Supersonic Transports Past, Present & Future

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Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design
- First generation SSTs
  - Concorde
  - Tu-144
  - Boeing 2707
- Second Generation Studies
  - Supersonic Cruise Aircraft Research
  - High Speed Civil Transport
  - DARPA Quiet Supersonic Platform
- Future
  - NASA/Lockheed X-59
  - Supersonic Bizjets
  - Supersonic Transports
- Conclusions

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- Wave Drag
  - Wave drag due to volume (zero-lift wave drag)
  - Wave drag due to lift

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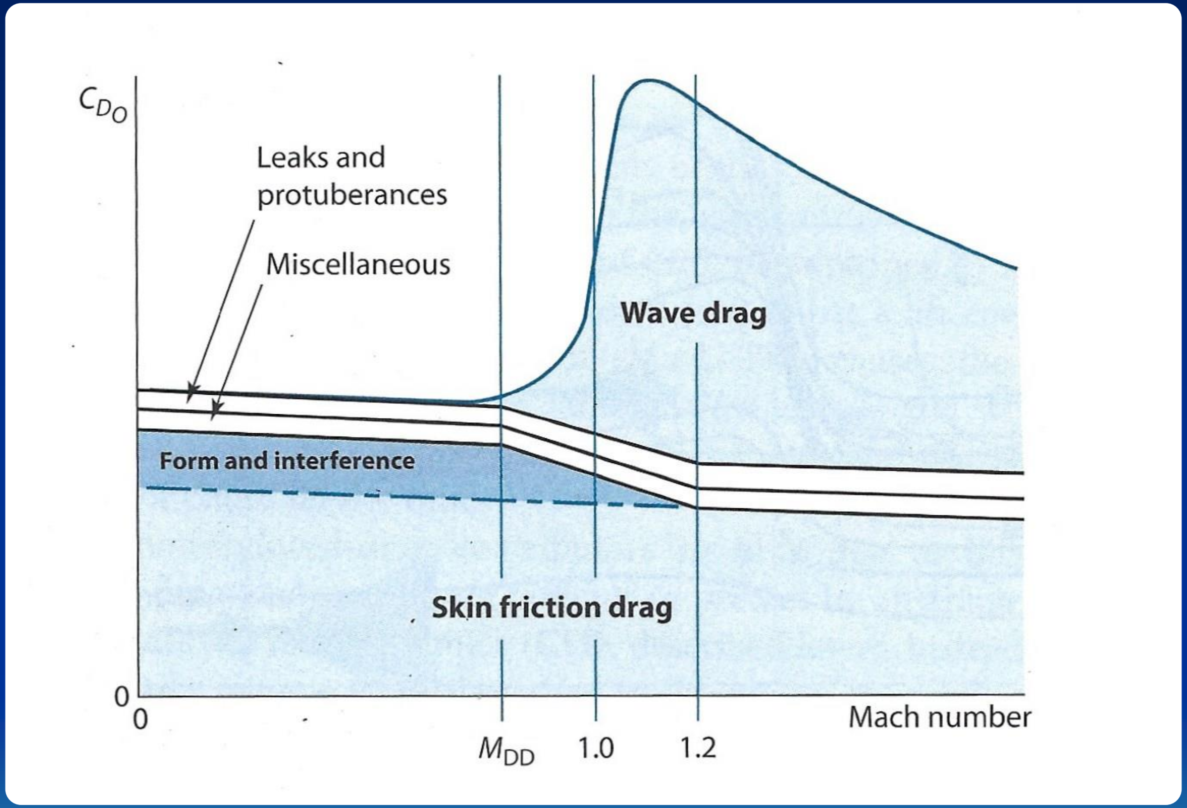
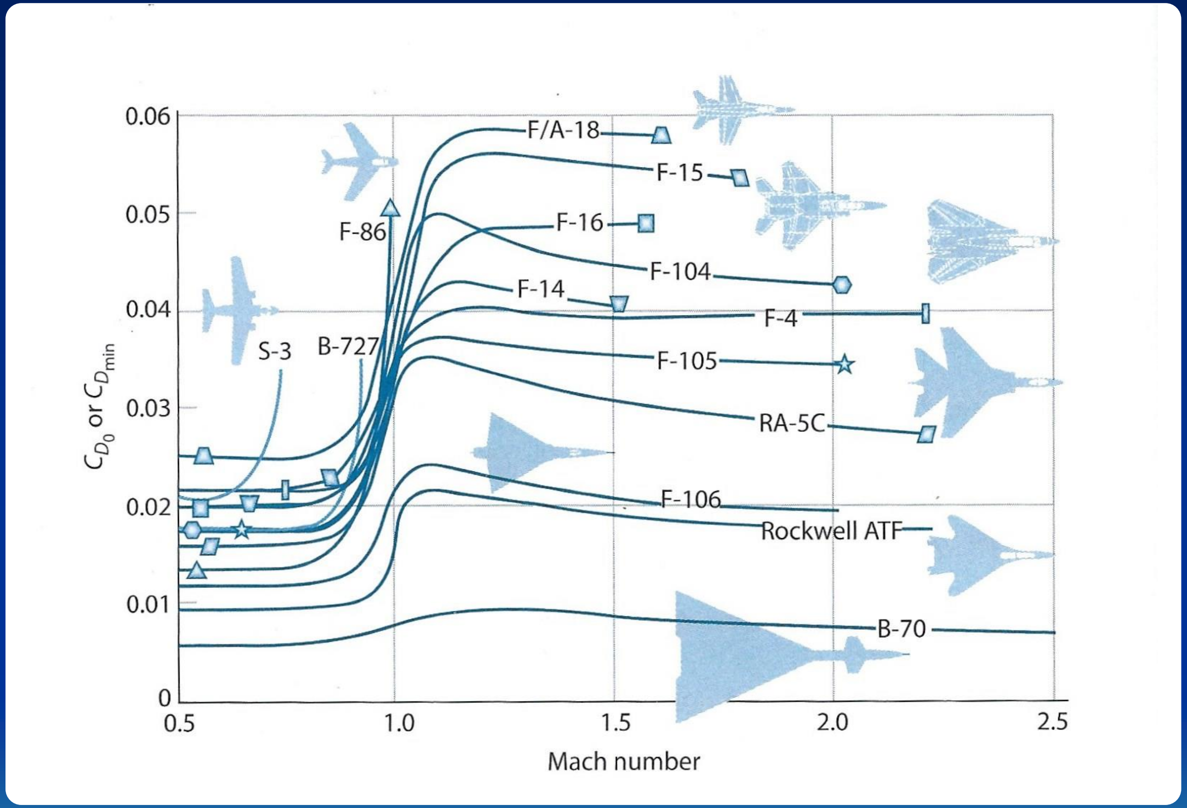
Zero-Lift Wave Drag

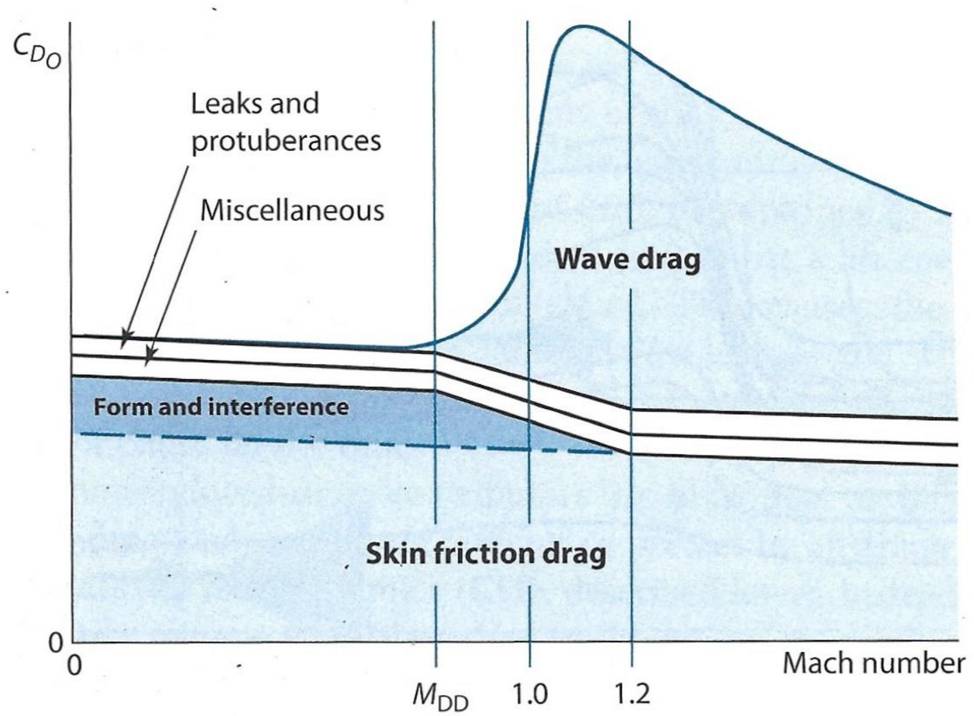


© Raymer Fig. 12.33



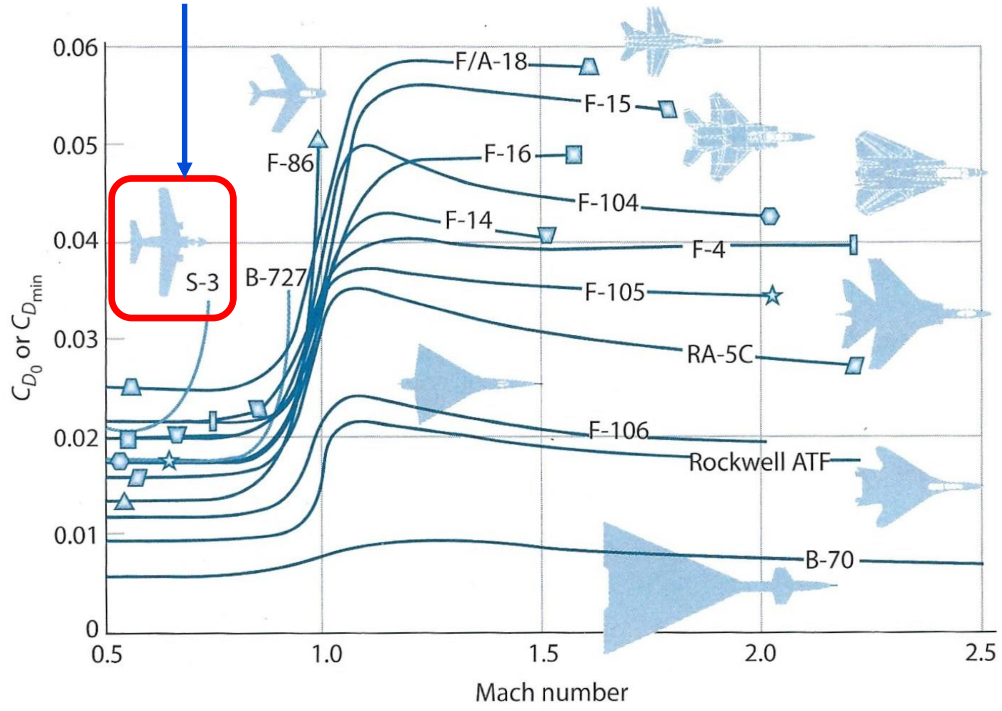
© Raymer Fig. 12.34

Zero-Lift Wave Drag



© Raymer Fig. 12.33

Why does S-3 have such an early drag rise?



© Raymer Fig. 12.34

ADAC Aircraft Design & Consulting

Lockheed S-3 Viking

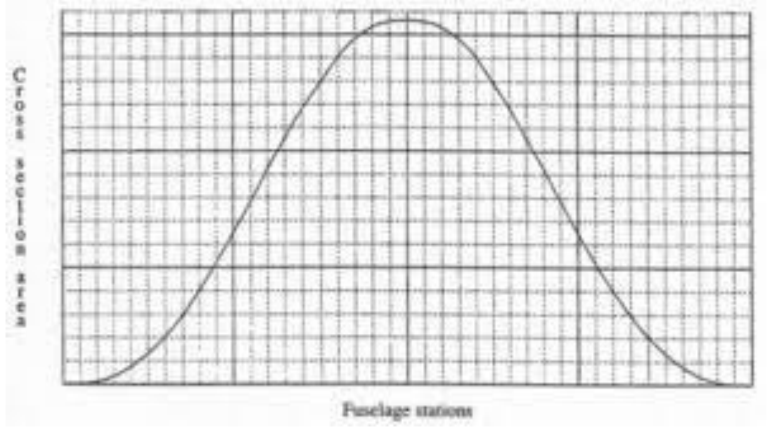
https://photos.daedalum.org/picture.php?/7507-_mg_7391/tags/4429-uss_midway

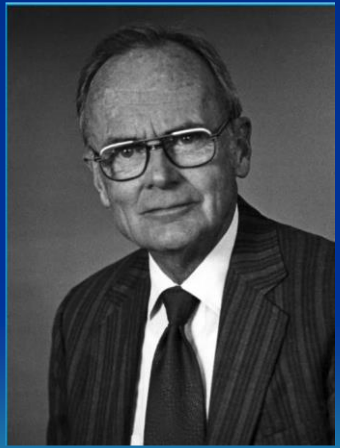
https://besthqwallpapers.com/airplanes/lockheed-s-3-viking-4k-american-army-us-navy-lockheed-132786

- Keep thrust line close to centerline for one engine inoperative (OEI) carrier approach
- Keep pylons close to centerline to minimize span with wings folded
- Critical flow (sonic velocity) between fuselage and nacelle

Sears-Haack Body

- Minimum transonic wave drag for given volume
- For Sears-Haack body:

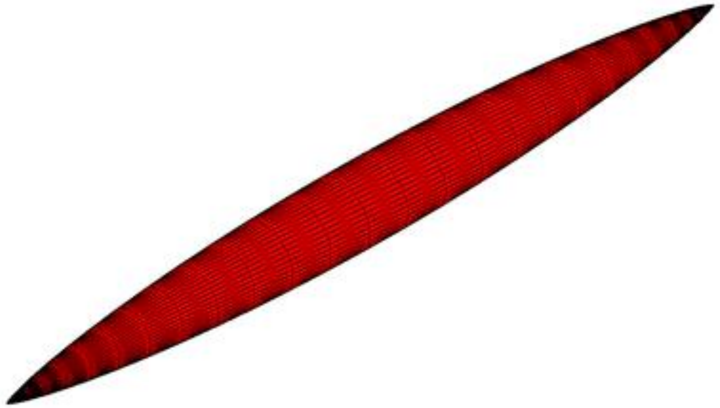




Bill Sears

$$\left(\frac{D}{q}\right)_{wave} = \frac{9\pi}{2}\left(\frac{A_{max}}{L}\right)^2$$

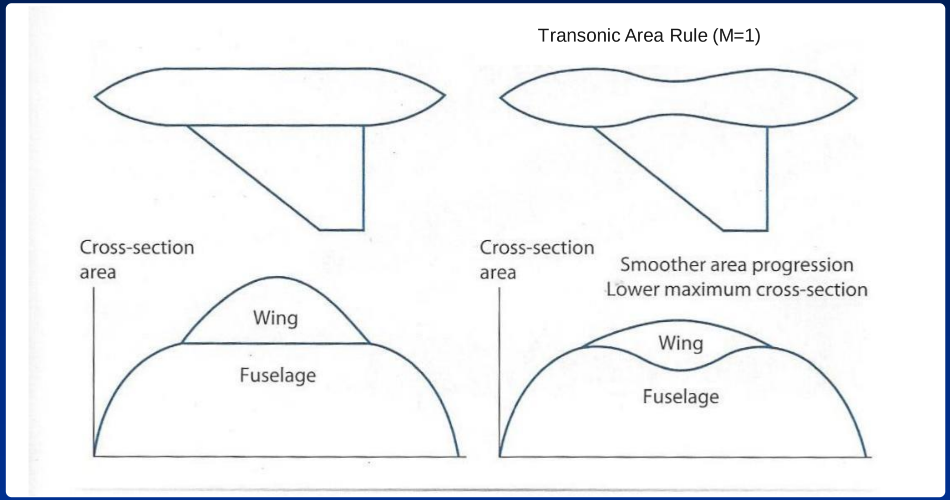
where A_{max} = max x/s area
L = overall length



Area Ruling

Public Domain, https://commons.wikimedia.org/w/index.php?curid=164928

YF-102



Raymer Fig 8.4

Whitcomb Transonic Area Rule:
Make total cross section area progression in a streamwise direction approximate to a Sears-Haack body

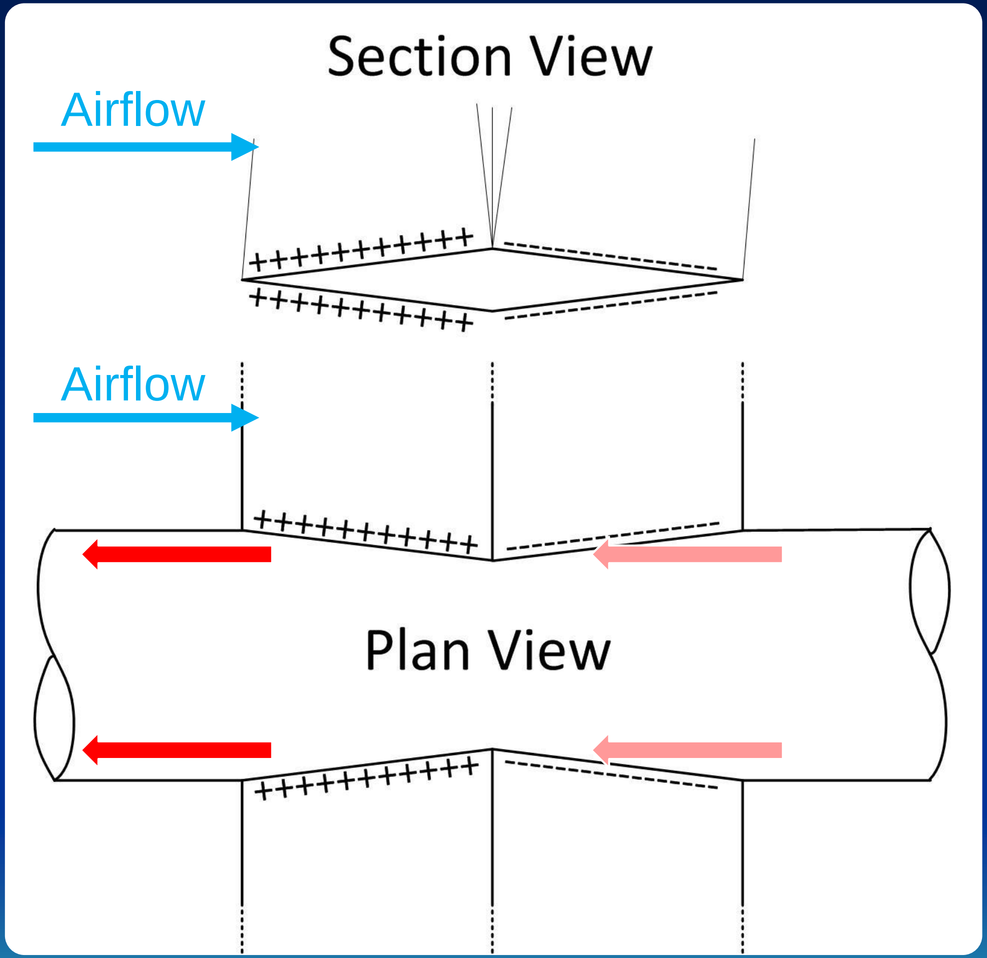
Richard Whitcomb

YF-102A

Transonic Area Ruling Simplified

Positive pressure on forward-facing wing surface increases drag

Positive pressure on aft-facing area of fuselage reduces drag



Negative pressure on aft-facing wing surface increases drag

Negative pressure on forward-facing area of fuselage reduces drag

The converse effect of the fuselage on the wing is also beneficial

Boeing Transonic Airliner

Airliners.net

- ~1995 Conceptual design
- Difficult and expensive to manufacture
- Inefficient seating
- Small reduction in flight time
- Small gain in aircraft and crew utilization
- Small gain in M L/D

Topics

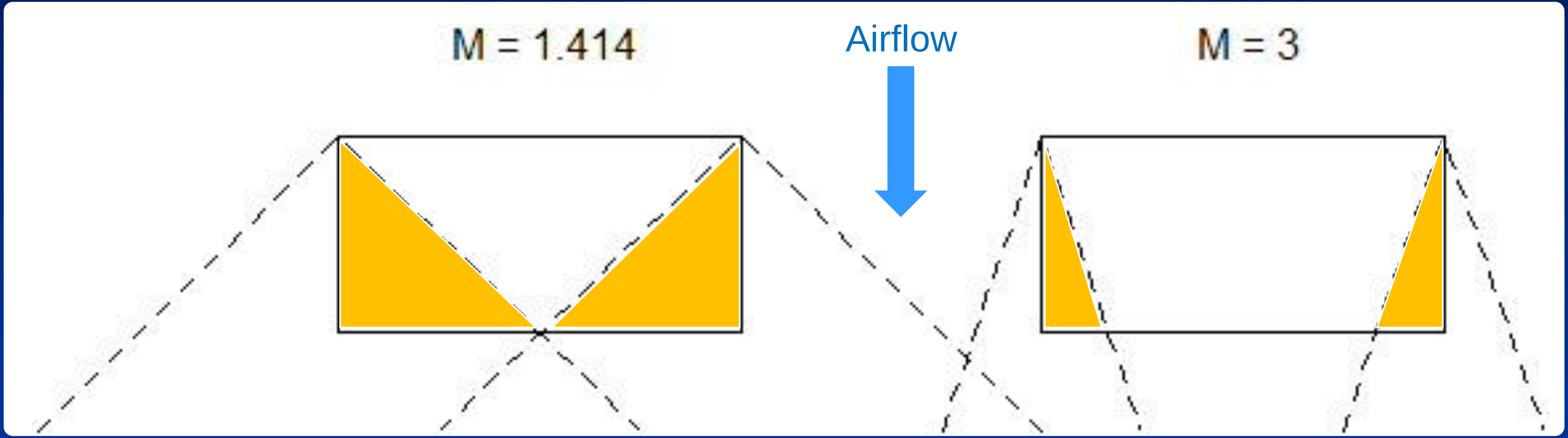
- Wave Drag
  - Wave drag due to volume (zero-lift wave drag)
  - Wave drag due to lift

Wave Drag due to Lift

"…although wave drag due to lift integral has the same form as that due to thickness, the source strength of the equivalent body depends on streamwise derivatives of the lift up to a streamwise station rather than the streamwise derivative of cross-sectional area"

Julian D. Cole and Norman D. Malmuth , "Wave drag due to lift for transonic airplanes" Proc. Royal Society A (2005) vol. 461, p. 541-560

Cones of Influence for AR=2 Wing



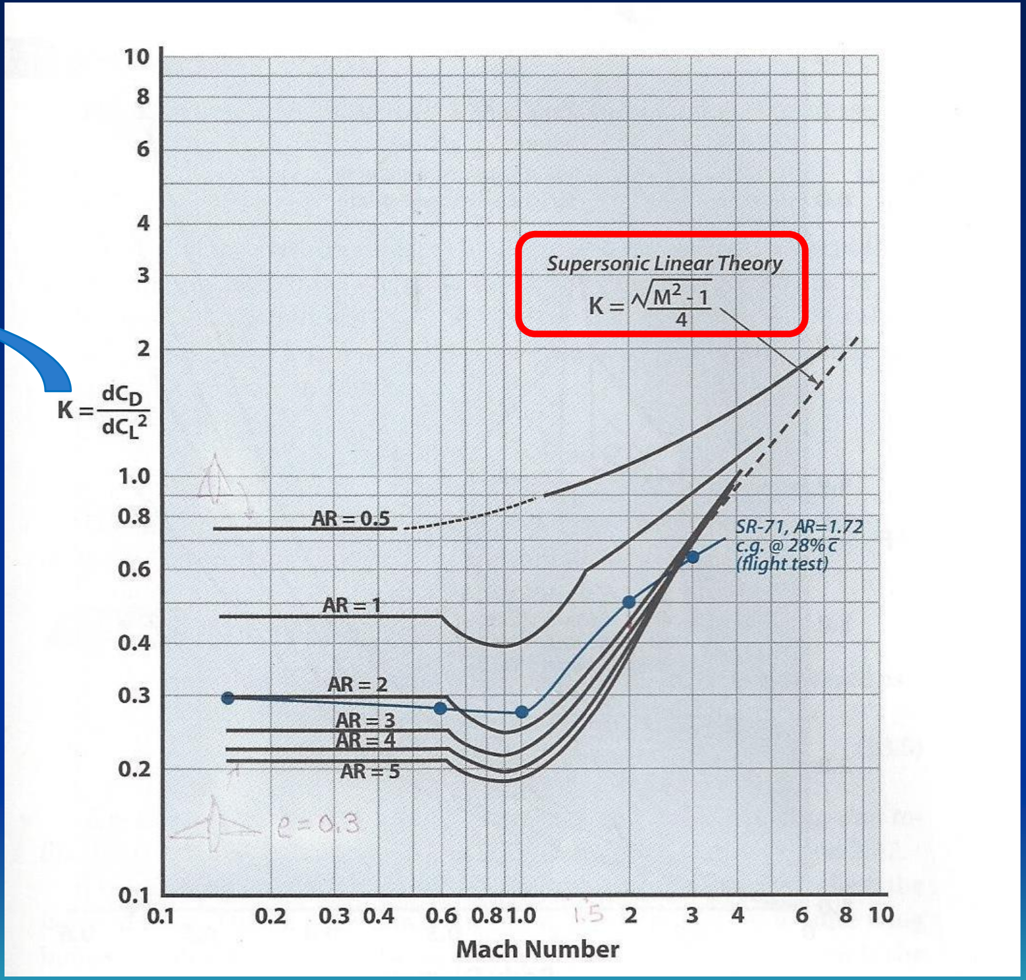
- As M increases, area of wing influenced by wingtips decreases and linear theory dominates
- High AR has little benefit at cruise

Estimation of K for Delta Wing Config.

In equation for drag polar

$$C_D = C_{D_0} + KC_L^2$$

In this figure: fuselage delta wing with l.e. radius = 0.045%



Source: Nicolai & Carichner Fig 13.3b

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  - Sonic Boom
  - Propulsion
  - Configuration Design

First Level Supersonic Flight

- Bell X-1
- First supersonic flight 1947-10-14
- Pilot: Col. Chuck Yeager
- Preliminary design project engineer: Ben Hamlin

Young, J.O. ,"Meeting the Challenge of Supersonic Flight"

- Source of double boom still not generally understood in 1954
  - Read Theodore von Kármán "Aerodynamics" Ch IV

https://en.wikipedia.org/wiki/Bell_X-1

Lack of Interest or Understanding of Sonic Boom

From “Aerodynamics” by Theodore von Kármán, Cornell University, 1954

“There is a strange phenomenon connected with these diving stunts which I want to mention. Assuming that the airplane approaches the observer at subsonic speed, makes a dive reaching supersonic speed, then recovers from the dive and continues in flight again at subsonic speed. In that case the observer on the ground frequently hears two booming sounds, rather closely following one another: “Boom, boom!” Some scientists have offered explanations of the origin of the sonic boom.”

Early Theoretical Studies

Theoreticians

Sonic Boom due to Volume:
Gerald Whitham's Ph.D. (Manchester U.,1953) related to shocks due to volume from asymmetric bodies (e.g. airplanes) under Sir James Lighthill. Later faculty of MIT, then CalTech.

Sonic Boom due to Lift:
Frank Walkden, British mathematician, published (1958) equations relating increase in sonic boom due to lift.

- By the end of 1957, only one paper related to sonic boom had been published in the U.S.

Sonic Boom Subjective Evaluation

1961-62 NASA collected data on the effects of sonic booms on people and structures in St. Louis, MO.

NASA personnel interviewed 1,000 residents

1964 NASA performed additional study in Oklahoma City, OK,

Interviewed 3,000 residents, and examined some damage to structures

Sonic Boom Research Conferences

Held at NASA Headquarters in Washington, DC

First Conference 1967-04-12
- NASA SP-147 5 invited papers plus 7 contributed remarks 118 pages

Second Conference 1968-05-09/10
- NASA SP-180 18 invited papers plus 7 contributed remarks 193 pages

Third Conference 1970-10-29/30
- NASA SP-255 29 papers plus 7 panel discussion comments 441 pages

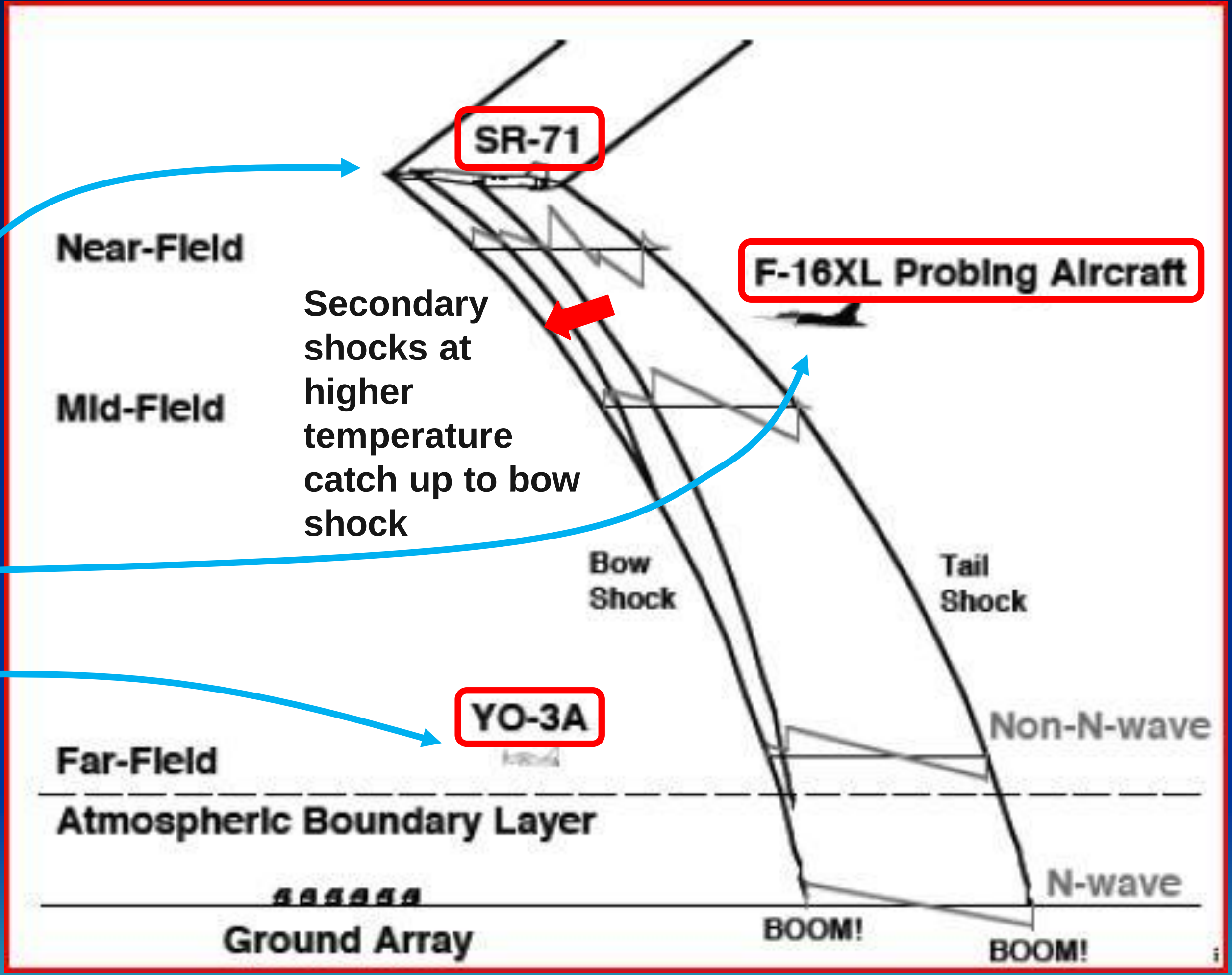
Other conferences held by the Acoustical Society of America

Good research summary:
Dominic Maglieri, et al., Sonic Boom, Six Decades of Research, NASA/SP-2014-622

Experimental Investigation of Shock Waves

- 1995-02 to 1995-04
- NASA Measurement of effects of shape of compression waves, atmospheric absorption, turbulence
- SR-71 flew at M 1.25 – 1.6, 31,000 ft – 48,000 ft
- F-16XL separated by 80 - 800 ft.
- YO-3A* flew at 1,000 ft AGL

* Lockheed YO-3A is a quiet observation aircraft used in Vietnam

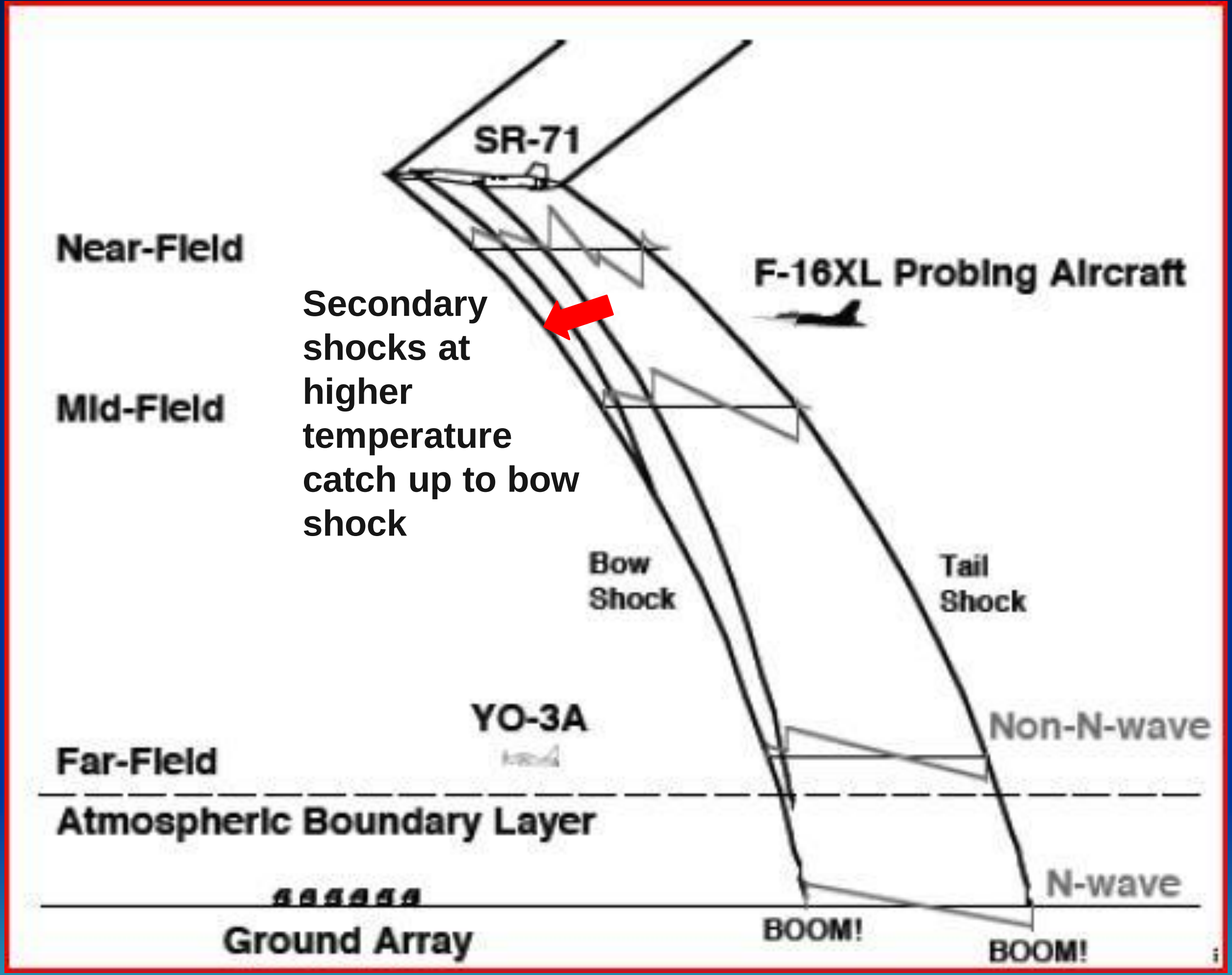


Benson, L.R., Quieting the Boom: The Shaped Sonic Boom Demonstrator and the Quest for Quiet Supersonic Flight

Longitudinal Shock Wave Refraction

If
- Altitude is high enough
- Speed is low enough (M ~ 1.15)

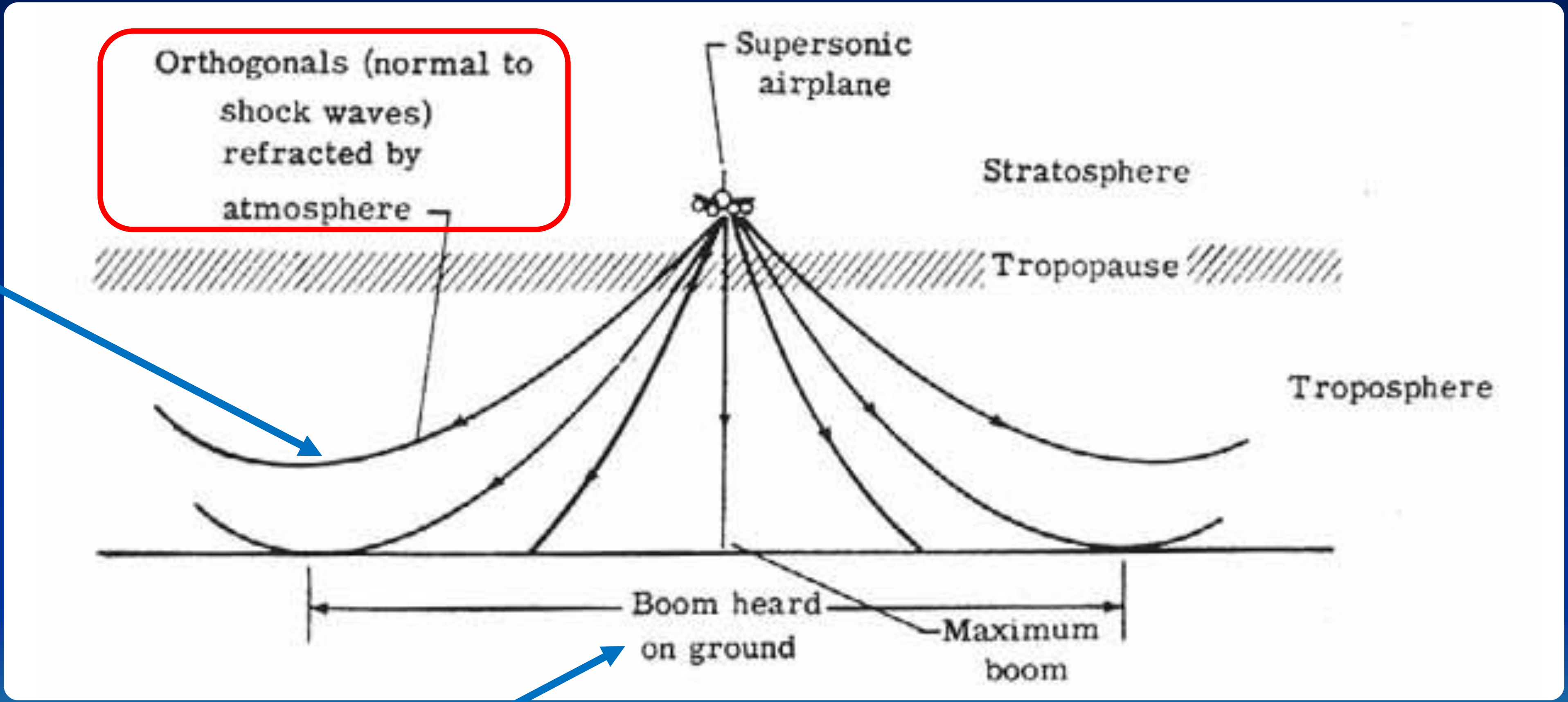
Then
- shock wave does not reach the ground



Benson, L.R., Quieting the Boom: The Shaped Sonic Boom Demonstrator and the Quest for Quiet Supersonic Flight

Lateral Shock Ray Refraction

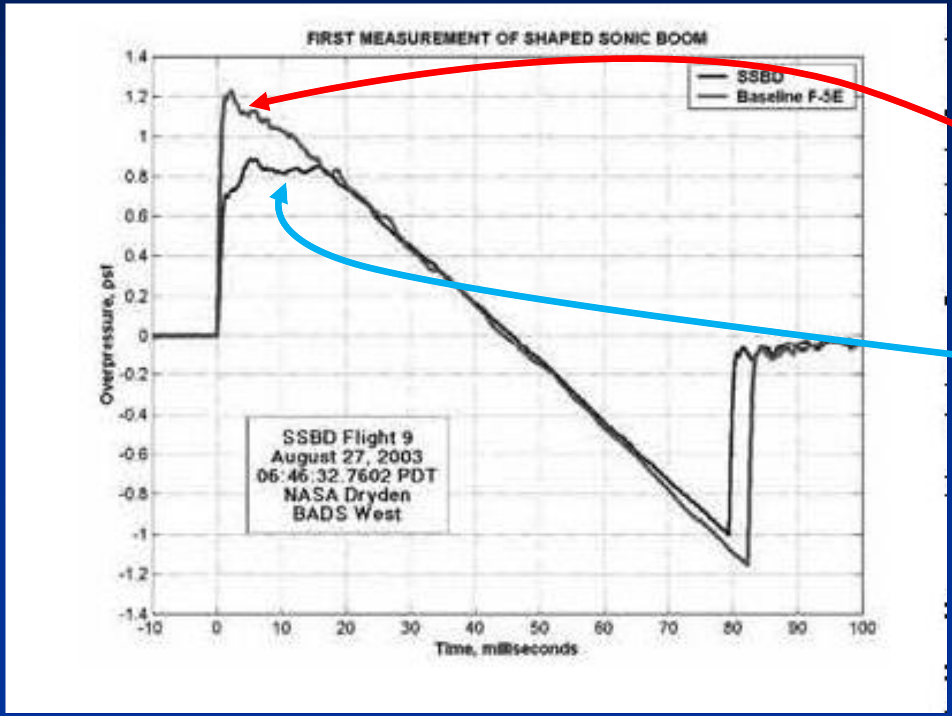
Ray trace normal to shock waves



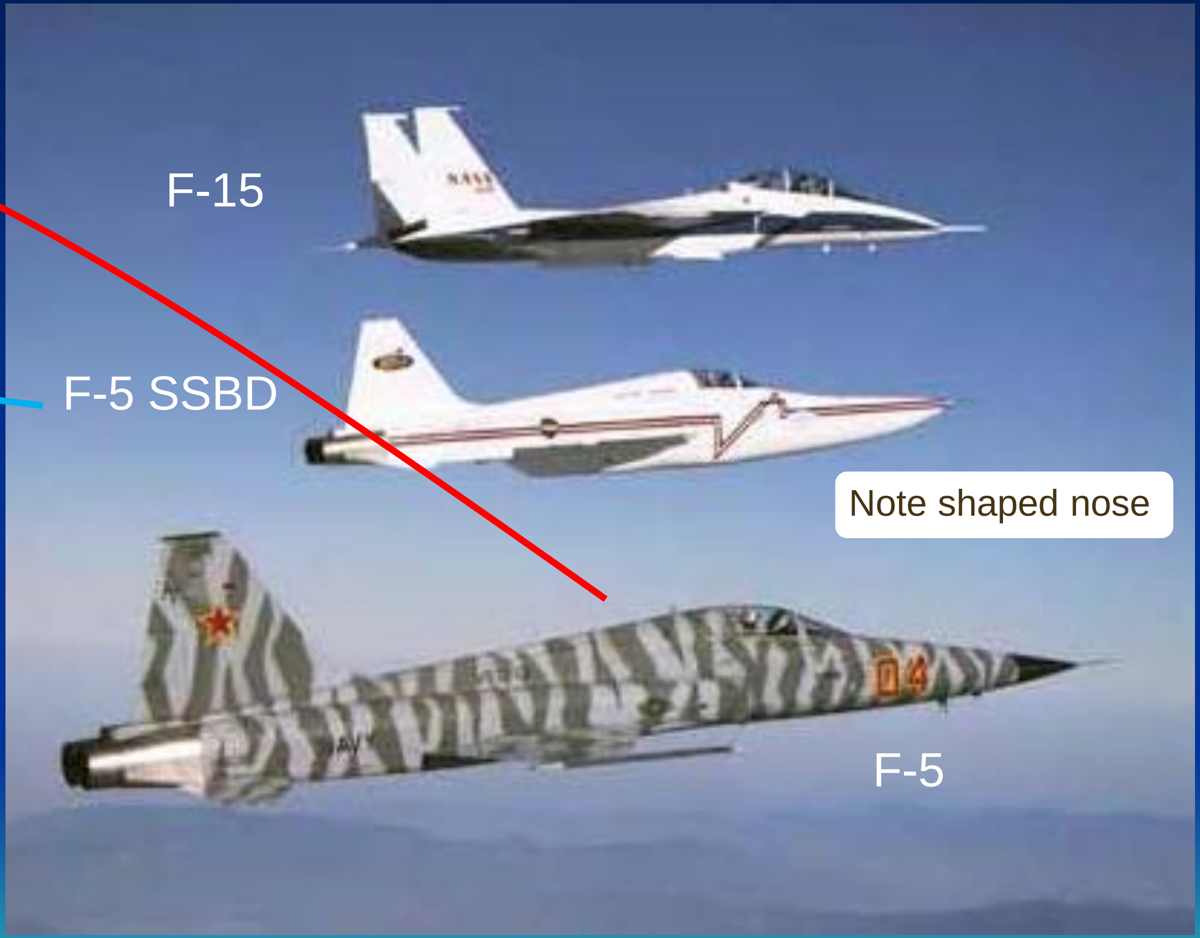
Benson, L.R., Quieting the Boom: The Shaped Sonic Boom Demonstrator and the Quest for Quiet Supersonic Flight

Sonic boom corridor

Northrop F-5 SSBD N-wave Comparison



2003-08 Reduction of N-wave overpressure from Shaped Sonic Boom Demonstrator (SSBD)

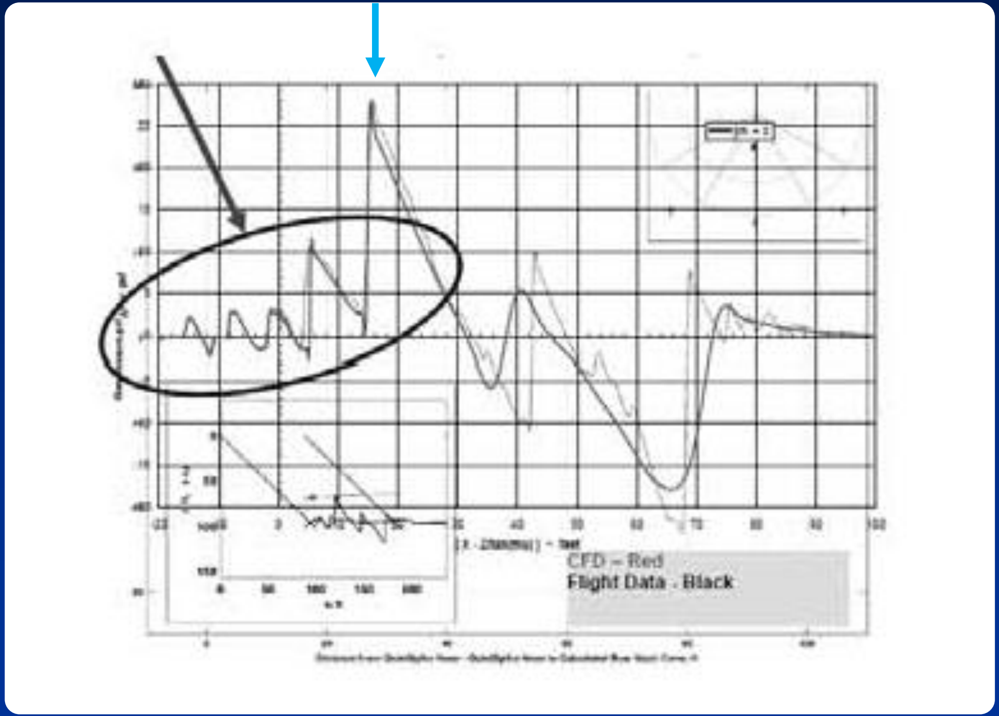


Shaped Sonic Boom Demonstrator

Roy Martin
Chief Test Pilot
Northrop Grumman

F-15 Quiet Spike

Inlet shock



Benson, L.R., Quieting the Boom: The Shaped Sonic Boom Demonstrator and the Quest for Quiet Supersonic Flight

Longitudinal pressure distribution at 95 ft below aircraft at M1.4

N-wave dominated by inlet shock

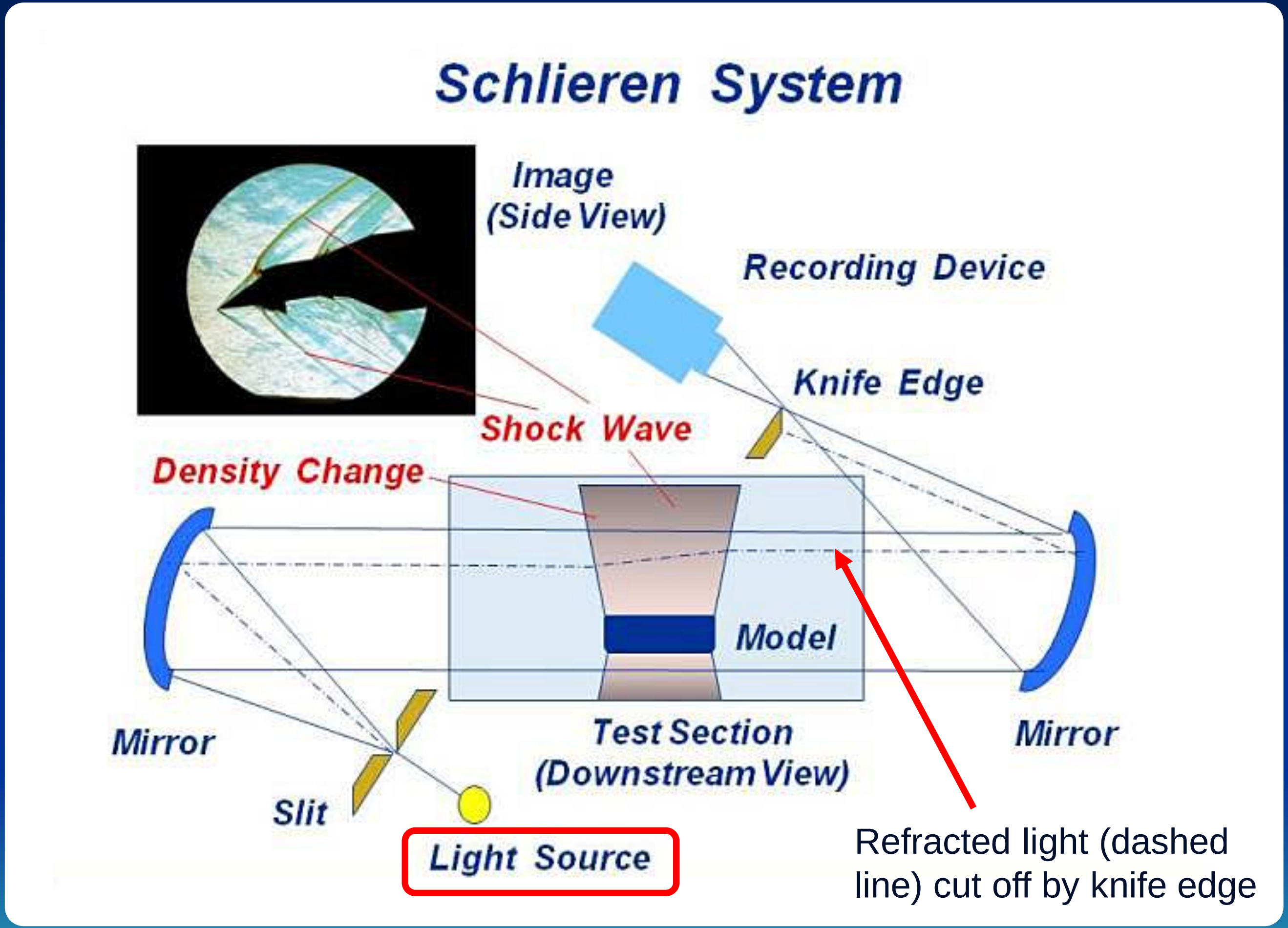
Benson, L.R., Quieting the Boom: The Shaped Sonic Boom Demonstrator and the Quest for Quiet Supersonic Flight

F-15B with Quiet Spike 2006-09

- Spike length variable from 14 to 24 ft
- Small reduction in bow shock

Schlieren Photography

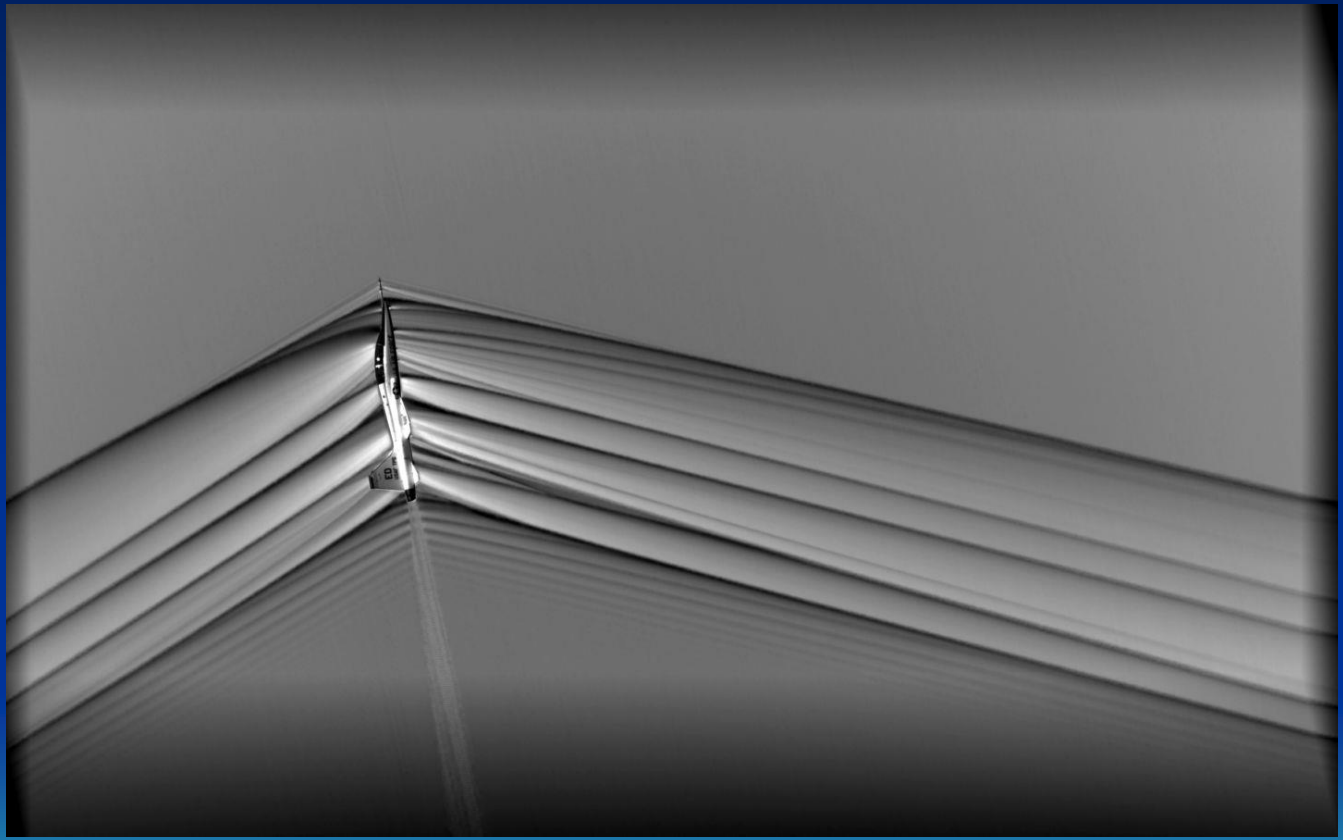
- Classical Schlieren images based on refraction of light source passing through shock
  - Light source is subsequently cut off by knife edge
- Can also view on commercial airliner if sun is aligned with wing shock
  - Local noon
  - Travelling east to west
  - High latitude



https://3c1703fe8d.site.internapcdn.net/newman/gfx/news/hires/2015/imagestarkbe.jpg

Background Oriented Schlieren

- Tests in 2011, 2014, 2015, 2018
- T-38 over Mojave Desert
- First take image of background pattern
- Shock waves deduced from distortions of background pattern resulting from changes in refractive index due to density gradients
- Chase aircraft: Beechcraft B200 Super King Air
- Camera frame rate of 1,470 frames/sec



https://arc.aiaa.org/doi/full/10.2514/1.J059495

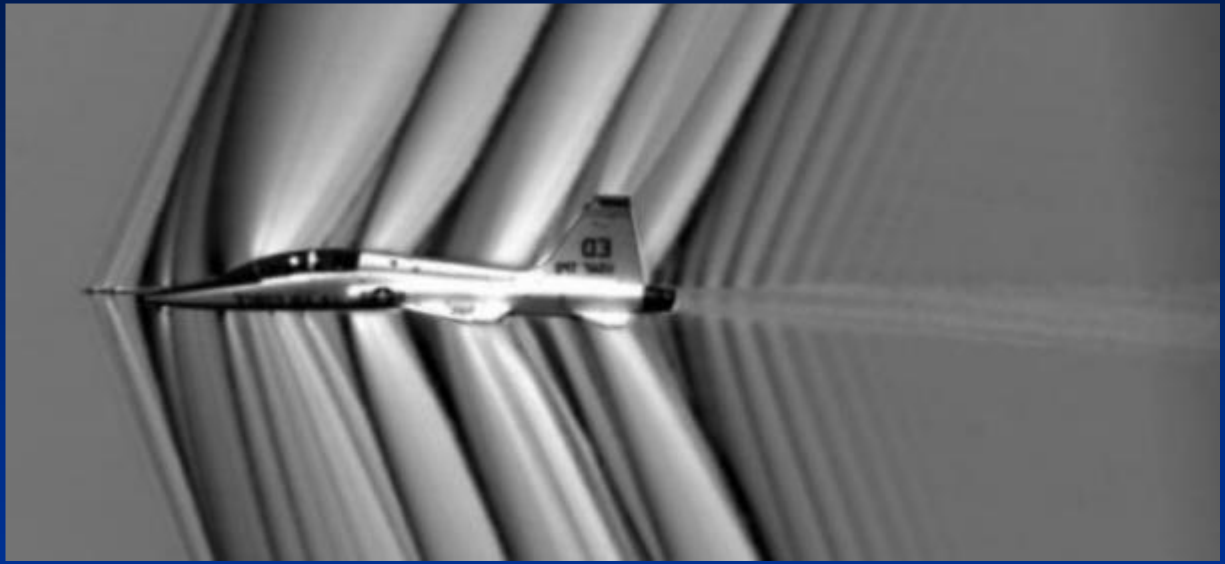
https://arstechnica.com/science/2019/03/nasa-visualizes-supersonic-shockwaves-in-a-new-awe-inspiring-way/

Why Mojave Desert?

- Location of NASA Armstrong Flight Research Center
- Desert floor is ideal background for background oriented Schlieren
- When photographing supersonic aircraft, background (i.e. desert floor) is compared with image refracted by shock waves

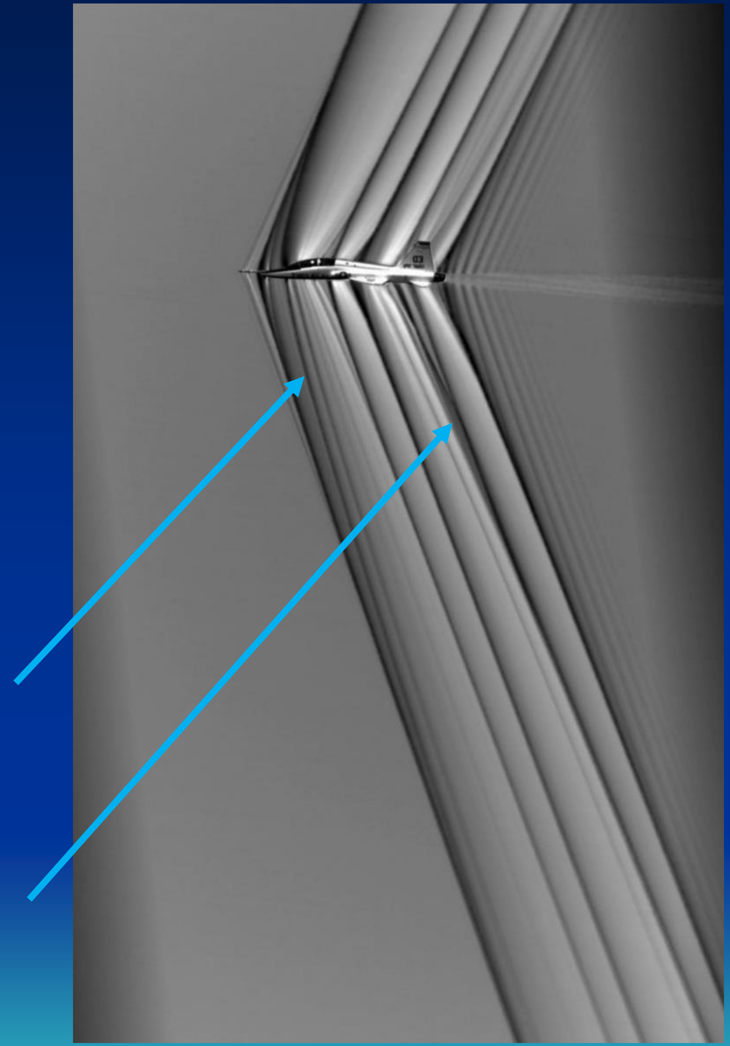
Source: LA Times 2021-01-03

Schlieren Views of T-38



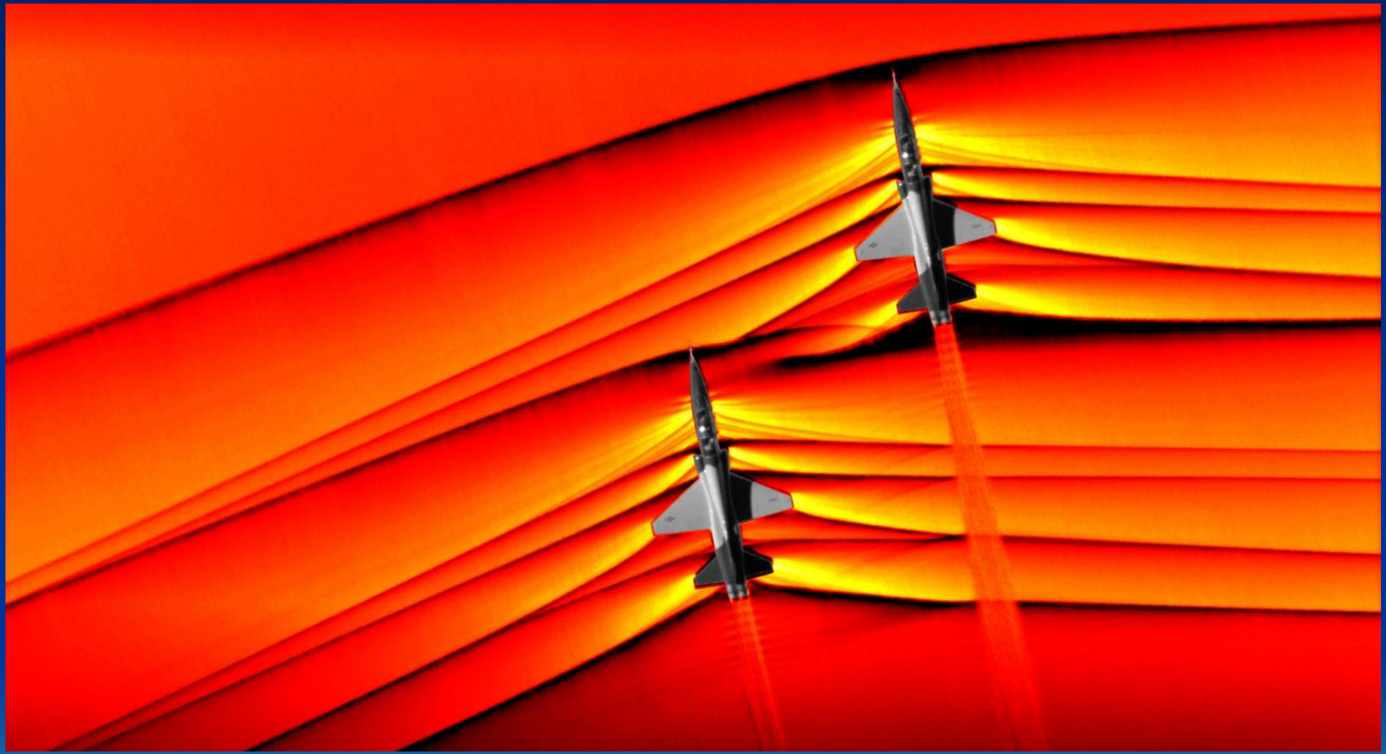
Forward shock waves coalescing with bow shock

Aft-body shock waves coalescing and migrating towards aft shock



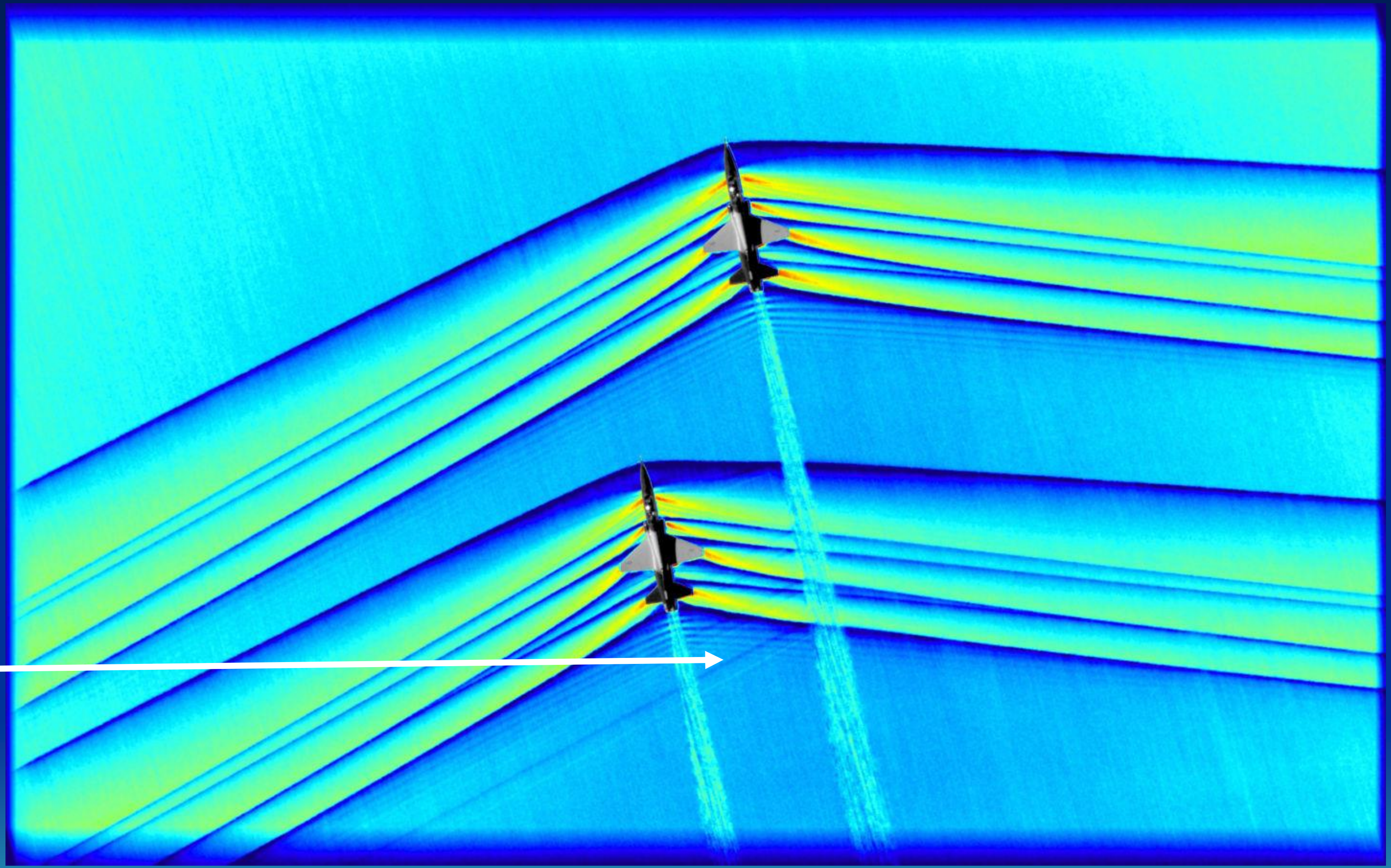
Schlieren Views of T-38s

- Background Oriented Schlieren (BOD) photo of T-38s over Mojave desert
- Typically two strong conical shock waves from nose and tail
- Intermediate shocks from canopy, wing and tail



https://arstechnica.com/science/2019/03/nasa-visualizes-supersonic-shockwaves-in-a-new-awe-inspiring-way/

Schlieren Views of T-38s



Shock partially reflected off hot exhaust

https://arstechnica.com/science/2019/03/nasa-visualizes-supersonic-shockwaves-in-a-new-awe-inspiring-way/

Sonic Boom due to Lift

https://www.nae.edu/190274/A-RICHARD-SEEBASS-19362000

Sonic boom intensity due to lift

$$\approx \frac{\text{Weight}}{\left(\text{Length}\right)^{1.5}}$$

Length = f(longitudinal distribution of lifting surface)

Richard Seebass warned that "the sonic boom due to lift cannot be avoided. The aircraft's weight must be transmitted to the ground."

Randall Greene and Richard Seebass, "A Corporate Supersonic Transport," in *Transportation Beyond 2000: Technologies Needed for Engineering Design, Proceedings of a Workshop Held in Hampton, Virginia, September 26–28, 1995*, NASA CP-10184 (February 1996), pt. 1, 491–508.

For Further Reading

History:

- Benson, L.R., “Quieting the Boom: The Shaped Sonic Boom Demonstrator and Quest for Quiet Supersonic Flight”, free download at https://www.nasa.gov/connect/ebooks/nasa-ebook-quieting-the-boom, 2013

Basic Research:

- Seebass, A.R., “Sonic Boom Research”, NASA SP-147, April 1967
- Schwartz, I.R., “Second Conference on Sonic Boom Research”, NASA SP-180, May 1968
- Schwartz, I.R., “Third Conference on Sonic Boom Research”, NASA SP-255, October 1970

Current:

- https://www.nasa.gov/mission_pages/lowboom/index.html

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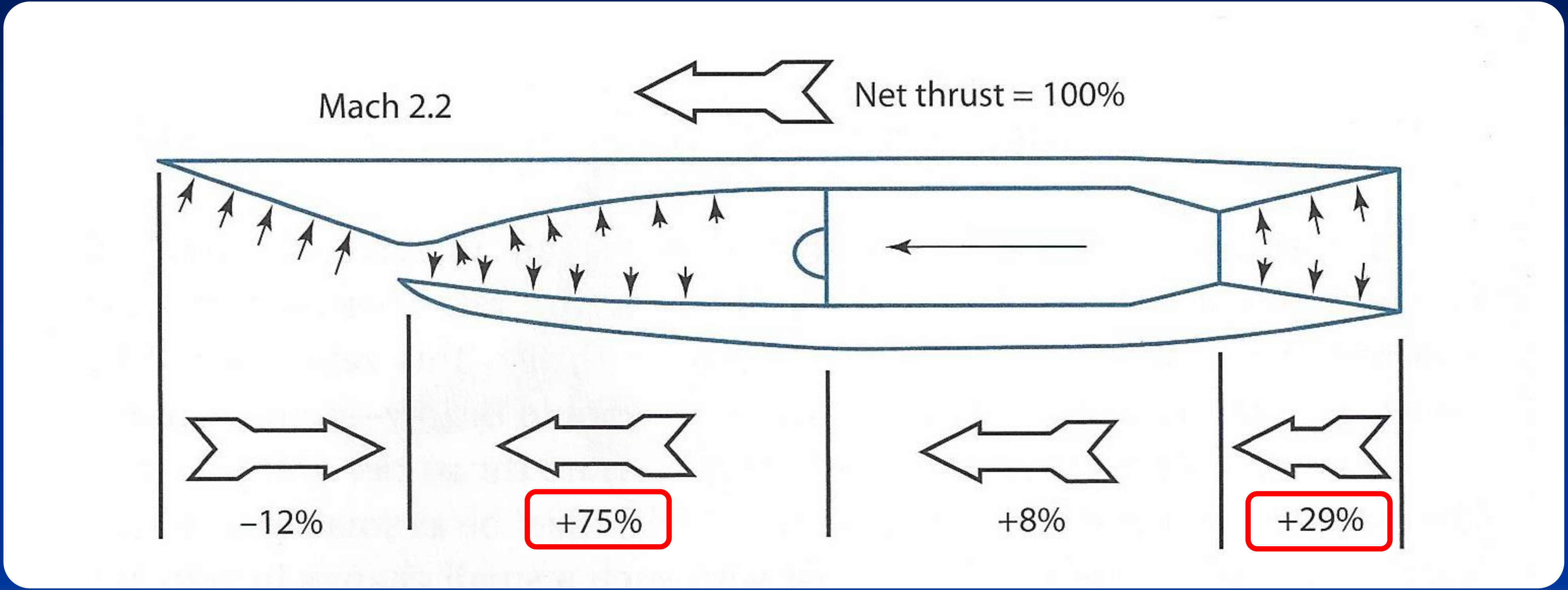
Nacelle Thrust – Drag Accounting



North American A-5 with GE J79 turbojets

Source: Raymer Fig 13.2

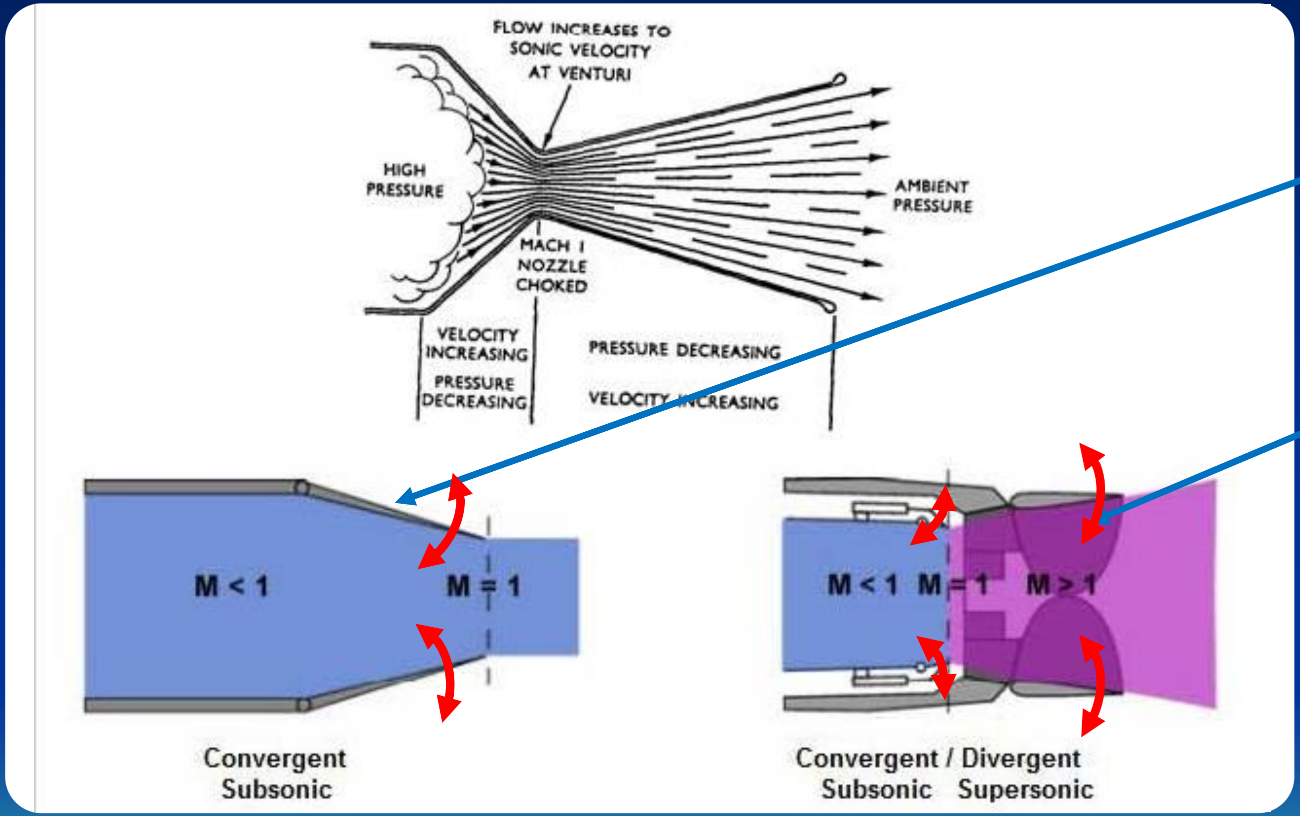
The majority of thrust is from the subsonic diffuser

Dynamic Pressure Performance Constraint

- F-15C, gross weight 38,000 lb
- 2x F100-PW120

https://www.key.aero/forum/modern-military-aviation/149000-su-57-news-and-discussion-version_we_lost_count?page=16

Nozzle Efficiency



- For convergent nozzle, control thrust by changing nozzle throat area
- Gain additional thrust by adding divergent section to nozzle

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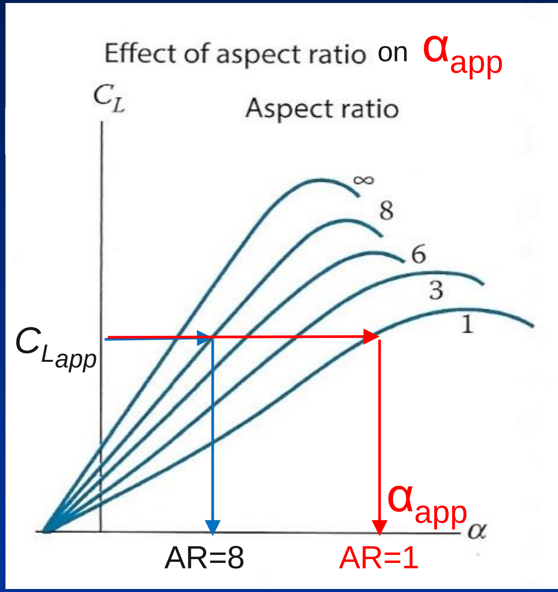
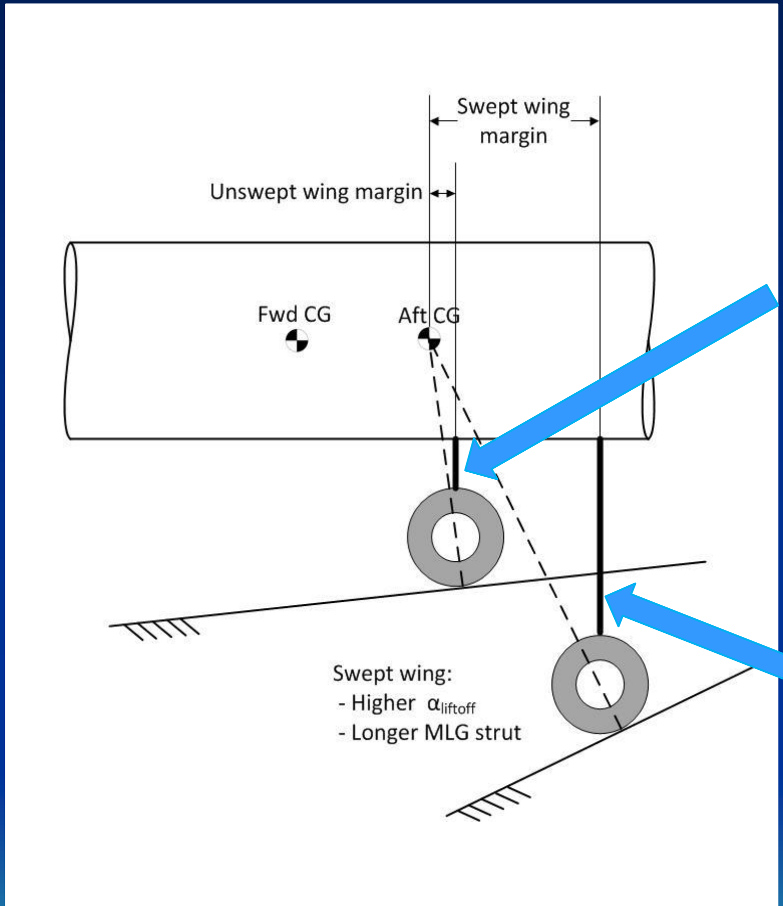
Effect of AR on MLG Length and Location



Raymer, Aircraft Design Fig. 12.5



Embraer Phenom

BAC/Sud Concorde

For low AR planform, $C_{L_{max}}$ at much higher α

With horizontal tail, can use flaps, reduce α_{app}

Landing gear must be strong

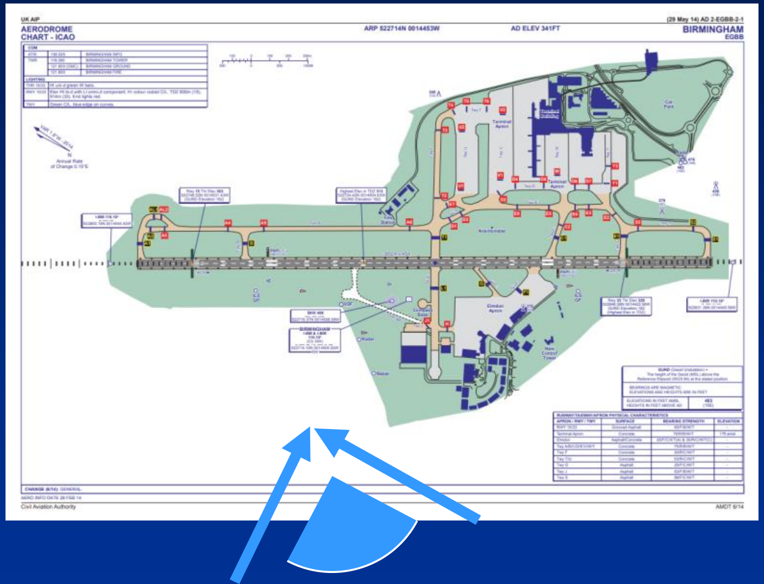
https://www.youtube.com/watch?v=xavLf8Y3A9A&ab_channel=flugsnug

Monarch A320 landing at BHX r/w 33

Landing at BHX is Challenging

https://www.youtube.com/watch?v=xavLf8Y3A9A&ab_channel=flugsnug

Monarch A320 landing at BHX r/w 33

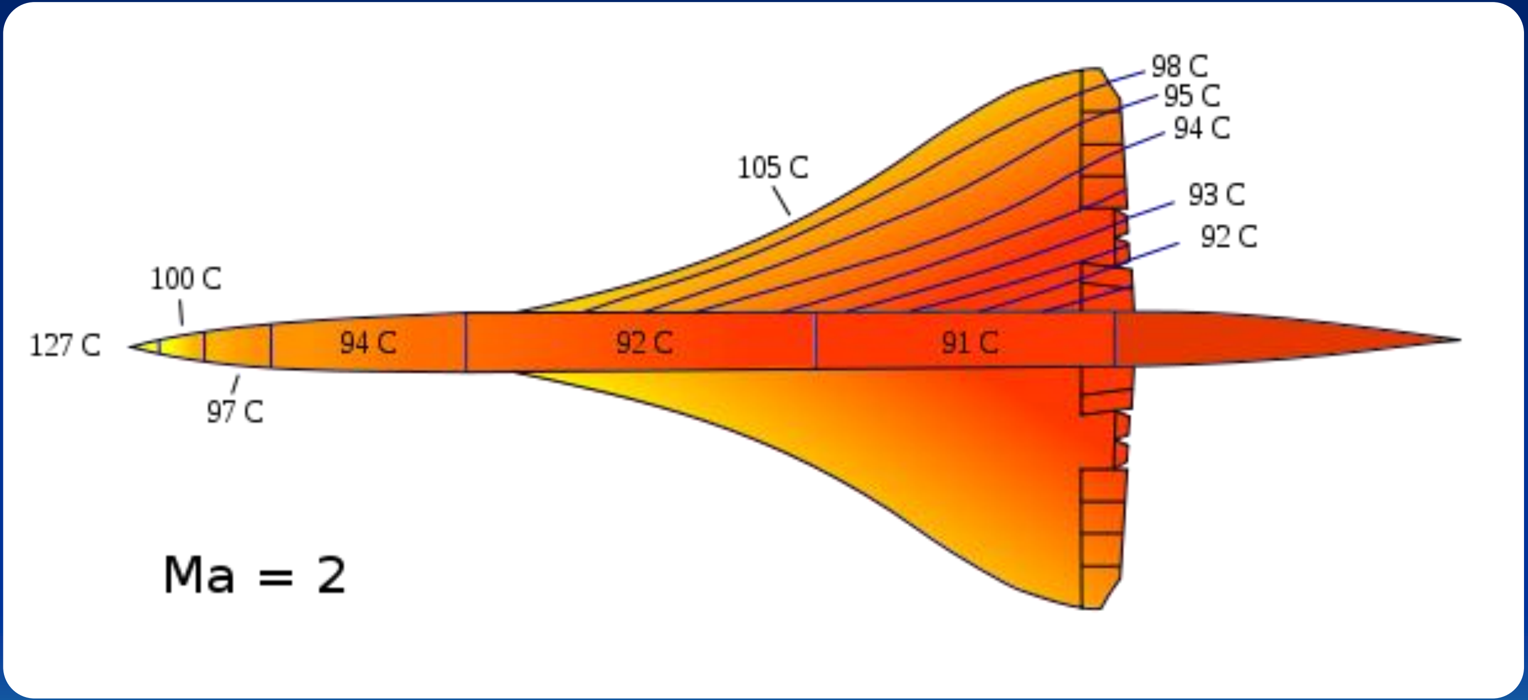


58% probability of wind between W and S

Aerodynamic Heating

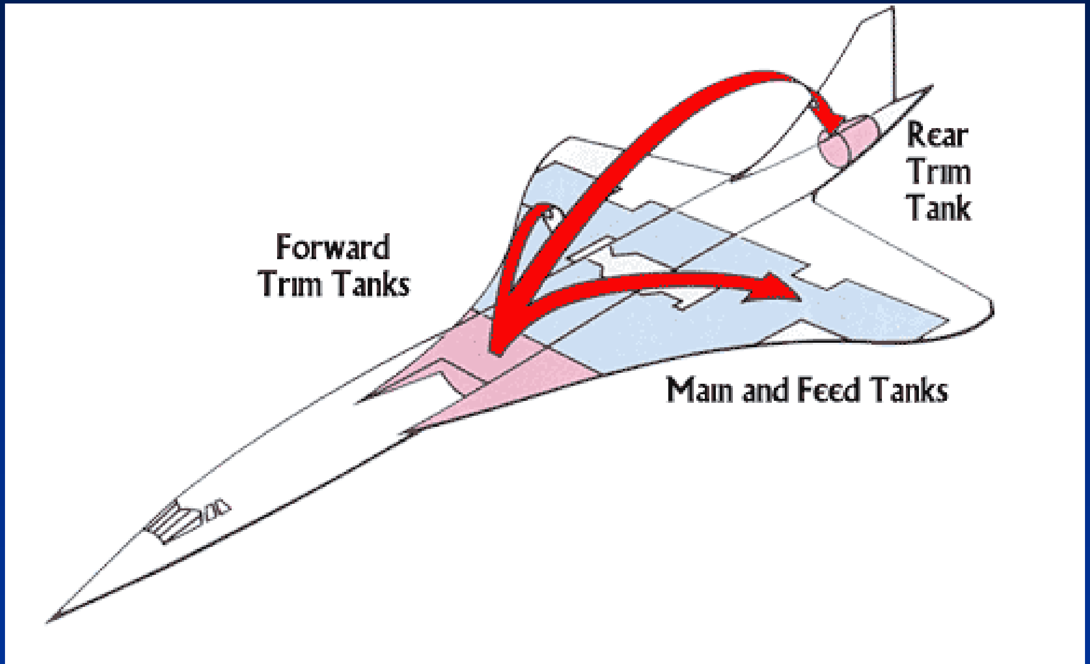
At M 2.2, T_{max} is 150 C

Difficult to certify for number of lifetime flight cycles (needs structural life of 30,000 hrs)

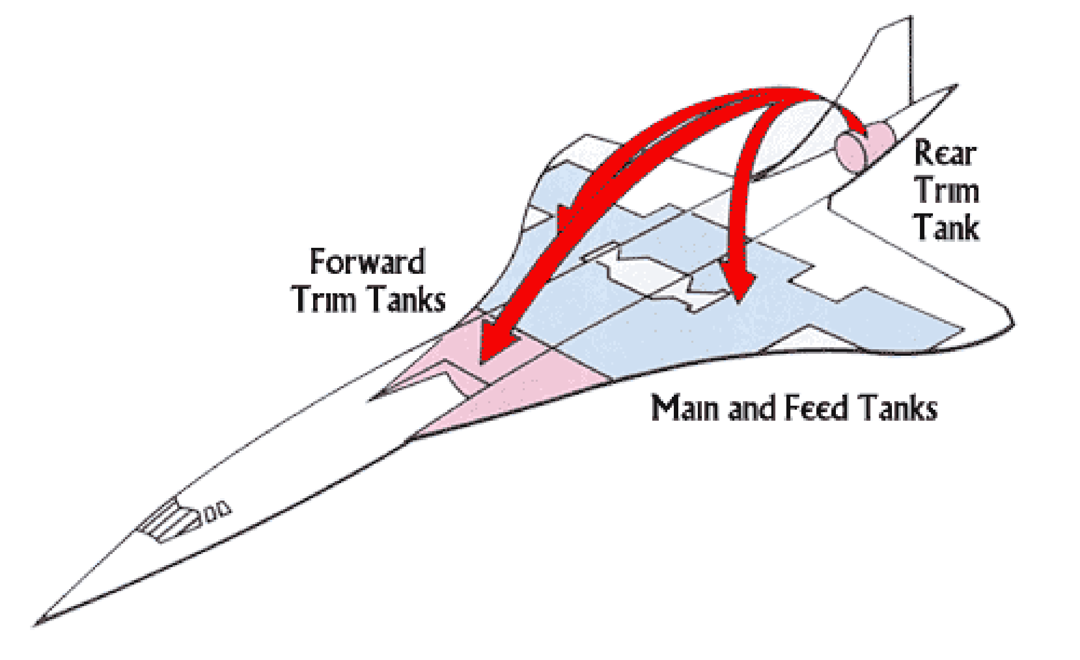


https://www.quora.com/How-hot-did-the-Concorde-fuselage-get-from-air-friction-during-full-speed-flight

Center of Gravity Control



https://www.heritageconcorde.com/fuel-transfer



https://www.heritageconcorde.com/fuel-transfer

- Before and during acceleration to M 2, flight engineer moves 20 tons of fuel to rear tank, moves c.g. by 2 m (6 ft)
- Before and during deceleration, flight engineer moves fuel forward. After landing, more fuel pumped forward

Flight Deck Visibility

Lower nose to provide adequate visibility at takeoff and landing

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De Havilland DH 108 Swallow

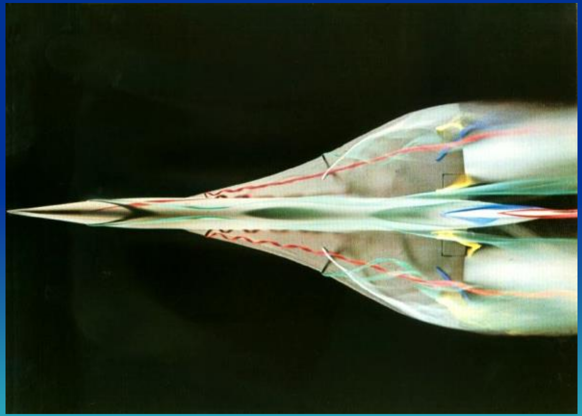
- 1948-09-09
- First British aircraft to exceed Mach 1
- Pilot John Derry
- Three aircraft built – all lost

https://www.baesystems.com/en/heritage/de-havilland-dh108-swallow

Early Studies

- 1954 - Morien Morgan forms committee at RAE to study feasibility
  - Baseline similar to enlarged Avro 730
- Johanna Weber and Dietrich Küchemann at RAE Farnborough showed benefits of slender delta
  - Streamwise vortices produce enhanced lift at high C_L

Avro 730 recce/ strategic bomber Mach 2.5 @ 60,000 ft (1957)



https://www.pprune.org/tech-log/353898-strongest-wing-tip-vortices-when-slow-clean-heavy-but-why-2.html

https://en.wikipedia.org/wiki/Johanna_Weber#/media/File:Johanna_Weber_1948.png

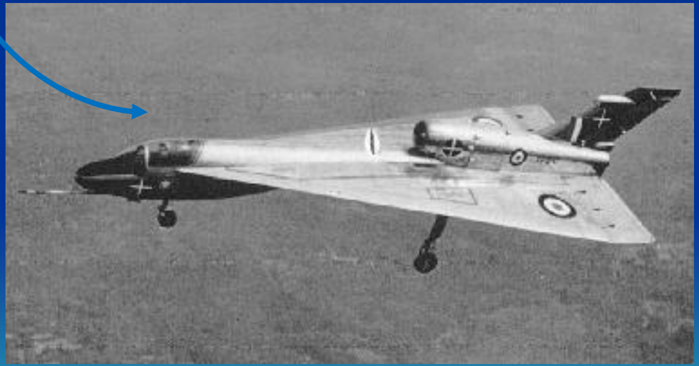
Dietrich Küchemann

Pub.: AIAA Education

Handley Page HP 115

- 1956-10 Supersonic Technology Advisory Committee (STAC) formed
  - Funded development of of Handley Page HP 115
  - Demonstrated safe handling down to 60 kt (111 km/hr)
- Believed economics similar to that of subsonic aircraft through higher utilization
- STAC proposed two SST models
  - Transatlantic range, 150 pax @ Mach 2
  - Shorter range, 100 pax @ Mach 1.2

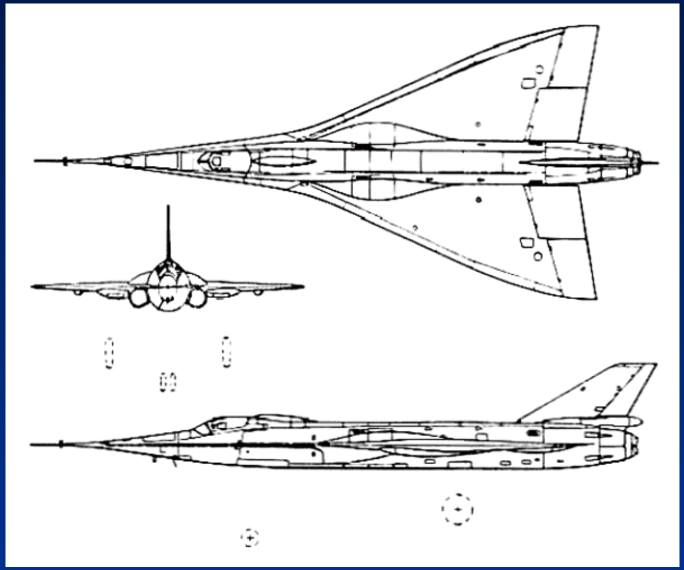
https://elpoderdelasgalaxias.wordpress.com/2018/12/12/handley-page-hp-115-low-was-the-new-high/



https://en.wikipedia.org/wiki/Concorde#/media/File:HP.115.gif

British Aircraft Corporation BAC 221

- Wind tunnel studies showed that ogive wing was preferred planform shape
- 1961 BAC converted Fairey FD2 to ogive wing with under-wing inlets
  - 6 ft fuselage extension for increased fuel capacity
  - Flight test up to Mach 1.6
- Flight testing from 1964 to 1971



https://hushkit.files.wordpress.com/2014/05/bac-221.gif

© Simon Thomas https://www.airliners.net/photo/British-Aircraft-Corporation/BAC-221/1019528

Anglo-French Teaming

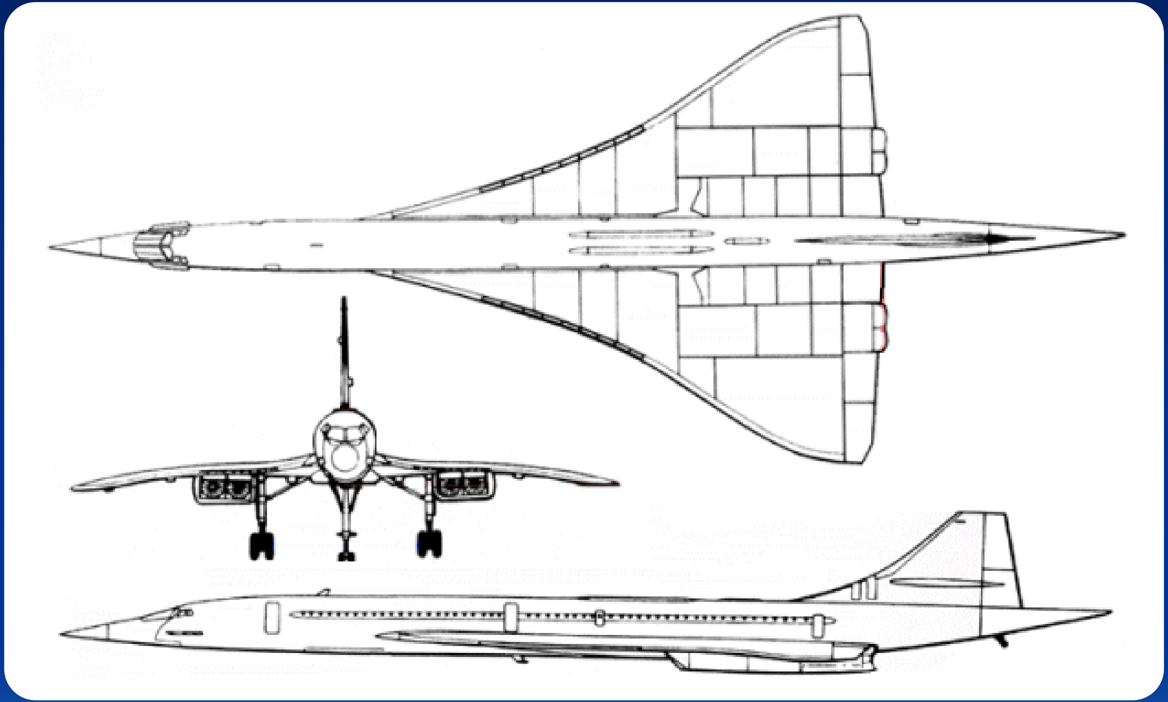
- Sud Aviation performed similar studies that produced similar results as to optimum configuration
- Initial development cost estimate was £150 million
- UK cabinet not enthused, but believed that joint Anglo-French program would improve chances of overcoming President Charles de Gaulle's veto of UK entry to Common Market
- 1962-10 two countries signed treaty with heavy cancellation penalties

http://news.bbc.co.uk/2/hi/uk_news/2934257.stm

Concorde Specifications

Why no area ruling? Supersonic area rule not the same as transonic area rule

- MTOGW: 185,065 kg (408,000 lb)
- EW: 78,700 kg (173,500 lb)
- Max P/L: 13,380 kg (29,500 lb)
- Length: 62.1 m (203.75 ft)
- Range (max fuel): 6,580 km (3,560 nmi)
- Range (max P/L): 6,230 km (3,365 nmi)
- M_{max}: 2.23
- M_{cruise}: 2.04 @ 51,300 ft
- Powerplant: 4 x RR/SNECMA Olympus 593 Mk 602 engines



http://www.aerospaceweb.org/aircraft/jetliner/concorde/

Bristol Siddeley Olympus Mk 320

- Avro Vulcan used as flying test bed (FTB) for Olympus Mk 320 for BAC TSR2
- On ground runup, LP turbine broke free from engine, hit ground, bounced and broke fuel lines, then ran about 200 yards across airfield
- Vulcan was destroyed by fire
- But concept proven successful in subsequent use of another Vulcan as FTB for Olympus 593 for Concorde

https://twitter.com/ron_eisele/status/1649831646831493122

Bristol Siddeley Olympus Mk 593

- Olympus originally developed for Avro Vulcan and Handley Page Victor (but not installed on Victor)
- For Olympus 593
  - OPR: 15.5:1
  - Design thrust: 142 kN (32,000 lb) dry, 169 kN (38,050 lb) with A/B (production engine)
  - Twin spool axial compressor
    - 7 stage LP - 1 stage turbine
    - 7 stage HP - 1 stage turbine
  - Cannular combustion chamber (16 vaporizers)
  - Sfc: 33.8 g/kN-s (1.2 lb/lb/sec)

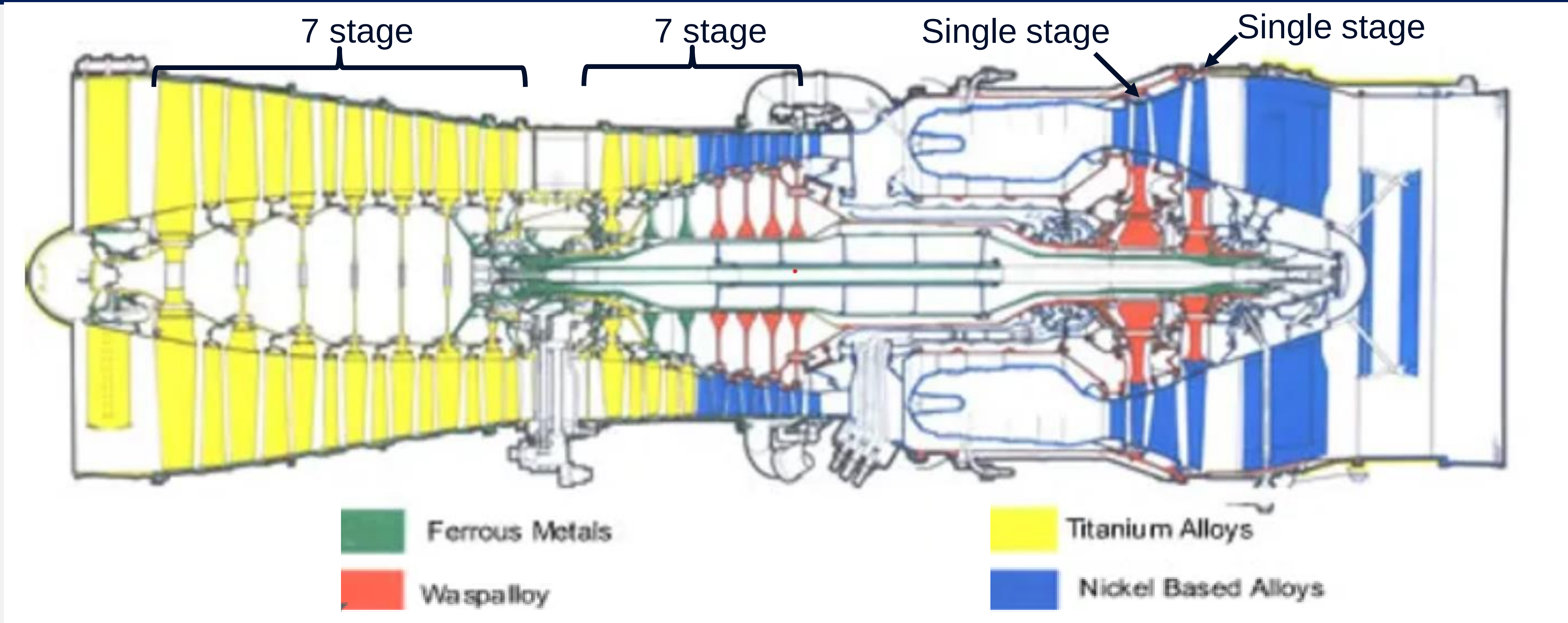
Vulcan flying test bed (FTB) with spray rig for icing test

https://avrovulcan.com/vulcan/engine-test-beds

Bristol Siddeley Olympus 593

https://www.gracesguide.co.uk/Rolls-Royce_Engines:_Olympus

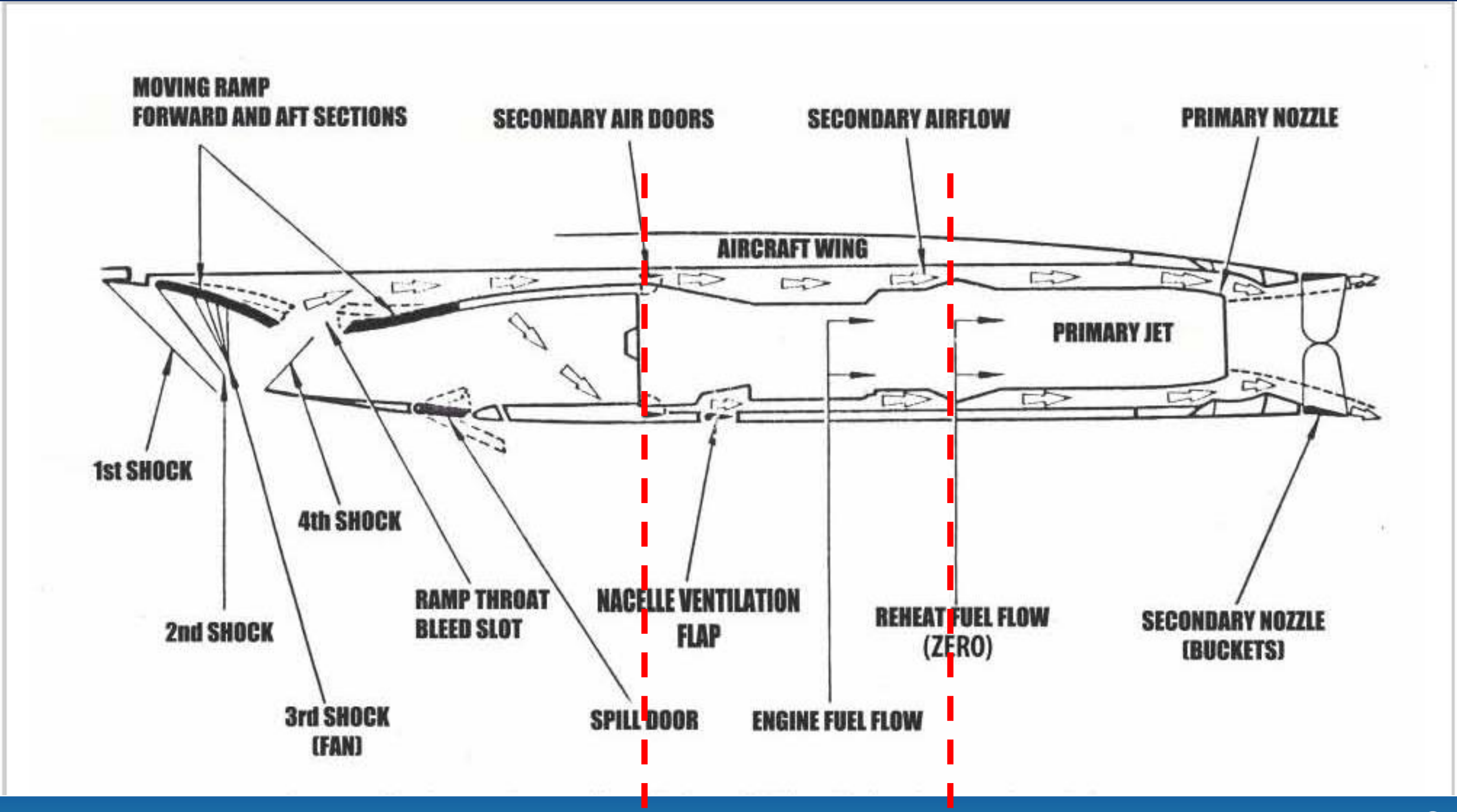
Bristol Siddeley Olympus 593 Mk 610



LP shaft: 3 bearing HP shaft: 2 bearing

Source: https://www.heritageconcorde.com/concorde-olympus-593-mk610-engines

Concorde Nacelle



Source: Leeham News

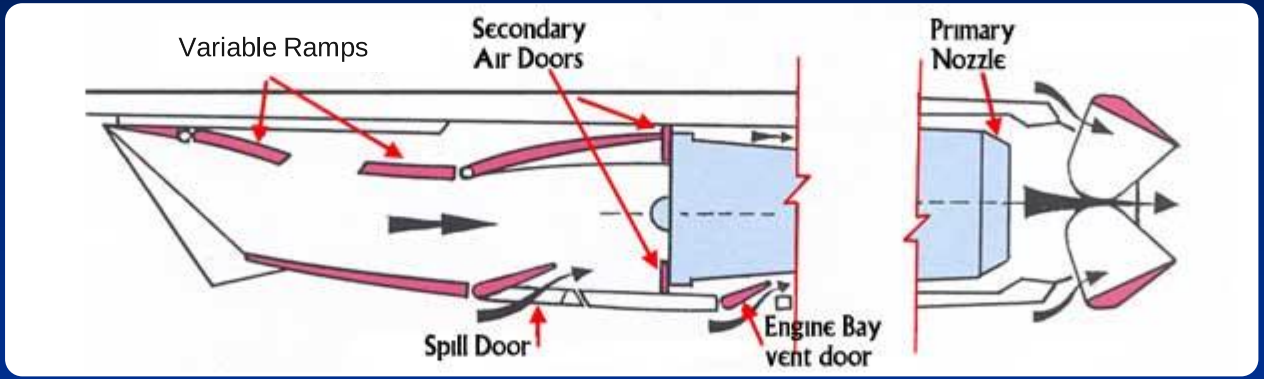
BAC

Bristol Siddeley
(now Rolls-Royce)

SNECMA

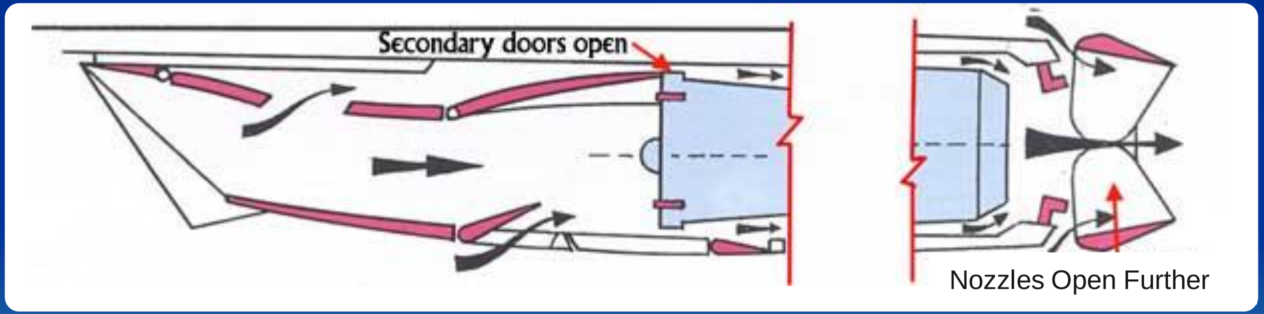
Concorde Engine Airflow Control

- Takeoff
  - Maximum airflow



Source: http://www.concordesst.com/powerplant.html#

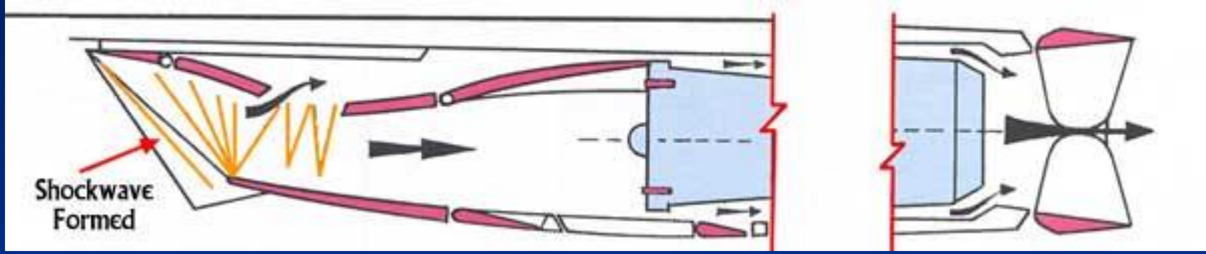
- Initial climb noise abatement



Source: http://www.concordesst.com/powerplant.html#

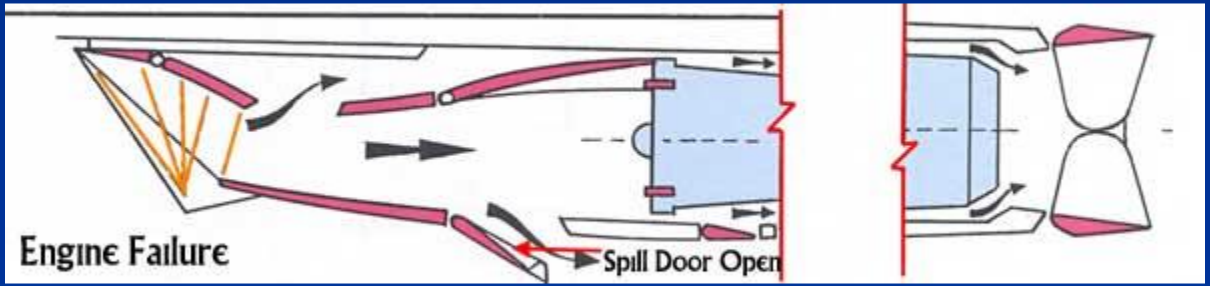
Concorde Engine Airflow Control

- Supersonic cruise
  - Mostly external compression



Source: http://www.concordesst.com/powerplant.html#

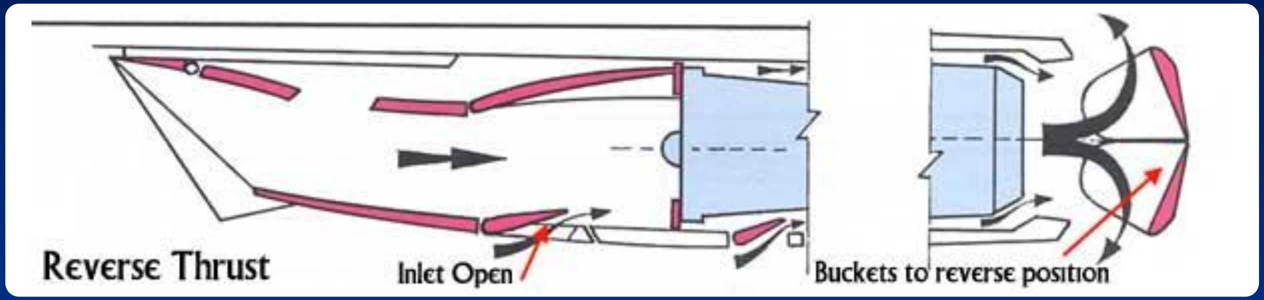
- Engine failure
  - Spill air to enable inlet restart



Source: http://www.concordesst.com/powerplant.html#

Concorde Engine Airflow Control

- Reverse thrust
  - Increase inlet airflow
  - Close Reverser buckets



- Air Intake Control Units (AICU)
  - Two for each inlet control ramp, aux. inlets and nozzle position

More information at:
https://www.heritageconcorde.com/fwd-mid-engineers-panel

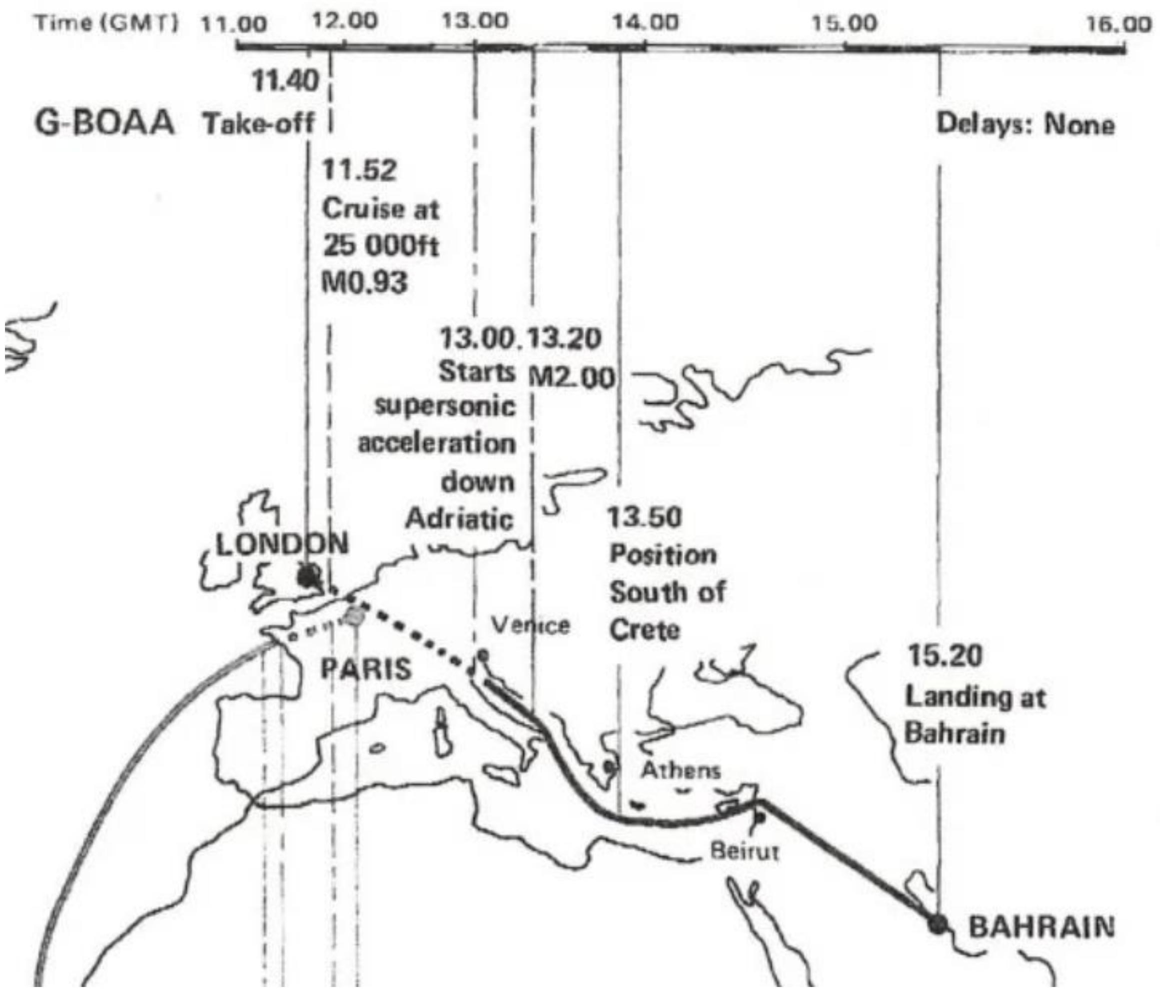
Operational History

- 1976-01-21 enters service London-Bahrain and Paris-Rio de Janeiro (via Dakar)
- 2000-07-25 AF 4590 suffered catastrophic fire resulting in crash. Loss of 100 pax, 9 crew
- 2003-04-10 BA, AF announce forthcoming retirement
- 2003-10-24 Last commercial flight (by BA)

https://commons.wikimedia.org/w/index.php?curid=5810282

https://worldwarwings.com/crash-concorde-sky-flames/

G-BOAA First Commercial Flight

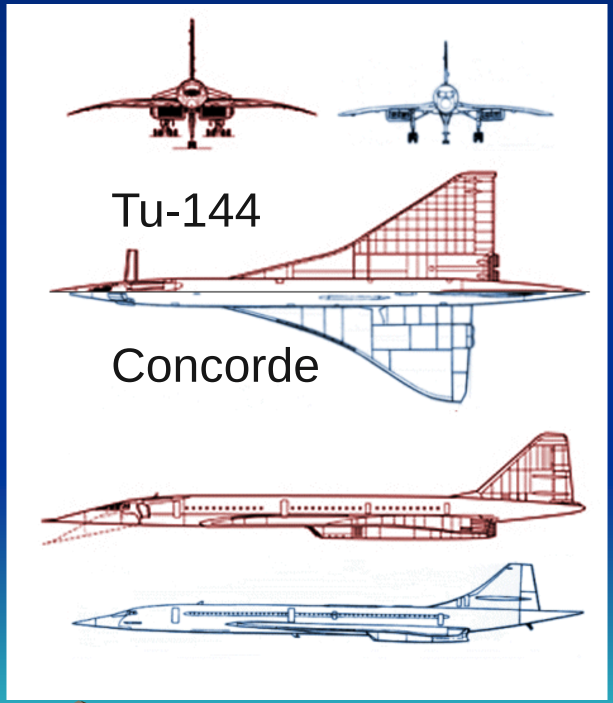


https://www.heritageconcorde.com/concorde-first-scheduled-services

Tupolev Tu-144

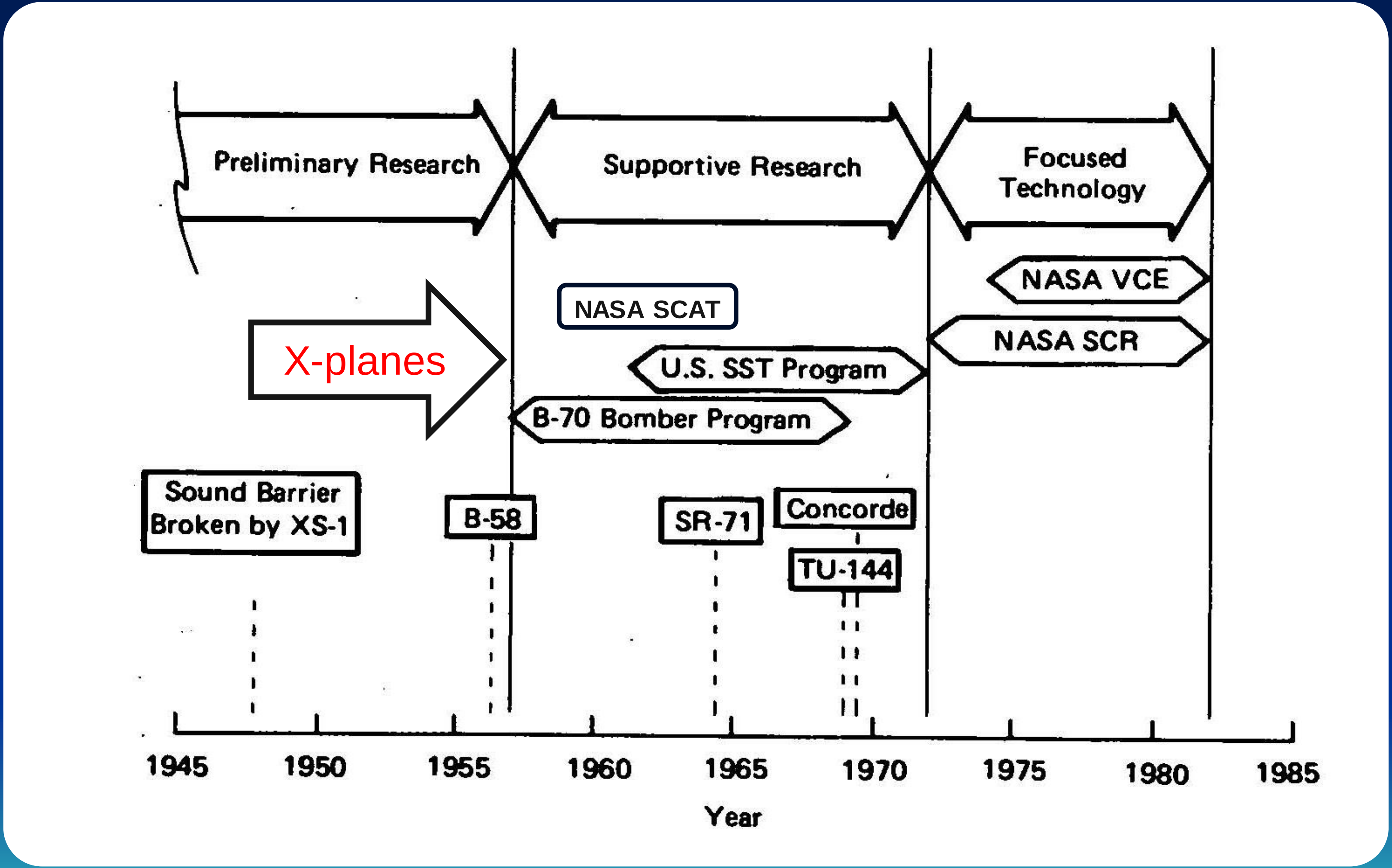
- 1968-12-31 First flight
- 1973 Crash at Paris Airshow
- 1977-11-01 Entry into service
- 1978-04 Crash on test flight during delivery
  – Retired from pax service
- 1999 Retired from service
- Number built 16

https://en.wikipedia.org/wiki/Tupolev_Tu-144



globalsecurity.org

US Supersonic Research



XS-1 was the original designation for the Bell X-1

McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

US Supersonic Research

Convair XF-92
(delta wing)

Douglas D-558-1
(stability
characteristics)

Bell X-1A
(transonic
flight)

Bell X-5
(variable sweep)

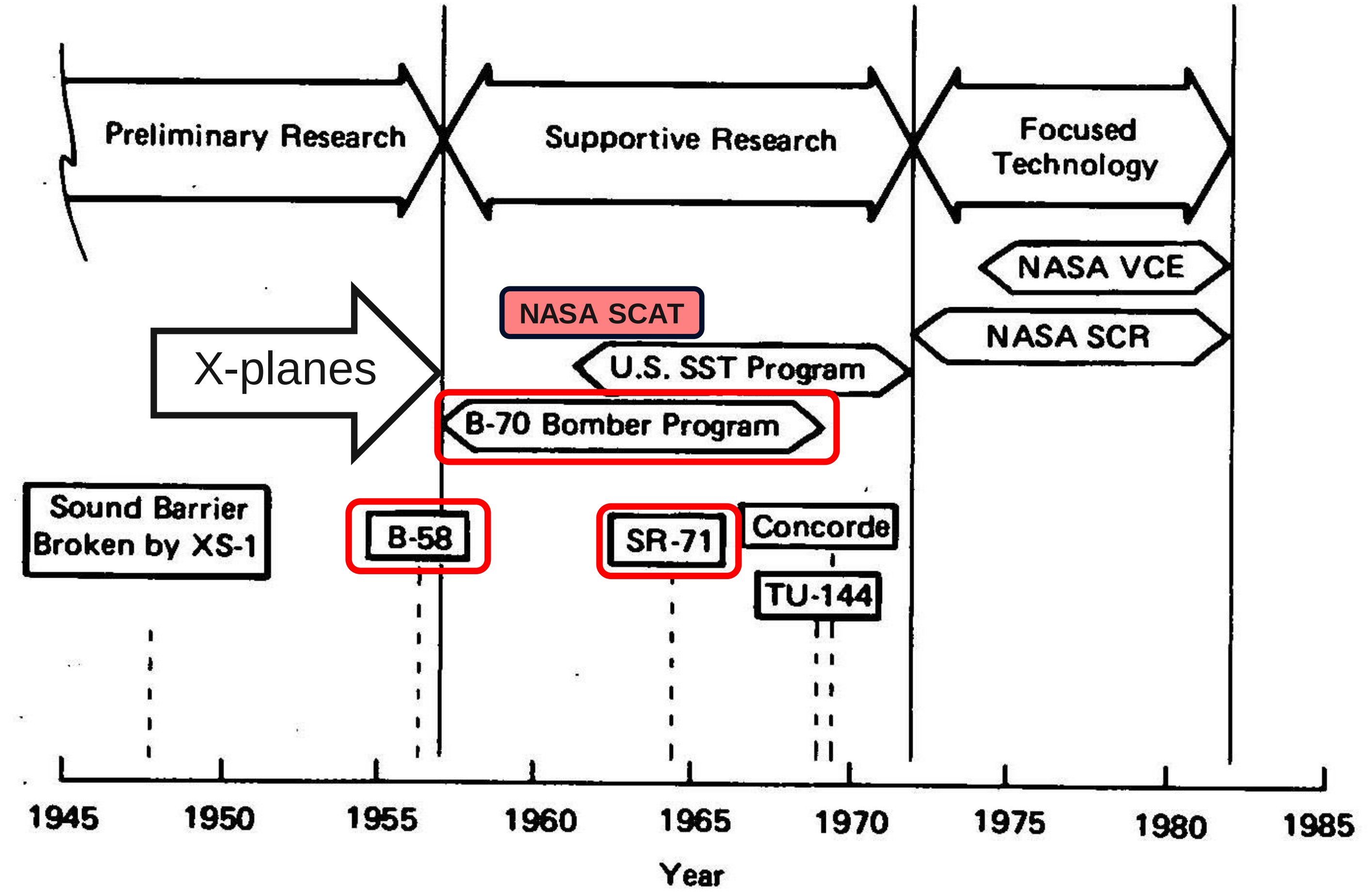
Douglas D-558-2
(stability
characteristics)

Northrop X-4
(tailless)

Douglas X-3
(Mach 3 design)

Hallion, R., NASA's Contribution to Aeronautics Vol 2, NASA, 2010

Supersonic Cruise Aircraft in Operation



McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

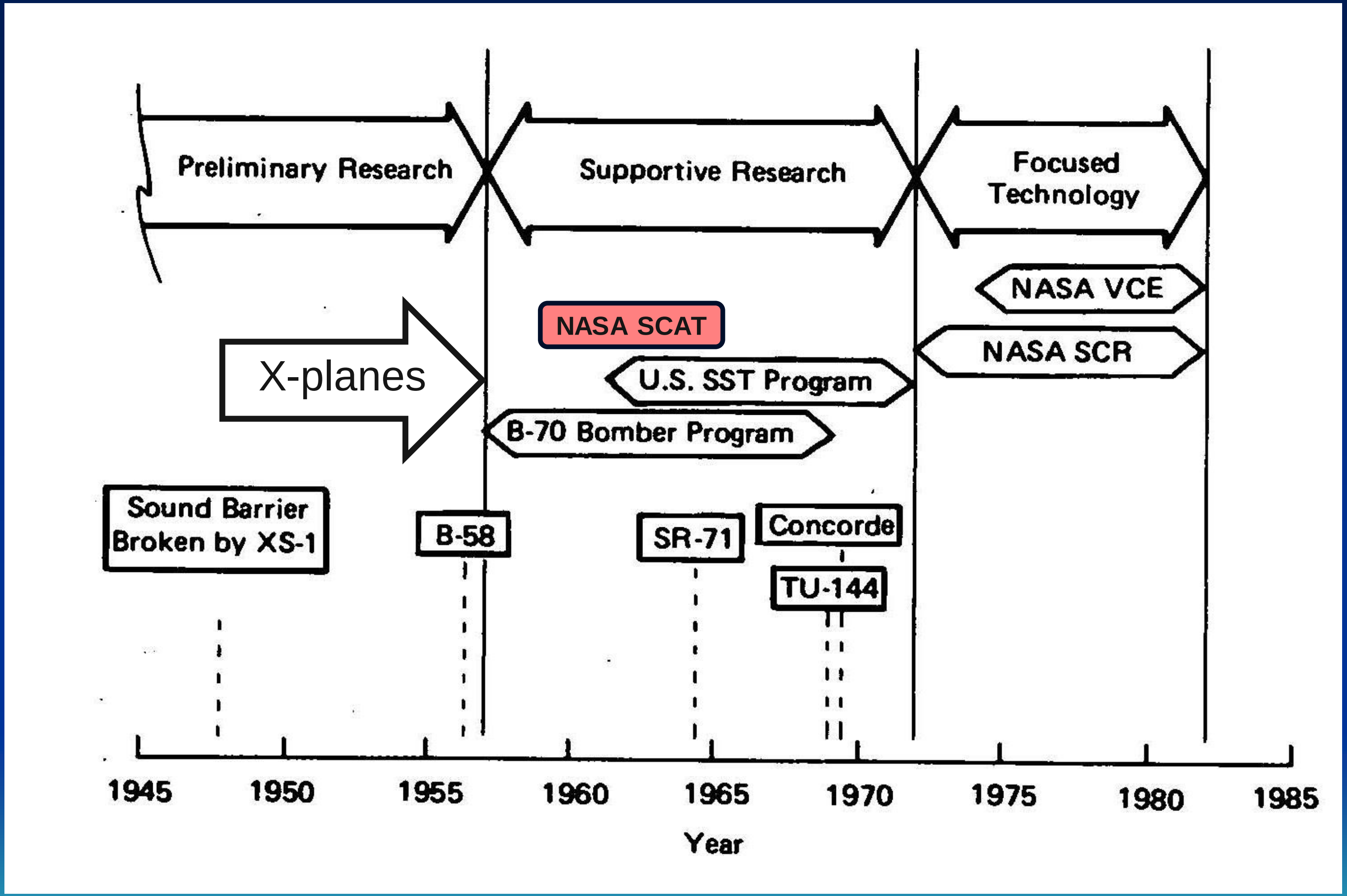
First Gen. Supersonic Cruise Aircraft

Convair B-58
M_{cruise}: 2.0
Radius: 3,220 km (1,510 nmi)
TOGW: 80,240 kg (176,890 lb)

North American XB-70
M_{max}: 3.1
Range: 6,901 km (3,725 nmi)
TOGW: 246,000 kg (542,000 lb)

Lockheed SR-71
M_{max}: 3.3
Range: 5,400 km (2,900 nmi)
TOGW: 78,000 kg (172,000 lb)

NASA Supersonic Cruise Aircraft Technology

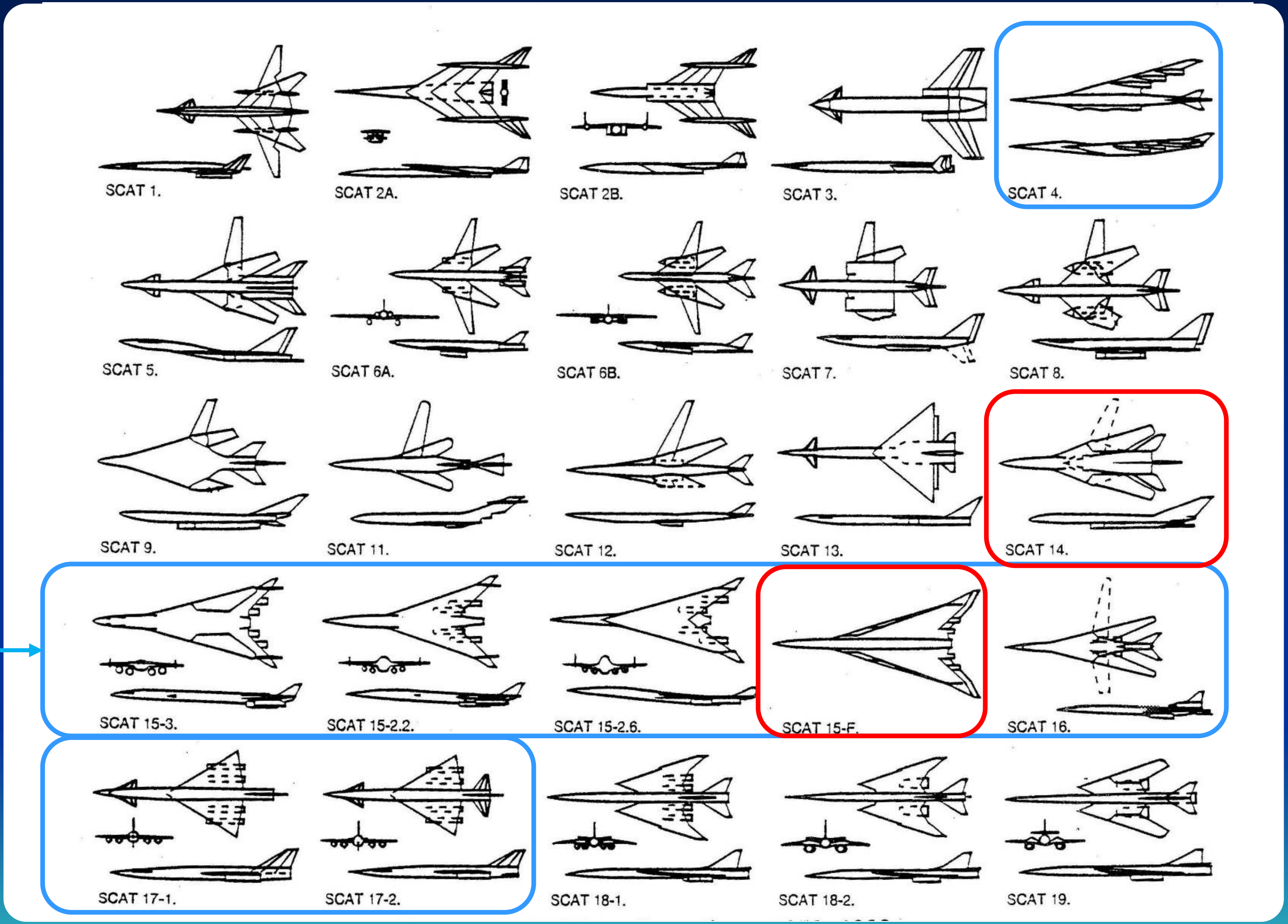


McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

XS-1 was the original designation for the Bell X-1

NASA Supersonic Cruise Aircraft Technology

- SCAT Configurations 1959 - 1966
- Work centered at NASA Langley with support from Ames and Lewis
- Leveraged technologies from B-58 and XB-70
- NASA concentrated on SCAT 4, 15, 16, 17 (blue boxes)
- Considerable effort on understanding sonic boom

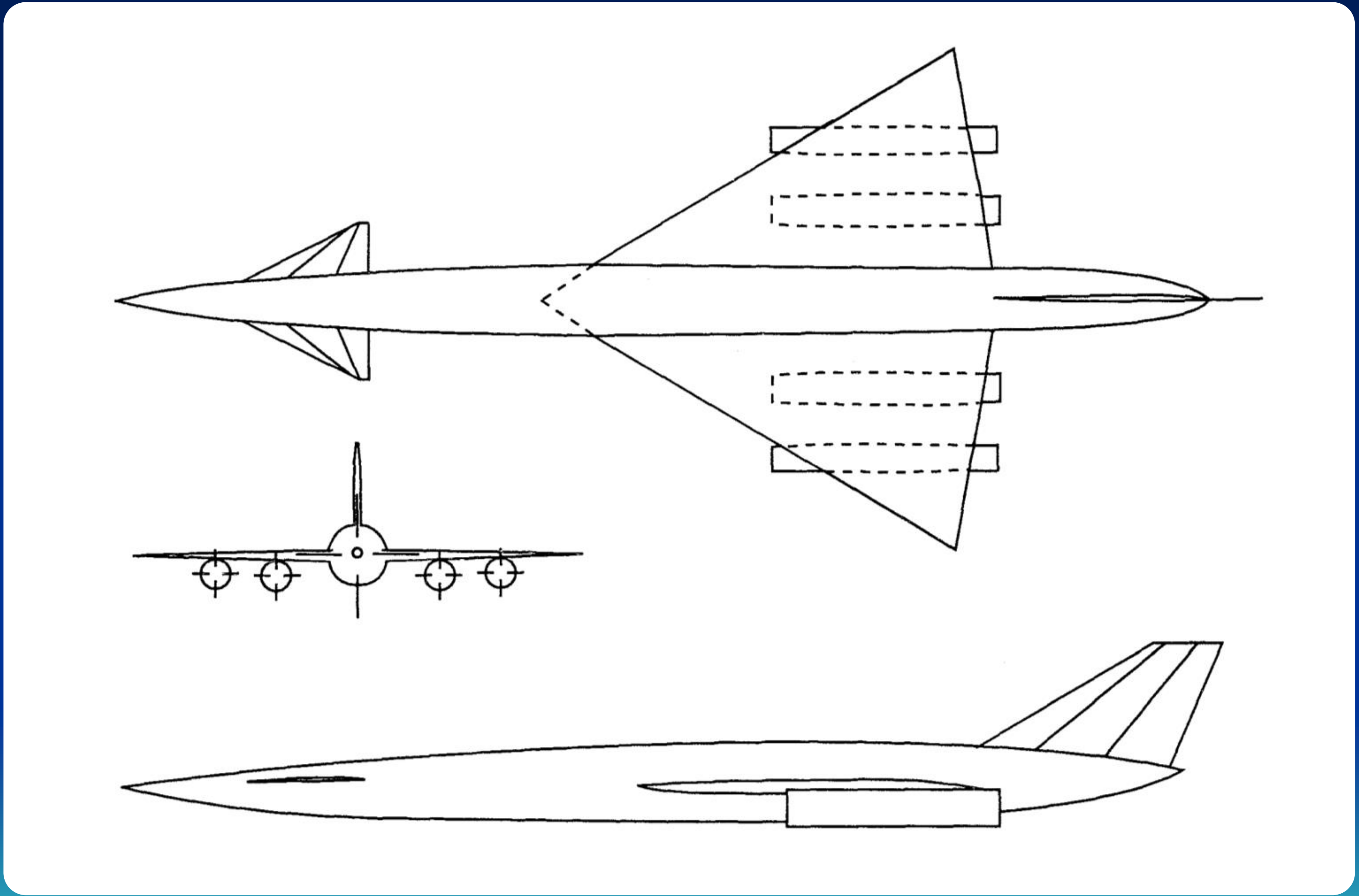


Spearman. The Evolution of the High-Speed Civil Transport, NASA TM 109089, Feb 1994

Lockheed Evaluation of SCAT 17-1

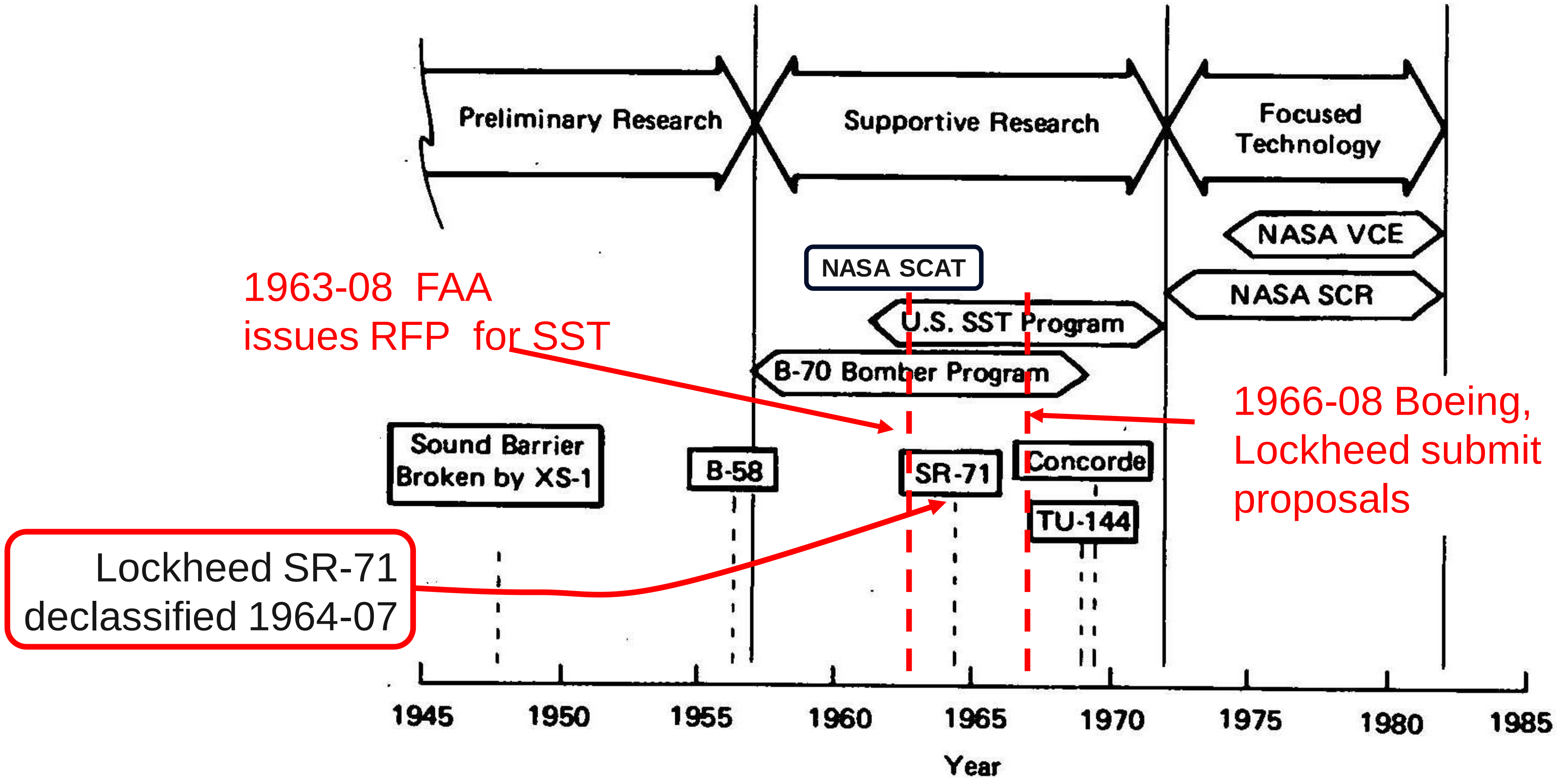
1963-02 Selected by NASA for evaluation under contract to Lockheed

Evolved as SCAT 17-2



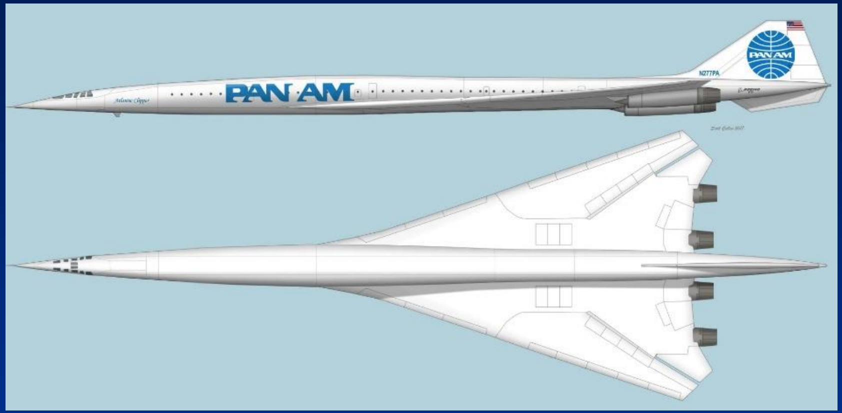
Proceedings of NASA Conference on Supersonic-Transport Feasibility Studies and Supporting Research - September 17-19,1963. NASA TM-905, 1963.

US Supersonic Transport



McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

SST Proposals to FAA



Boeing 2707

Lockheed L-2000

- 1963-08 FAA issues RFP for SST
- 1966-08 Boeing, Lockheed submit proposals

Boeing 2707

globalsecurity.org

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B.2707-200

- Variable geometry
- MTOGW = 306,175 kg (675,000 lb)
- Range = 7,871 km (4,250 nmi)

Cannot achieve Transpac

- 350 pax
- 2-3-2 seating
- M_{cr} = 2.7

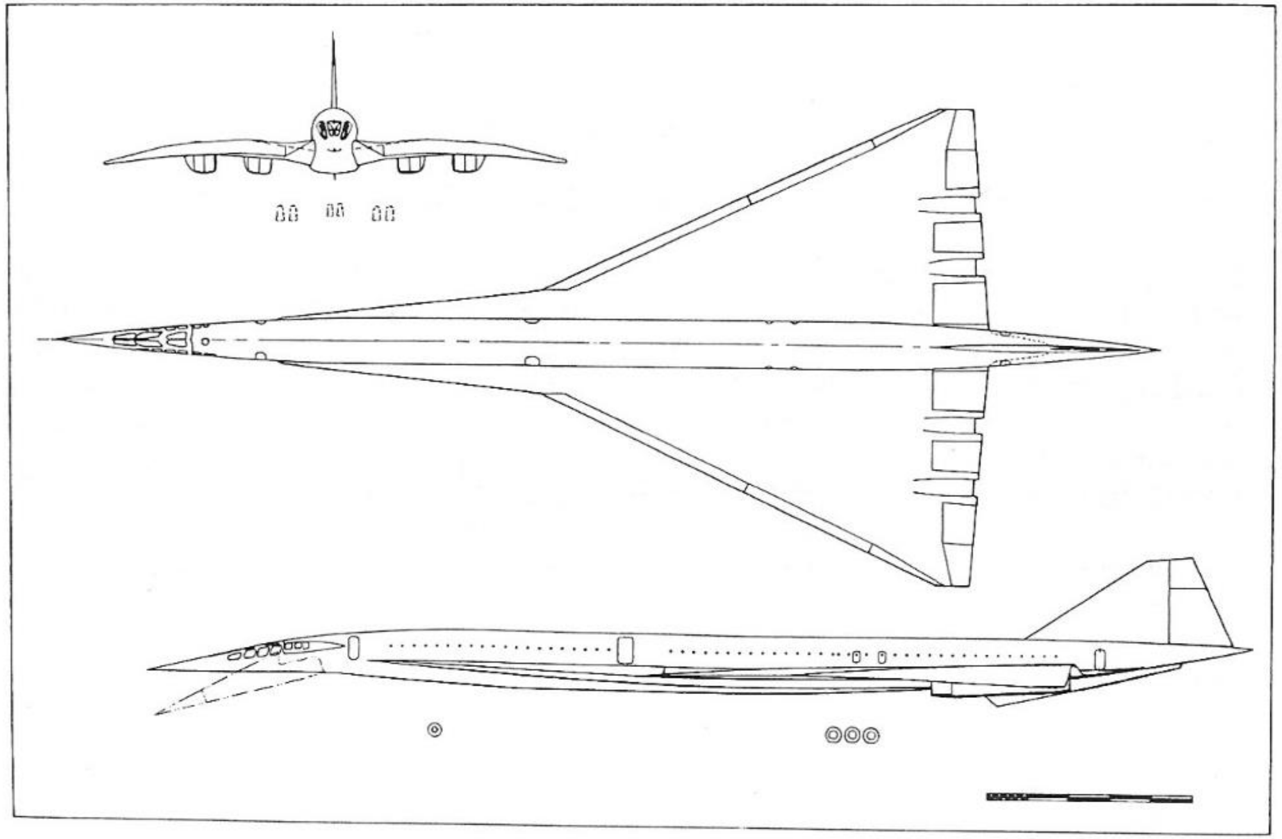
Variable-geometry Configurations

General Dynamics F-111B
MTOGW: 45,300 kg (100,000 lb)
M_{cr}: 2.5
Ferry range: 5,950 km (3,210 nmi)
First flight: 1964-12-21 (F-111A)

Grumman F-14D
MTOGW: 33,720 kg (74,350 lb)
M_{cr}: 2.34
Ferry range: 2,960 km (1,600 nmi)
First flight: 1970-12-21 (F-14A)

North American B-1B
MTOGW: 216,400 kg (477,000 lb)
M_{cr}: 1.25 @ 40,000ft
Range: 9,400 km (5,100 nmi)
First flight: 1974-12-23 (B-1A)

Lockheed L-2000-7A



Lockheed L-2000-7A (CL-823-42-1) project

MTOGW = 267,620 kg (590,000 lb)
Pax = First:28 + Economy:230
Range = 4,000 nmi (7,400 km)
M_{cr} = 3.0
Engines: GE4/J5M or P&W JTF17A-21L

Francillon: Lockheed Aircraft Since 2013

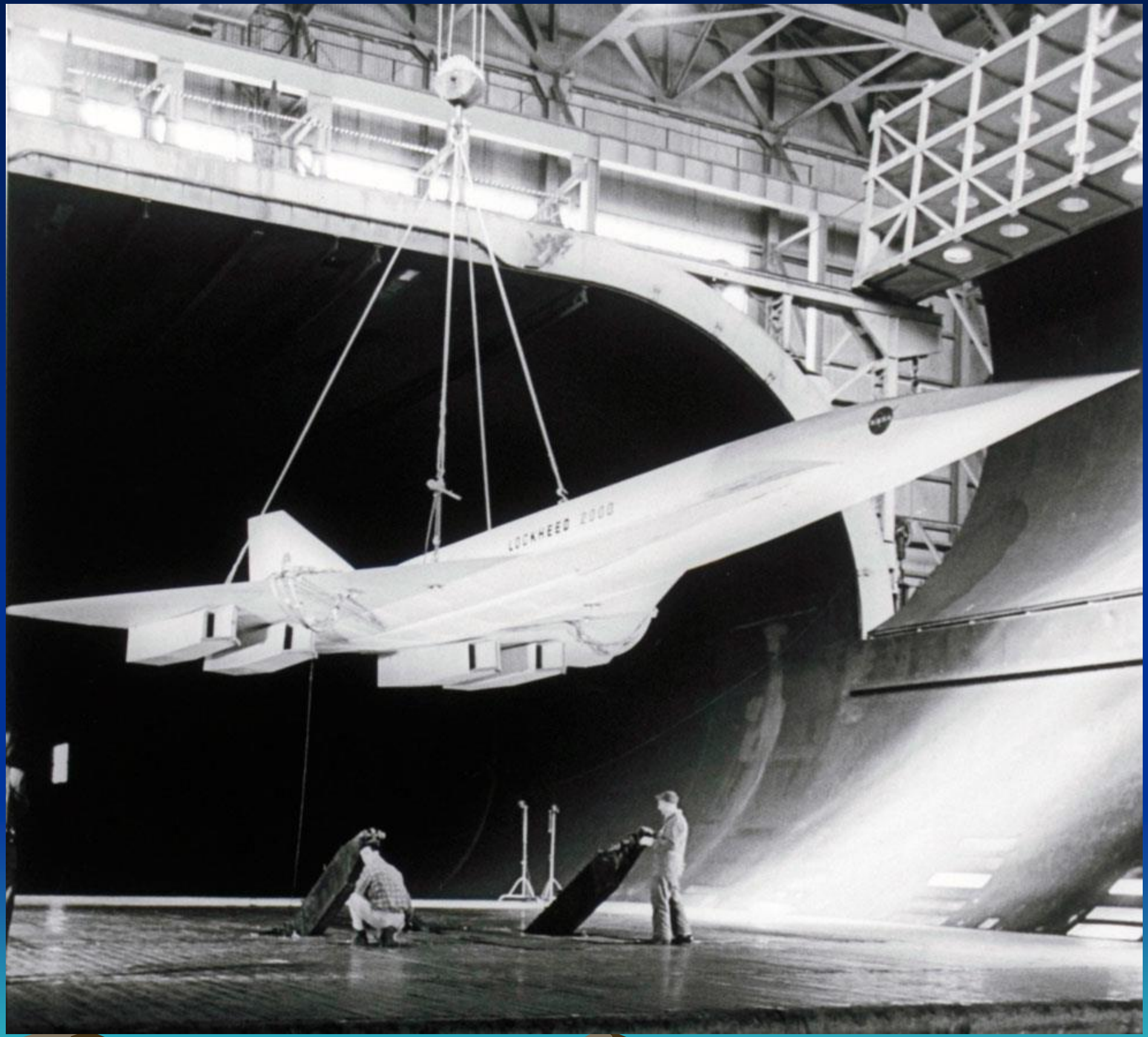
L-2000 Mockup

Construction of wooden mockup in Burbank hangar

https://i.redd.it/tfp0dm3oowva1.jpg

L-2000 Low Speed Testing

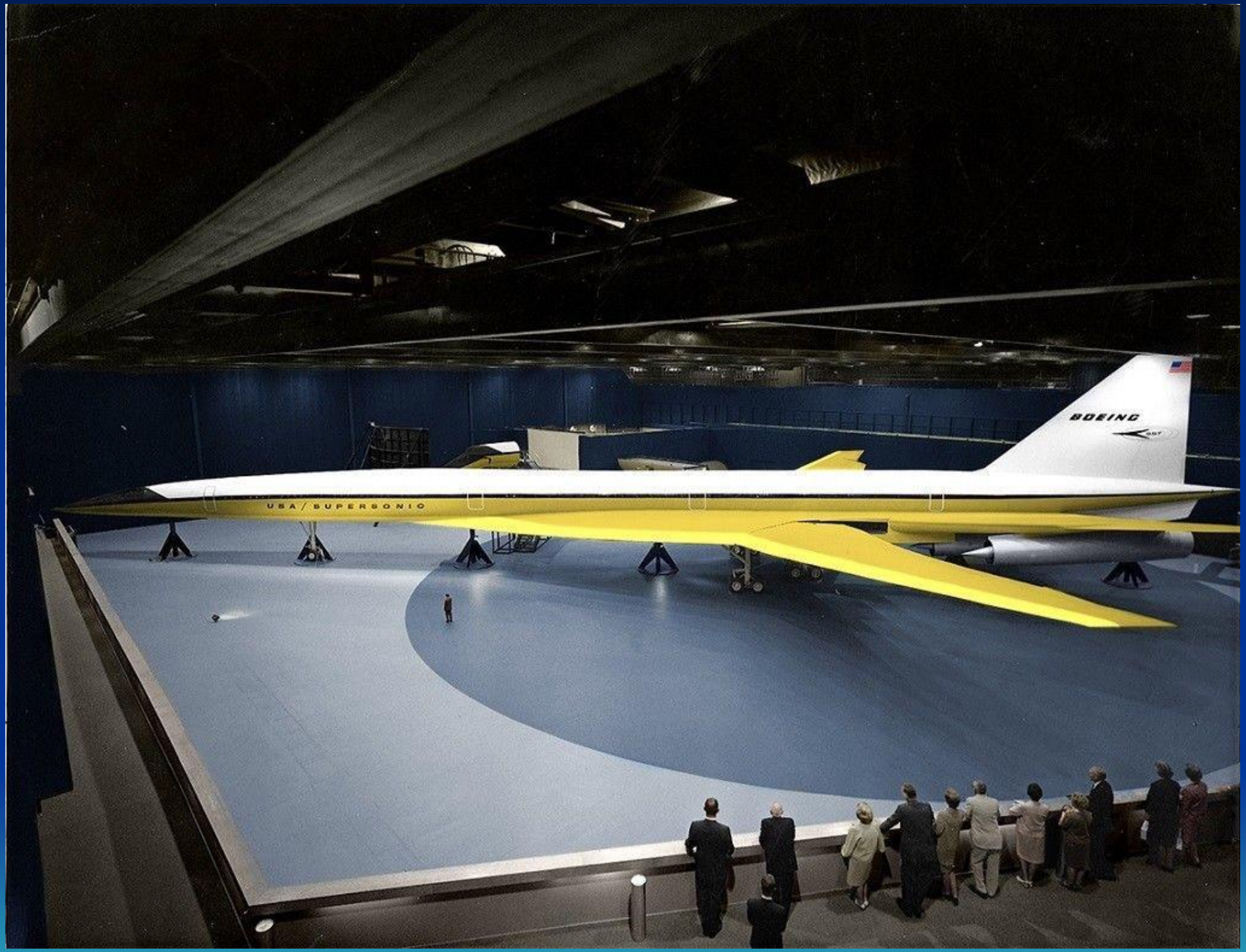
L-2000 model in NASA Ames 40 x 80 ft Low Speed Wind Tunnel



https://theaviationgeekclub.com/wp-content/uploads/2018/02/L-2000.jpg

Boeing 2707-200

Subscale model of variable geometry configuration



https://i.redd.it/1m77uj18u8m51.jpg

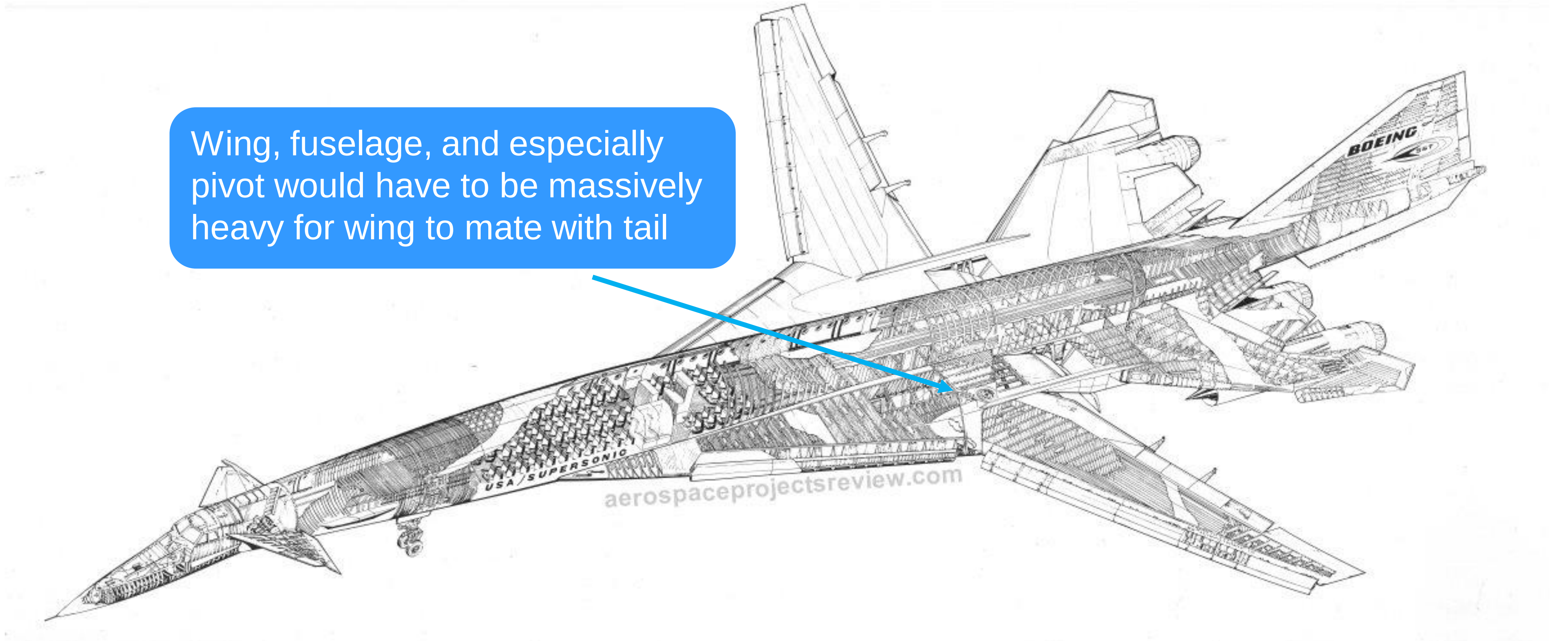
Boeing 2707-200

1967-01-01 FAA selects Boeing design

© Gaël Élégoët www.airsoc.com

Boeing 2707-200

Wing, fuselage, and especially pivot would have to be massively heavy for wing to mate with tail



Design Analysis Sequence

- Conceptual Design
- Preliminary Design
  - CFD/wind tunnel studies
  - **Performance analysis**
  - Preliminary weights analysis
- Detail Design
  - Establish outer mold line (OML)
  - Aerodynamic loads analysis
  - Inertial loads analysis
  - Detailed structural design
  - **Detailed weights analysis**

Famous Engineers

1. Name a famous aerodynamicist –

Famous Engineers

1. Name a famous aerodynamicist –

Osborne Reynolds
Claude-Louis Navier
Sir George Stokes
Jacob Bernoulli
Ernst Mach

Theodore von Kármán
Richard Whitcomb
R.T. Jones
Bill Sears
……………

Famous Engineers

2. Name a famous weights engineer –

ADAC
Aircraft Design & Consulting

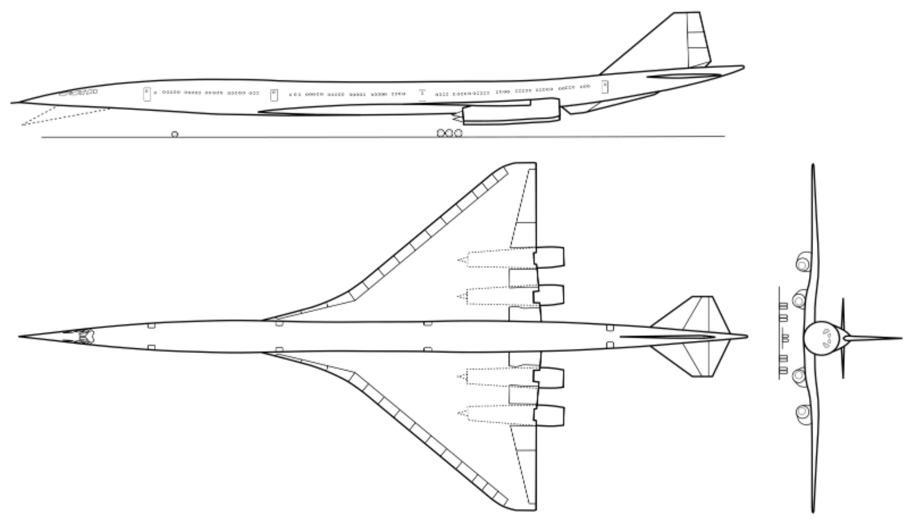
Boeing 2707-300

Model of fixed geometry configuration in 1970

https://secure.boeingimages.com/archive/Boeing-SST-Mockup-Press-Show-1970-2JRSXLJQRFHB.html

Boeing 2707-300

http://fantastic-plastic.com/Boeing2707-300.htm



By Nubifer - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=19969846

1969-07 Sonic boom, NO_x concerns raised
1969-10 Change design to delta wing with tail
GE-4 engine now too small for takeoff
FAA requested Lockheed provide L-2000 data

But engine development takes longer than airframe development

1971-01 U.S. Senate cancels funding
1971-05 U.S. House cancels funding
Boeing lays off 7,000 workers*
GE lays off 6,000 workers*

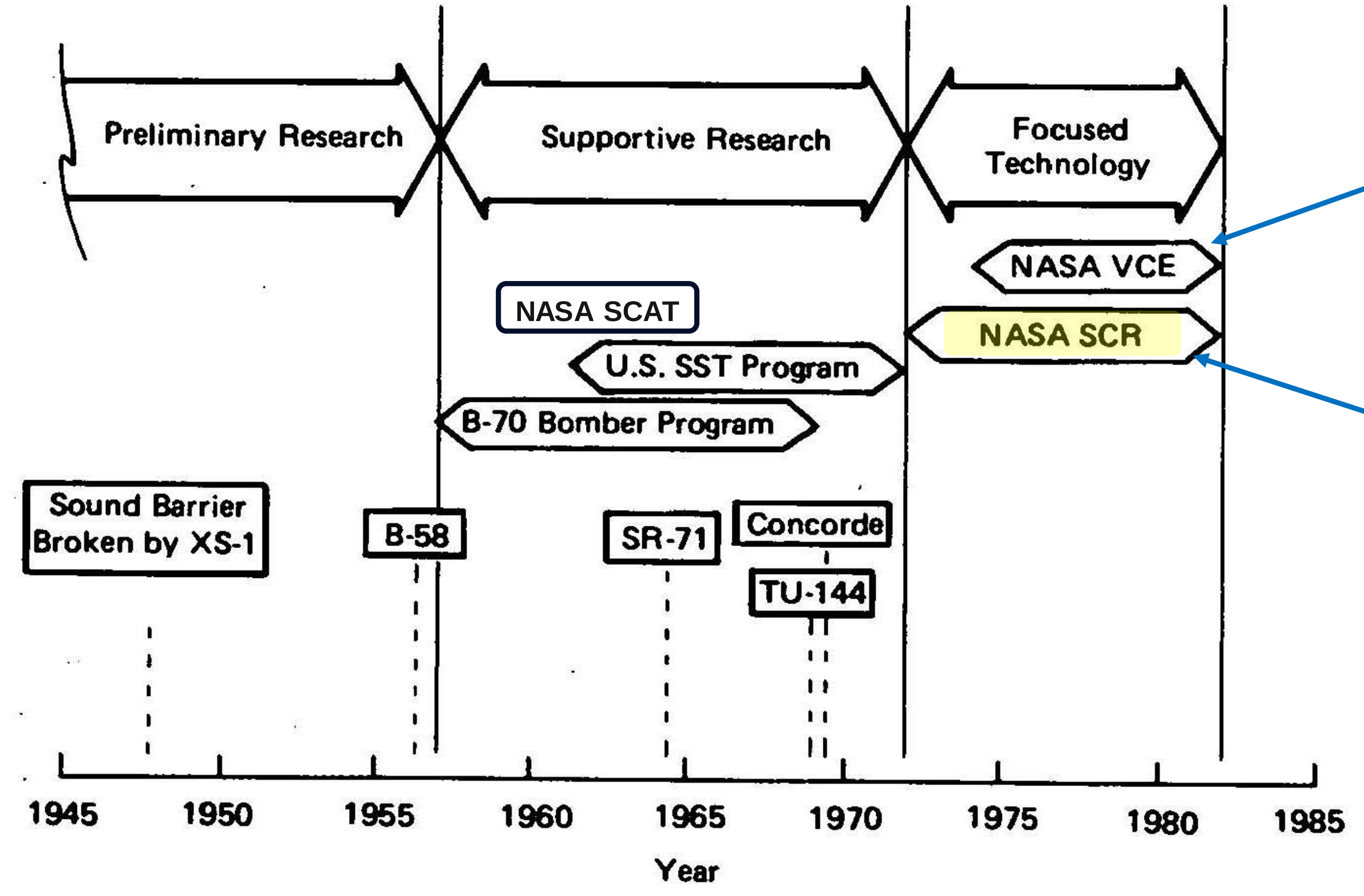
Boeing had 115 orders from 25 airlines

* Roughly the same time as 747, L-1011, DC-10, C-5 and Apollo became operational

Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design
- First generation SSTs
  - Concorde
  - Tu-144
  - Boeing 2707
- Second Generation Studies
  - Supersonic Cruise Research
  - High Speed Civil Transport
  - DARPA Quiet Supersonic Platform
- Future
  - NASA/Lockheed X-59
  - Supersonic Bizjets
  - Supersonic Transports
- Conclusions

NASA Supersonic Cruise Research



Variable Cycle Engine

Supersonic Cruise Research

McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

NASA Supersonic Cruise Research

1972-1982 revived NASA-Langley SCAT 15-F “arrow wing” developed in 1964, but not used in SST program

Symbolic arrow wing in NASA logo

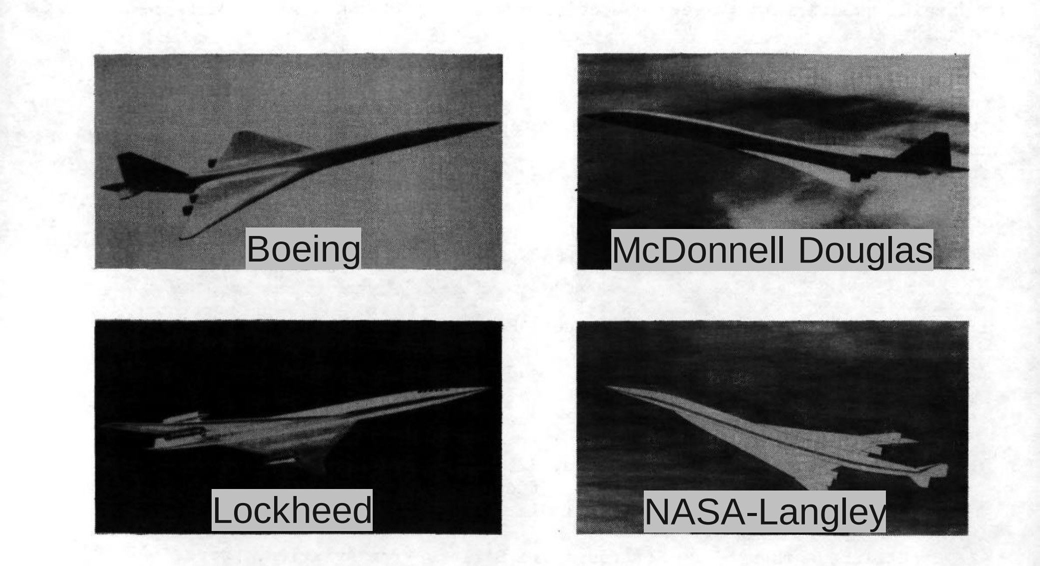
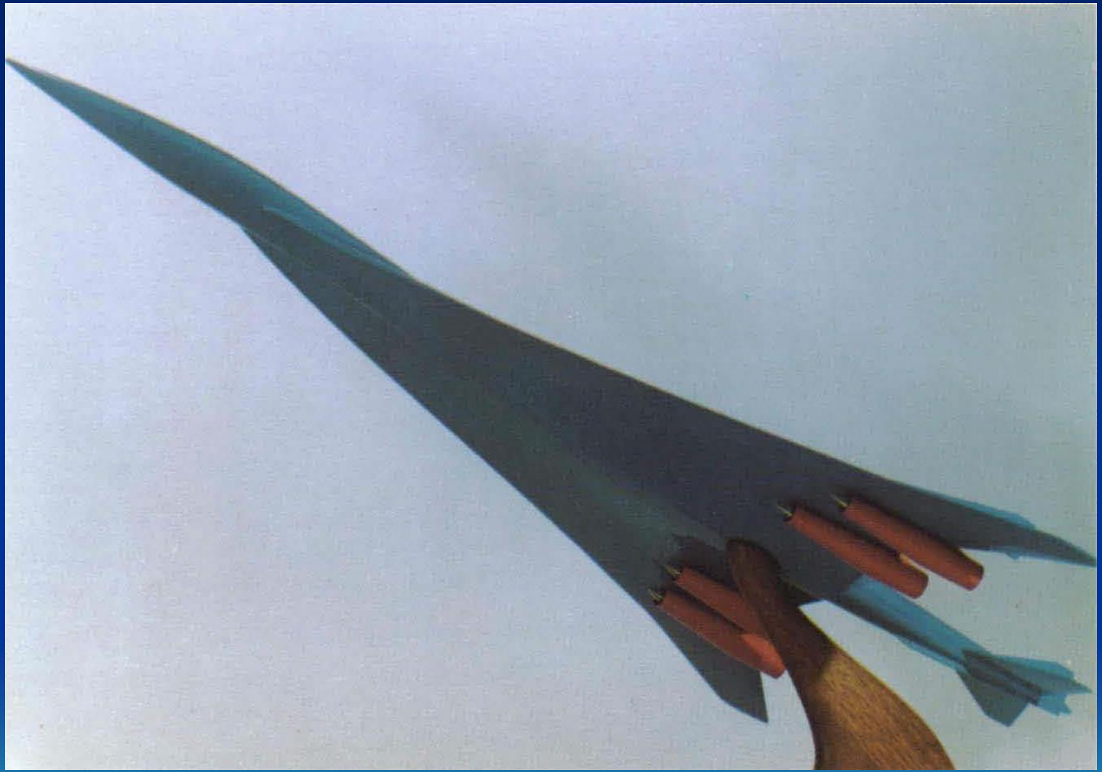


Figure 1.- Advanced supersonic cruise aircraft configurations.

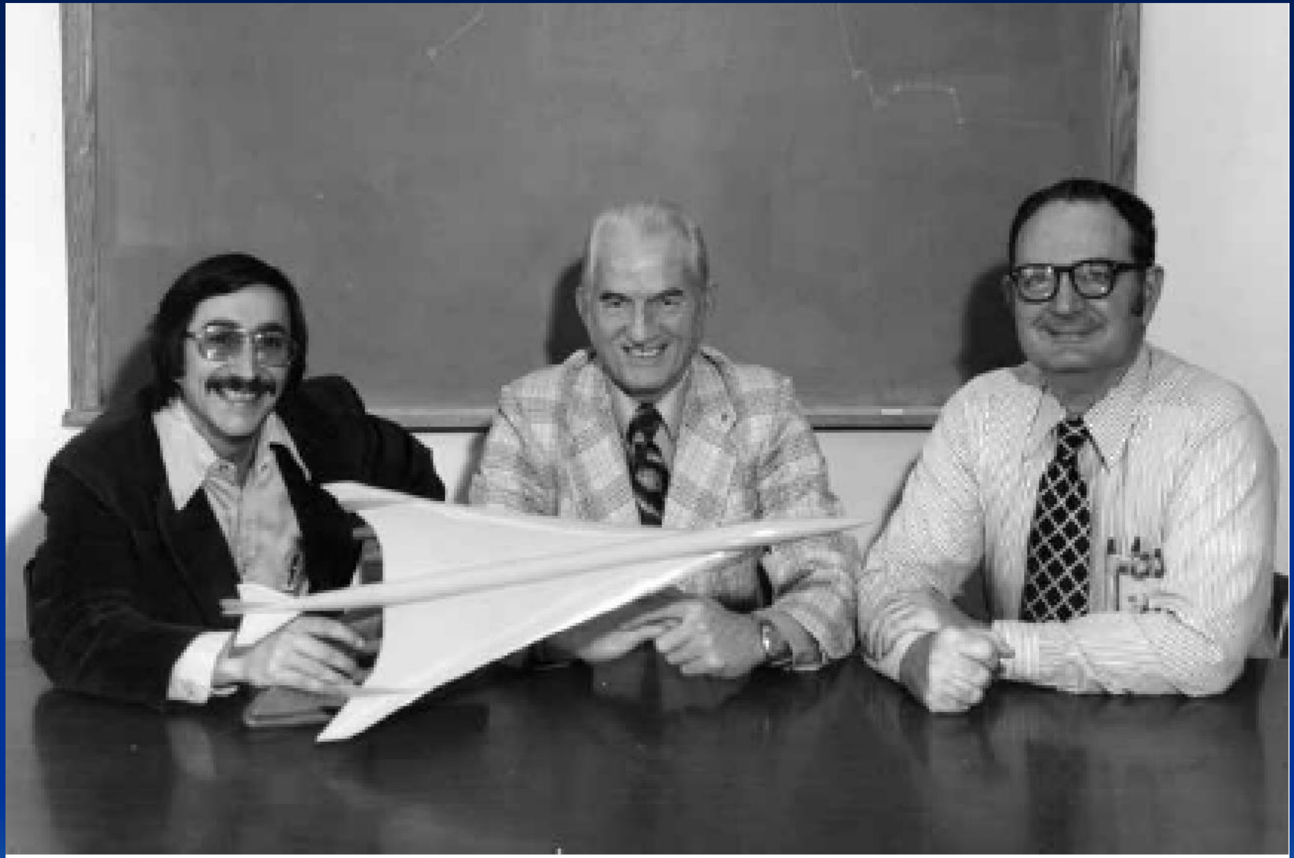
Driver, C., Progress in Supersonic Cruise Aircraft Technology, NASA TM-78695, May 1978



McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

NASA SCR Management

Vince Mascitti
Ed McLean
Neil Driver

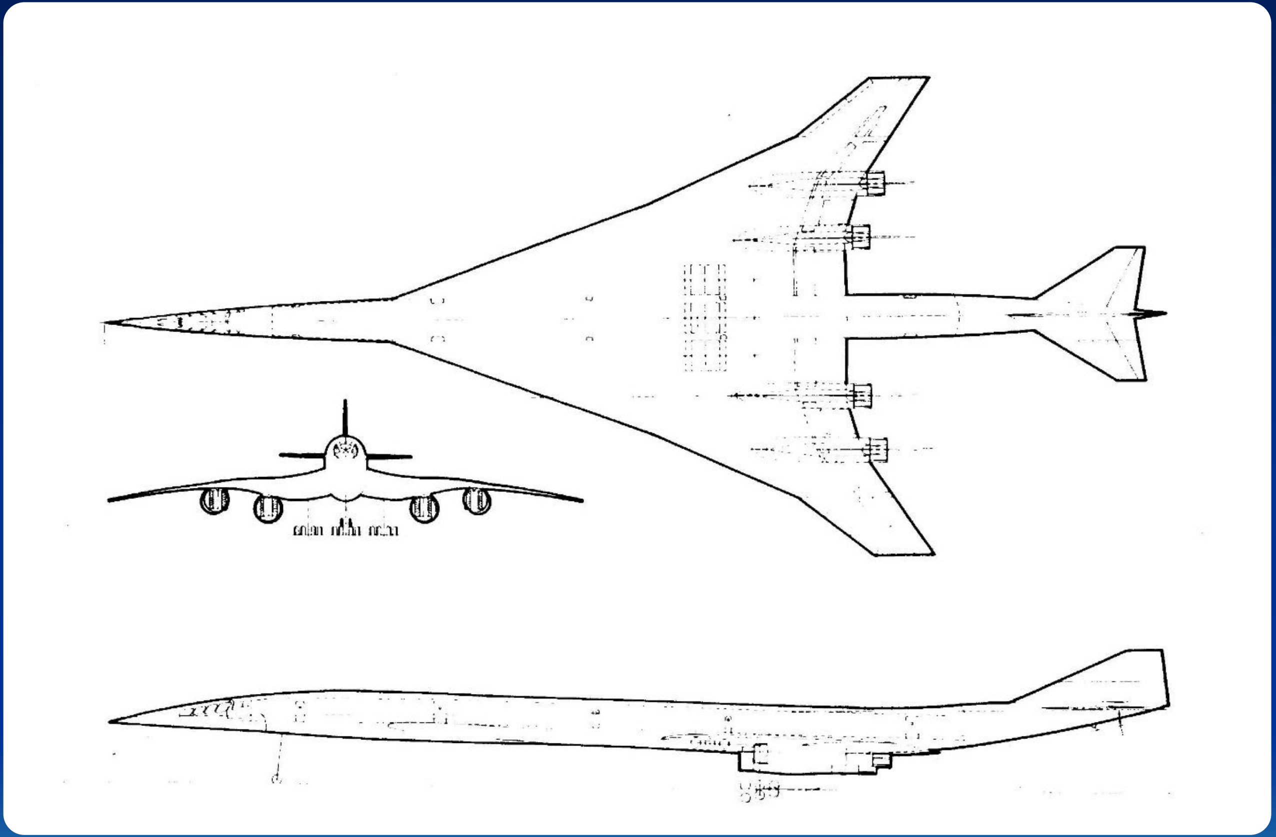


Vincent R. Mascitti, F. Edward McLean, and Cornelius Driver in the mid-1970s with a Lockheed AST model. (NASA)

Lawrence Benson “Quieting The Boom”

Lockheed CL1627-1 Common Case Study

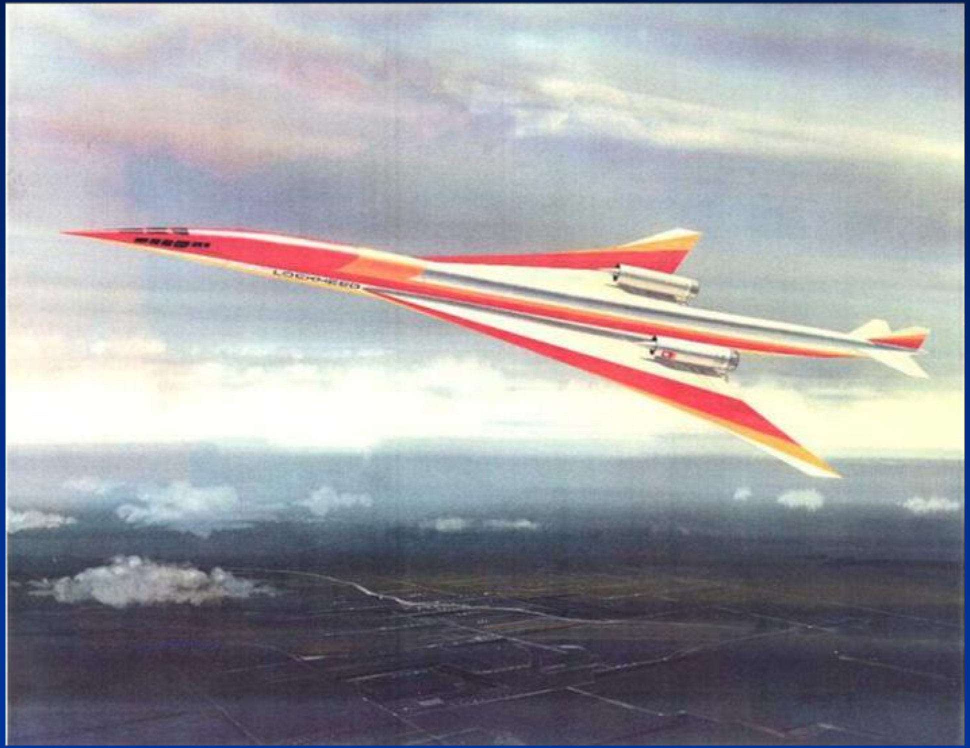
Study performed for the International Civil Aviation Organization (ICAO) by
- United States
- United Kingdom
- France
- Soviet Union



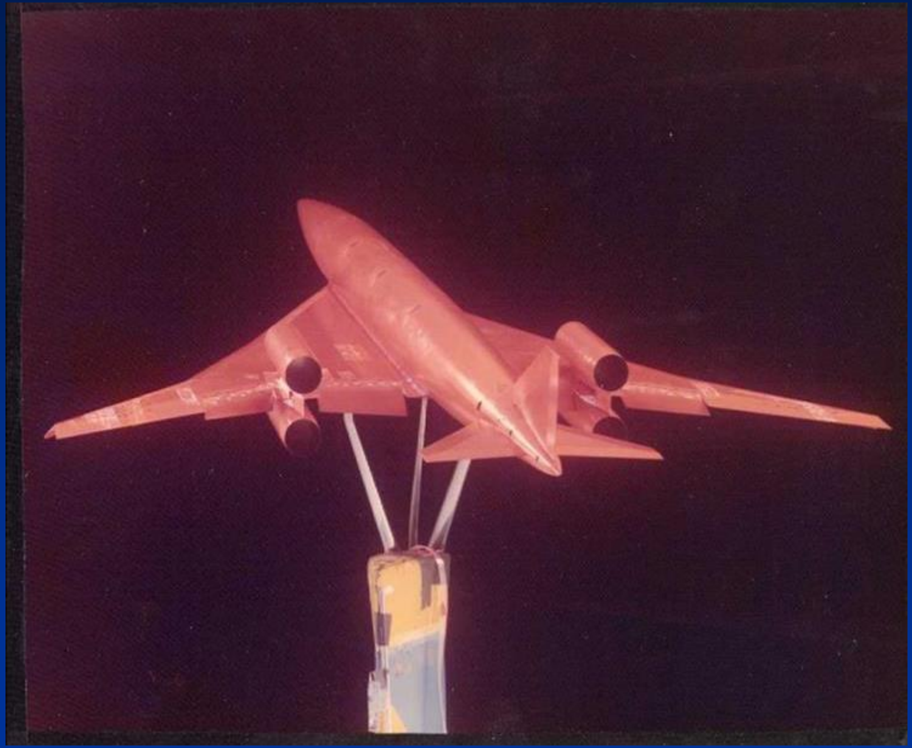
Clauss, J.S., Hays, A.P., Wilson, J.R., The Common Case Study, NASA CR-158935, 1978

- MTOGW: 269,483 kg (594,109 lb)
- Payload: 23,247 kg (51,250 lb)
- Range: 7000 km (3780 nmi)
- M_{cr}: 2.2
- TOFL: 3,505 m (11,500 ft)

Lockheed Over-Under Engine Concept

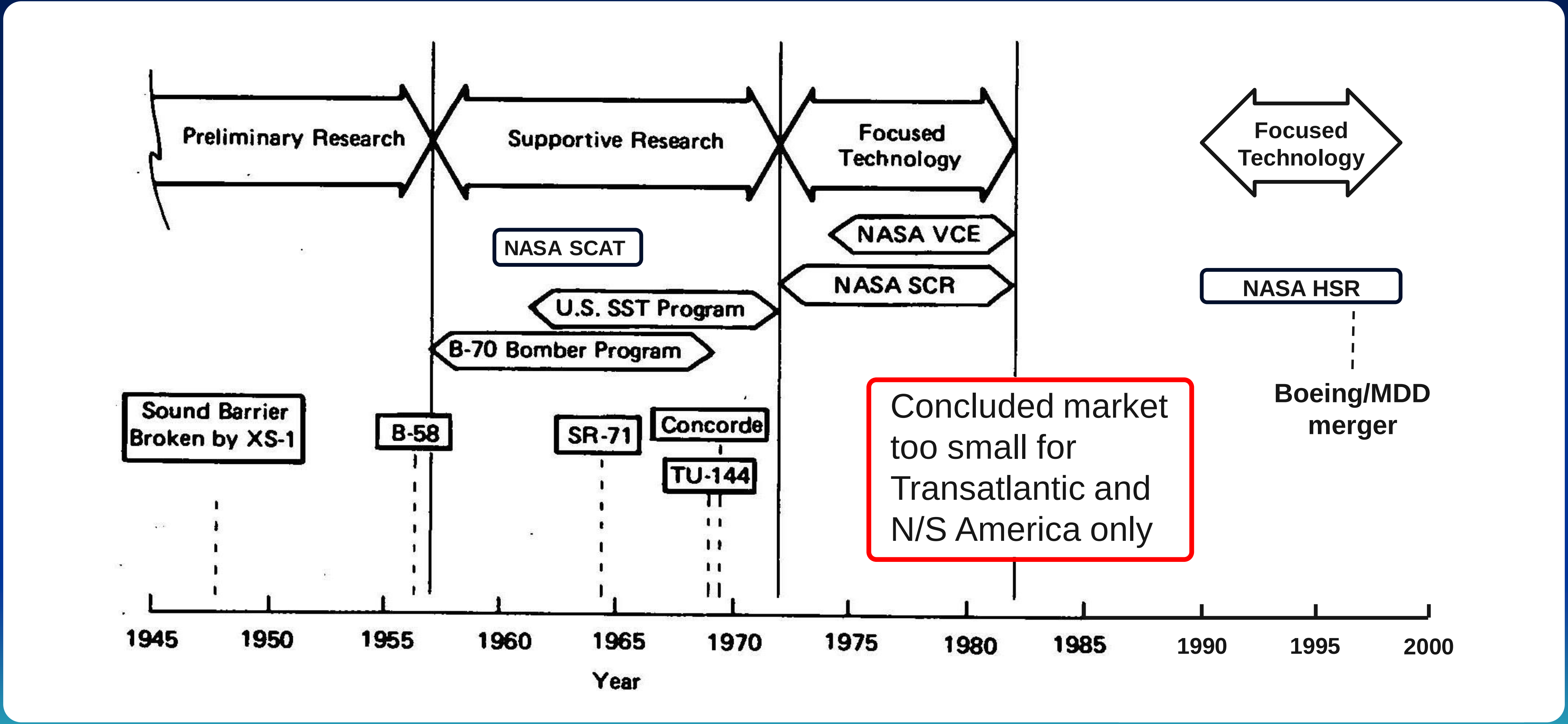


CL1611



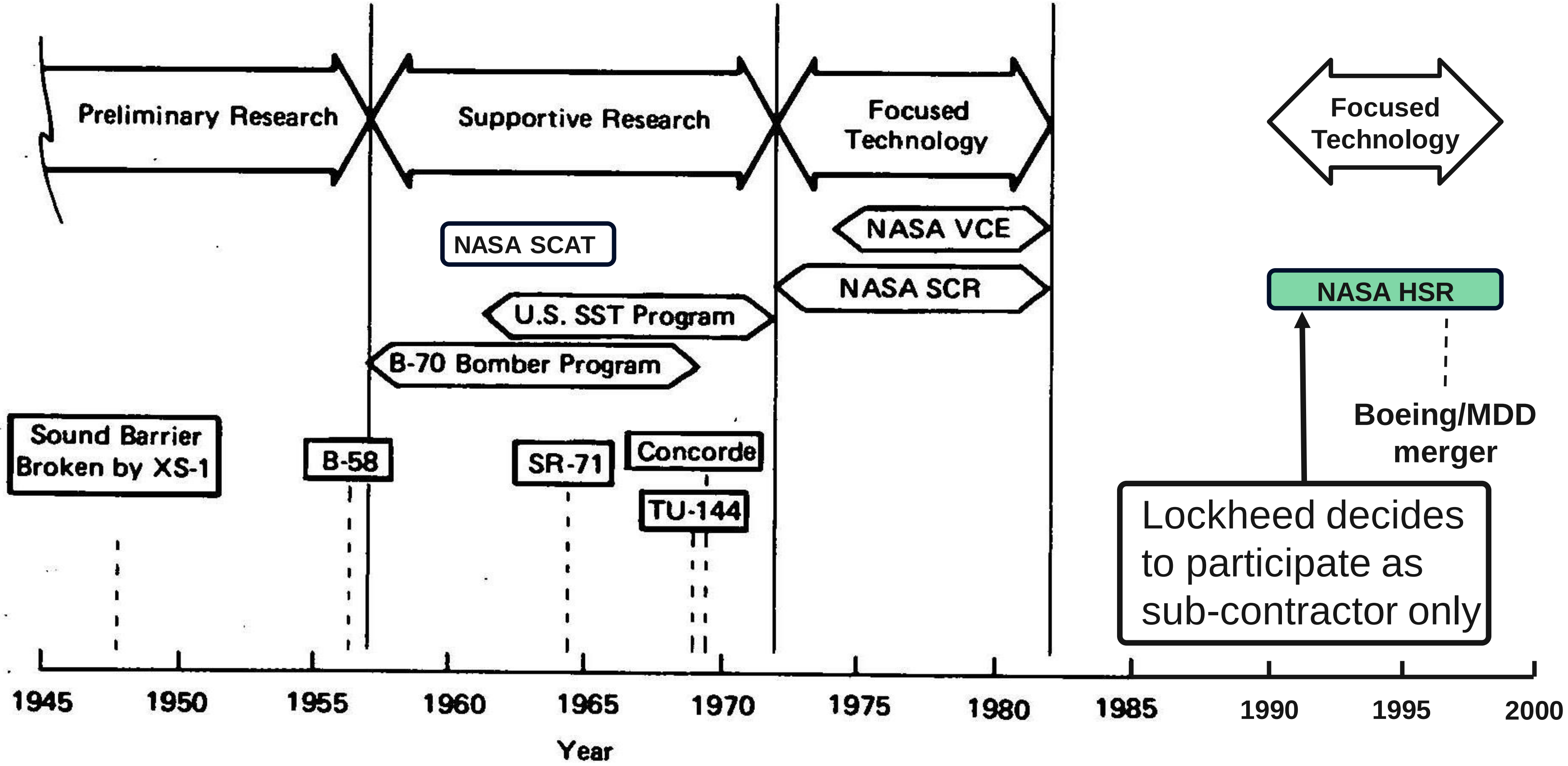
Over/Under Engine Concept
in Low Speed Wind Tunnel

NASA High Speed Civil Transport



McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

NASA High Speed Civil Transport



McLean, F.E., Supersonic Cruise Technology, NASA SP-472, 1985

Boeing/NASA High Speed Civil Transport

- 1990 - 1999
- 300 pax
- Trans-Pacific range
- M_{cr}: 2.4
- Boeing and Douglas as prime contractors (Lockheed as sub-contractor)

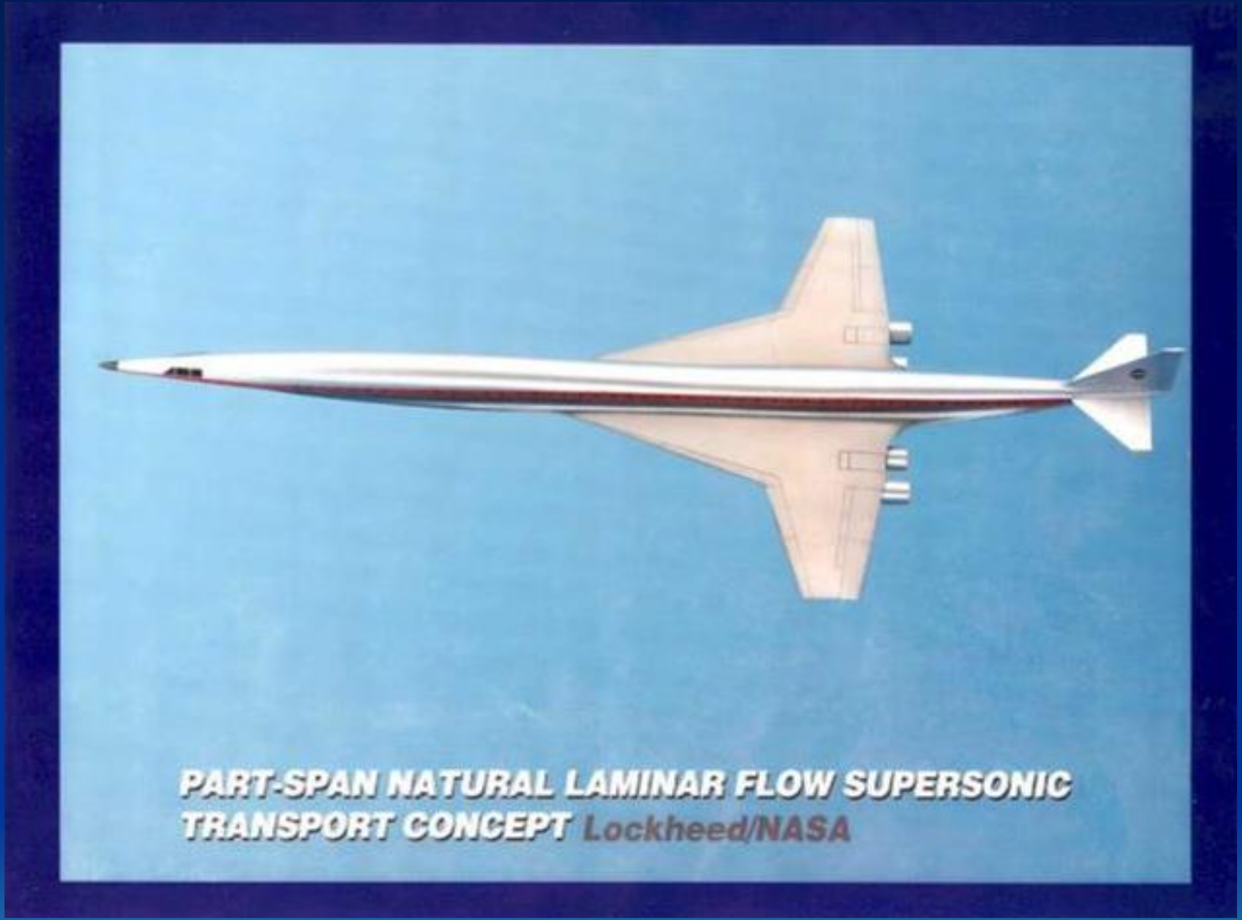
"High-Speed Civil Transport Study: Summary". NASA CR-4234. Boeing Commercial Airplanes. 1989.

Lockheed/NASA NLF SST Concept

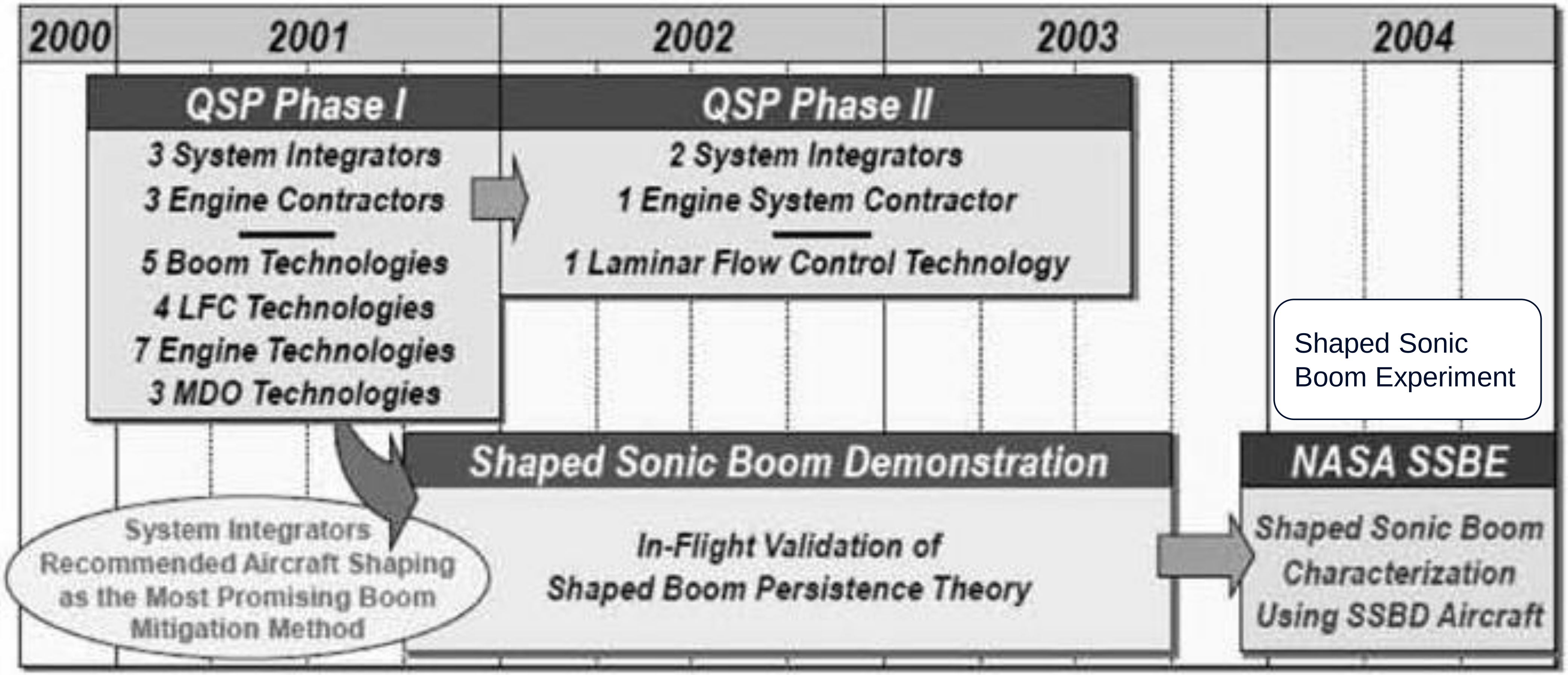
C. 1994

Natural Laminar Flow (NLF) easier to achieve under supersonic conditions

Primary benefit from improved takeoff and landing performance



DARPA Quiet Supersonic Platform



DARPA Quiet Supersonic Platform

- 2000-10
- Issued contracts to
  - Northrop Grumman (NGC)
  - Lockheed Martin (LM)
  - Boeing

Goals

- Overpressure < 0.3 psf
- M_{max} 2.4
- TOGW < 100,000 lb
- Payload 9,070 kg (20,000 lb)
- Range 11,120 km (6,000 nmi)
- Payload > 20% TOGW

https://www.globalsecurity.org/military/systems/aircraft/qsp.htm

DARPA Quiet Supersonic Platform - NGC

Mentioned earlier

Lockheed Supersonic Bizjet

Based on Julian Wolkovitch concept

OEI Takeoff? Would need large rudder

Source: Aviation Week

Difficult to get required fineness ratio without very small x-section cabin

Joined wing permits thinner wing sections, but where do you put the fuel?

For similar concept see https://en.wikipedia.org/wiki/SAI_Quiet_Supersonic_Transport

Lockheed Martin 12 Pax. QSST

- Supersonic Aerospace International (SAI)*
- $25M from Allen Paulson (Gulfstream)
- Quiet Small Supersonic Transport
- M_{max} = 1.8
- Cruise altitude: 60,000 ft
- Estimated sonic boom 1% of that of Concorde

* Founded in 2001 by Michael Paulson, son of Gulfstream Aerospace founder Allen Paulson

https://priveaccess.com/supersonic-business-jet-qsst/

Lockheed Martin 2nd Gen. SST

- Lockheed Martin N+2
- 80 passengers
- 3 engines
- 4,000 nmi range
- M_{cruise} 1.6
- Low sonic boom

http://www.supersonic-business-jet.com/prototypes/lockheed-martin-n2.html

Lockheed Martin 2nd Gen. SST

- Technically feasible
- Questionable economics
- Expensive to buy, but operational efficiency (pax-miles/hr) can be doubled

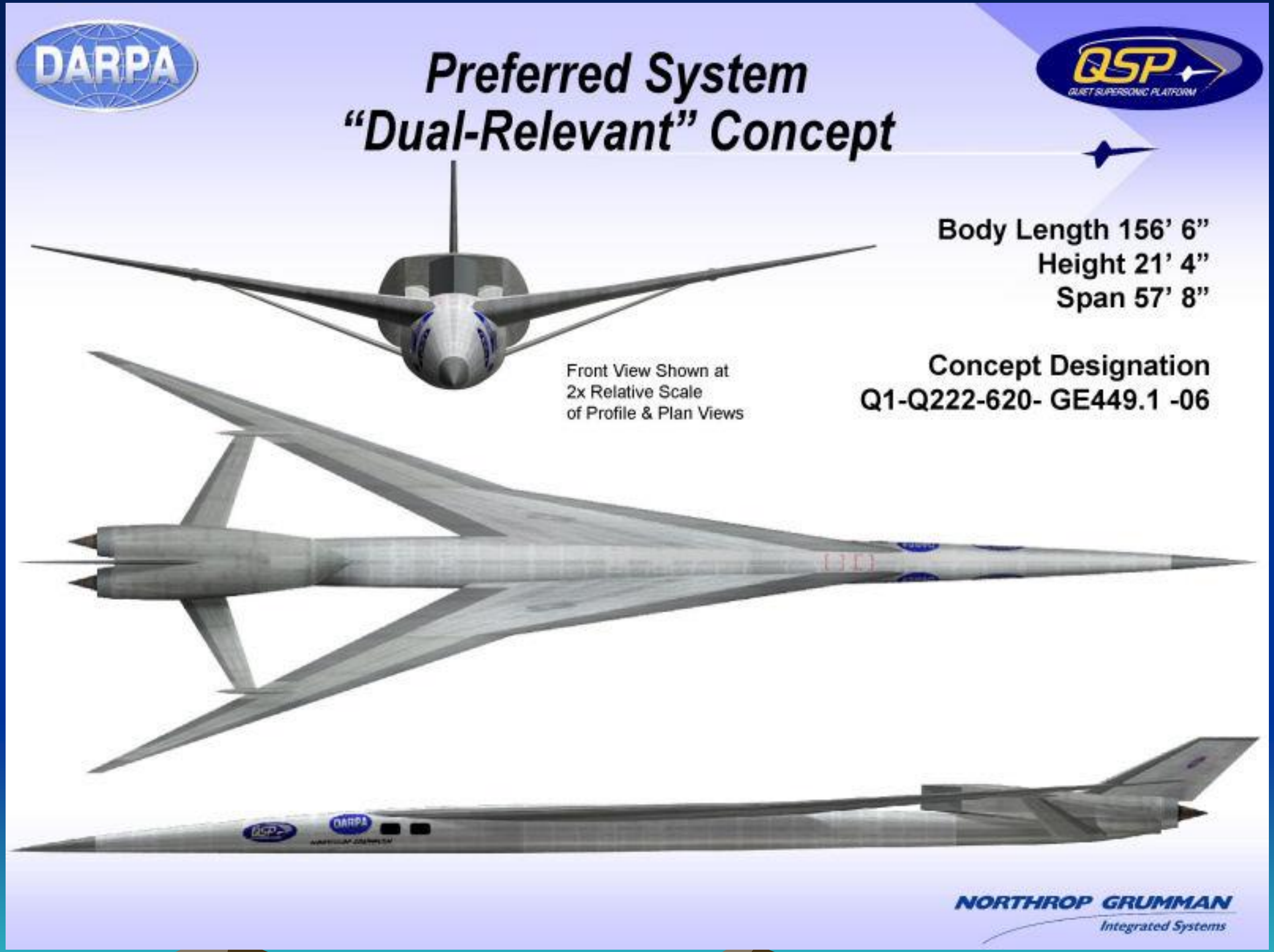
Source: Aviation Week

Boeing Supersonic Bizjet

Source: Aviation Week

Northrop Grumman Strike/Bizjet c. 2002

- Isentropic compression inlet
- Assumed extensive laminar flow
- 0.3 psf boom overpressure
- M_{cruise} 2.0
- Payload: 9,080 kg (~ 20,000 lb or 80 pax)
- Range: > 6,000 nmi



https://www.globalsecurity.org/military/systems/aircraft/qsp.htm

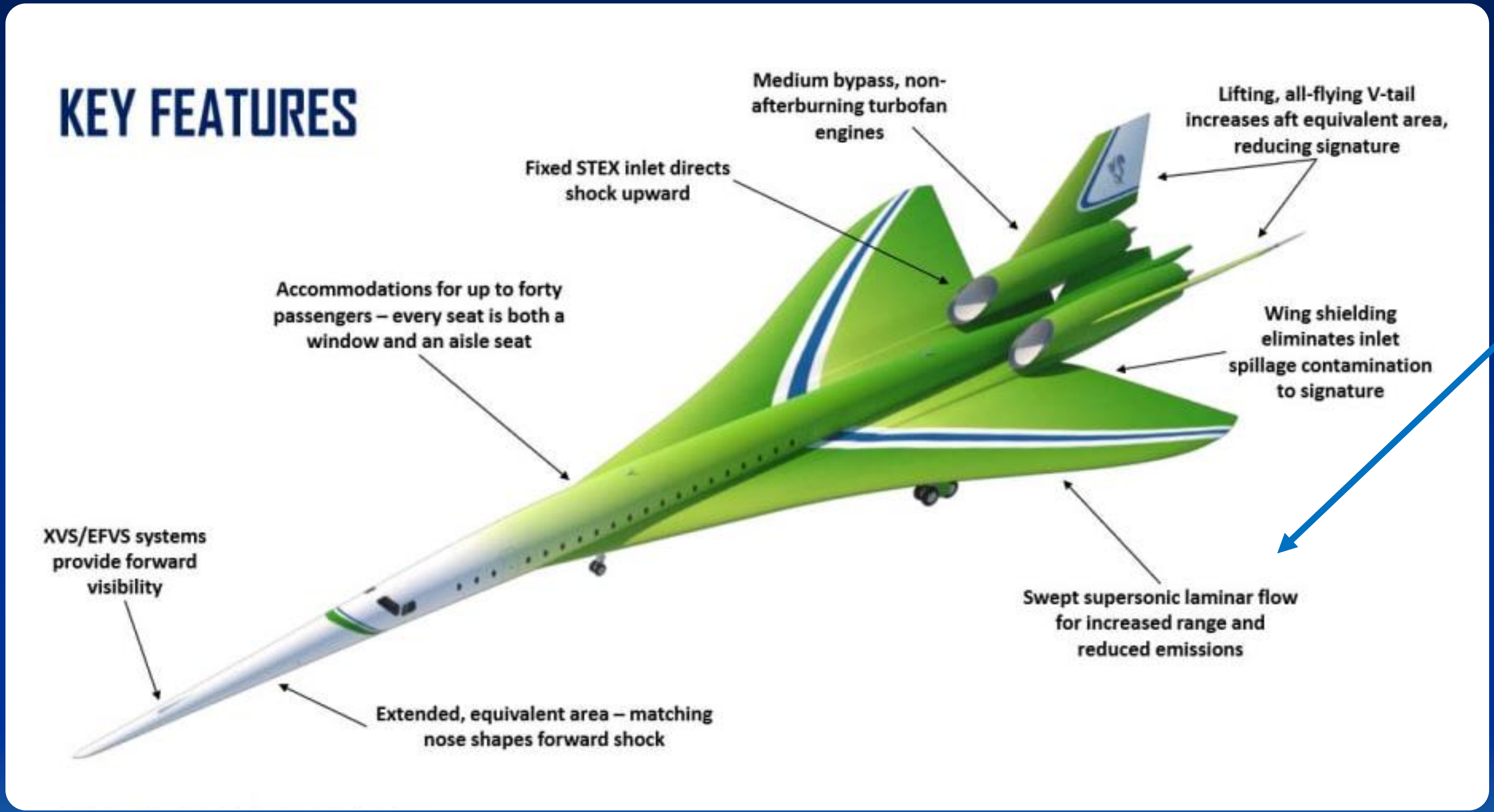
Lockheed Martin 40 pax SST

- M 1.8
- Threshold range = 7780 km (4,200 nmi)
- Goal range = 9820 km (5,300 nmi)
- TOFL = 3,200 m (10,500 ft)
- Length = 69 m (225 ft)
- Estimated boom = 75 PLdB* (Concorde boom = 105 PLdB)

* Perceived Loudness in decibels

https://www.lockheedmartin.com

Lockheed Martin 40 pax SST



https://www.lockheedmartin.com/en-us/products/quesst.html

- Difficult to achieve swept wing laminar flow (subject to crossflow vortex instability)
- Must fly at M < 1.2 over land
- Must prove reliability of XVS

Sukhoi – Gulfstream SSBJ

- Russian-US supersonic business jet proposed in early 1990s
- 6-10 pax
- MTOGW 51,800 kg (114,200 lb)
- M_{cr} 2.25
- Range 4,369 km (2,360 nmi) @ M 1.4
- Range 7,403 km (4,000 nmi) @ M 0.9
- Cancelled by 2012

Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design
- First generation SSTs
  - Concorde
  - Tu-144
  - Boeing 2707
- Second Generation Studies
  - Supersonic Cruise Aircraft Research
  - High Speed Civil Transport
  - DARPA Quiet Supersonic Platform
- Future
  - NASA/Lockheed X-59
  - Supersonic Bizjets
  - Supersonic Transport
- Conclusions

Topics

Future

- NASA/Lockheed X-59
- Supersonic Bizjets
- Supersonic Transports

Supersonic Flight Banned for Civil Ops.

14 CFR § 91.817 – Civil Aircraft Sonic Boom

14 CFR § 91 is Title 14 of the Code of Federal Regulations (Aeronautics and Space) Part 91 "General Operating and Flight Rules" (§ 91.817 enacted 1972)

§ 91.817 Civil aircraft sonic boom.

(a) No person may operate a civil aircraft in the United States at a true flight Mach number greater than 1 except in compliance with conditions and limitations in an authorization to exceed Mach 1 issued to the operator under appendix B of this part.

(b) In addition, no person may operate a civil aircraft for which the maximum operating limit speed M_{M0} exceeds a Mach number of 1, to or from an airport in the United States, unless –

(1) Information available to the flight crew includes flight limitations that ensure that flights entering or leaving the United States will not cause a sonic boom to reach the surface within the United States; and

(2) The operator complies with the flight limitations prescribed in paragraph (b)(1) of this section or complies with conditions and limitations in an authorization to exceed Mach 1 issued under appendix B of this part.

Supersonic Ban may be Reconsidered

Supersonic Passenger Flights

Congressional Research Service

https://fas.org/sgp/crs/misc/R45404.pdf

“The FAA Reauthorization Act of 2018 (P.L. 115-254) directs the Federal Aviation Administration (FAA) to take a leadership role in creating federal and international policies, regulations, and standards to certify safe and efficient civil supersonic aircraft operations within U.S. airspace.”

2020-11 FAA response was low-key https://www.faa.gov/newsroom/supersonic-flight

Topics

Future

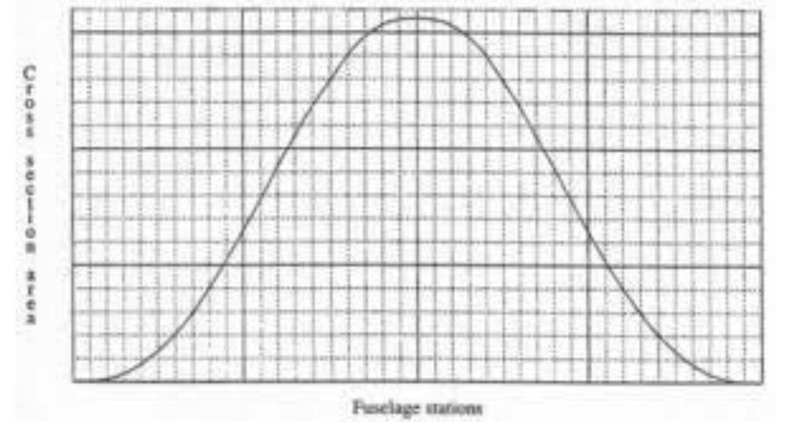
- NASA/Lockheed X-59
- Supersonic Bizjets
- Supersonic Transports

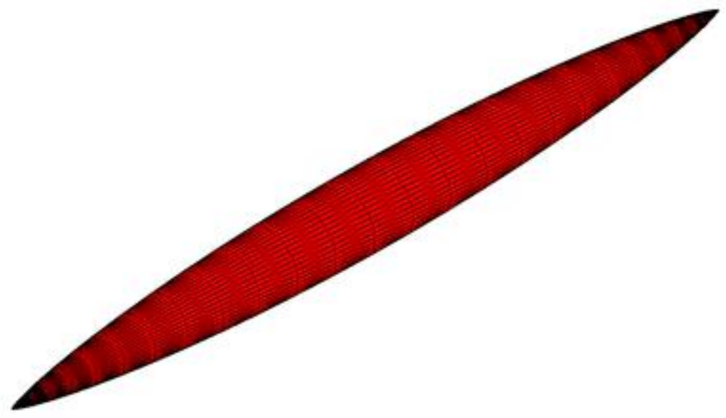
Sears-Haack Body

- Minimum transonic wave drag for given volume
- For Sears-Haack body:

$$\left(\frac{D}{q}\right)_{wave} = \frac{9\pi}{2}\left(\frac{A_{max}}{L}\right)^2$$

where A_{max} = max x/s area
L = overall length





Lockheed Martin X-59 QueSST

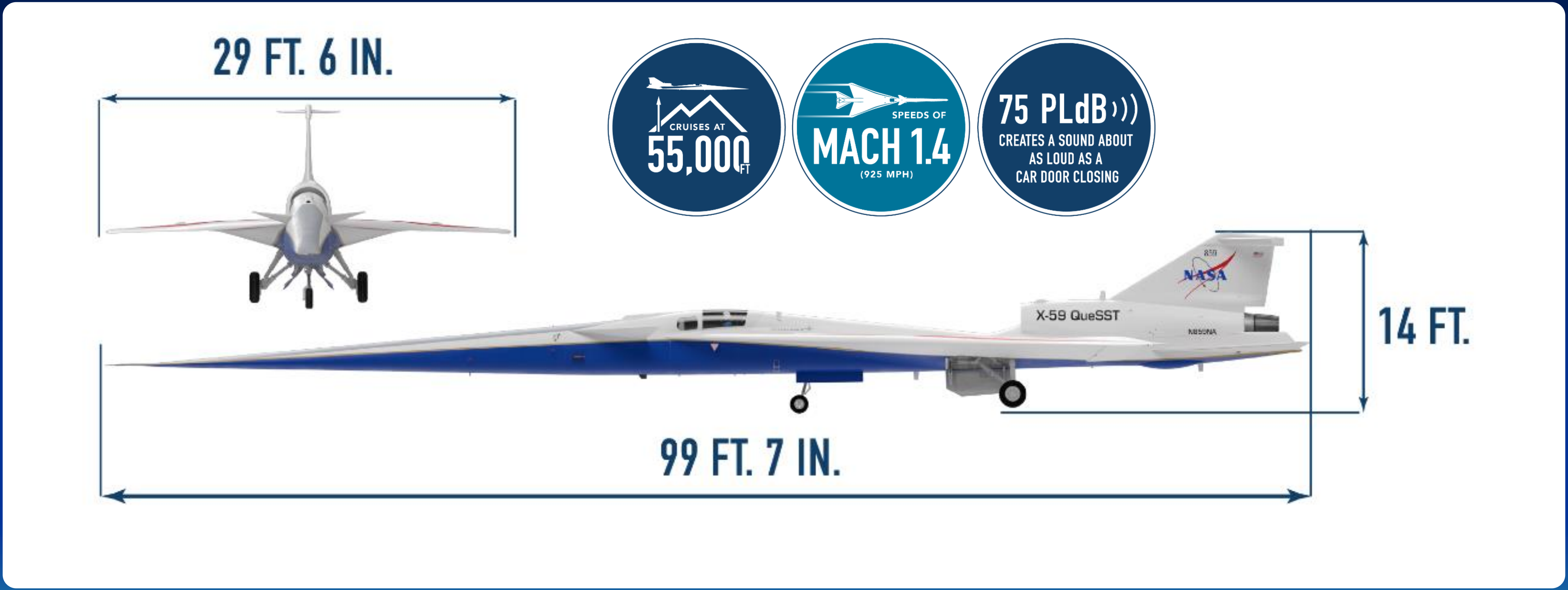
https://www.lockheedmartin.com/en-us/products/quesst.html

2018 LM awarded contract to design, build and fly Low Boom Flight Demonstrator (LBFD)

2021-22 planned first flight (now 2023 first flight)

2023 planned operational

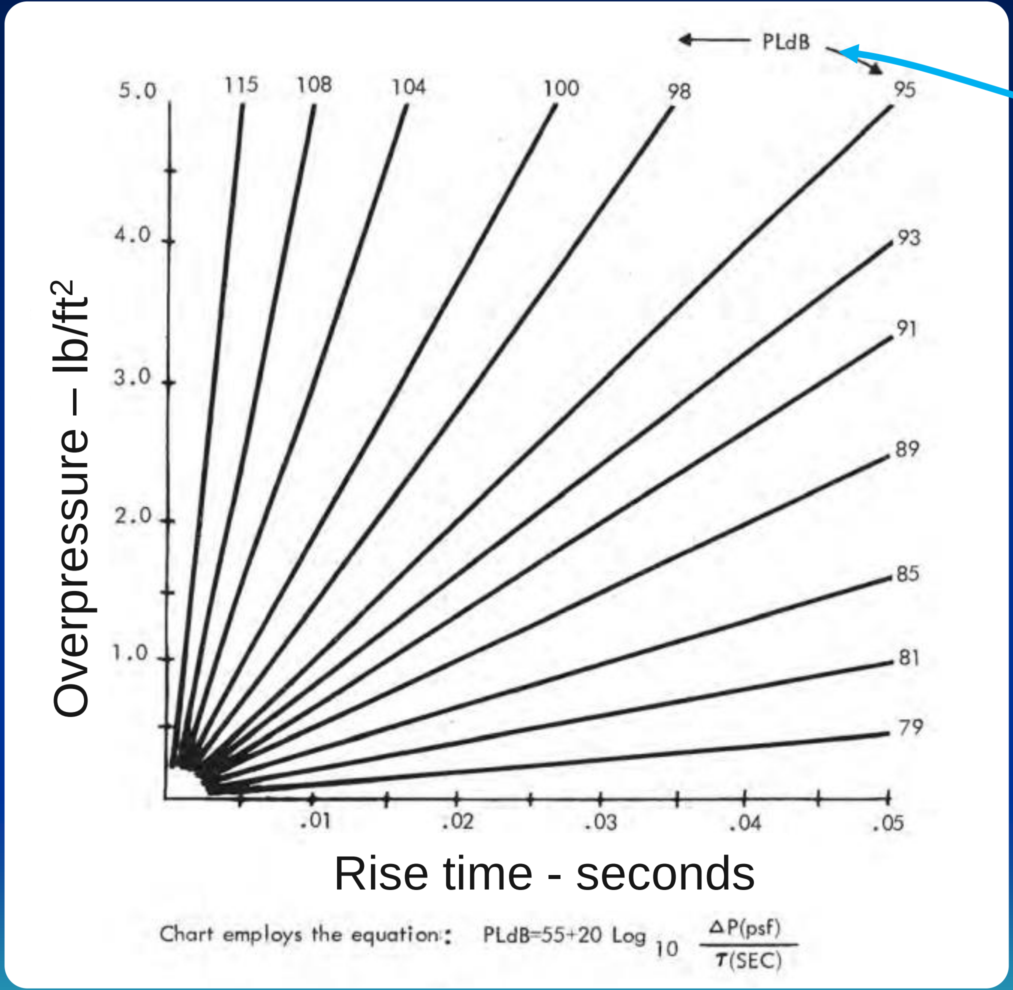
Lockheed Martin X-59 QueSST



https://www.lockheedmartin.com/en-us/products/quesst.html

For reference: Length of 737-100: 94 ft   Seats: 100

Perceived Loudness in dB (PLdB)



https://www.tc.faa.gov/its/worldpac/techrpt/rd73-116.pdf

$$PLdB = 55 + 20\ Log_{10} \frac{\Delta P\,(psf)}{\tau\ (SEC)}$$

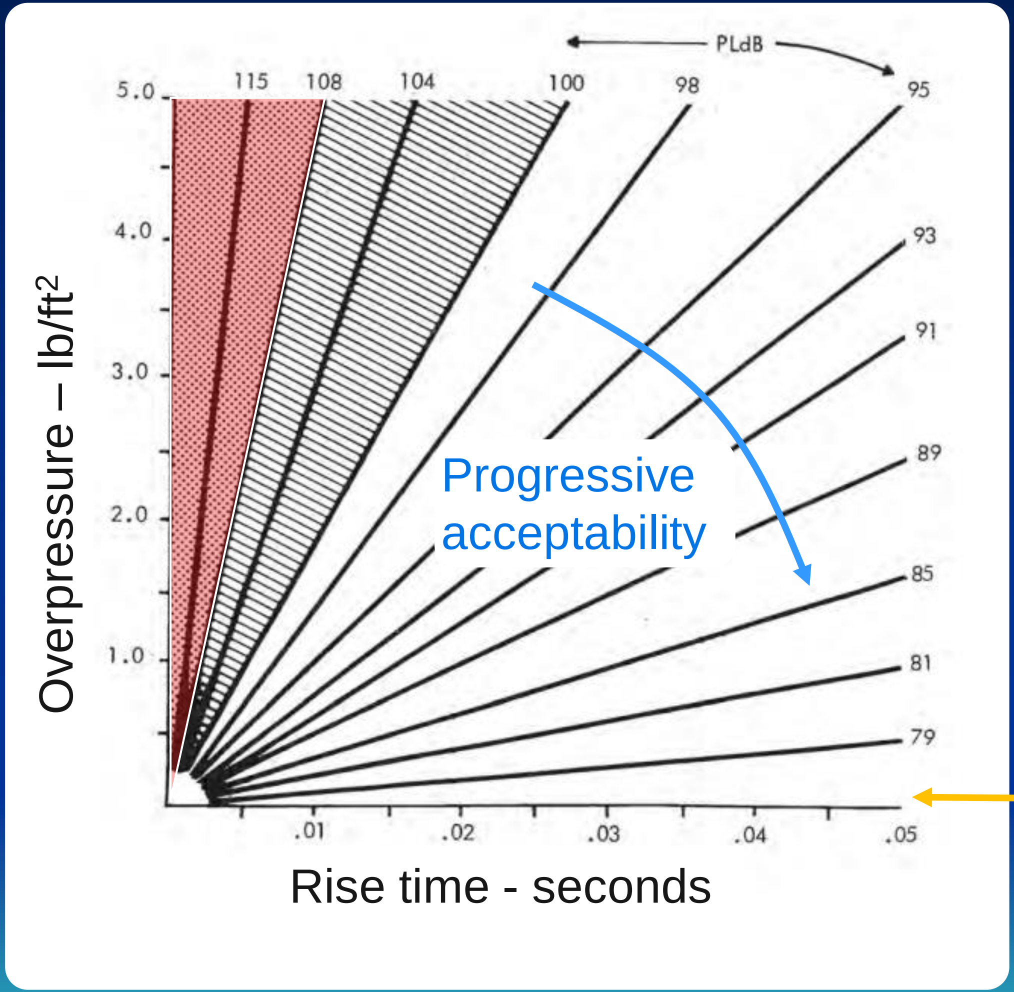
ΔP = overpressure

τ = rise time

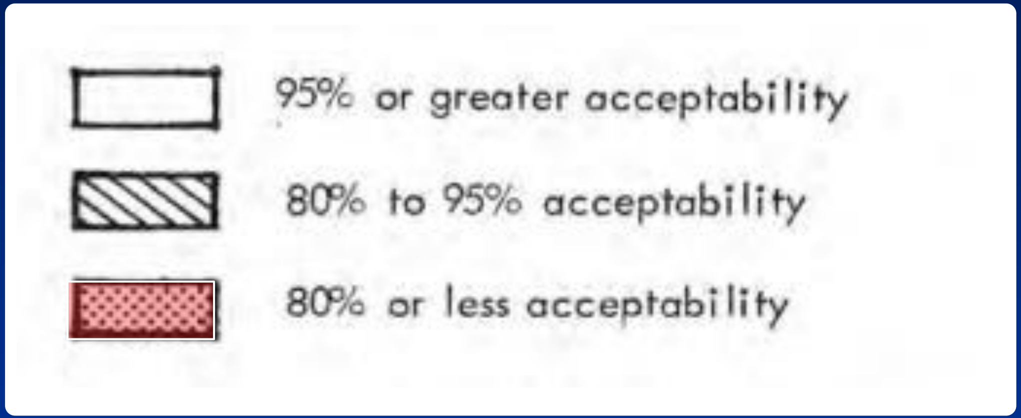
Perceived Loudness in dB is a measure of perceived loudness of a sonic boom

It is different from Perceived Noise in dB (PNdB) in that it does not consider frequency distribution of the sound

Perceived Loudness in dB (PLdB)



https://www.tc.faa.gov/its/worldpac/techrpt/rd73-116.pdf



Lockheed claims X-59 PLdB of 75

Lockheed Martin X-59 QueSST

- $247.5 million contract
- Length: 29 m (94 ft)
- Span: 9.0 m (29.5 ft)
- MTOGW: 14,700 kg (32,300 lb)
- M_{max}: 1.5
- M_{cruise}: 1.42 at 55,000 ft
- Enhanced Flight Vision System
- Sonic boom equivalent to closing car door

https://www.lockheedmartin.com/en-us/products/quesst.html

Lockheed Martin X-59 QueSST

- Engine: GE F414 as installed in F/A-18E/F
- Cockpit, ejection seat and canopy from Northrop T-38 Talon
- Landing gear from F-16 Falcon

https://www.lockheedmartin.com/en-us/products/quesst.html

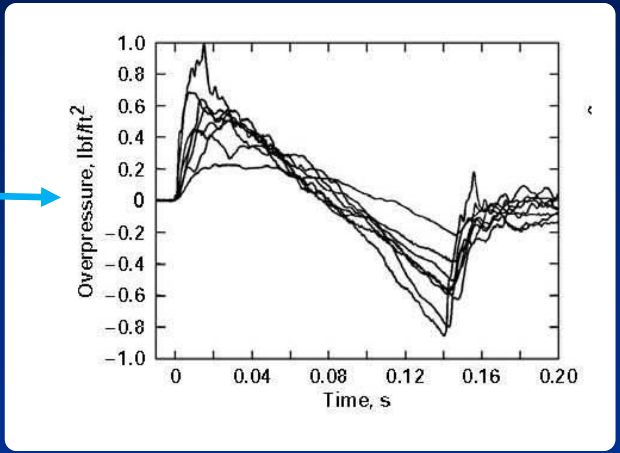
Lockheed Martin X-59 Cockpit

- External vision system (XVS) Conformal Display
- Enhanced vision system camera (EVS) located under nose
- Twin Collins Pro Line Fusion displays

Source AWST

Softening the N-wave

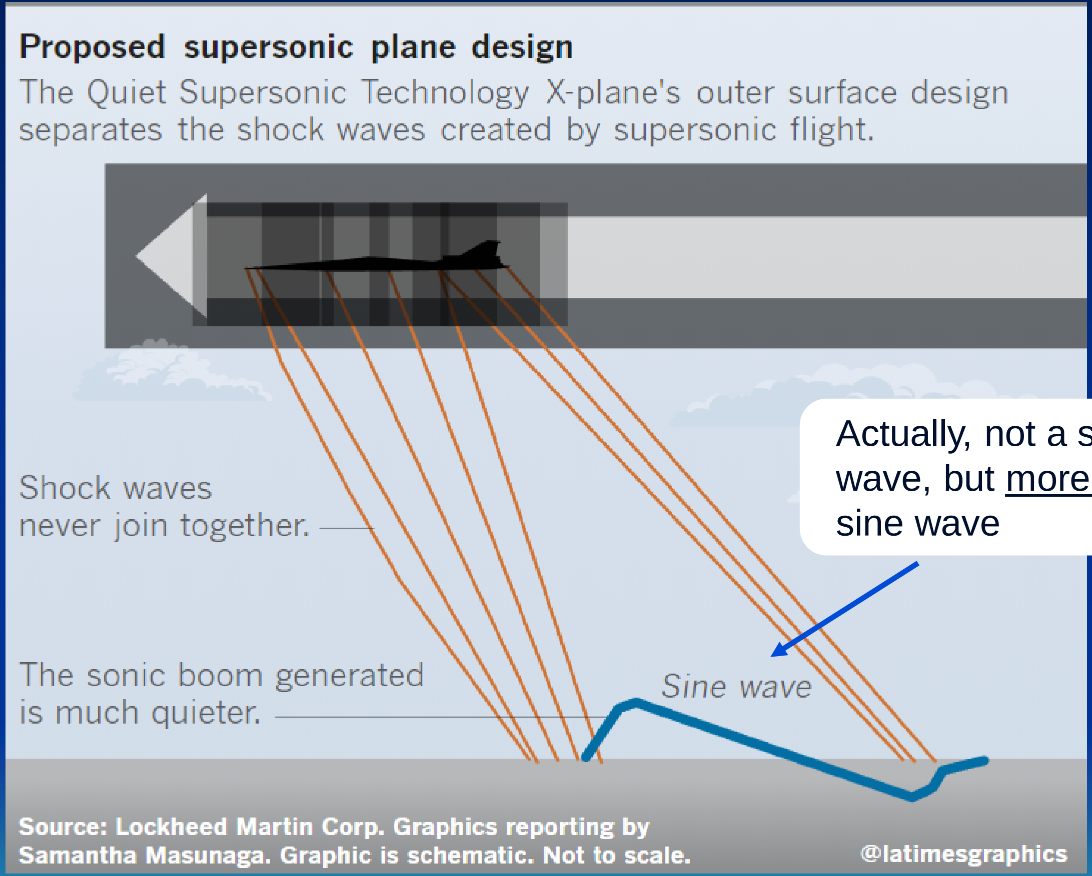
Instead of sonic boom N-wave



Hearing, E.A., et al.,Flight Demonstration Of Low Overpressure N-Wave Sonic Booms And Evanescent Waves

F/A-18B Sonic Boom

Acoustic energy is spread over a longer rise time, reducing total pressure rise and startle effect

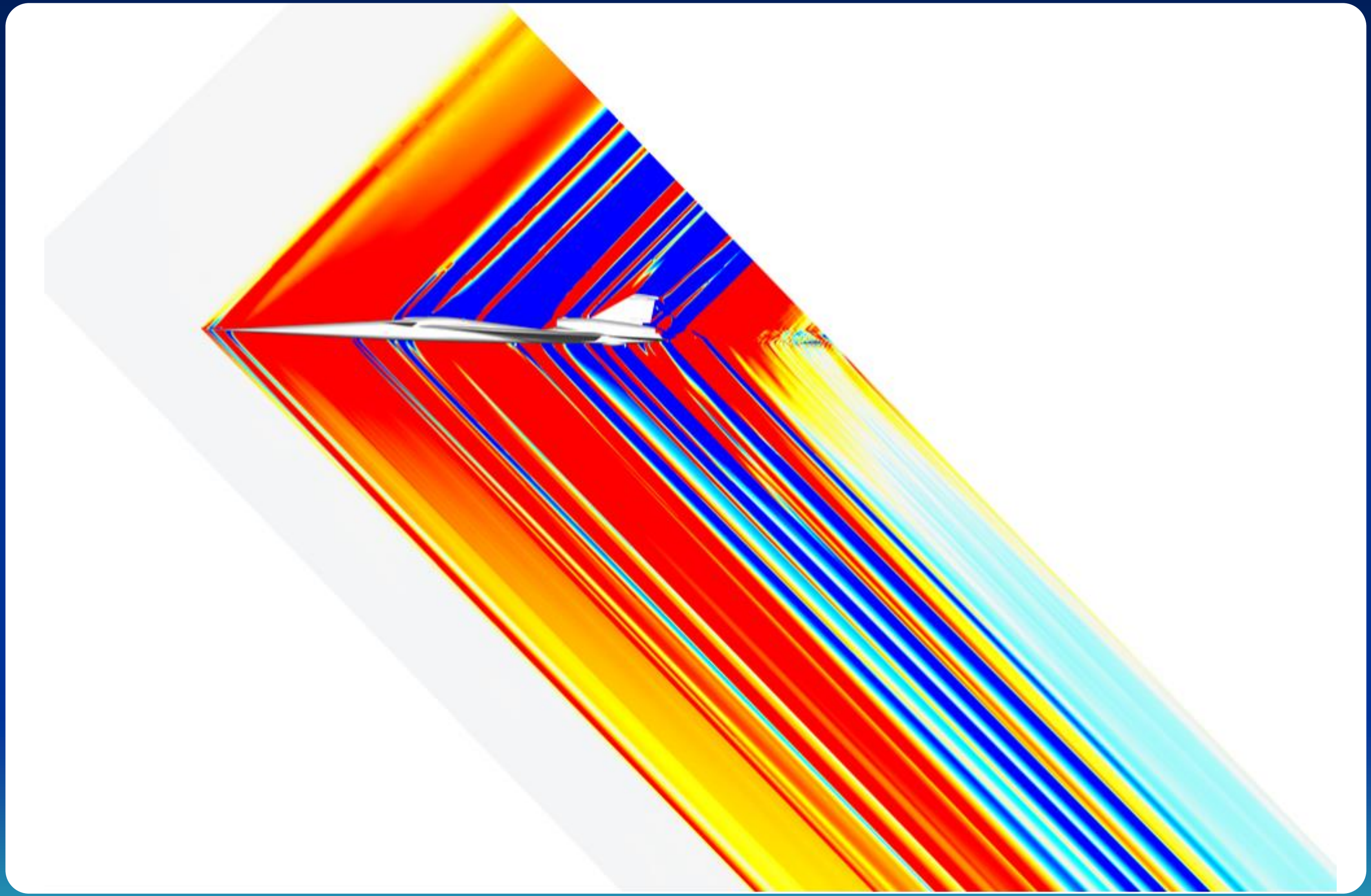


Actually, not a sine wave, but more like a sine wave

https://www.lockheedmartin.com/en-us/products/quesst.html

Lockheed Martin X-59 Shock Prediction

- Generated at NASA Ames Advanced Supercomputing Facility using Cart3D inviscid flow analysis package



https://www.nasa.gov/aeroresearch/supercomputers-aid-quesst-researchers-in-predicting-x-59s-sound

Lockheed Martin X-59 QueSST

Vortex generators required to keep flow attached at aft end of canopy

https://www.lockheedmartin.com/en-us/products/quesst.html

X-59 Current Status

https://www.lockheedmartin.com/en-us/products/quesst.html

Topics

Future

- NASA/Lockheed X-59
- Supersonic Bizjets (< 40 pax)
- Supersonic Transports

Great Circle Distances (nmi)

	PEK	HKG	**LHR**	JFK	SDU	SFO	SIN	SYD	**NRT**
Beijing (PEK)		1042	4420	5958	9361	5150	2395	4817	1134
Hong Kong (HKG)	1042		5207	7001	9556	5998	1395	3983	1552
London (LHR)	4420	5207		2991	4995	4652	5871	9188	5874
New York (JFK)	5958	7001	2991		4172	2241	8283	8647	5874
Rio de Janeiro (SDU)	9361	9556	4995	4172		8937	8498	7302	10027
San Francisco (SFO)	5150	5998	4652	2241	8937		7338	6453	4476
Singapore (SIN)	2395	1395	5871	8283	8498	7338		3401	2864
Sydney (SYD)	4817	3983	9188	8647	7302	6453	3401		4219
Tokyo (NRT)	1134	1552	5179	5874	10027	4476	2864	4219	

Minimum range requirements for transoceanic operations

Aerion AS-2 (pre 2020-04)

- Earlier teamed with Airbus then Lockheed Martin for design

- On 2019-02-05 Boeing announced “significant investment” in program
  - Gained 2 of 5 seats on Board of Directors

- 12 pax
- SuperCruise: M 1.6
- Boomless Cruise: M 1.1-1.2
- Long range cruise: M 0.95
- Range: 4,750 nmi
- TOGW: 60,328 kg (133,000 lb)
- First flight 2023

https://www.architecturaldigest.com/story/worlds-first-supersonic-private-jet-being-built

Dr. Richard Tracy

Dr. Richard R. Tracy serves as Chief Technology Officer of Aerion Corporation. Dr. Tracy developed the natural laminar flow supersonic wing, and conducted research on its capabilities privately and under subsequent DARPA grants. He worked on both civil aircraft and defense programs, including the Global Hawk and the single-stage-to-orbit X-30. He led the initial design on the Learstar 600 for Bill Lear, later produced as the Canadair Challenger. He serves as Director of Aerion Corporation. Dr. Tracy holds B.S., M.S. and Ph.D. degrees from Caltech, the latter in Hypersonic Aerodynamics.

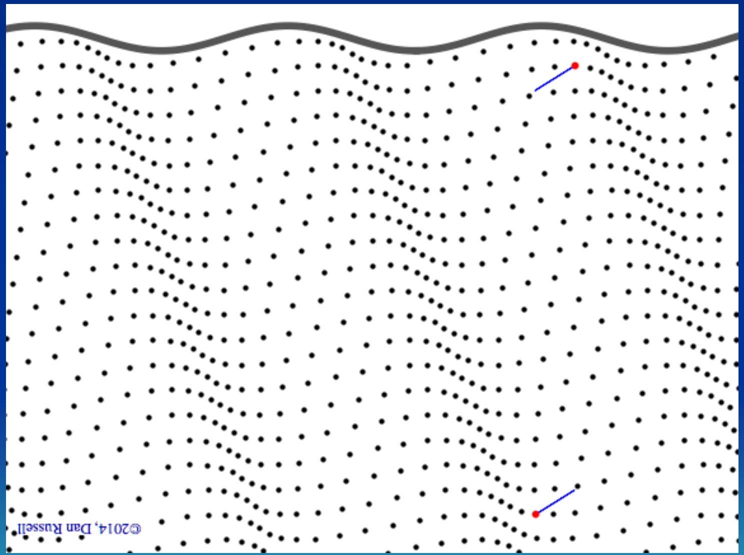
Aerion AS-2

- Flexjet is launch customer with 20 aircraft
  - List price $120 million for 12 pax model
- Range: @ M 1.6 – 8,800 km (4,750 nmi)
- @ M 0.95 - 10,000 km (5,400 nmi)

Source: Aerion

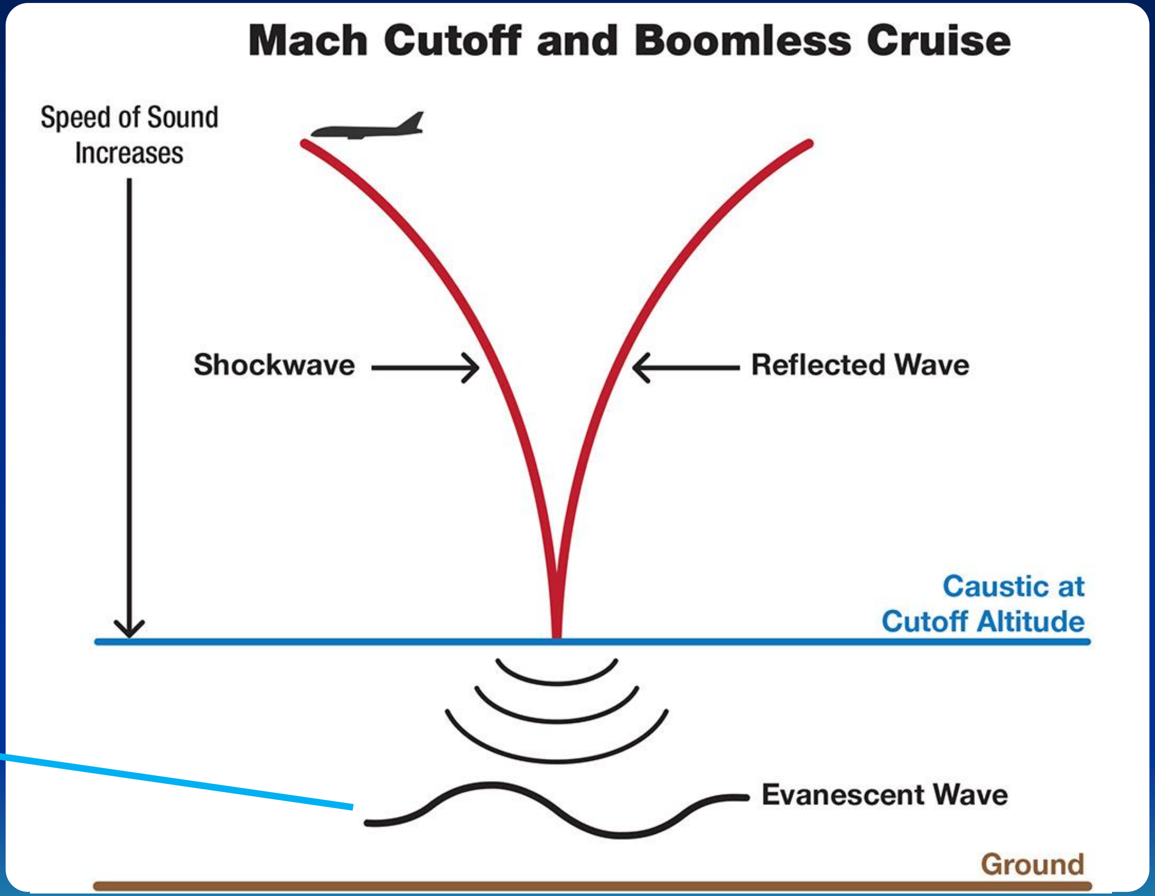
Aerion AS-2 Boomless Cruise

- Conditions shown here are for standard atmosphere
- Even then, boomless cruise probably only feasible for M<1.15



https://www.acs.psu.edu/drussell/Demos/EvanescentWaves/EvanescentWaves.html

©2014 Dan Russell



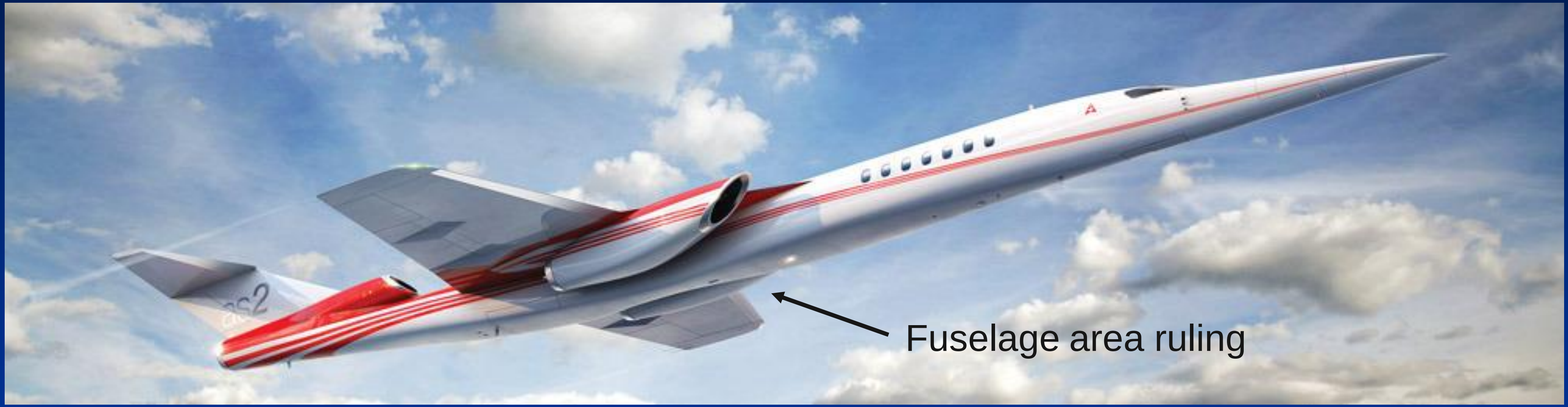
Aerion.com

Aerion AS-2 (Pre 2020-04)

- Laminar flow wing
- Fuel must go in fuselage
- All crew and payload (except bags) forward of c.g.

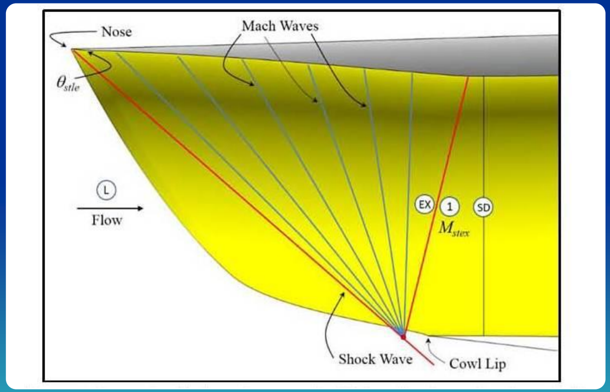
https://www.designlisticle.com/the-aerion-as2-the-supersonic-renaissance-airplane/

Aerion AS-2 (Pre 2020-04)



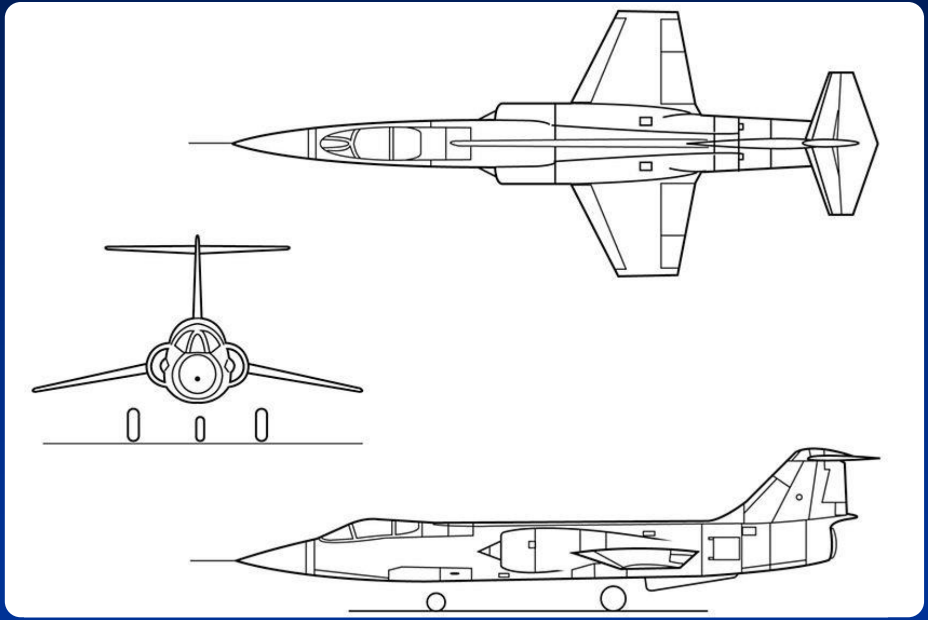
https://robbreport.com/motors/aviation/aerion-as2-could-become-worlds-first-supersonic-private-jet-eg18-2808106/

- Inlets designed using streamline traced external (STEX) method
- Lower external wave drag (higher L/D)

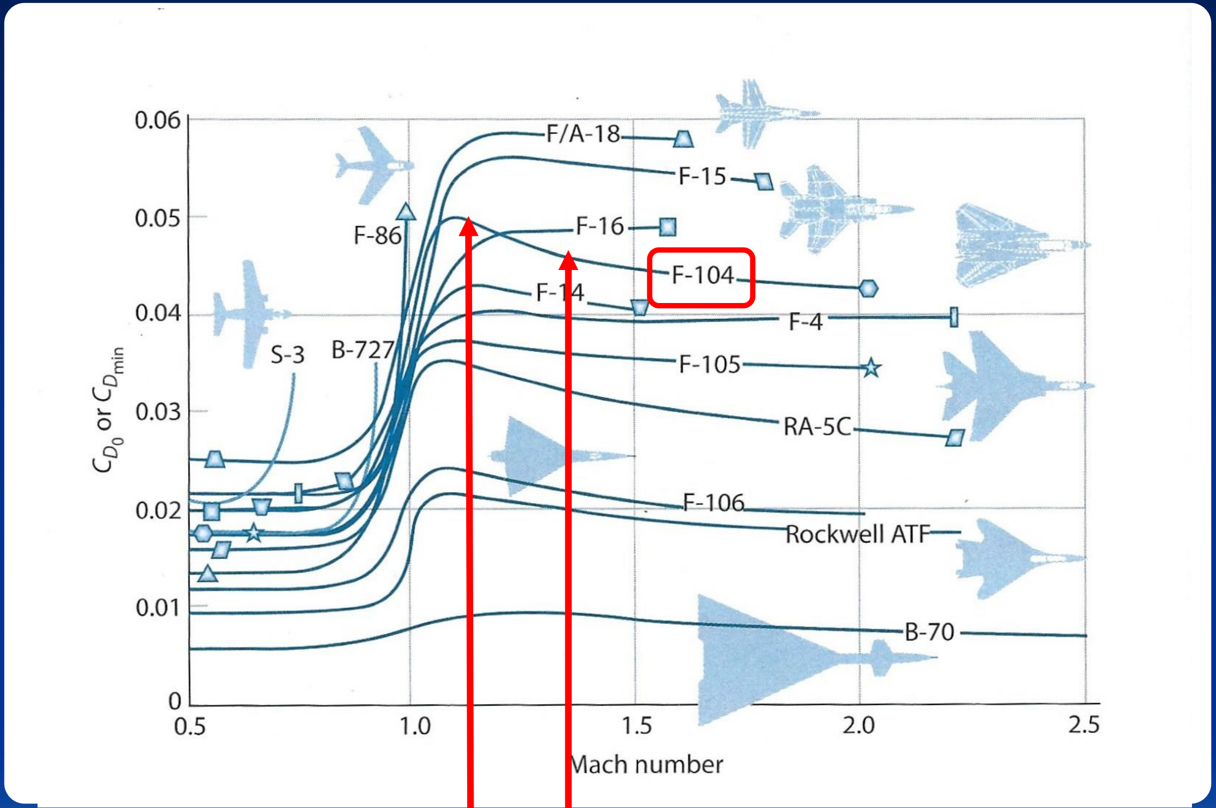


Slater, J.W.* " Enhanced Performance of Streamline-Traced External-Compression Supersonic Inlets" ISABE-2015-20140

Zero-Lift Wave Drag



https://commons.wikimedia.org/wiki/File:F-104_3-view.jpg



Boomless Cruise

Supercruise

© Raymer Fig. 12.34

ADAC Aircraft Design & Consulting

Aerion AS-2 Revised Design

- TOGW: 139,000 lb
- Range: 4,200 nmi (i.e. SEA-NRT)
- M_{cruise} : 1.4
- Modified cranked arrow planform
- Wing trailing edge:
  - Inboard: high-speed flaperons
  - Midspan: flaps
  - Outboard: low speed ailerons
- Wing leading edge
  - Outboard of nacelles: l.e. flaps
- External compression axi-symmetric inlets

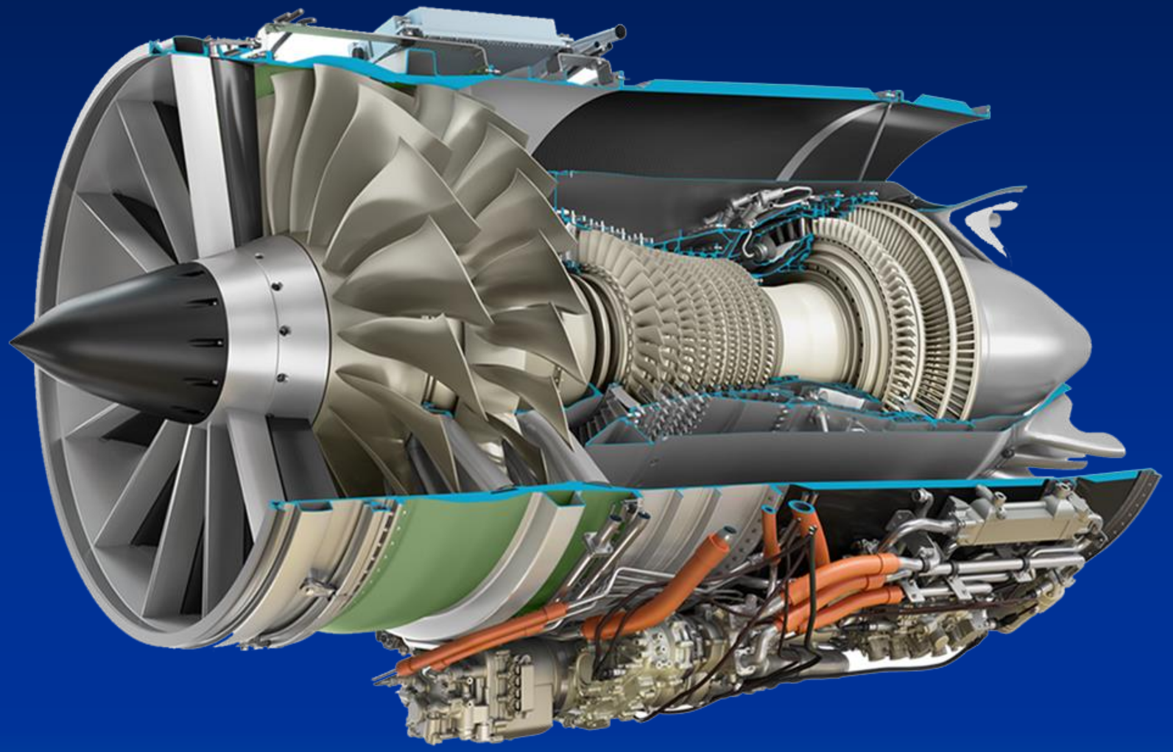
https://privatejetcardcomparisons.com/aerion-as2-supersonic-private-jet-2/#:~:text=The%20supersonic%20AS2%20promises%20a,in%20orders%20for%20the%20AS2
.

https://aviationweek.com/business-aviation/aerion-unveils-major-updates-as2-supersonic-business-jet-design

Aerion AS-2 Revised Design

GE Affinity engine for Aerion AS-2

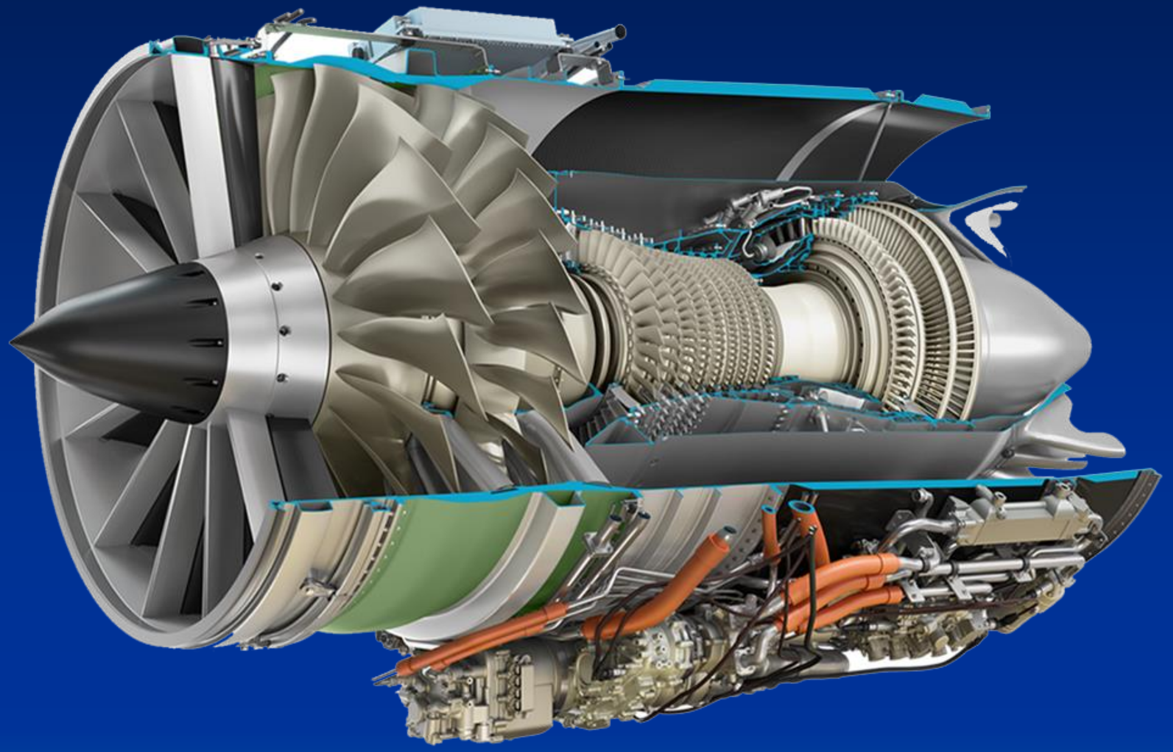
- Core from CFM56
- 2 fan stages, 9 HP compressor stages
- Turbine: 1 HP, 2 LP stages
- Max thrust: 80 kN (18,000 lb) SLS
- Cruise thrust: 16 kN (3,500 lb)
- BPR: ~ 3:1
- Fan PR: 2.8
- HP compressor PR: ~ 10
- Designed to meet FAR 36 Stage 5



https://www.architecturaldigest.com/story/worlds-first-supersonic-private-jet-being-built

GE Affinity engine for Aerion AS-2

- New configuration required modified engine design
- 2021-05-24 GE decides not to provide additional funding for engine development



https://www.architecturaldigest.com/story/worlds-first-supersonic-private-jet-being-built

Aerion Program Shuts Down

2021-05-24

> *"The AS2 supersonic business jet program meets all market, technical, regulatory and sustainability requirements, and the market for a new supersonic segment of general aviation has been validated with $11.2 billion in sales backlog for the AS2.*
>
> *"However, in the current financial environment, it has proven hugely challenging to close on the scheduled and necessary large new capital requirements to finalize the transition of the AS2 into production.*
>
> *"Given these conditions, the Aerion Corporation is now taking the appropriate steps in consideration of this ongoing financial environment."*

https://mentourpilot.com/aerion-supersonic-shutting-down-company-operations/

Spike Aerospace S-512

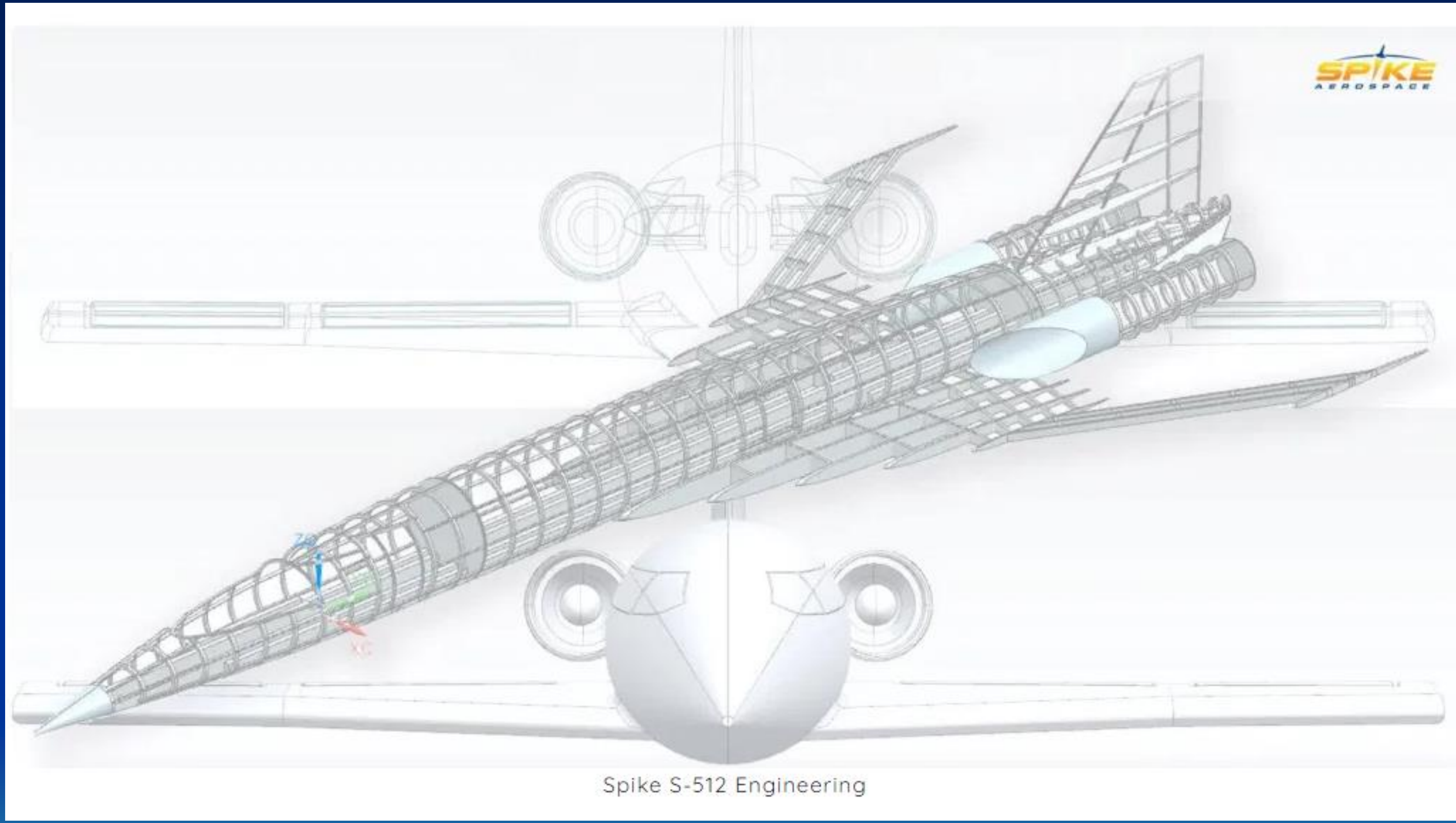
- Cruise Mach: 1.6
- Pax: 12-18
- MTOGW: 52,163 kg (115,000 lb)
- Engines: 2 x 88.9 kN (20,000 lb)
- Range: 11,482 km (6,200 nmi)
- Cruise alt: 15,240 m (50,000 ft)
- TOFL: 1,828 m (6,000 ft)
- Price: ~ $100 million

Highly unlikely

https://www.spikeaerospace.com/supersonic-aircraft-rd-efforts-heating-up/

Spike Aerospace S-512

- Unlikely to achieve field length of 6,000 ft without flaps (and ability to trim)
- “Quiet Supersonic Flight” claim of being able to operate at M 1.6 without supersonic boom is unproven
- Would need engine optimized for M 1.6 cruise



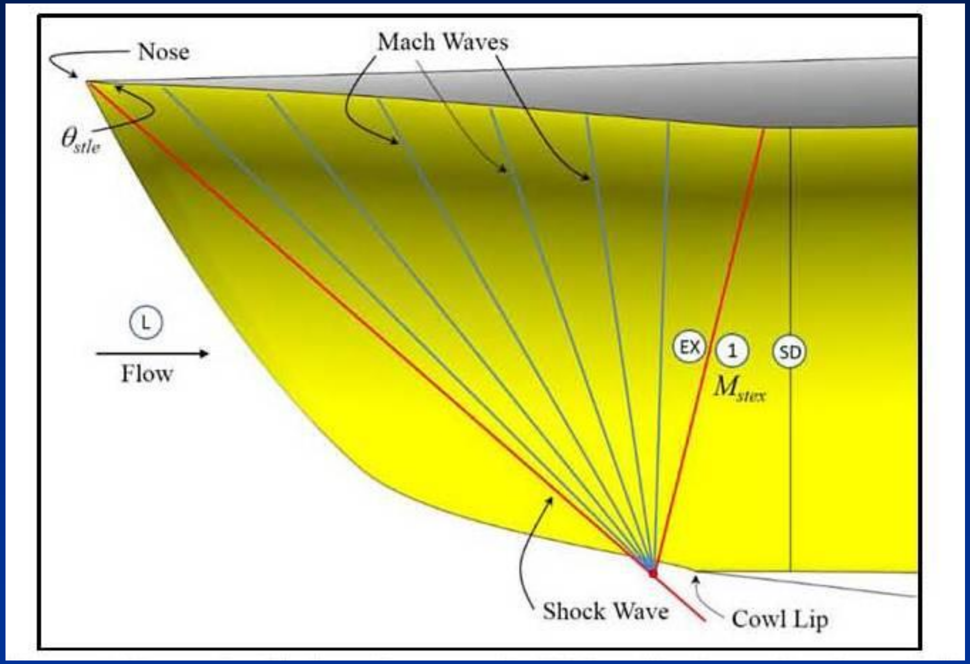
https://www.spikeaerospace.com/s-512-supersonic-jet/specifications-performance/

Spike Aerospace S-512

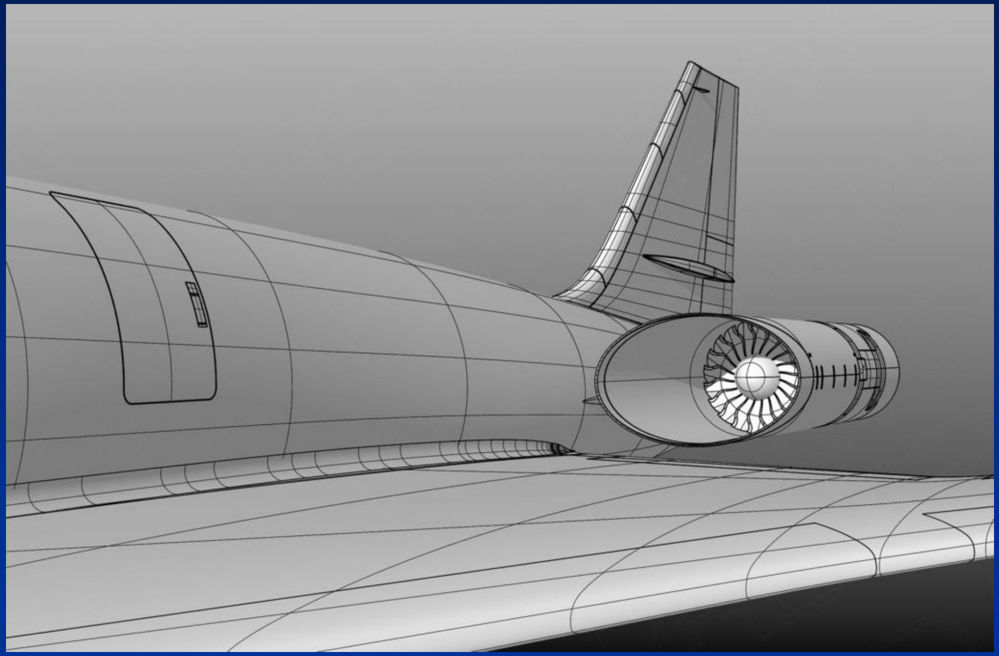
- Synthetic exterior display

http://www.spikeaerospace.com/spike-images/

Spike Aerospace S-512 STEX Inlet



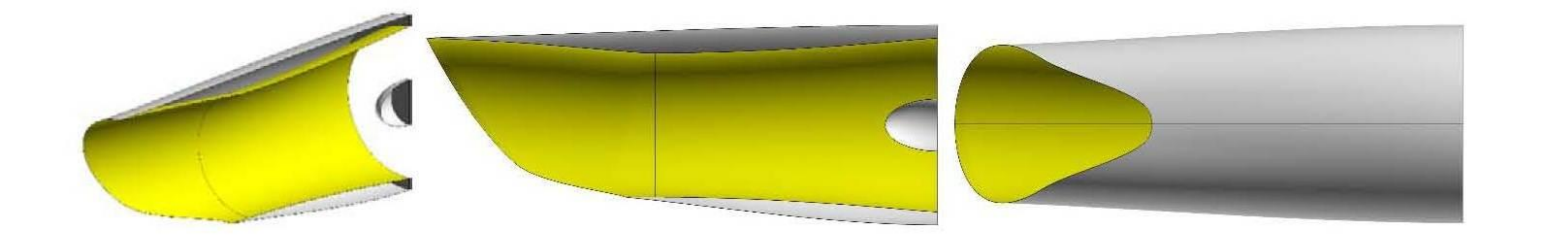
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160010068.pdf
Slater, J.W., “SUPIN: A Computational Tool for Supersonic Inlet Design”



https://www.spikeaerospace.com/spike-aerospace-evaluating-engines-for-supersonic-jet-with-two-major-suppliers/

Supersonic diffuser for streamline traced external (STEX) inlet using SUPIN (SUPersonic INlet design and analysis tool)

STEX Inlet for M 1.6 Design

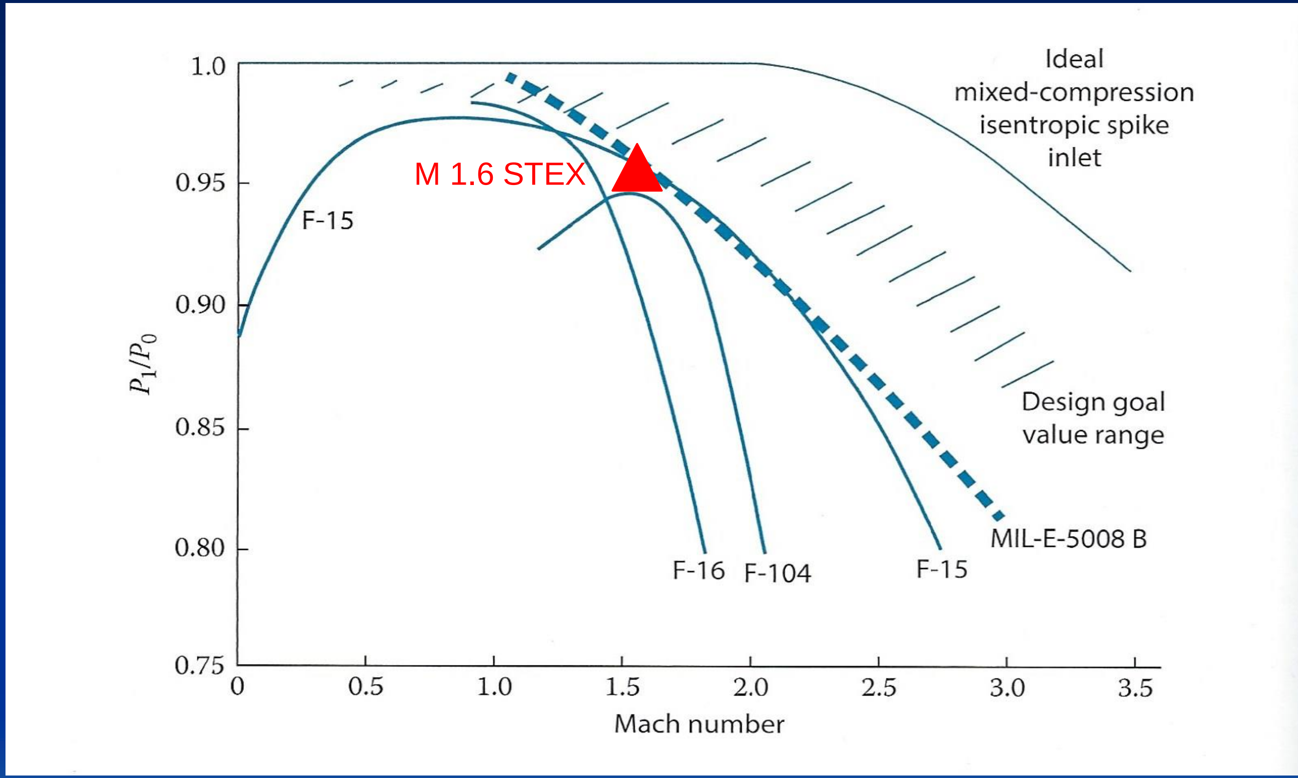


https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160010068.pdf
Slater, J.W., "SUPIN: A Computational Tool for Supersonic Inlet Design"

Comparison of Different Inlet Types

- M 1.6 STEX inlet shown at 98% inlet flow ratio

P_o = freestream total pressure
P_1 = fan/compressor face total pressure



Raymer Fig. 13.6 modified

Dr. Shreekant Agrawal

Dr. Shreekant Agrawal – Head of Engineering Strategy

- 29 years at the Boeing Company
  - technical fellow in 1996 from Boeing Research & Technology Flight Sciences
  - leader of Boeing's High-Speed Aerodynamics Technology group and as IPT leader of the NASA/Industry High Speed Research program

Topics

Future

- NASA/Lockheed X-59
- Supersonic Bizjets
- Supersonic Transports (40+ pax)

Boom Technology SST (old configuration)

https://boomsupersonic.com/

- 55 pax
- Range 4,500 nmi (SFO-NRT)
- Mach 2.2
- Engines in 67-89 kN (15-20,000 lb) thrust class turbofan
- Biz-class airfares
- Options for 10 aircraft from Richard Branson (76 total commitments)

Boom Technology SST

https://www.bbc.com/news/business-41972529

- Use enhanced flight vision system (EFVS) on approach
- Difficult to meet FAR 36 Stage 4 (type certification filed before end of 2017)
- Challenge to meet FAR 25 with high temp composites
- Difficult BL diversion at rear of fuselage, esp. at high α (old configuration, now 4 underwing nacelles)
- Need engine design with HP compression ratio < 7 (current engines ~ 15)

Boom Technology SST (current configuration)

https://techcrunch.com/2022/08/16/american-airlines-to-buy-20-jets-from-boom-supersonic/

- Development cost ~ $6 – 8 billion ← Boom estimate, but note:
  - Concorde development cost about $20 billion (in current dollars)
  - Boeing 787 development cost about $16 billion
- Must amortize development cost over small production run
- Total funding $ 270 million (2023-02)

https://www.seattletimes.com/business/boeing-celebrates-787-delivery-as-programs-costs-top-32-billion/

Boom Overture Interior

https://boomsupersonic.com/overture

https://boomsupersonic.com/overture

- No overhead bins
  - Carry-on bags in underseat storage

- Seat pitch 75”
  - UA A320 first class seat pitch 39”
  - UA 757 Polaris seat pitch 76”

Boom Technology SST Current Configuration

- “UA will purchase 15 aircraft, once Overture meets United’s demanding safety, operating and sustainability requirements, with options for 35 additional aircraft…”

  boomsupersonic.com

- “American Airlines announces agreement to purchase Boom Supersonic Overture aircraft, Places deposit on 20 Overtures” 2022-08-16

  https://news.aa.com/news/news-details/2022/American-Airlines-Announces-Agreement-to-Purchase-Boom-Supersonic-Overture-Aircraft-Places-Deposit-on-20-Overtures-FLT-08

Boom Technology SST (current configuration)

- MTOGW 170,000 lb
- M_{cruise} 1.7
- Pax 65-88
- Range 4,250 nmi

SEA–NRT time: 6 hours (4,144 nmi)
(subsonic time: 10 hours 10 min)

- Price $200 million
- JFK-LHR fare $5,000 (Concorde was $20,000 inflation-adjusted)

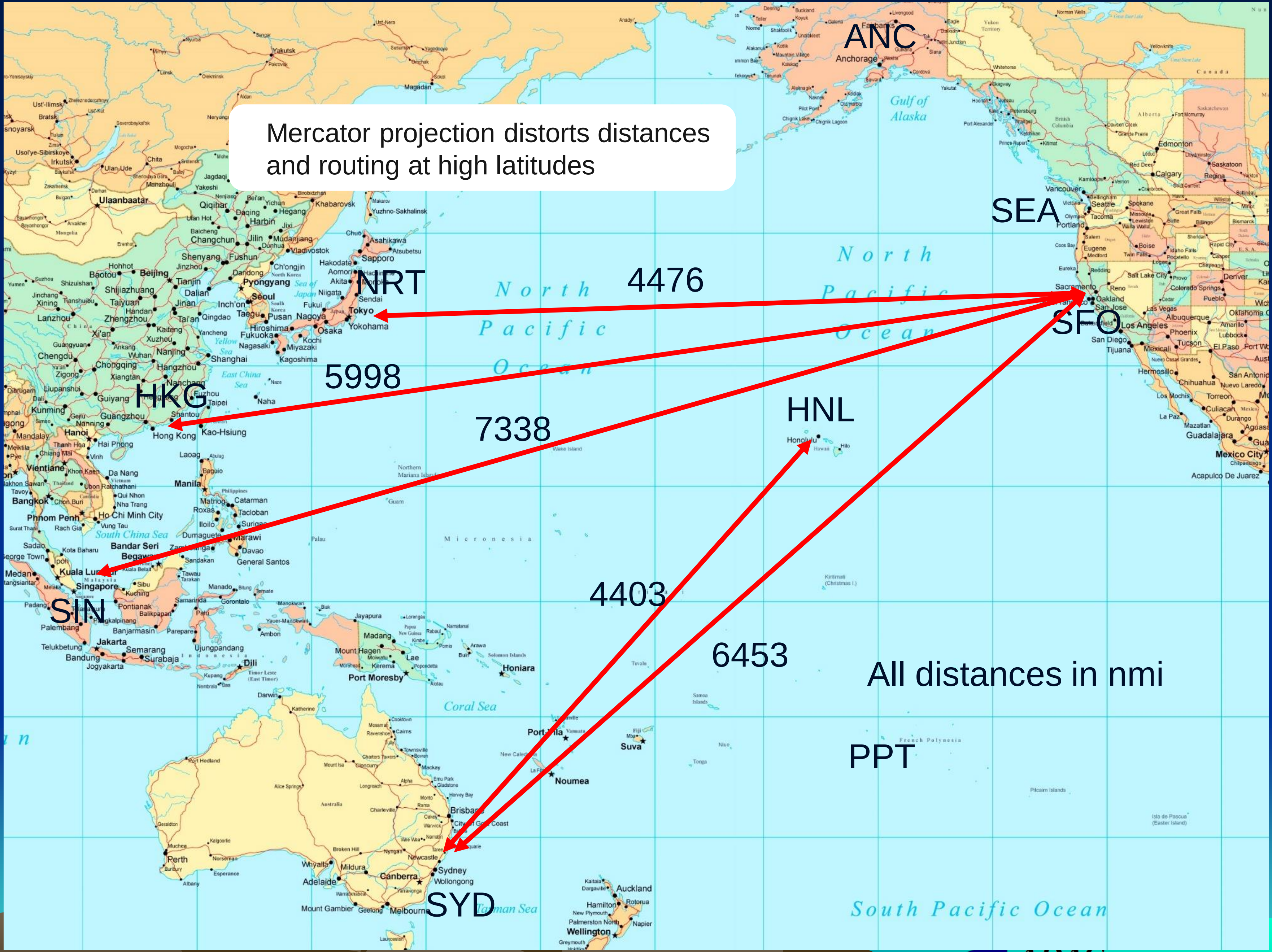
Source: Wikipedia

Can fly SEA-NRT (4,144 nmi), but only AS and DL have hub in SEA

To fly SFO-NRT Overture would typically fly SFO-ANC-NRT

Examples of current subsonic routes that Overture cannot fly

To fly SFO-SYD, Overture could possibly fly SFO-PPT-SYD



Boom Technology XB-1

- 1/3 scale design similar to full-scale
- Range 1,900 km (1,026 nmi)
- Mach 2.2
- TOGW = 6,100 kg (13,500 lb)
- 3 x 19 kN (4,300 lb) J85-15 non A/B
- T/W = 0.96
- Carbon/epoxy structural material by TenCate Advanced Composites
- V/G inlets and nozzles (but note that nacelle design and location are inconsistent with current Overture nacelle design)
- Flight testing begins in 2023

https://time.com/collection/best-inventions-2021/6112684/xb-1-boom-supersonic/

Boom Technology XB-1

https://boomsupersonic.com/

https://boomsupersonic.com/xb-1

Current Overture configuration has axisymmetric inlets

- Ground testing

Boom Loses P&W as Engine Supplier

Boom Supersonic Continues To Search For Engine Manufacturer

P&W says it is "100% focused on current projects."

2022-10-17

BY **LINNEA AHLGREN** PUBLISHED OCT 17, 2022

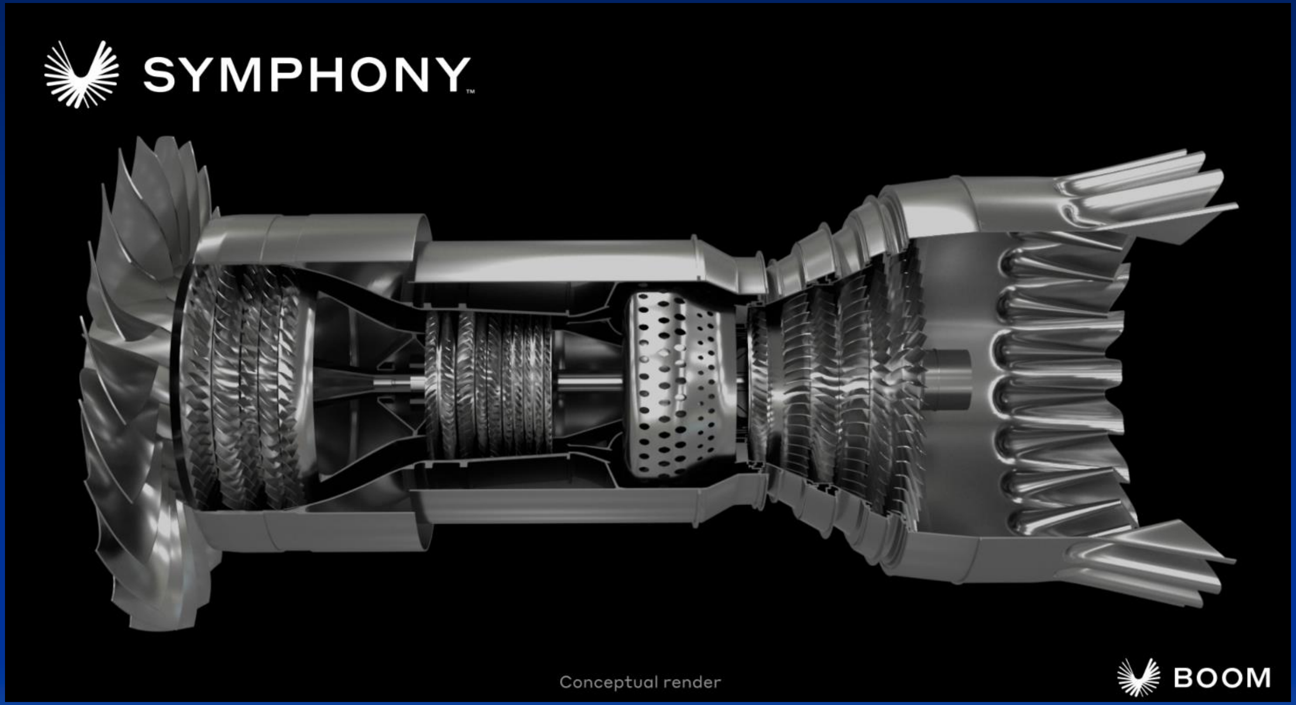
https://simpleflying.com/boom-supersonic-continues-to-search-for-engine-manufacturer/

A nice way of saying that P&W won't support Boom any longer

New Engine Developers

2022-12-13 "Boom Supersonic, the company behind what is touted to be the next supersonic passenger aircraft – Overture – has finally secured an engine maker to deliver the powerplants for its jet."

"Announced today at its Greensboro site, the home of its future manufacturing facilities, Boom revealed plans to work with Florida Turbine Technologies, StandardAero and GE Additive, a unit of GE Aerospace, to develop the engines it needs for the Overture."



https://simpleflying.com/boom-supersonic-engine-makers-overture/

Richard Aboulafia, an aerospace analyst at Teal Group, said he believes that if there were a profitable market for supersonic airliners, Boeing and Airbus would be building them.

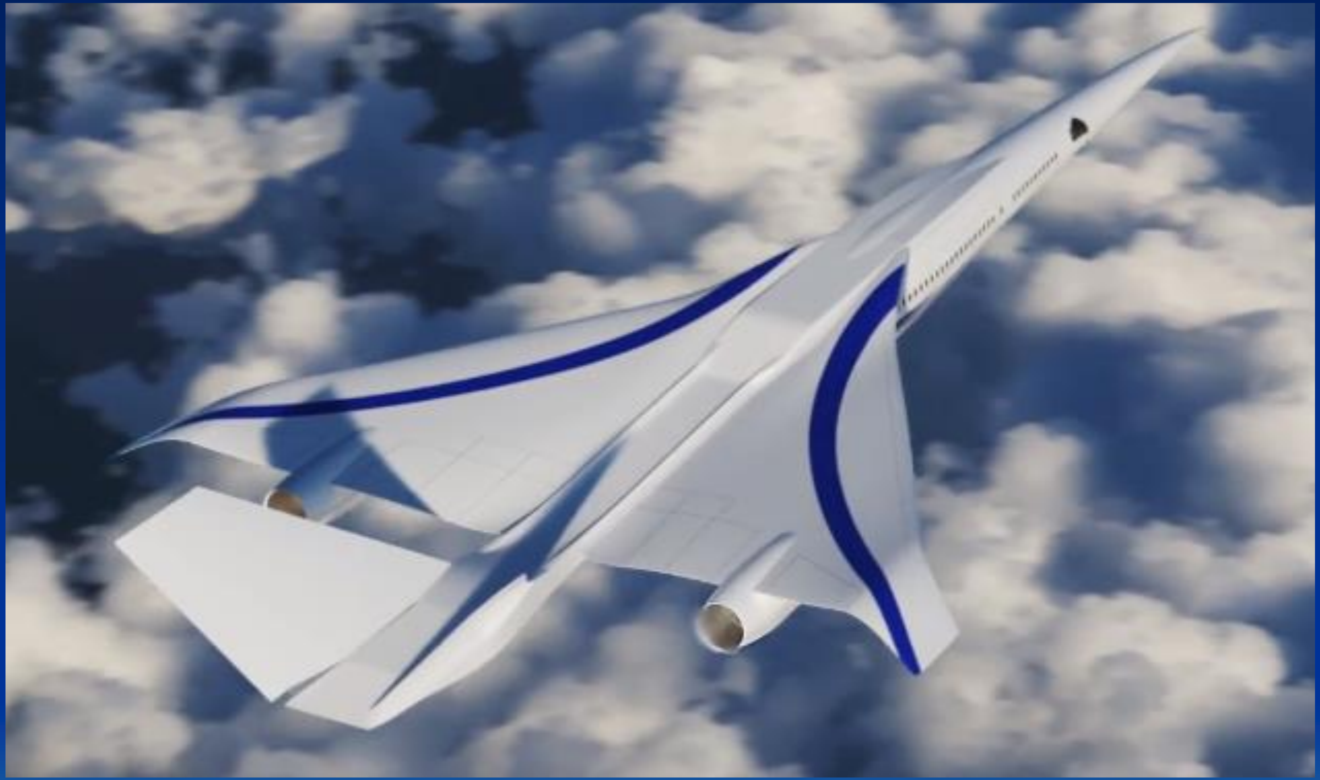
"It tells you that the enormous, established players don't see it," he said. "There is no reason they couldn't do this. There is no secret sauce that Boom keeps in a safe somewhere."

https://www.seattletimes.com/business/united-airlines-sees-a-supersonic-future/

Richard Aboulafia is now Managing Director of AeroDynamic Advisory

Exosonic Airliner/USAF Executive Airlift

- M_{cruise} 1.8
- 50-70 pax
- 5,000 nmi range
- As of 2022-05 has raised $5.5M
- 2-year USAF contract for $1M
- Subscale prototype ~2025
- IOC ~2035



https://exosonic.com/supersonic-jet/

Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design
- First generation SSTs
  - Concorde
  - Tu-144
  - Boeing 2707
- Second Generation Studies
  - Supersonic Cruise Aircraft Research
  - High Speed Civil Transport
- Future
  - NASA/Lockheed X-59
  - Supersonic Bizjets
  - Supersonic Transports
- Conclusions

Conclusions

- Over 60 years of R&D produced two production aircraft types, neither of which could make a profit
- Supersonic cruise at ~ M 2 feasible, but challenges are
  - Economics
  - Sonic boom
- Physics of sonic boom generation suggests that significant reduction of subjective boom effect is very difficult for $M_{cruise} > 1.2$
- Currently US overland flight illegal for $M_{cruise} > 1$ (but law can be changed)
  - Small market for overwater routes only, unless range > 4,500 nmi
- Currently no supersonic civil aircraft likely to go into production

AIAA
Shaping the Future of Aerospace
Orange County Section

Thanks for your interest

An expanded and annotated pdf of this presentation is available
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