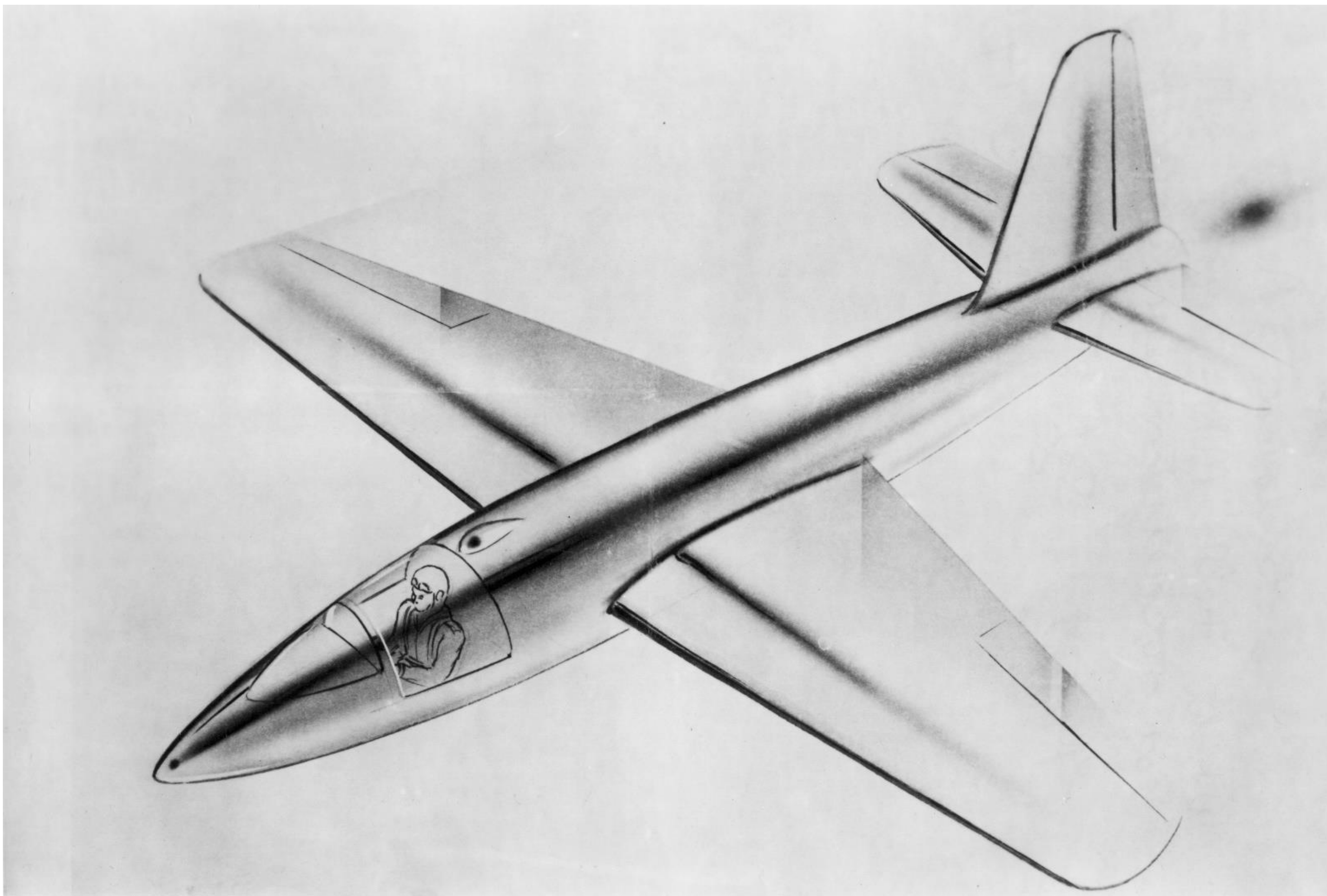
The Navy-NACA Approach: Jet-Propelled



Douglas D-558 Skystreak Design Concept, 1945

FDR Library

The AAF Approach: Rocket-Propelled



Ezra Kotcher's "Mach 0.999" Study, 1944

Kotcher via RPH

The XS-1:
A Pragmatic Design

-Straight Wing (8% or 10% t-c)

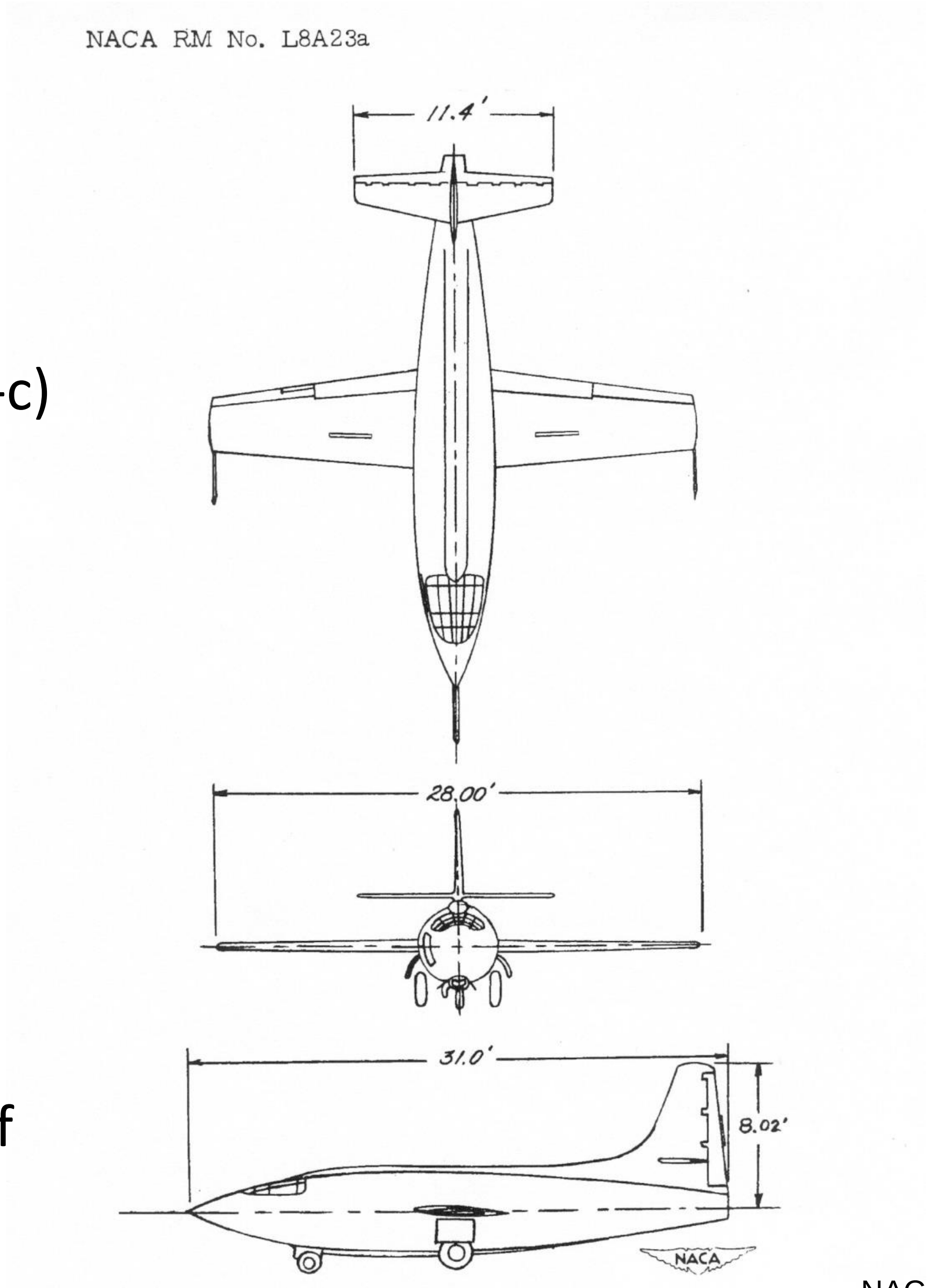
-18 g load limit

-0.50 cal. body shape

-Adjustable horizontal tail

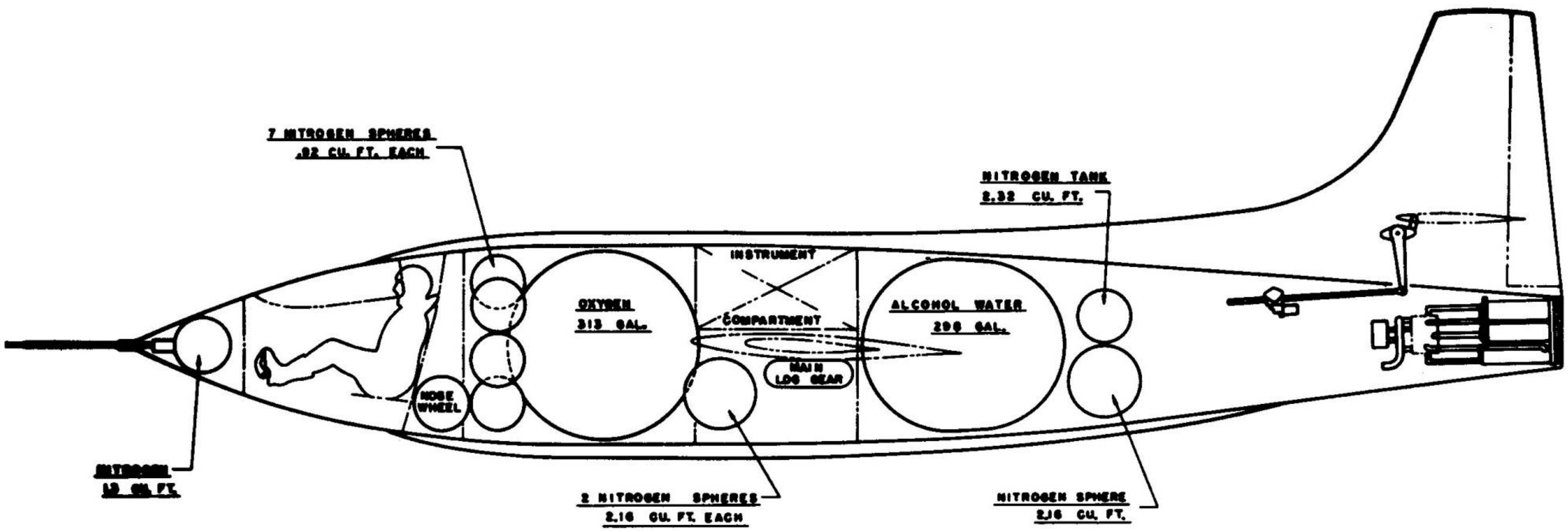
-500 lb instrument package

-Intended for ground takeoff



NACA

XS-1 Inboard Profile



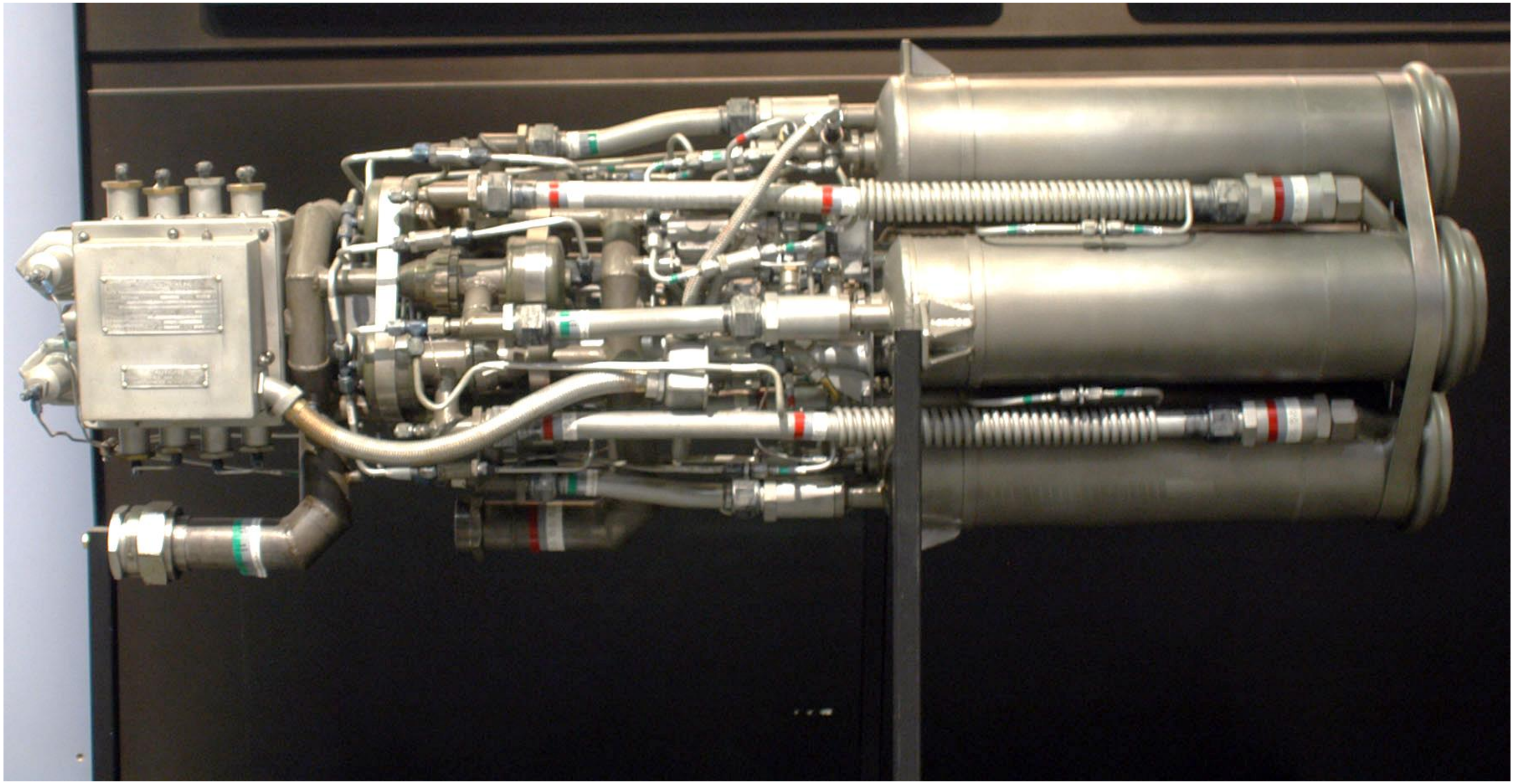
INBOARD PROFILE

PRESSURIZED FUEL SYSTEM

XS-1

USAF

Reaction Motors XLR 8/11 Engine



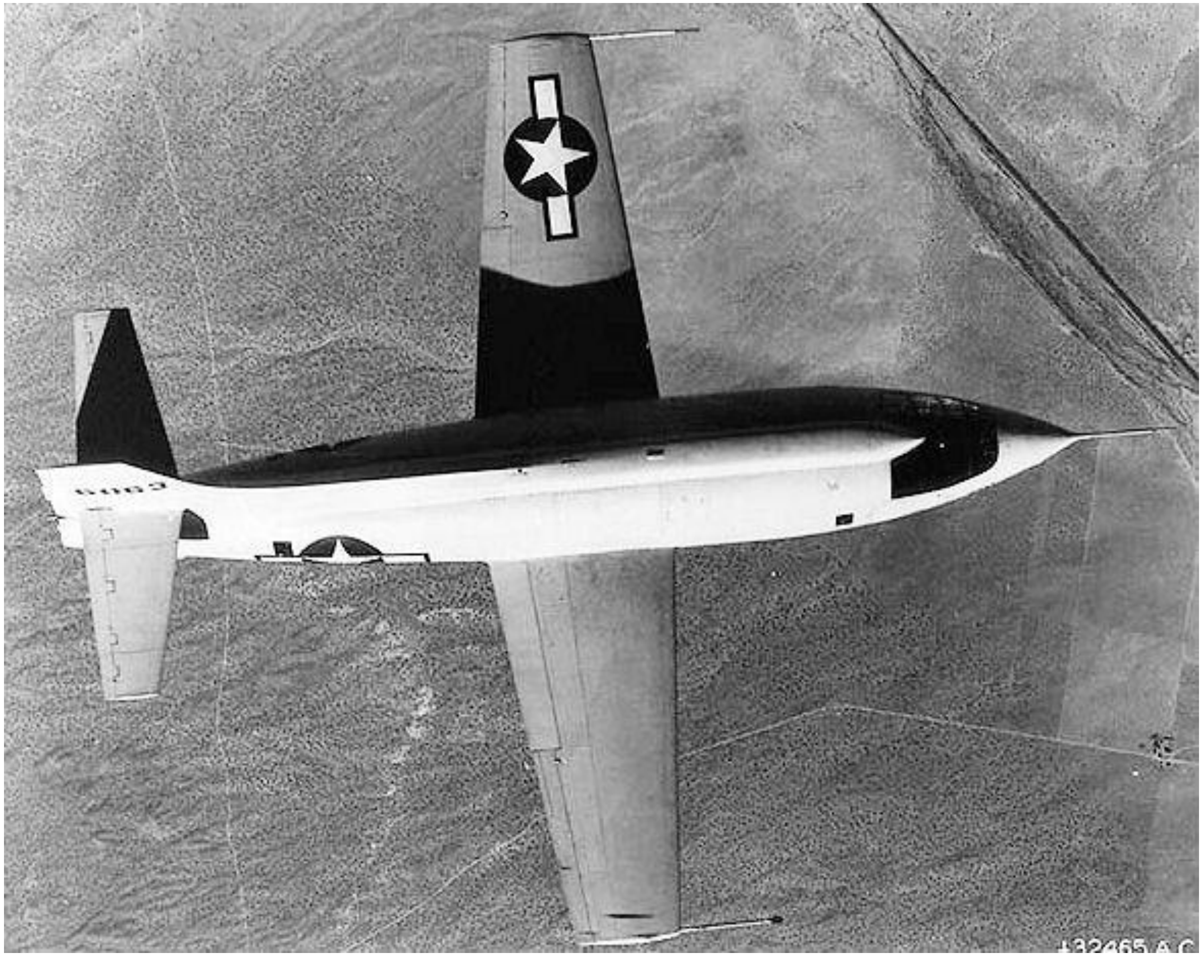
Reaction Motors Inc. XLR-11 6,000-lb Thrust 4-Chamber Rocket Engine

NMUSAF

…A Flying Wind Tunnel & Loads Lab…

NASA

Contractor Glide and Powered Tests



Launch of XS-1 #2, 1946

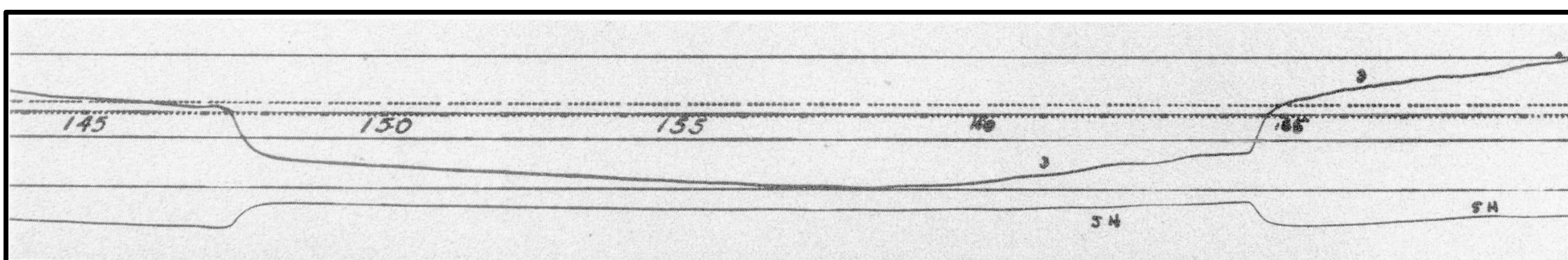
NMUSAF

XS-1 USAF-NACA Test Team

L-R: Joe Vensel, Gerald Truszynski, Chuck Yeager, Walt Williams, Jack Ridley, De Elroy Beeler

NASA

XS-1 and Supersonic Data Trace, 14 Oct 1947



The Avis Airplane…

Douglas D-558-1 Skystreak

NASA

Why Not a Sweptwing XS-1?

NASA

Initial American Sweptwing Flight Research

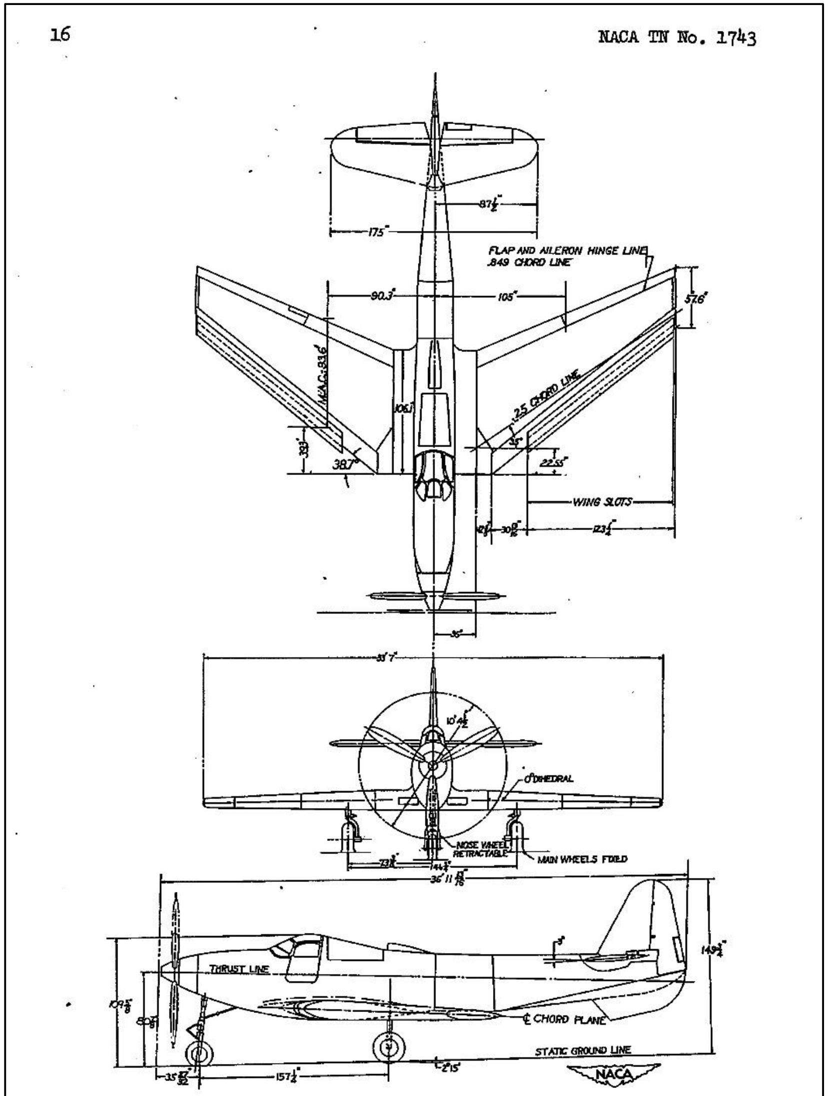
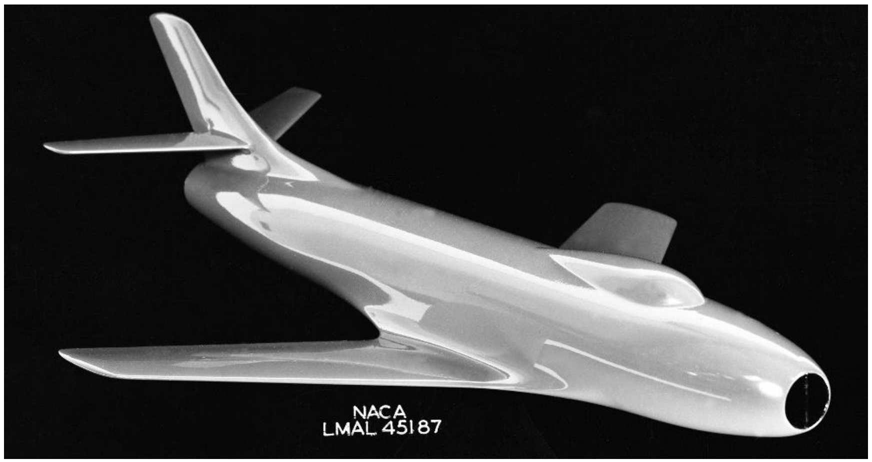


Figure 1.- Three-view drawing of test airplane.

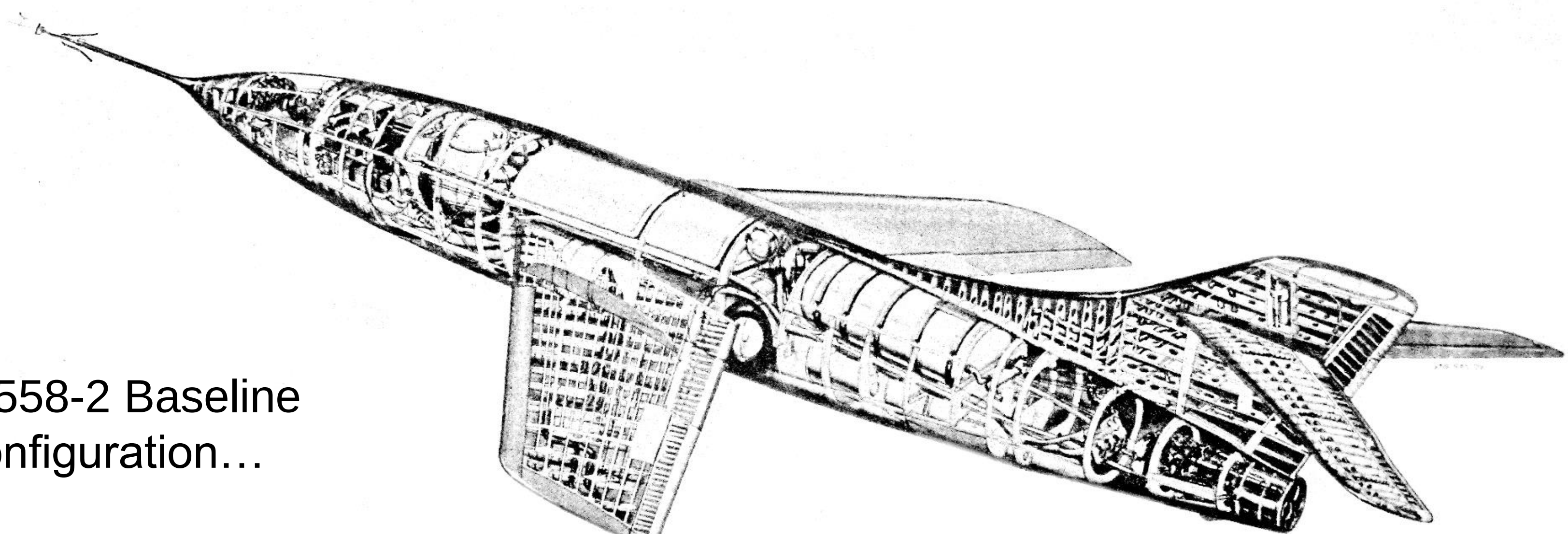
Bell L-39 no. 1 at LMAL, c 1946-47

NASA

Whither the D-558 Program?



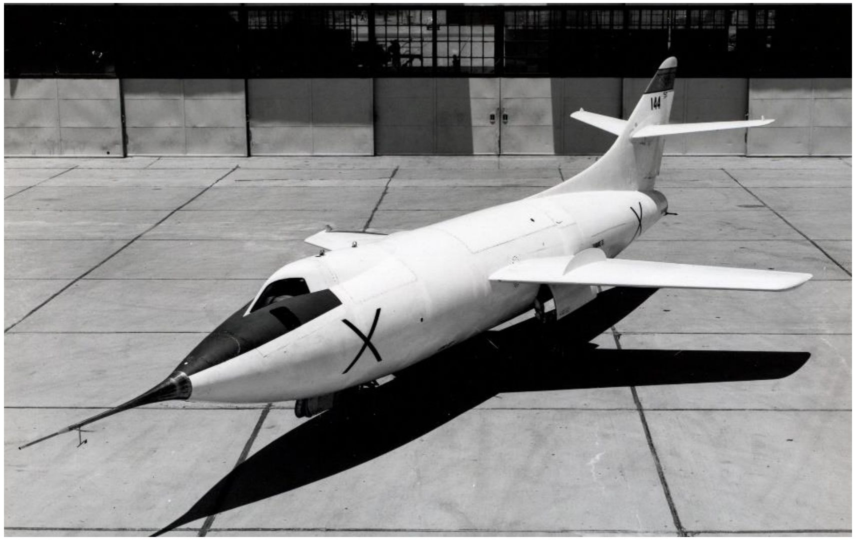
NACA Sweptwing Concept…



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

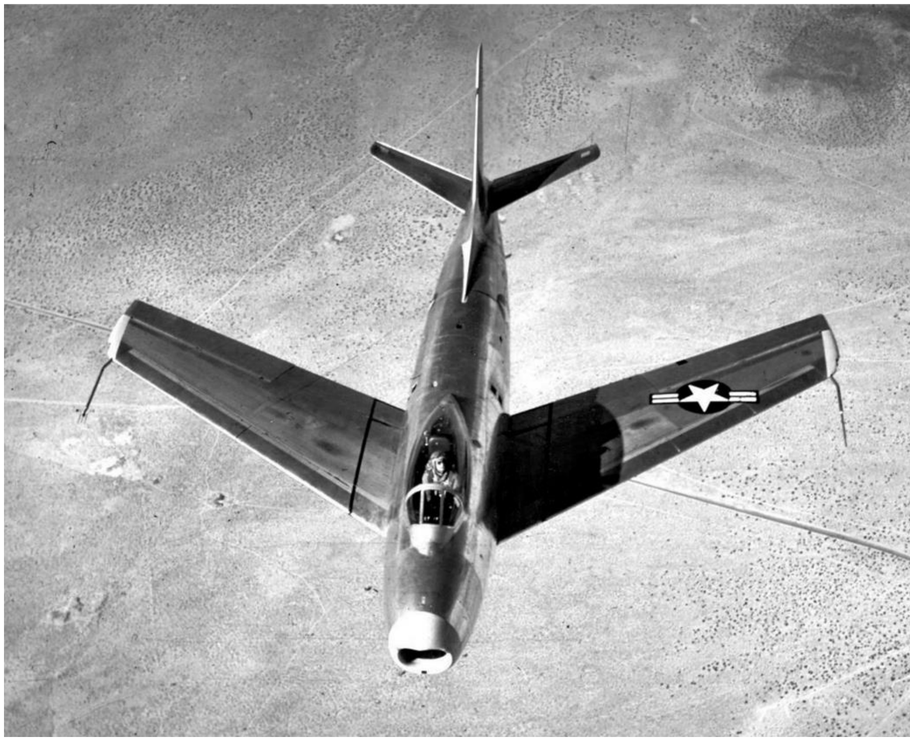
The 1st Mach 2 Piloted Flight,

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

NMUSAF

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)

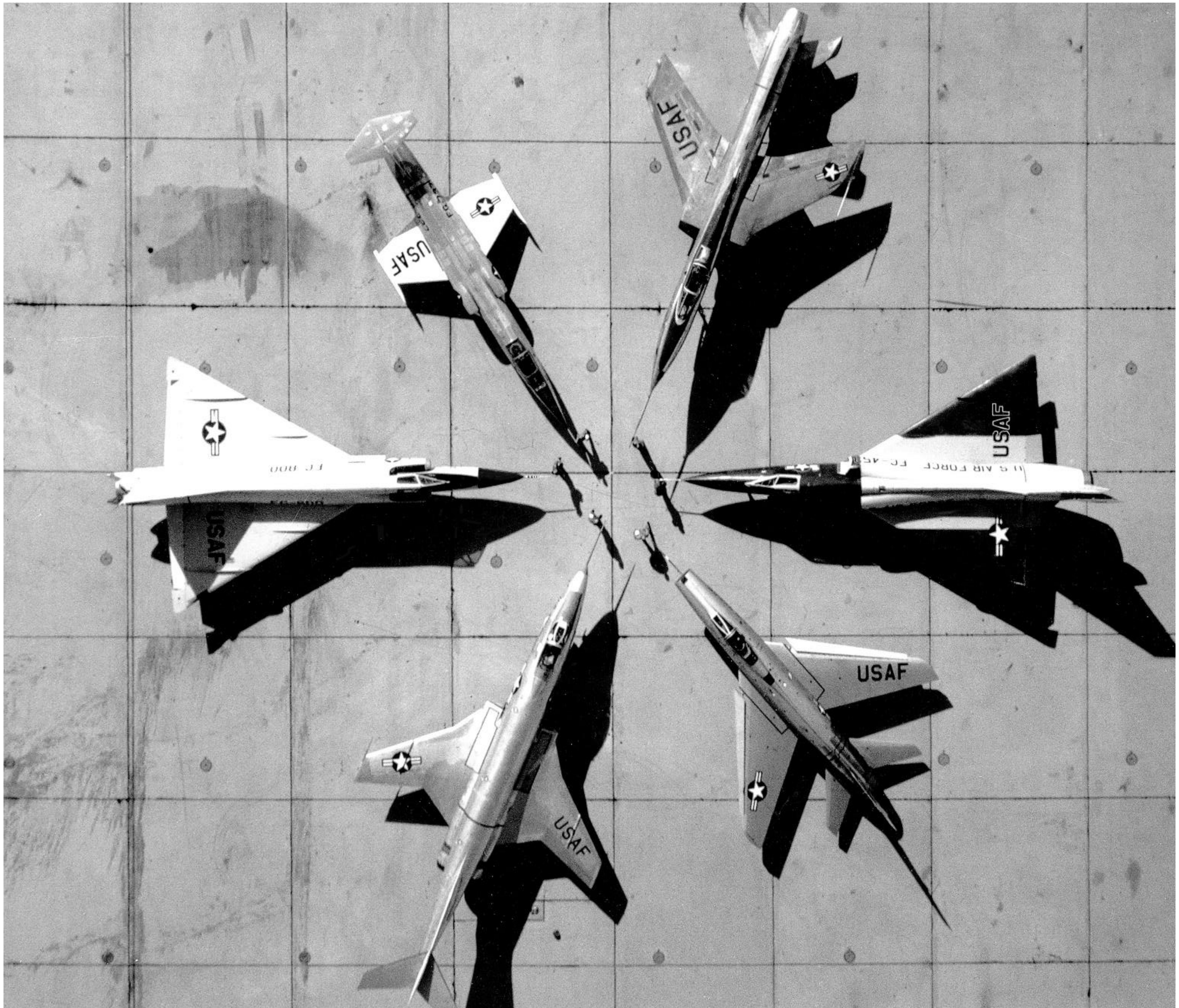
NASA

The First Mach 3 Airplane

Bell X-2 no 1 (46-674) at AFFTC, 1956

USAF

…First Military Supersonic Designs…



The F-100: A Troubled Design

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

USAF

The F-100…

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

The difference in tail shape…

Final Fin, F-100A, SN 52-5778

USAF

The F-101: The Limits of the T-tail

McDonnell F-101A Voodoo SN 53-2434 c 1957

USAF

The F-102: Area Rule Pioneer

Convair F-102A Delta Dagger SN 55-3372 c 1956

USAF

Before and After…

YF-102 without Whitcomb Area Rule

After Area Ruling

USAF

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

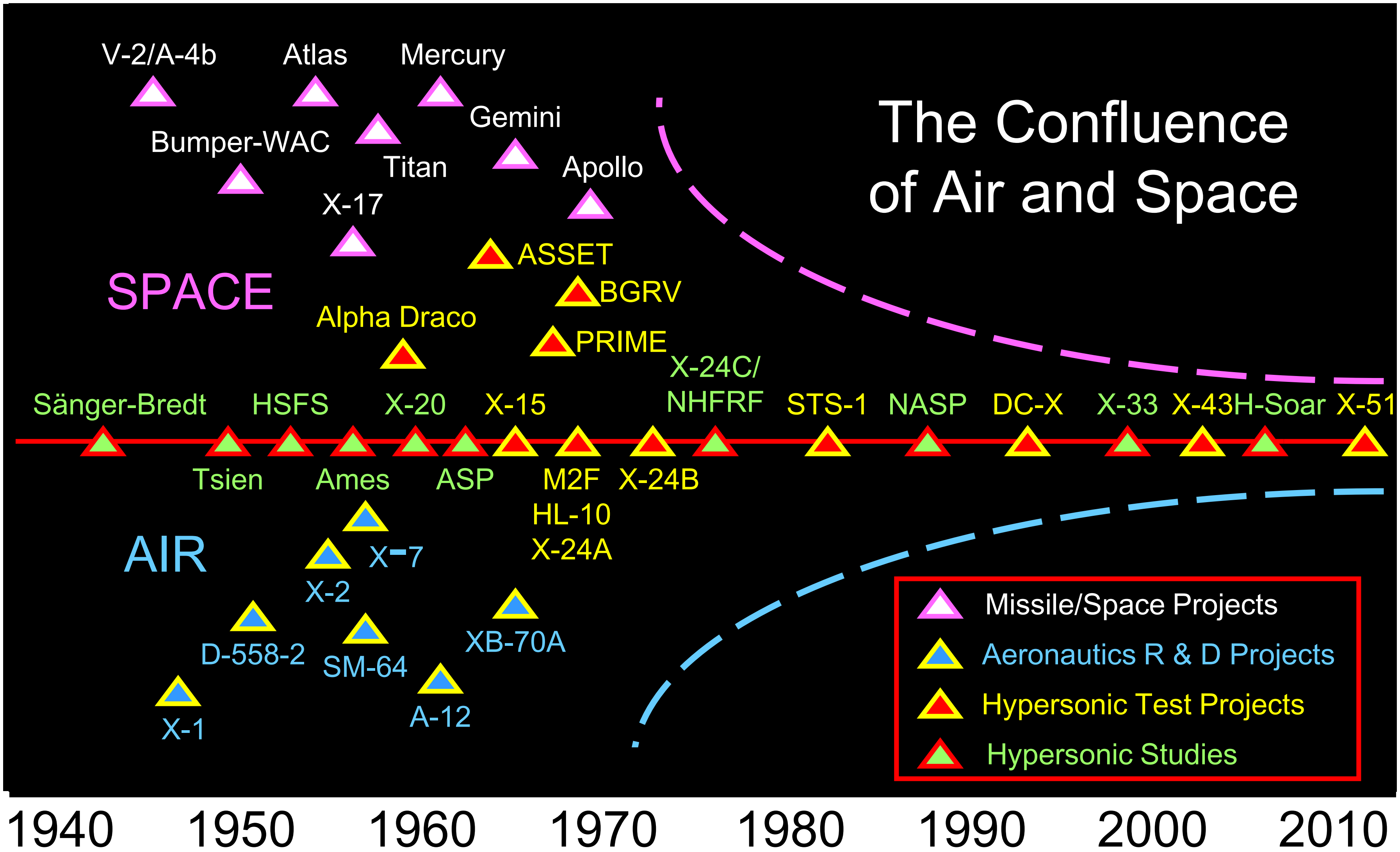
Richard.Hallion@floridapoly.edu

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…

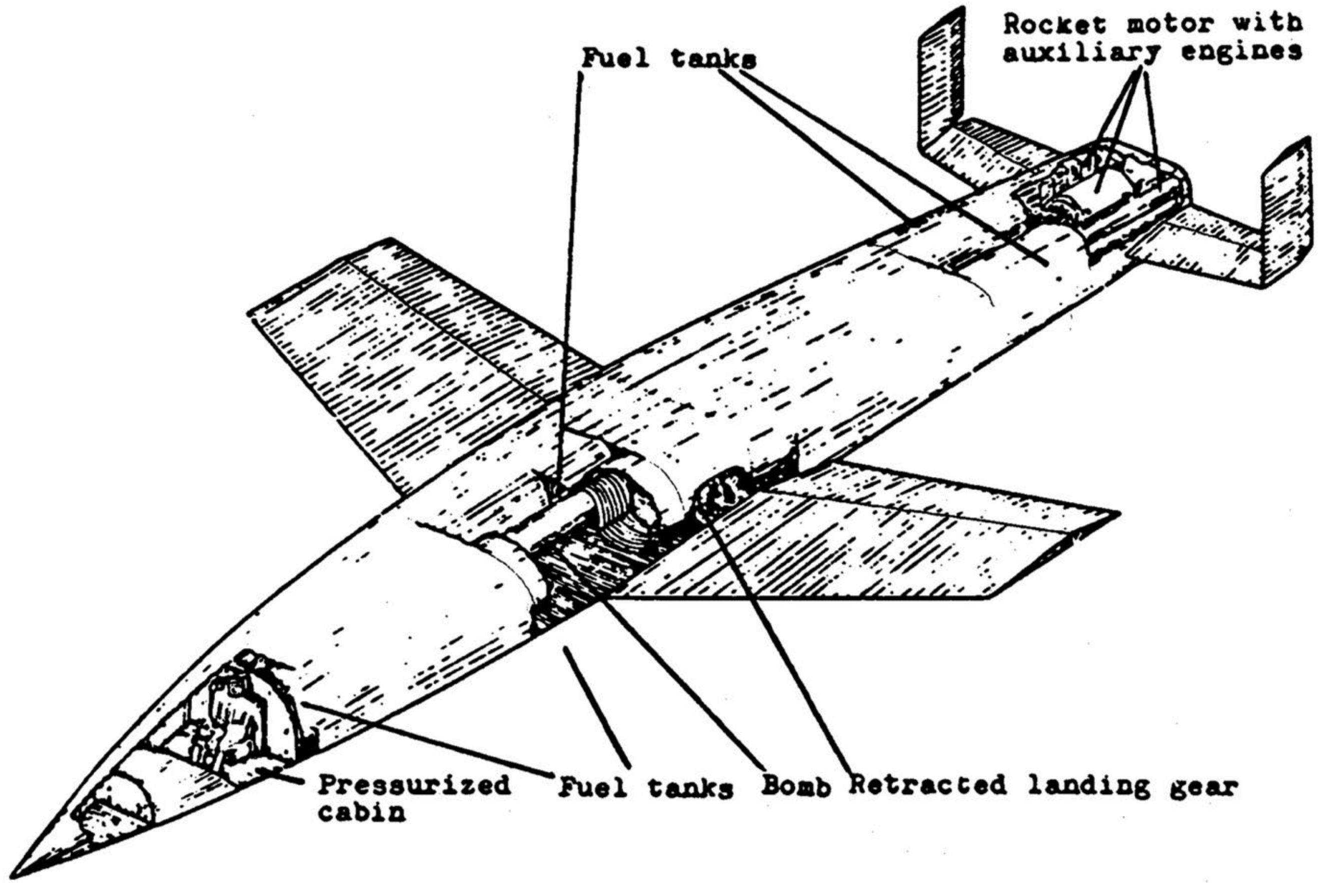


R. P. HALLION, 5/07

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)

NMUSAF

The Hypersonic Transfer from Europe

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

L/D = 4

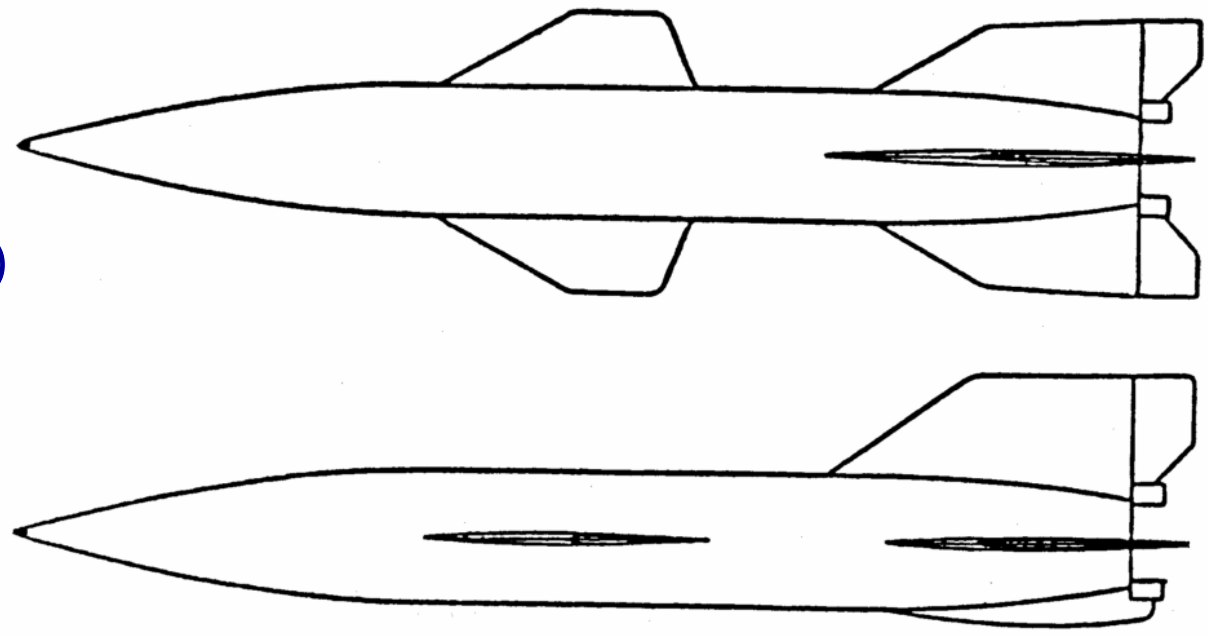
96,500 lb. GLOW

(inc. 72,400 lb. fuel)

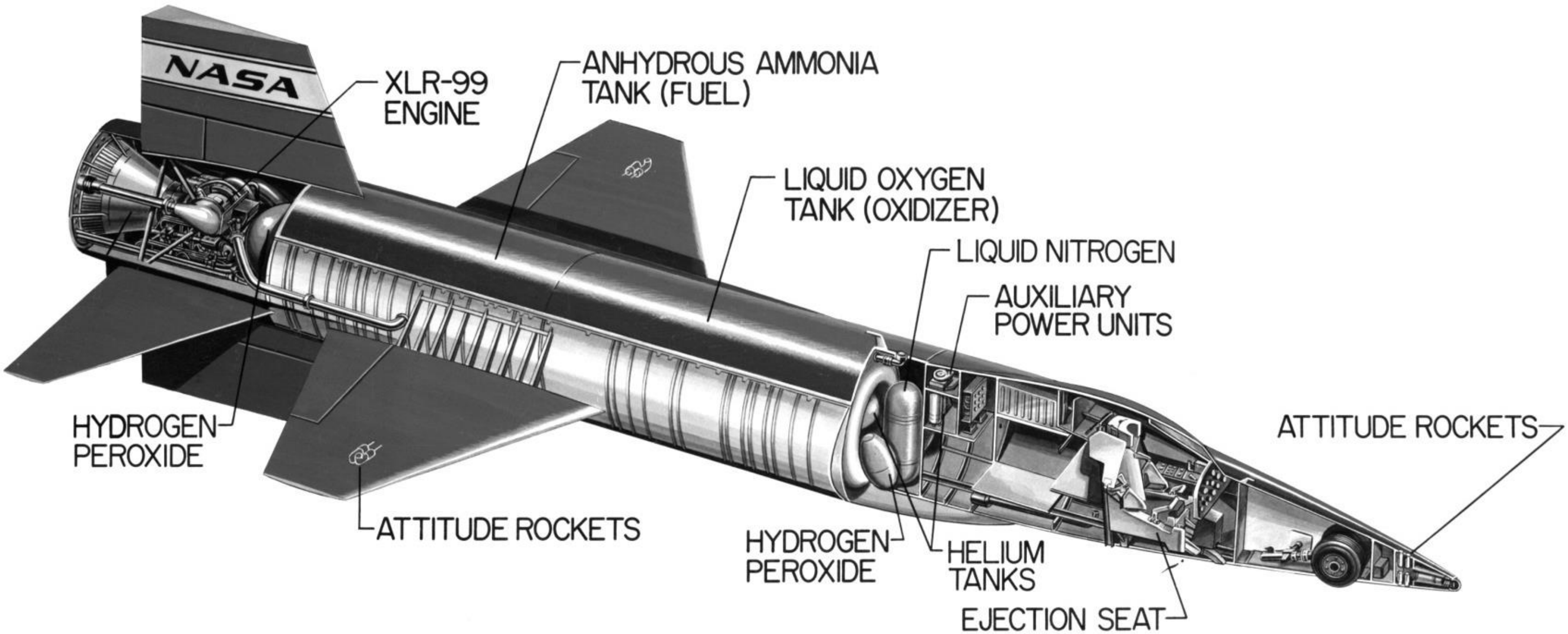
Length: 78.9 ft.

Wingspan: 18.9 ft.

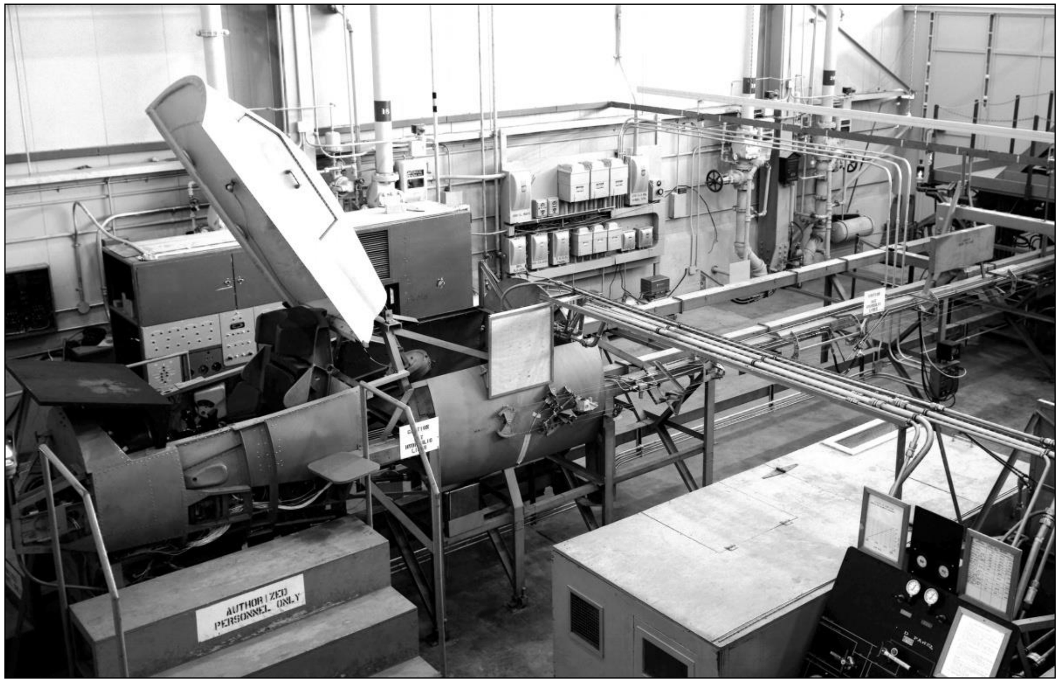
Height: 16.5 ft.



“Round Two:” The X-15



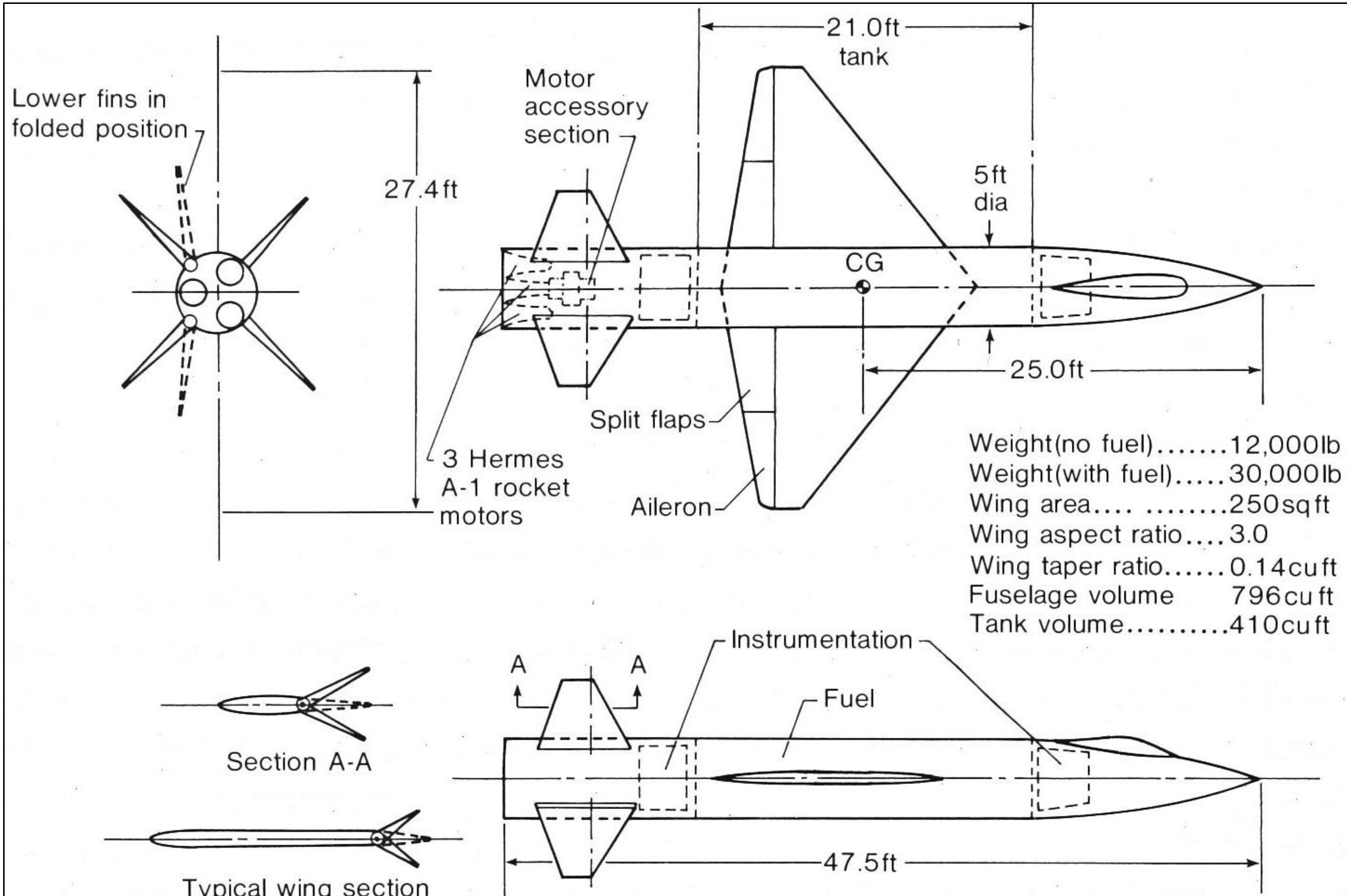
X-15 Simulation and Crew Protection



X-15 Proficiency and Planning Simulator

Neil Armstrong
and Clark MC-2
Pressure Suit

The Becker Hypersonic Study, 1954

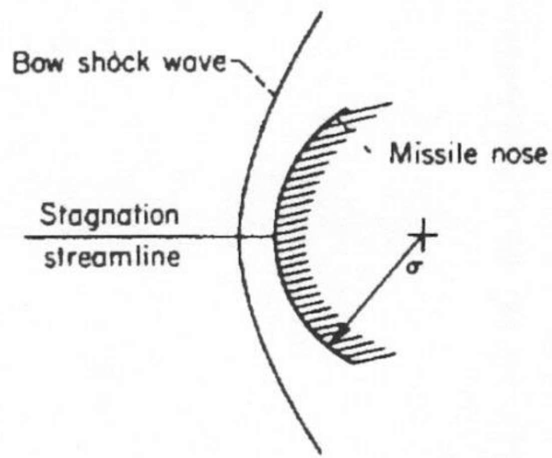


X-15A-2: M = 6.70, 3 Oct 1967

Maj. William J. Knight and the X-15A-2

Allen & Eggers Enunciate Blunt Body (1953)

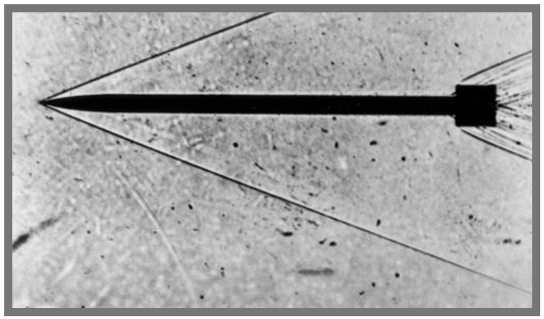
It is well known that for any truly blunt body, the bow shock wave is detached and there exists a stagnation point at the nose. Consider conditions at this point and assume that the local radius of curvature of the body is σ (see sketch).



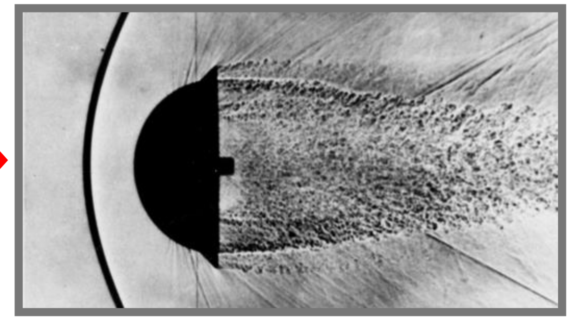
The bow shock wave is normal to the stagnation streamline and converts the supersonic flow ahead of the shock to a low subsonic speed flow at high static temperature downstream of the shock. Thus, it is suggested that conditions near the stagnation point may be investigated by treating the nose section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

From H. Julian Allen and A. J. Eggers, Jr., “A Study of the Motion and Aerodynamic Heating of Ballistic Missiles Entering the Earth’s Atmosphere at High Supersonic Speeds,” NACA TR-1381 (1953), p. 7

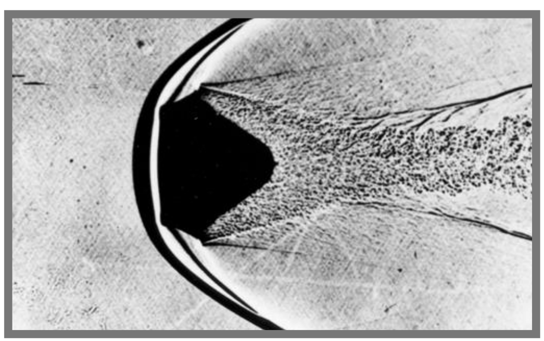
Early Ames Blunt Body Research…



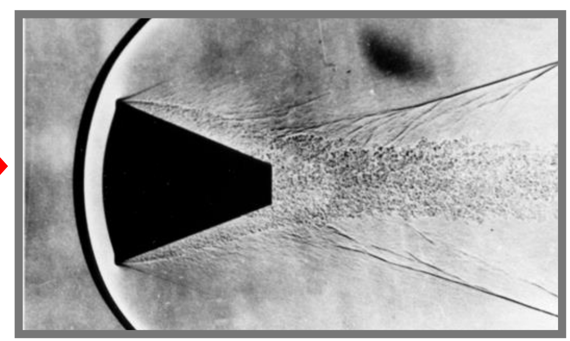
Conventional



Initial Concept



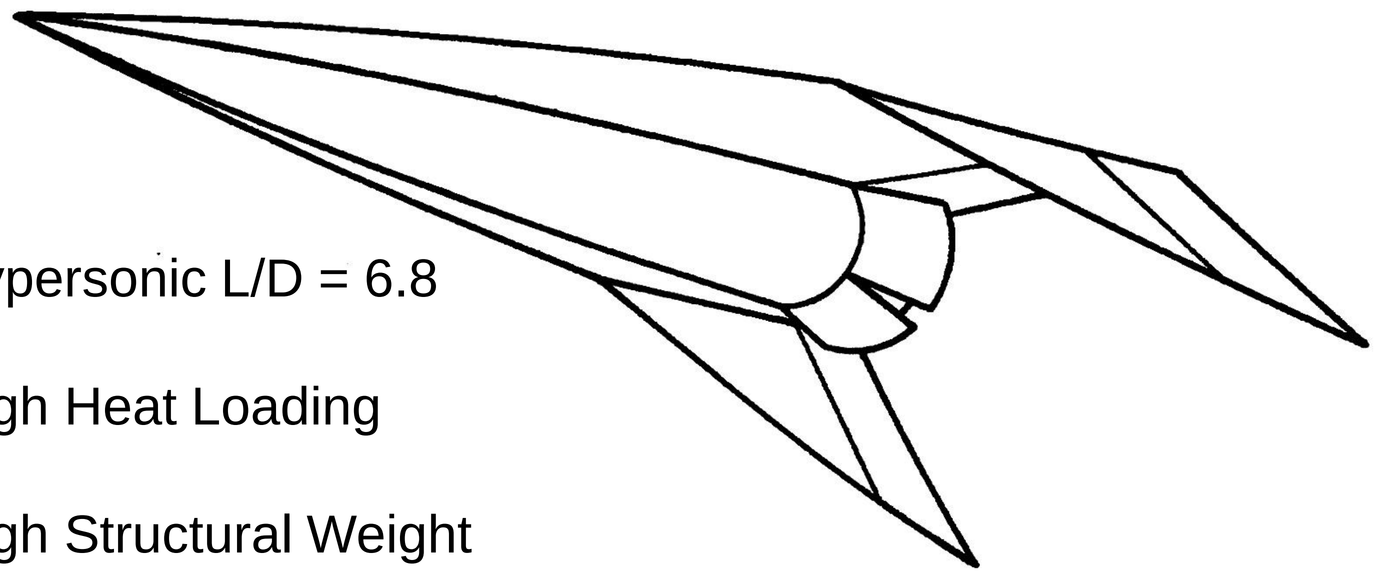
Missile Warheads



Manned Studies

NASA Photo

Eggers-Syvertson Flat Top Concept (1956)



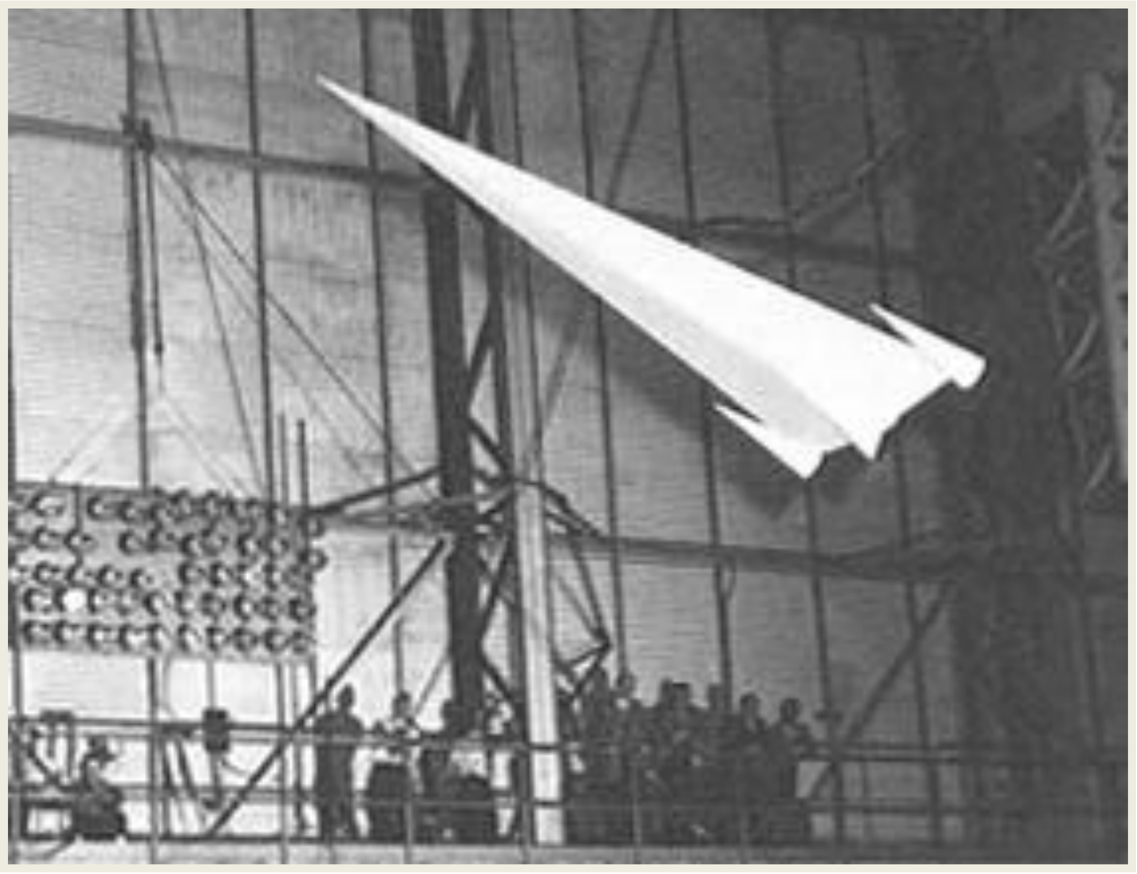
Hypersonic L/D = 6.8

High Heat Loading

High Structural Weight

From A. J. Eggers and Clarence Syvertson, “Aircraft Configurations Developing High Lift-Drag Ratios at High Supersonic Speeds,” NACA RM A55L05 (1956)

NACA-Langley *Hywards* Study (1956)



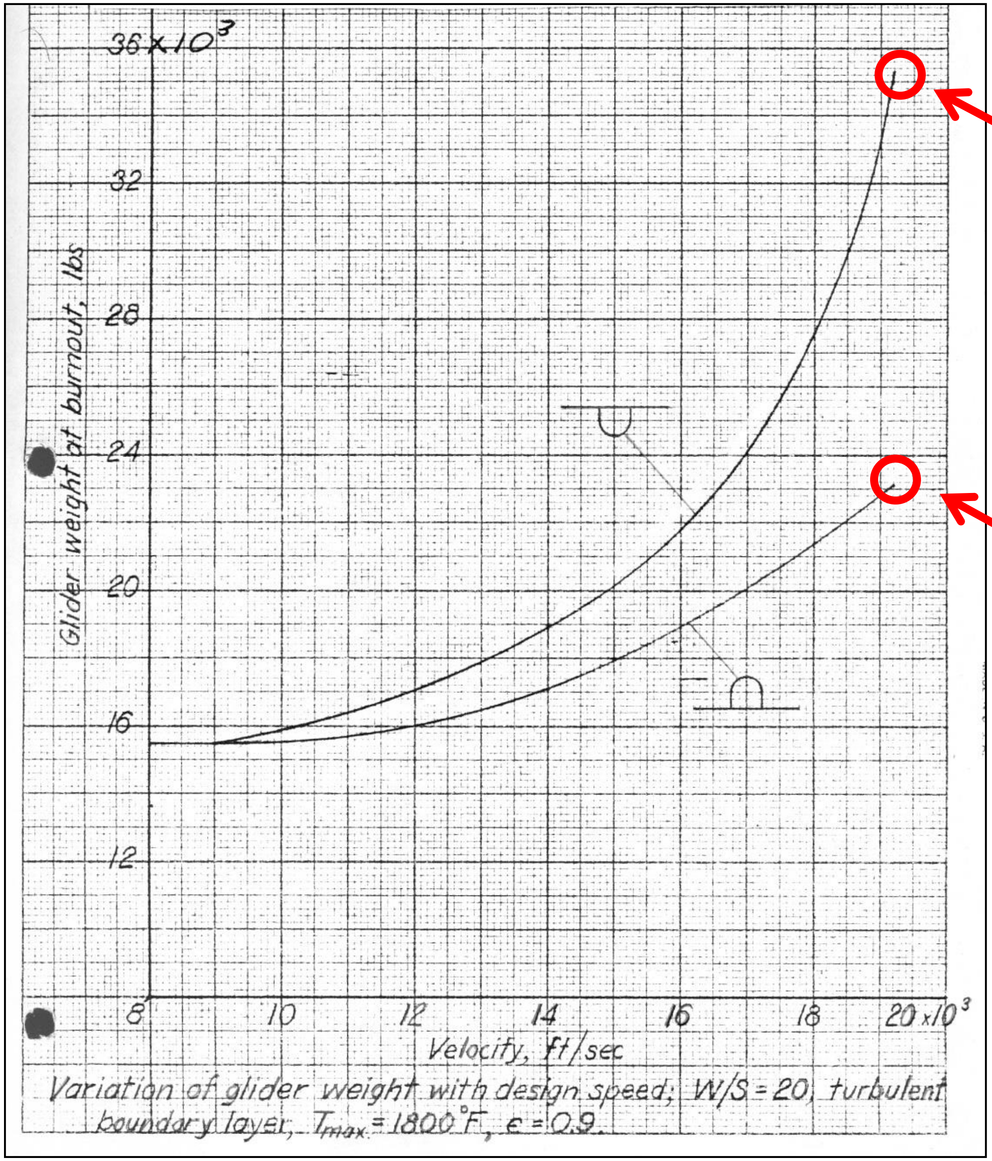
Hywards
“flying” in the
NACA LMAL
Full-Size
Tunnel

Ames Flat-top vs. Langley Flat-bottom

"Heavy"

TPS-driven Structural Weight versus Speed

"Light"

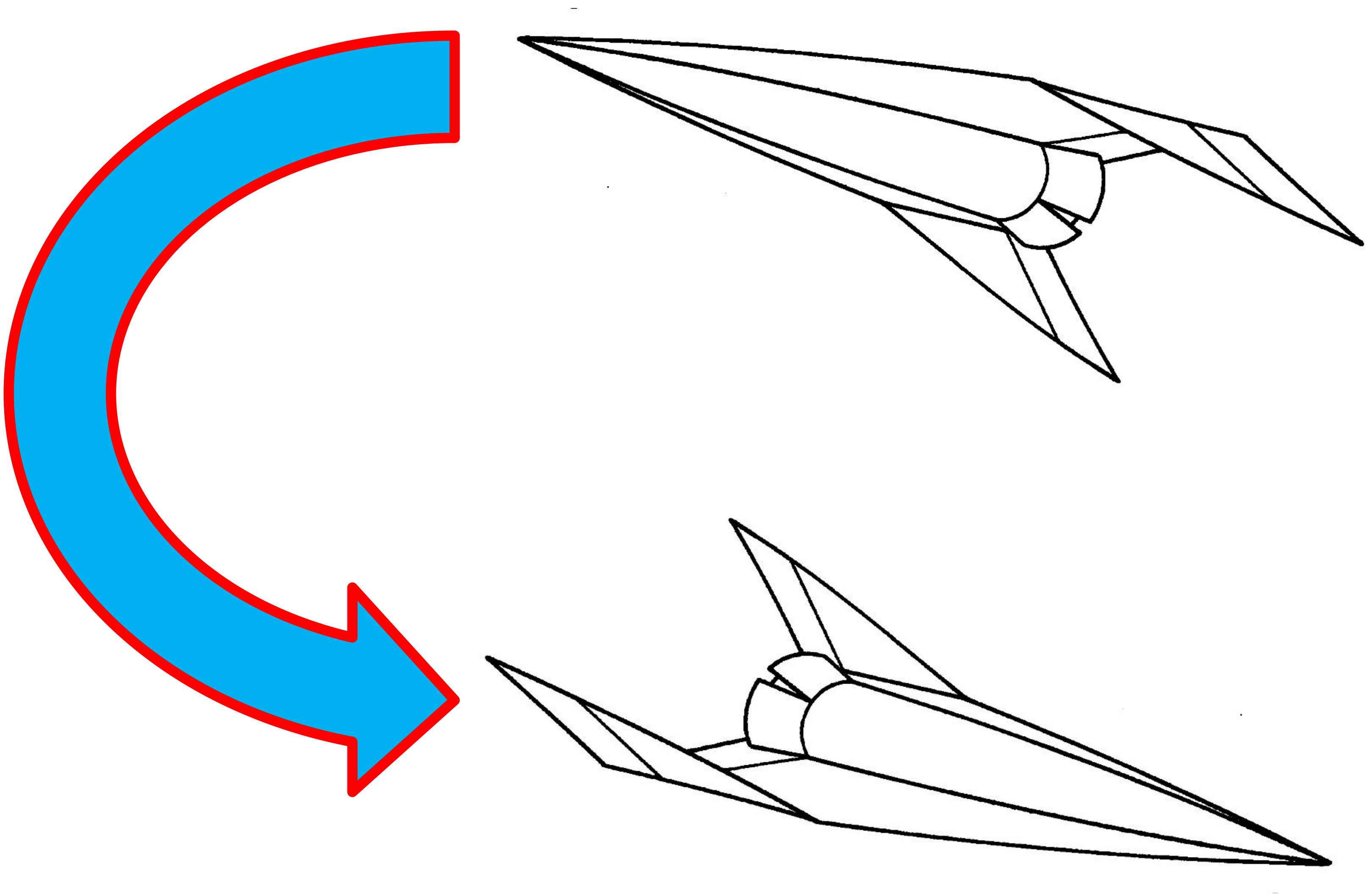


Ames
High L/D
High Heat
Flat Top

Langley
Low L/D
Low Heat
Flat Bottom

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

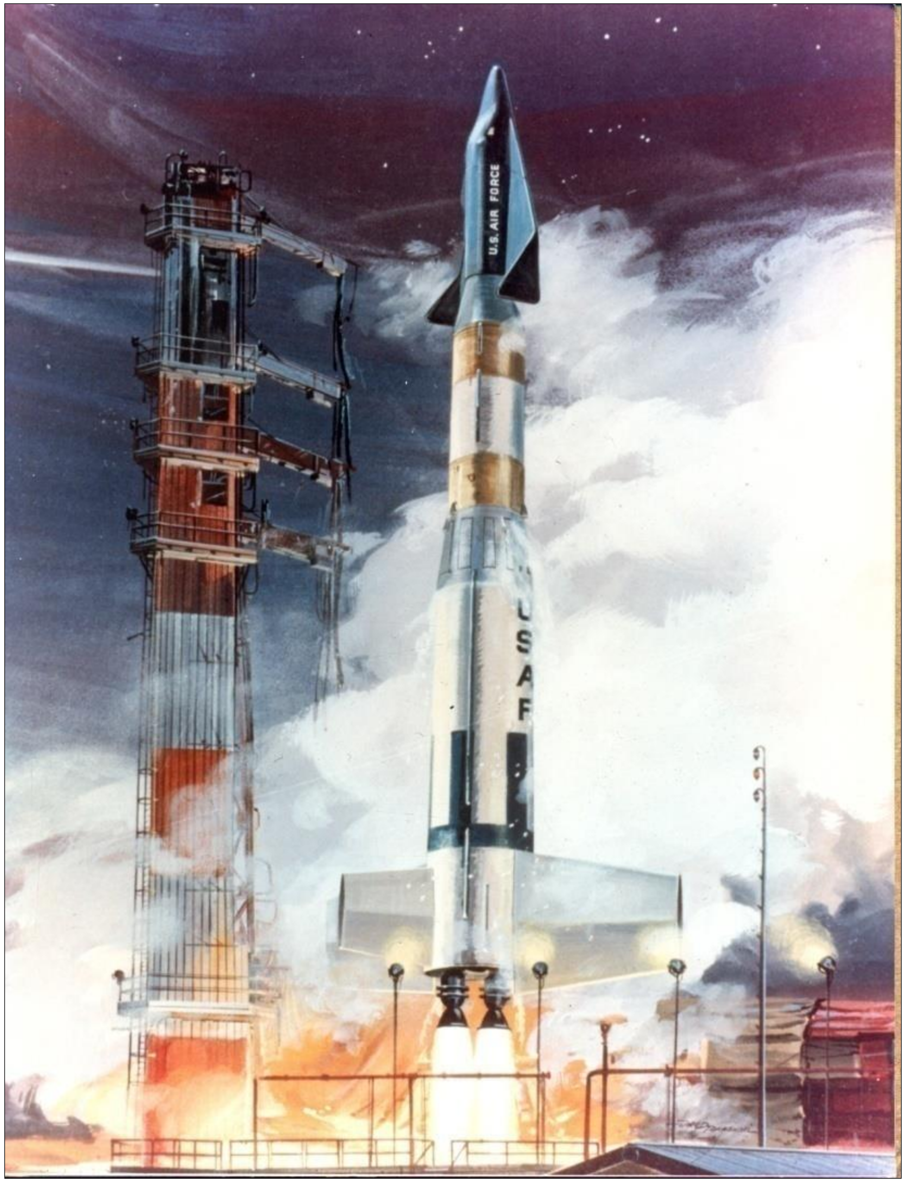
Slender Delta

Sloped Aft End

Radiative Cooled

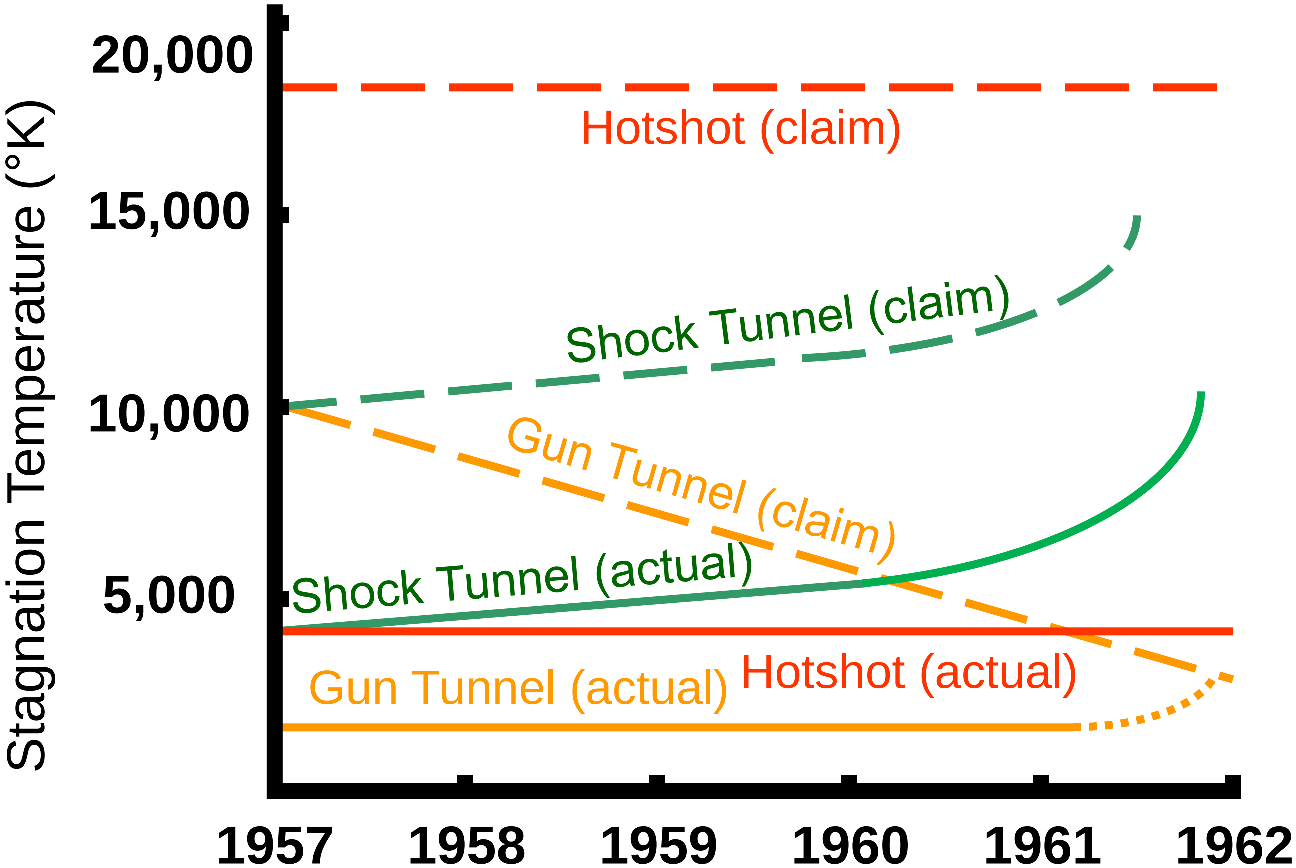
Blended Controls

Skid Landing Gear



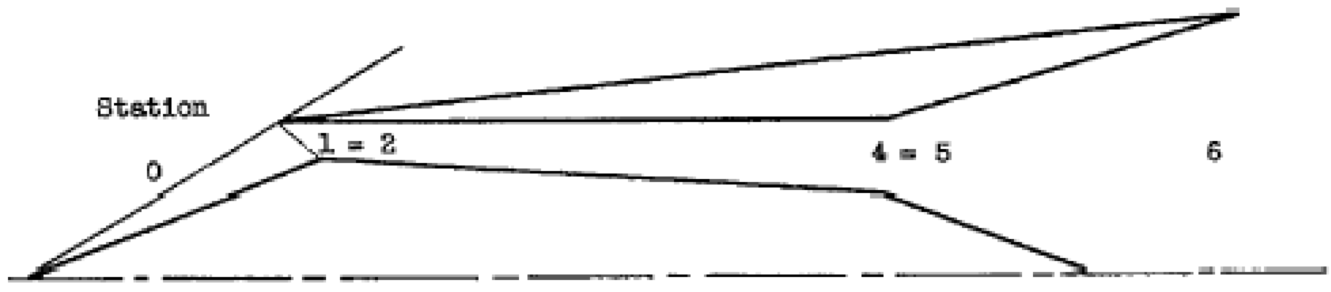
NMUSAF Photo

Simulation: Claims versus Realities



Adapted from Julius Lukasiewicz, *Experimental Methods of Hypersonics* (NY: Dekker, 1973), p. 247

The Weber-MacKay Study, 1958

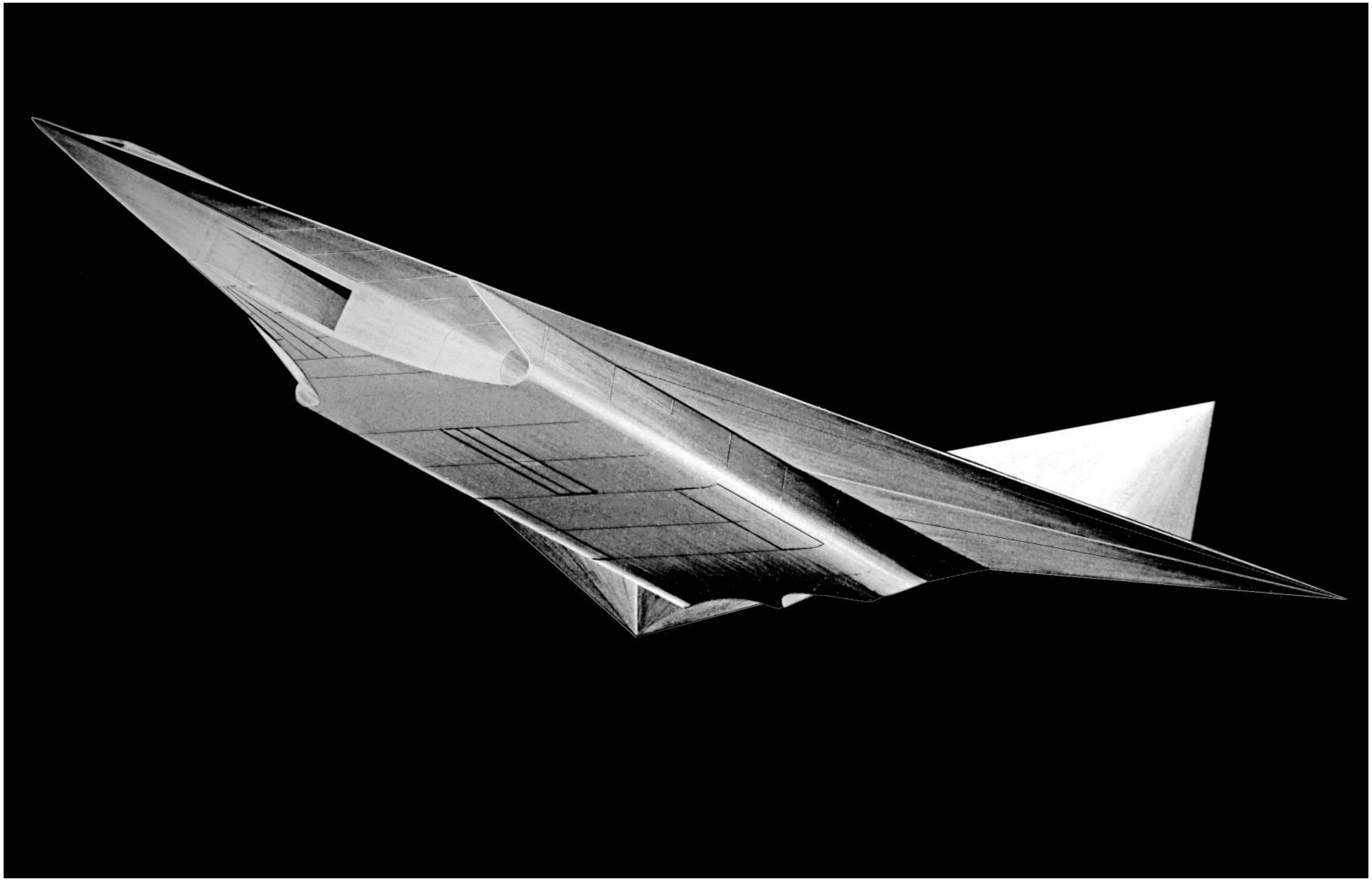


(a) Supersonic-combustion ramjet.

"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."*

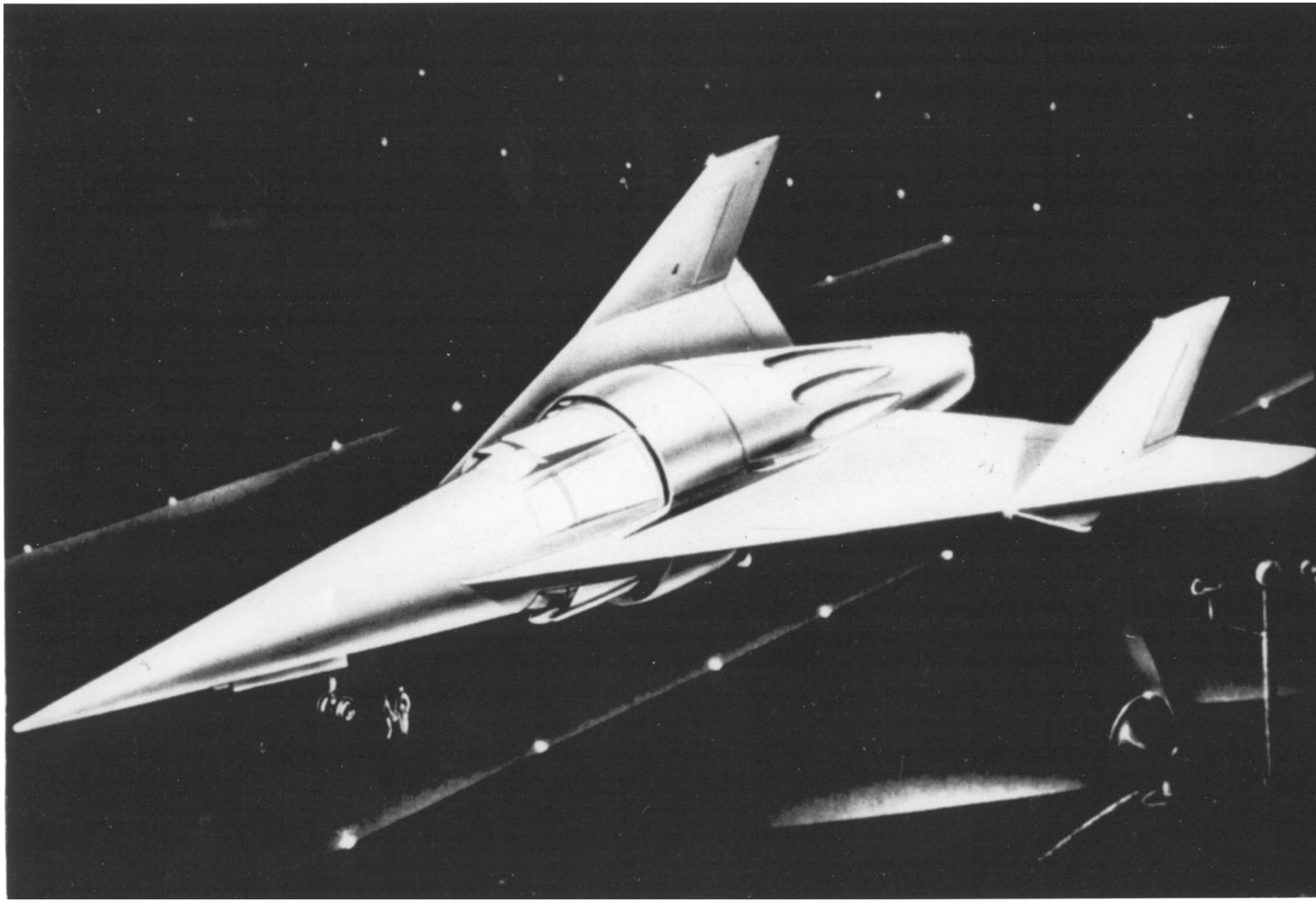
From Richard J. Weber and John S. MacKay, "An Analysis of Ramjet Engines Using Supersonic Combustion," NACA TN 4386 *(*1958), p. 22.

Republic Aviation Design Concepts



Kartveli Mach 7 Hypersonic Strategic Cruiser

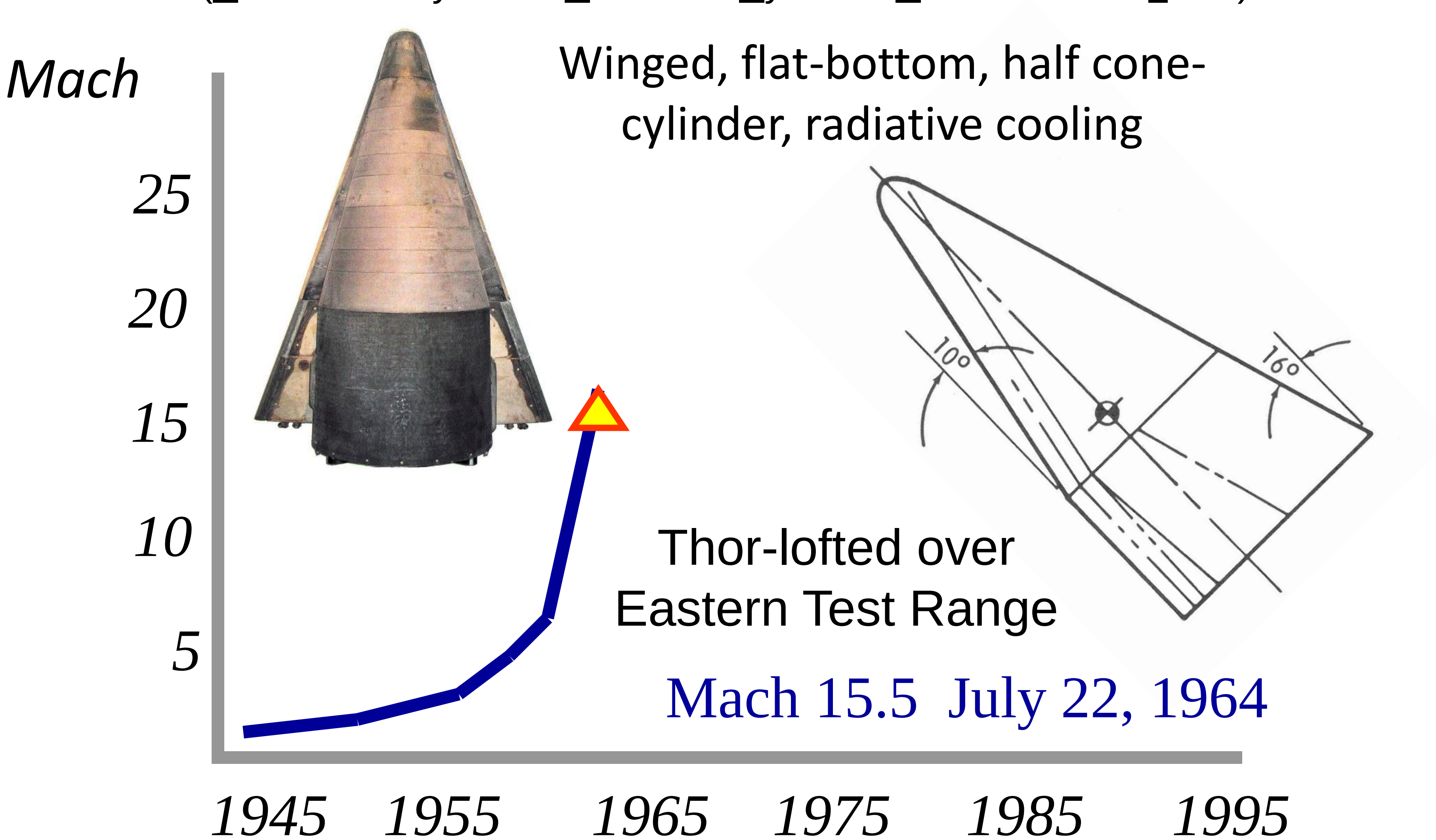
…Aerospaceplane…



McDonnell ASSET

(Aerothermodynamic-Structural Systems Environmental Tests)

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

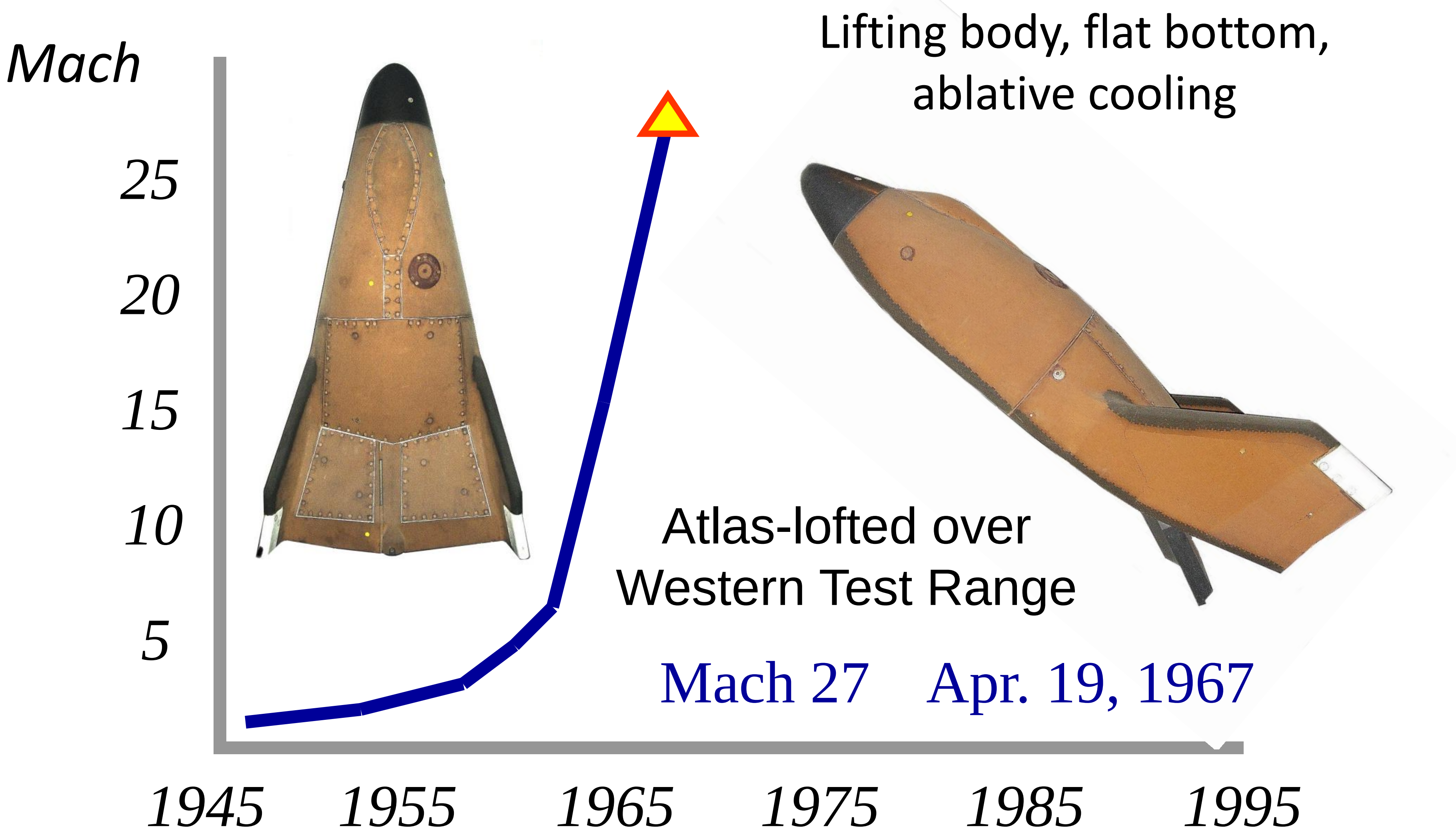


Thor-lofted over Eastern Test Range

Mach 15.5 July 22, 1964

Martin SV-5D PRIME

(Precision Recovery Including Maneuvering Entry)



…The NASA-USAF Lifting Bodies…

X-24B
1973

M2-F1
1963

USAF

NASA

X-24A 1969

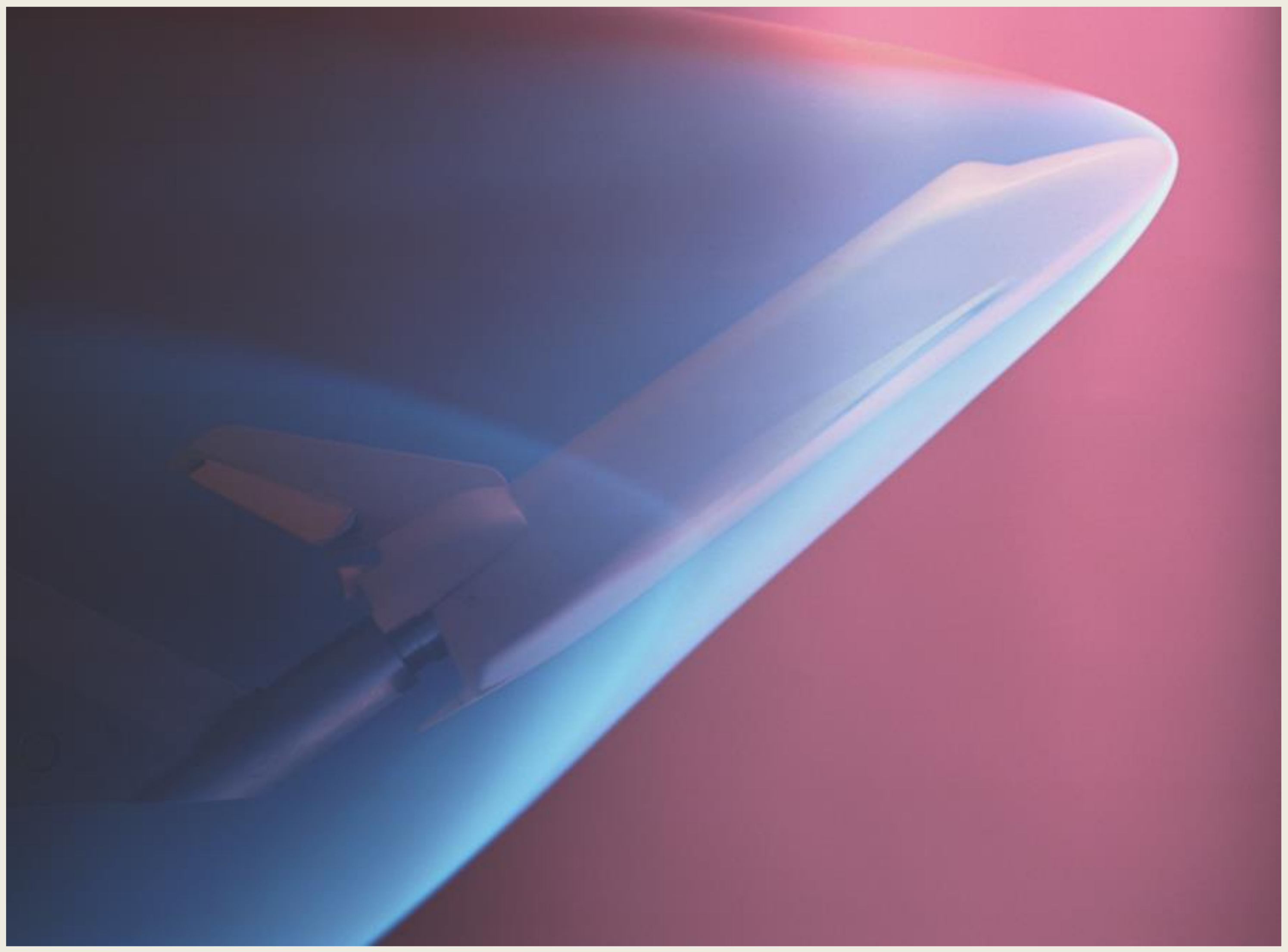
M2-F3 1970

HL-10 1966

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

NASA Photo

…Post-Shuttle Boost-Glide Transatmospherics…

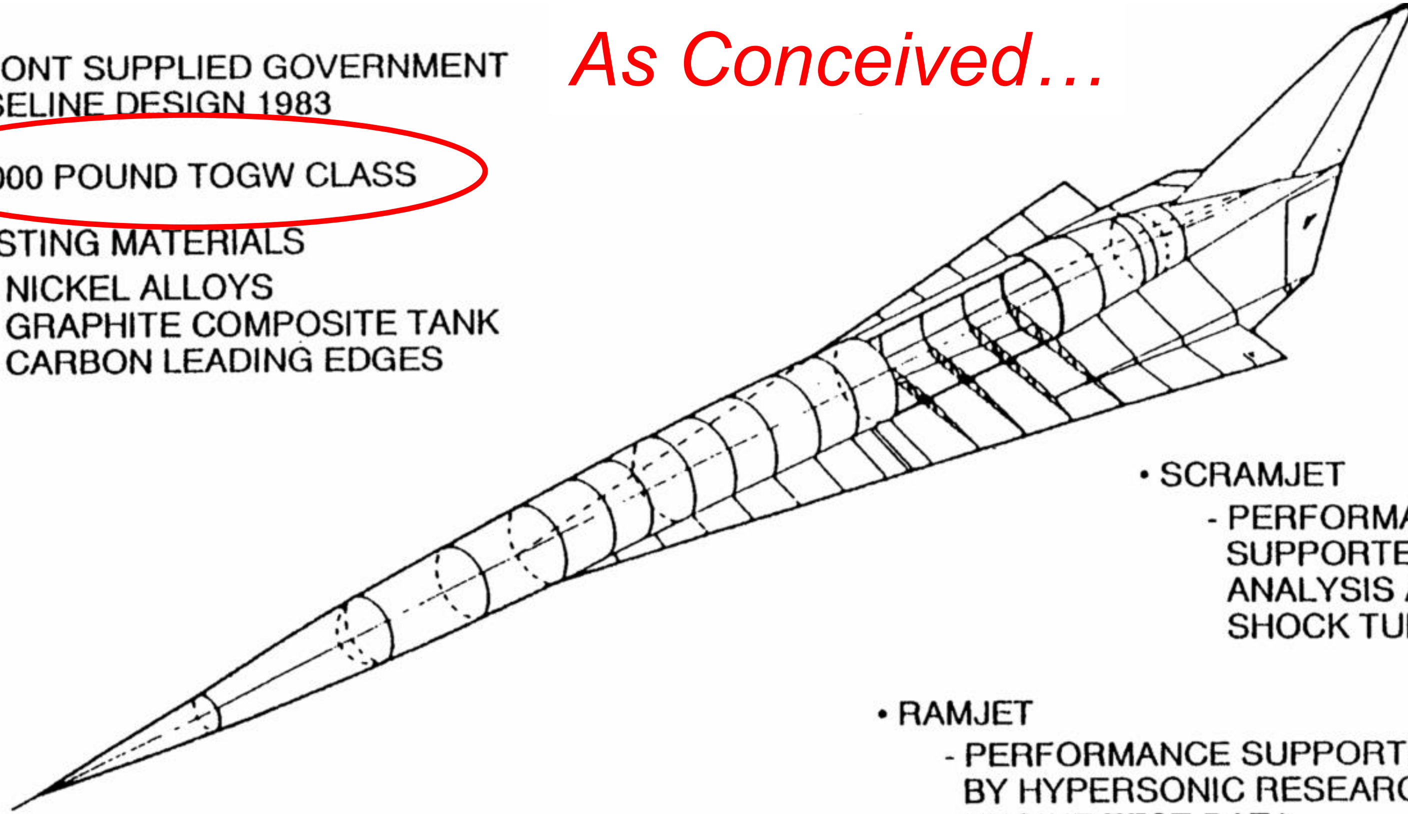
Boeing X-37B launch…

…and Recovery…

Return of the Air-Breather: NASP (X-30)

As Conceived…

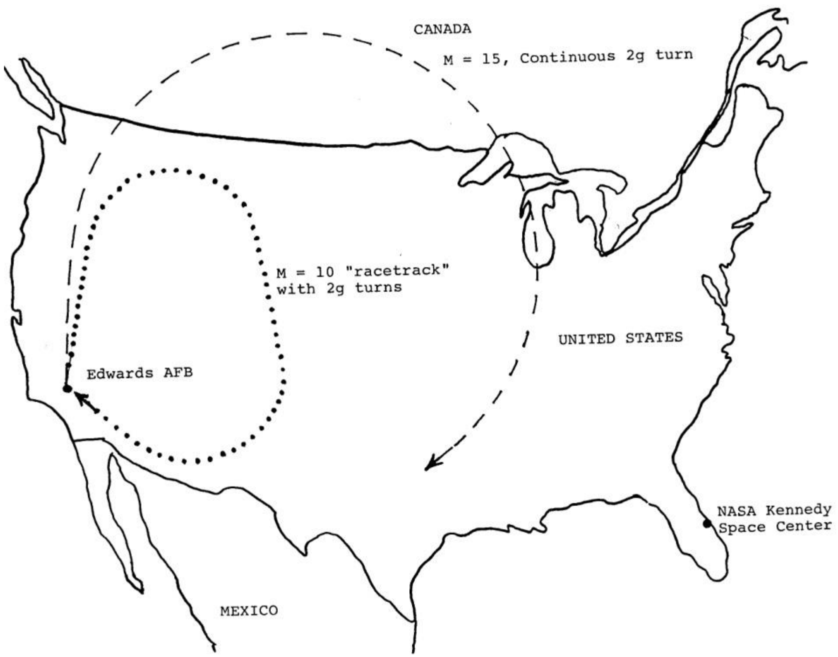
- duPONT SUPPLIED GOVERNMENT BASELINE DESIGN 1983
- 50,000 POUND TOGW CLASS
- EXISTING MATERIALS
  - NICKEL ALLOYS
  - GRAPHITE COMPOSITE TANK
  - CARBON LEADING EDGES



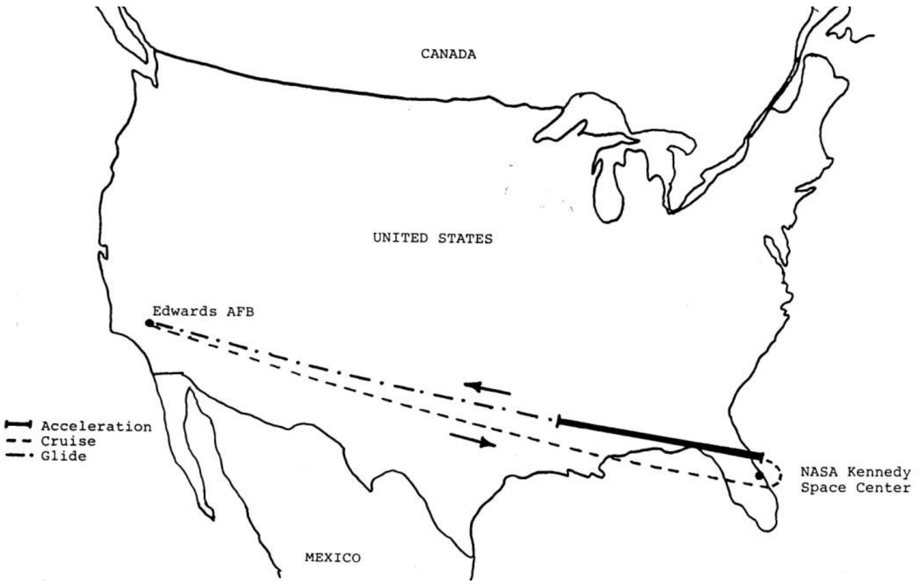
- SCRAMJET
  - PERFORMANCE SUPPORTED BY ANALYSIS AND SHOCK TUNNEL
- RAMJET
  - PERFORMANCE SUPPORTED BY HYPERSONIC RESEARCH ENGINE TEST DATA
- ACCELERATION ENGINE
  - U.S. PATENT ISSUED TO A. duPONT
  - PERFORMANCE VERIFIED BY GASL AND PW TESTS
- DRAG LEVEL VERIFIED
  - NASA WIND TUNNEL TESTS
  - BOEING SUPPLIED MODEL

…NASP: Test Range Challenges

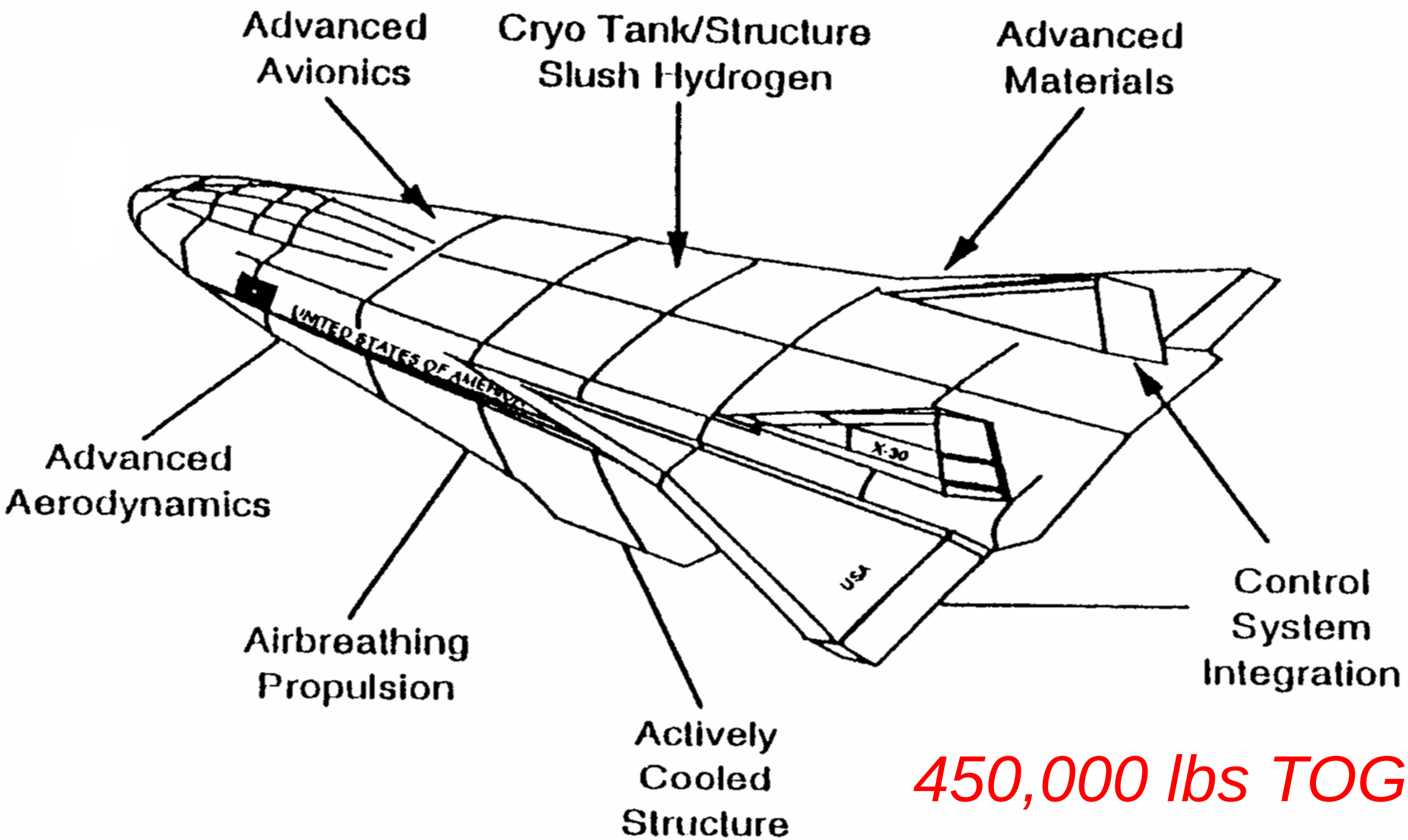
"Local" Ground Track…



Envelope Expansion…



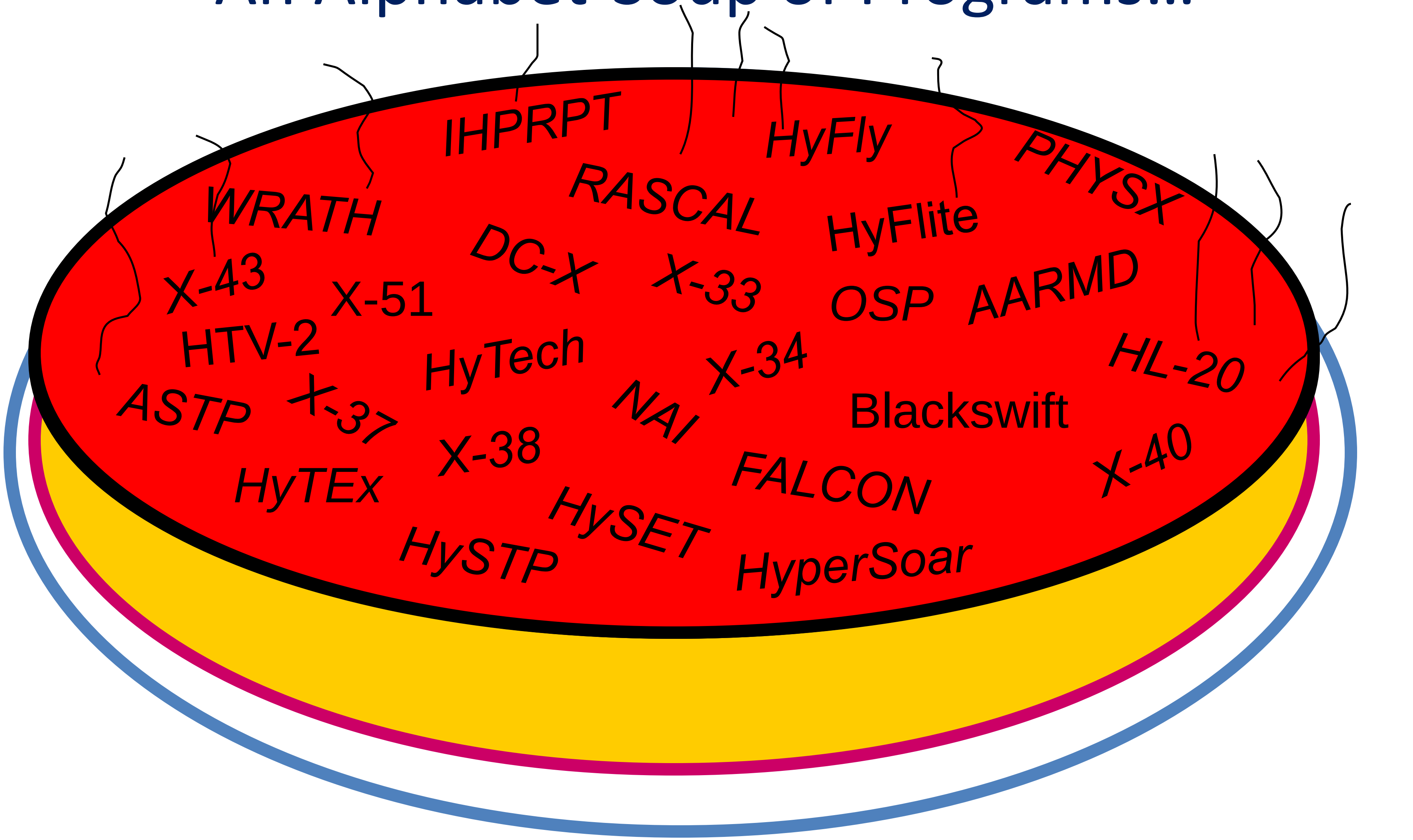
X-30 NASP when Shelved…



450,000 lbs TOGW

NASA Dwg

An Alphabet-Soup of Programs…



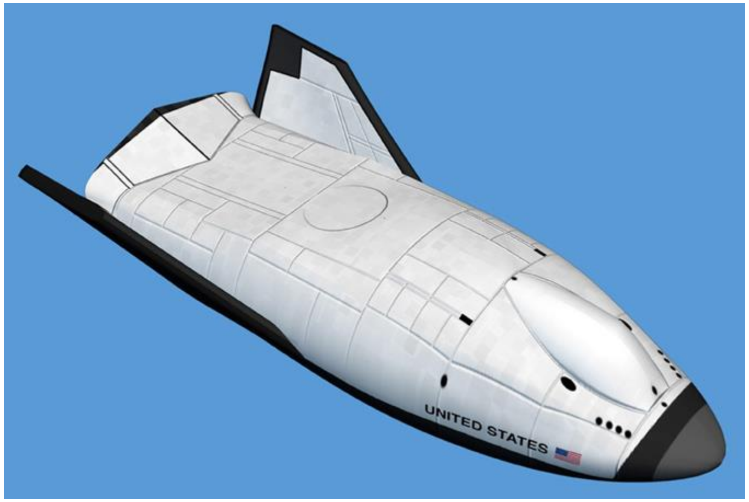
Promising (Re) Beginnings. . .

Photograph Courtesy Centre for Hypersonics, University of Queensland

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

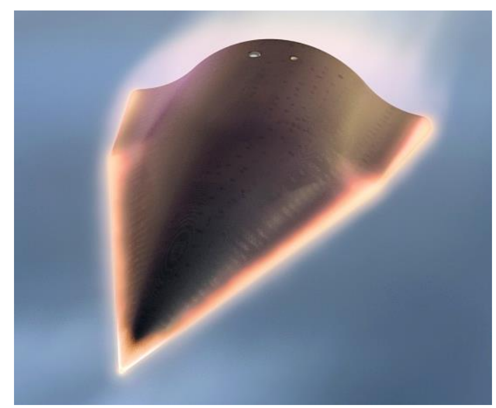
X-34

...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

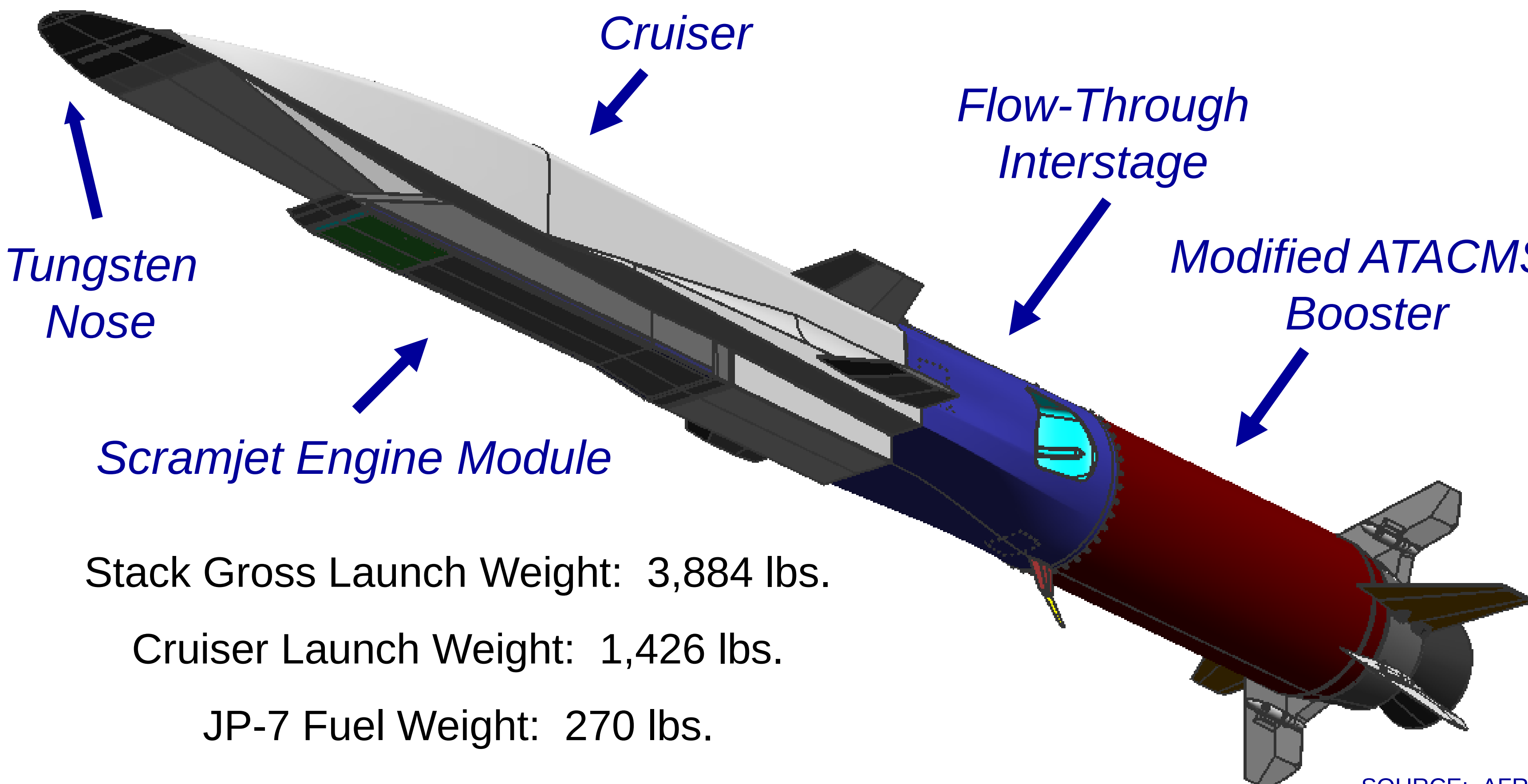
Overall Stack length: 301 inches

Cruiser max width: 23 inches

$240 million

5 minute flights

1st Flight 2010



Stack Gross Launch Weight: 3,884 lbs.

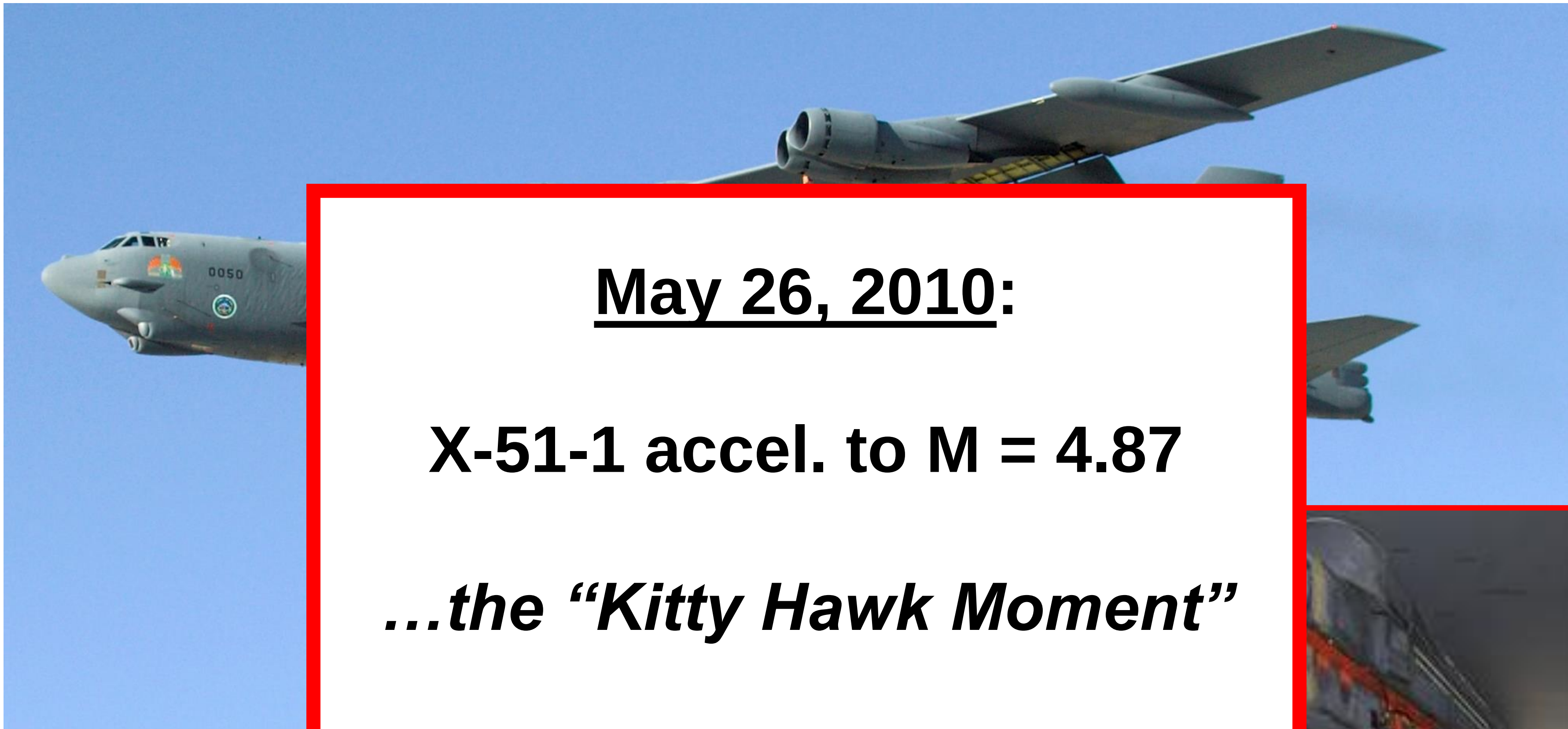
Cruiser Launch Weight: 1,426 lbs.

JP-7 Fuel Weight: 270 lbs.

SOURCE: AFRL

X-51 Flight Test

X-51 Flight Test

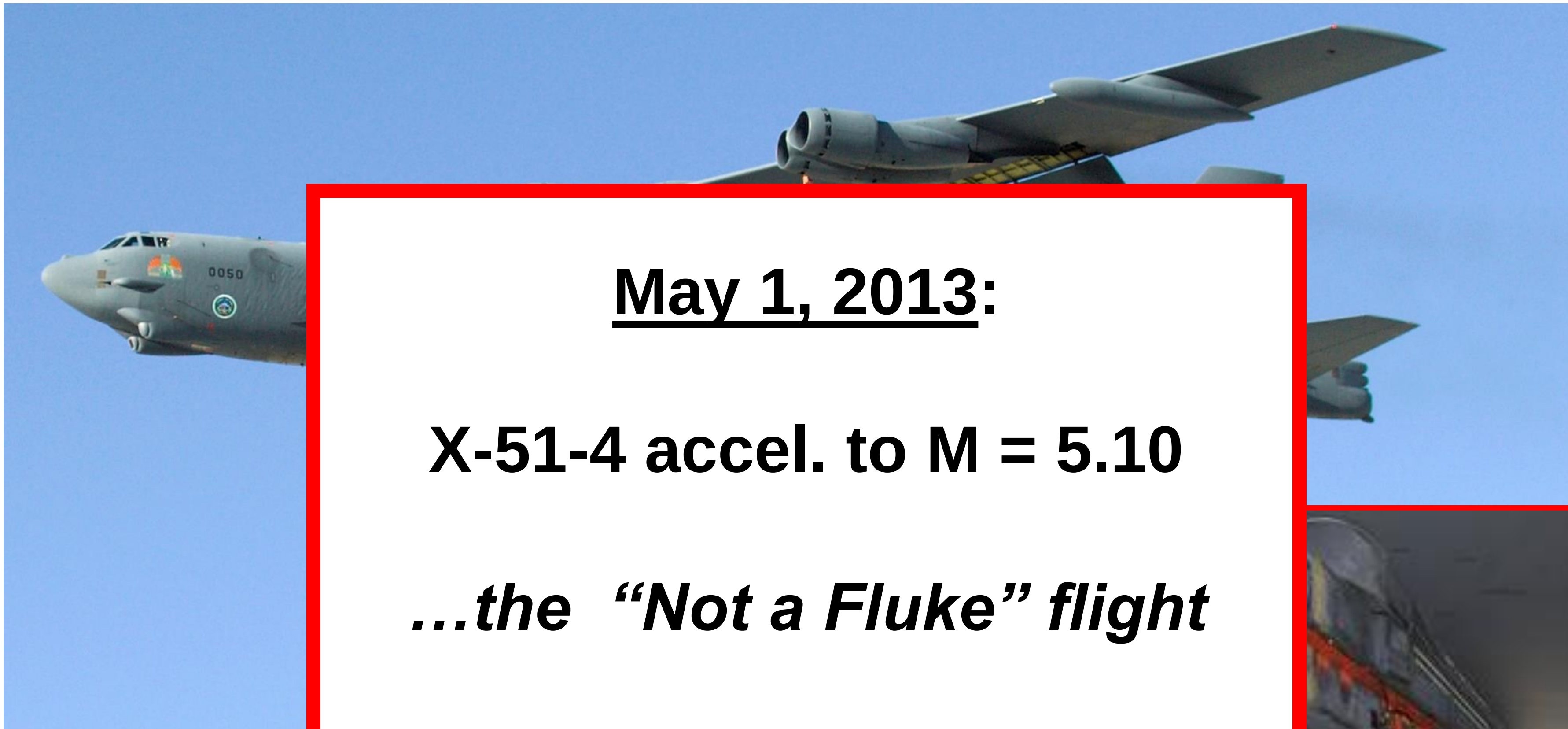


<u>May 26, 2010</u>:

X-51-1 accel. to M = 4.87

…the "Kitty Hawk Moment"

X-51 Flight Test

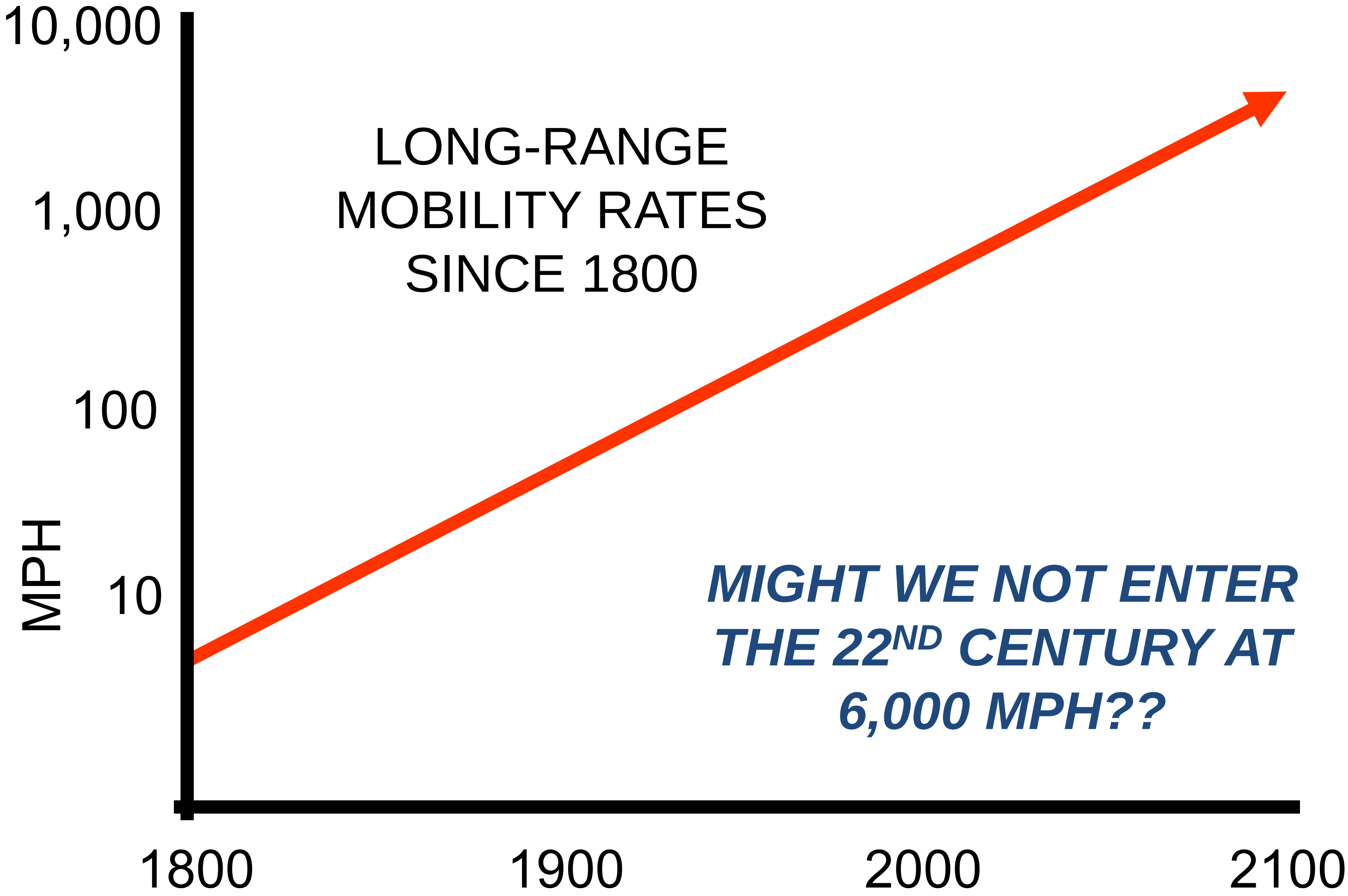


<u>May 1, 2013</u>:

X-51-4 accel. to M = 5.10

…the “Not a Fluke” flight

A Possible Future—but Will It be Ours?



Questions?

Dr Richard P Hallion

DrHypersonic1@Hotmail.com

Richard.Hallion@floridapoly.edu