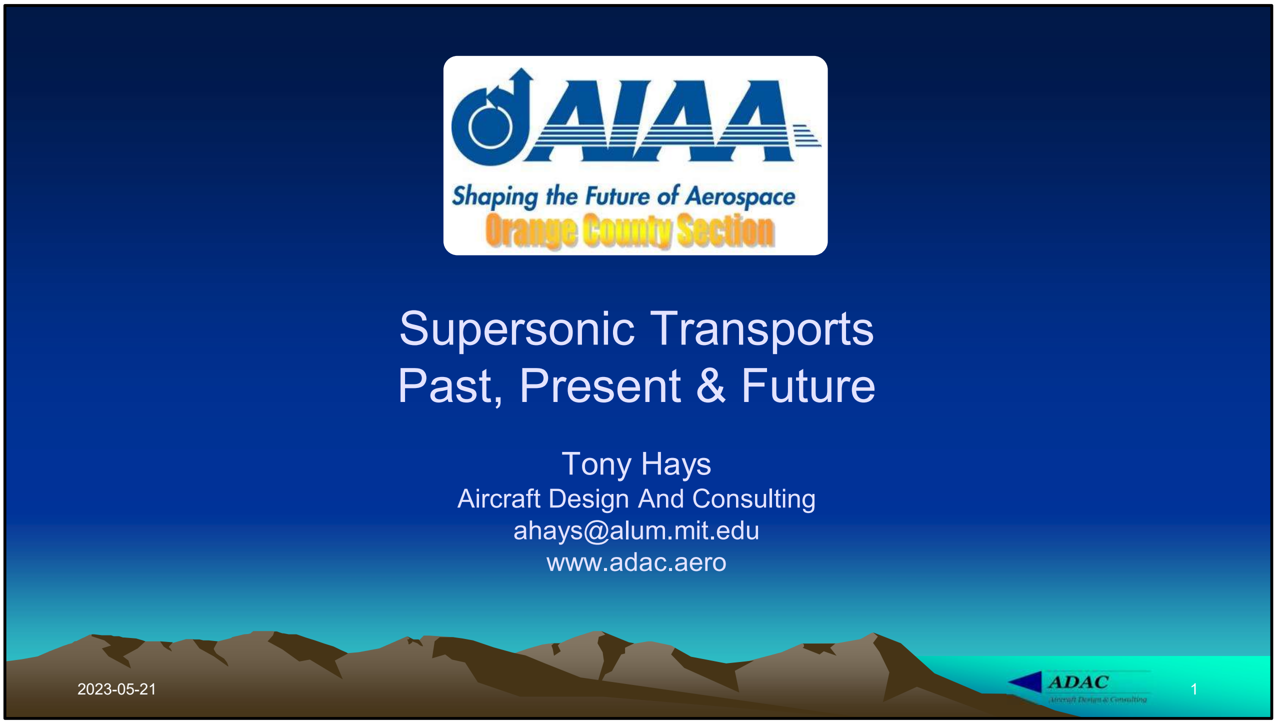


The US is the only country that shows dates as MM-DD-YYYY. This presentation shows dates in ISO 8601 format, which is YYYY-MM-DD

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

Summary of topics to be covered.

Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design

Topics

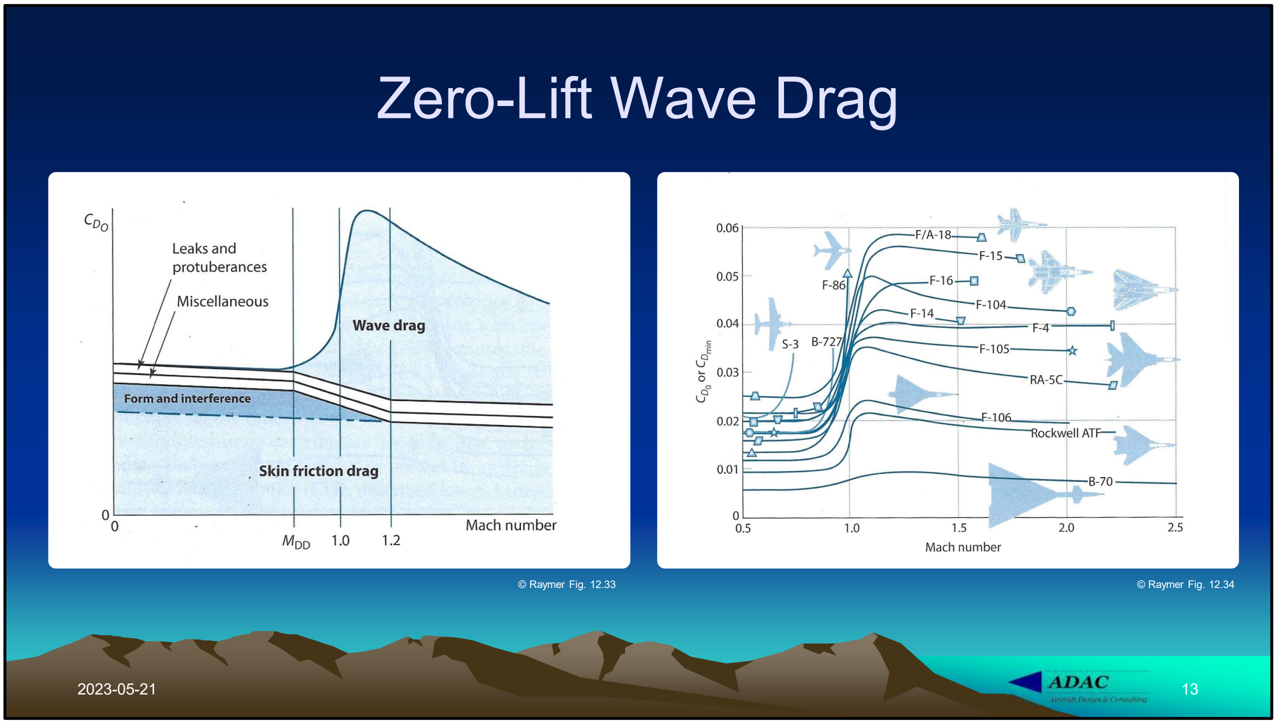
- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design

Topics

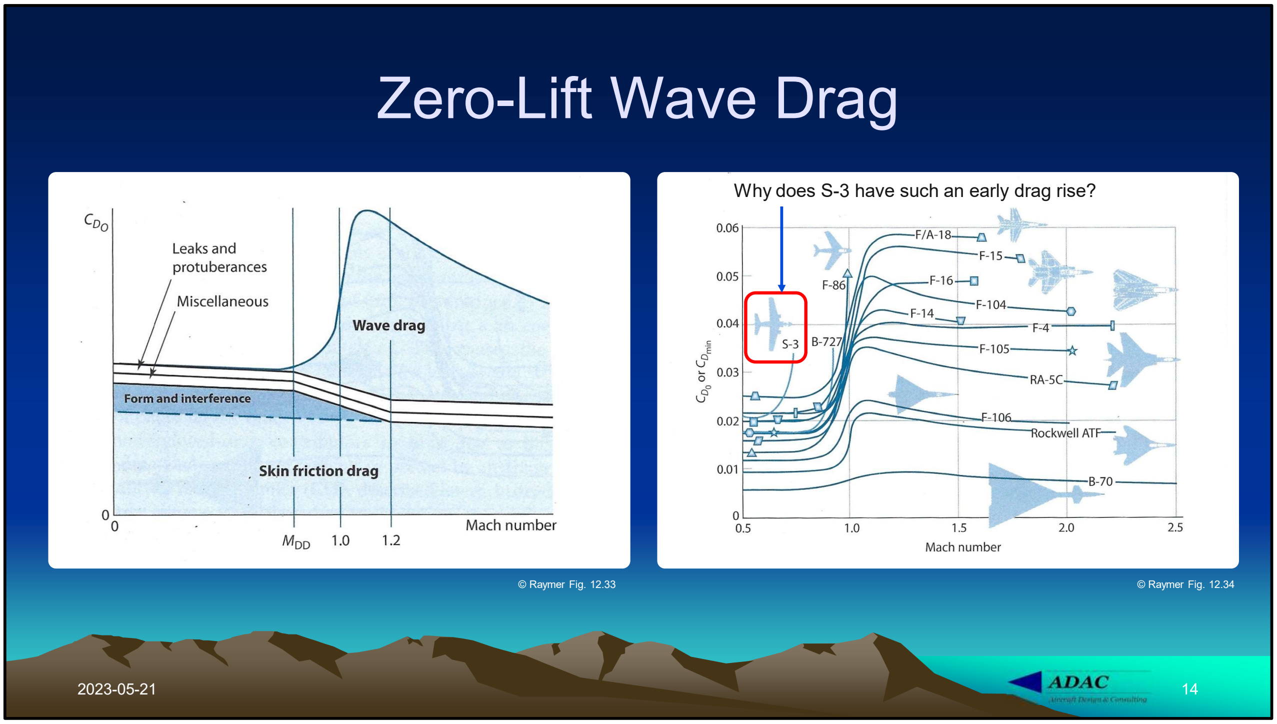
- Wave Drag
  - Wave drag due to volume (zero-lift wave drag)
  - Wave drag due to lift

Topics

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



If the volume distribution is stretched out (i.e. large length/(max cross-section)), then wave drag is significantly reduced. It's very difficult to design a low-drag executive jet. Note the early drag rise on the S-3



If the volume distribution is stretched out (i.e. large length/(max cross-section)), then wave drag is significantly reduced. It's very difficult to design a low-drag executive jet. Note the early drag rise on the S-3

Lockheed S-3 Viking

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

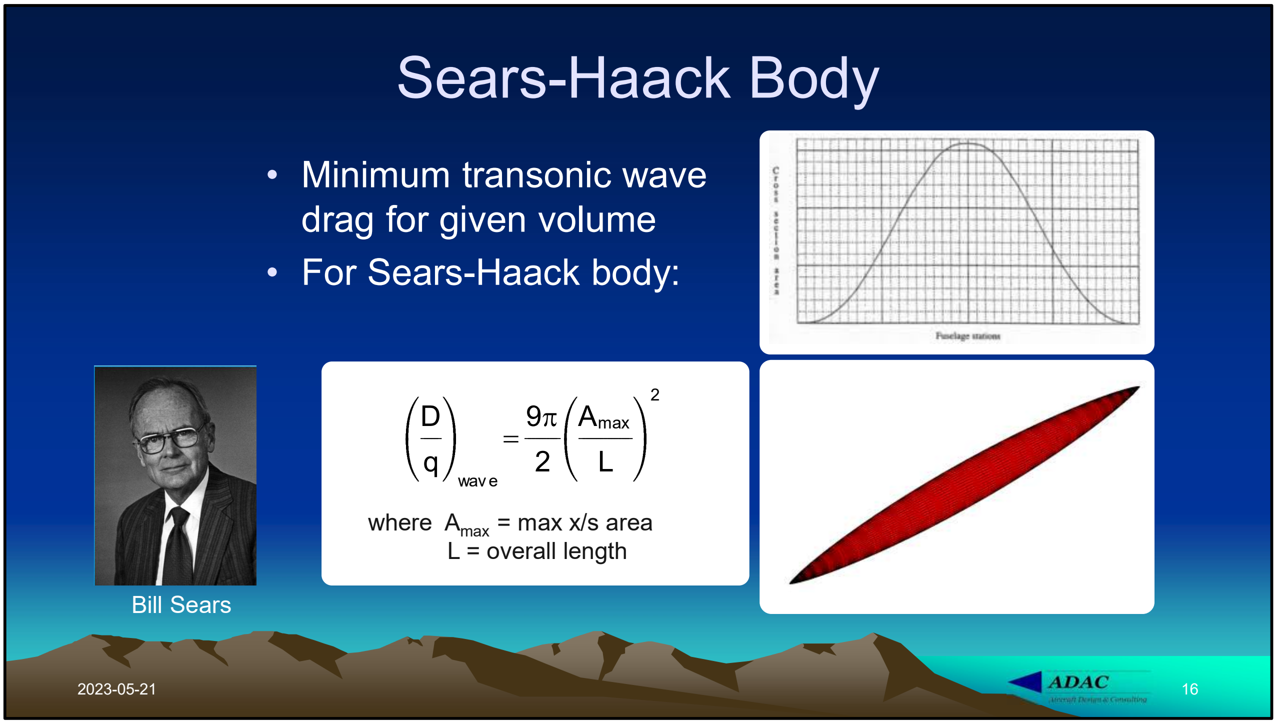
https://besthqwallpapers.com/airplanes/lockheed-s-3-viking-4k-american-army-us-navy-lockheed-132786

- 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

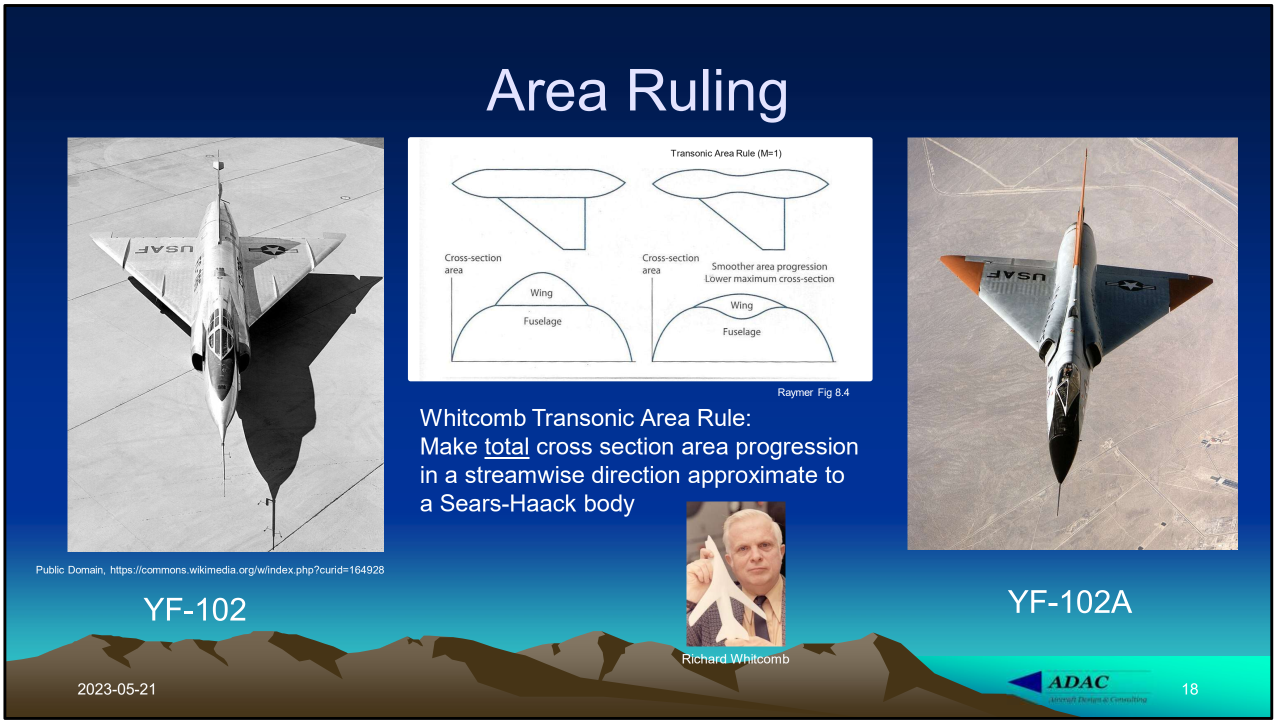
ADAC
Aircraft Design & Consulting

15

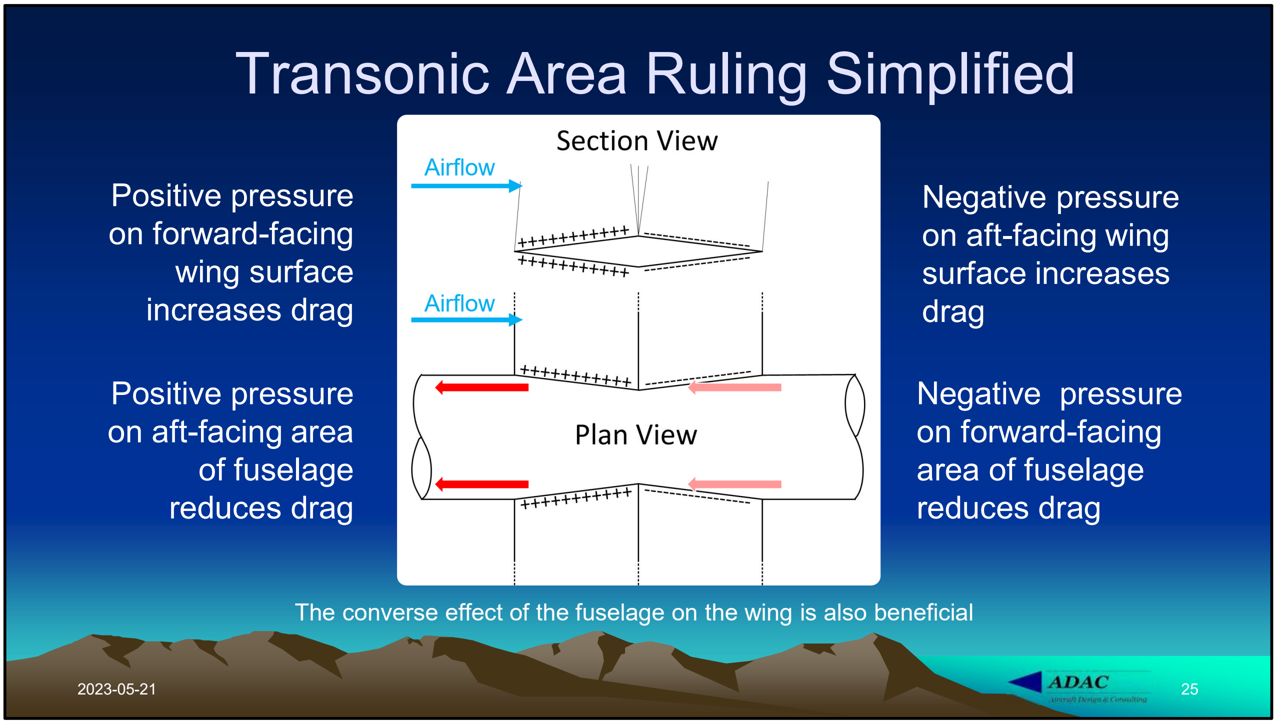
If you are wondering why the drag of the S-3 is so high, it's because the nacelles have to be as close to the aircraft centerline as possible to enable the aircraft to make a single-engine approach to the carrier deck without an unacceptable bank angle. Critical flow occurs in the gap between the fuselage and nacelle.



Bill Sears founded the Cornell Aeronautical Labs (CAL), did fundamental research in wing theory, unsteady flow, transonic aerodynamics. He left in 1974 to join Department of Aerospace and Mechanical Engineering at the University of Arizona. Retired in 1978, but remained active faculty member. I learned about the Sears-Haack body as an undergraduate. Sometime in the mid 1980s I shared a taxi with Dr. Sears from Dayton Airport to a conference hotel. I thought I was sharing a taxi with God.



The YF-102, without area ruling, was unable to reach supersonic speeds in level flight. The YF-102A, with area ruling was able to fly supersonically.



This shows an example of a diamond section wing at zero incidence and at M=1 with an area-ruled fuselage. The weak compression wave from the forward-facing wing surface induces thrust on the aft-facing area of the fuselage. The weak expansion wave on the aft-face wing surface also produces thrust on the forward-facing area of the fuselage. The converse effects of the fuselage on the wing also reduce drag.

Boeing Transonic Airliner

Airliners.net

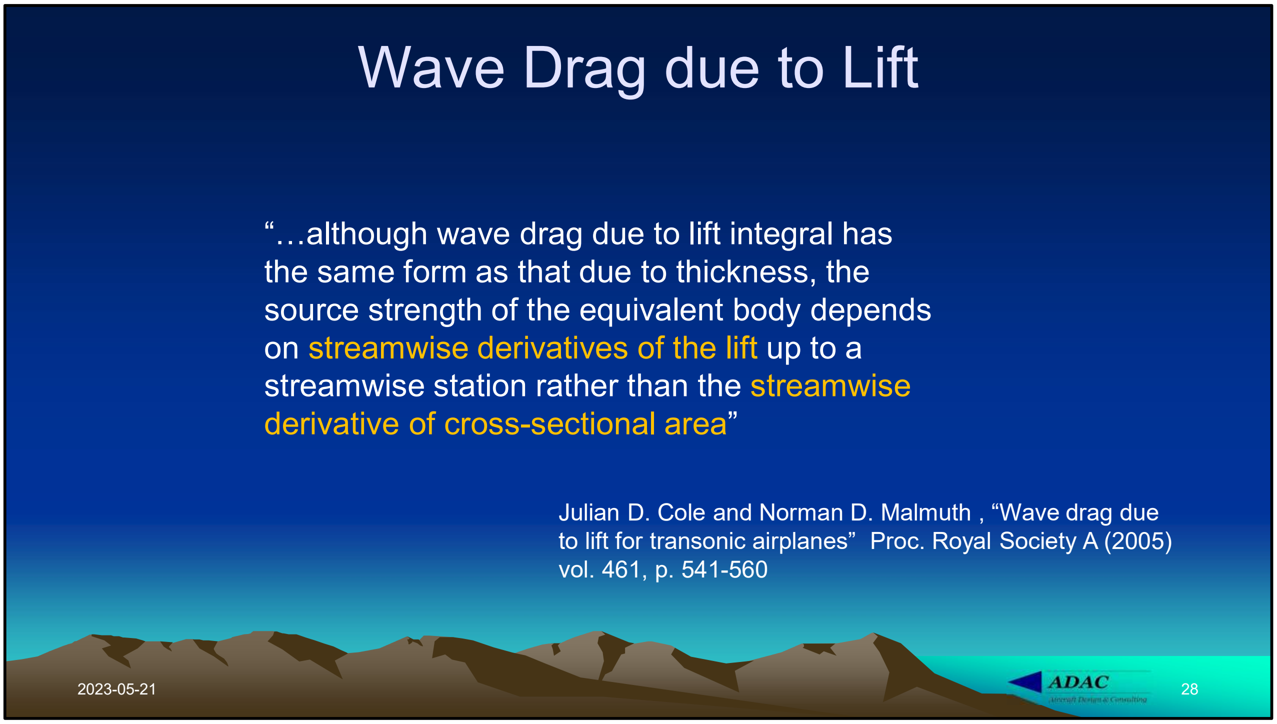
- ~1995 Conceptual design
- Difficult and expensive to manufacture
- Inefficient seating
- Small reduction in flight time
- Small gain in aircraft and crew utilization
- Small gain in M L/D

2023-05-21 ADAC Aircraft Design & Consulting 26

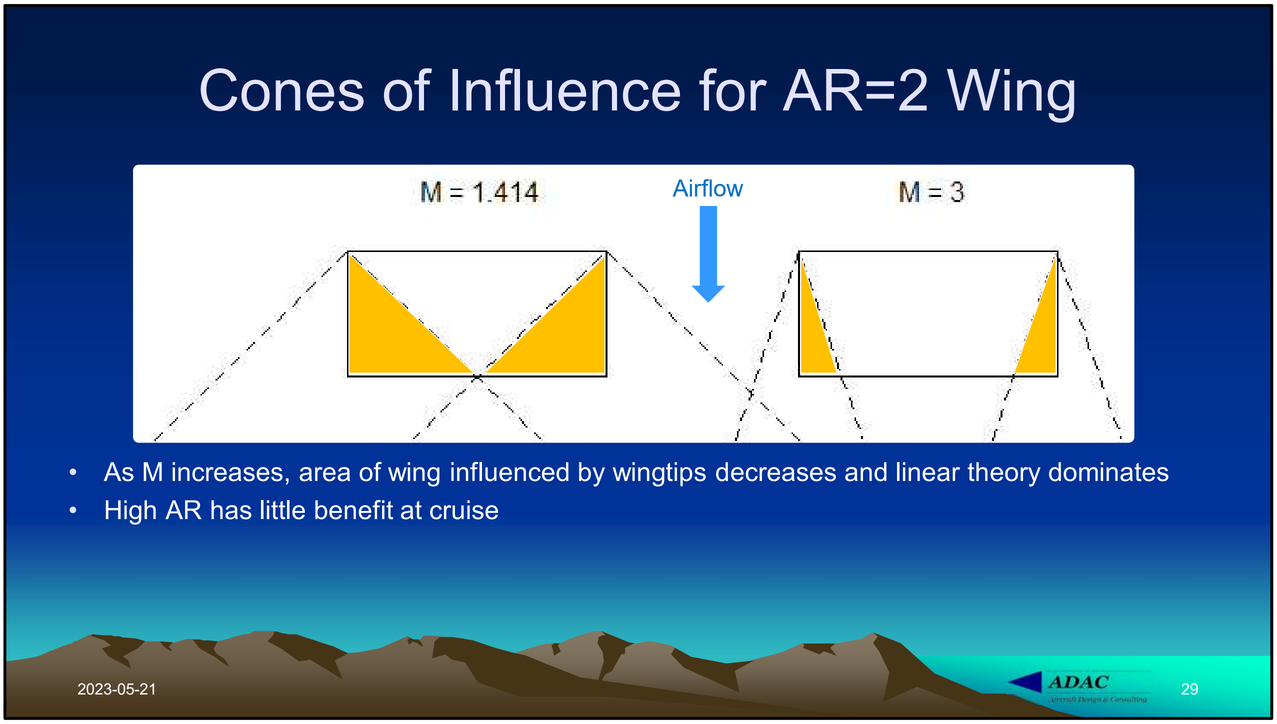
Cost of fuselage construction and inefficient passenger layout offset gains in ML/D. At supersonic speeds the area distribution must be evaluated using conical cuts at the appropriate Mach angle. The effect of a highly-swept wing also stretches out the effect on the fuselage. The combined effects reduce the benefit of coke-bottling the fuselage.

Topics

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



Wave drag due to lift is more complicated



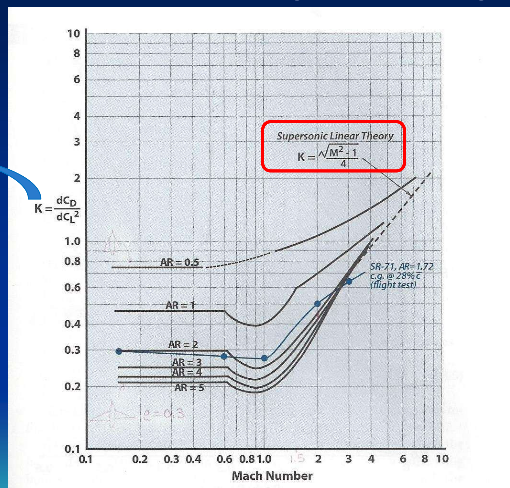
The white area on the planform is not affected by the existence of the wing tips.

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

Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - 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

Ben Hamlin was largely responsible for the design of the airplane, and is closely associated with its success. Ref: Young, J.O., "Meeting the Challenge of Supersonic Flight", Air Force Flight Test Center History Office, Edwards AFB, California 412TW-PA-19326. I shared an office with Ben when we both worked at De Havilland Canada in 1993

Lack of Interest or Understanding of Sonic Boom

From "Aerodynamics" by Theodore von Kármán, Cornell University, 1954

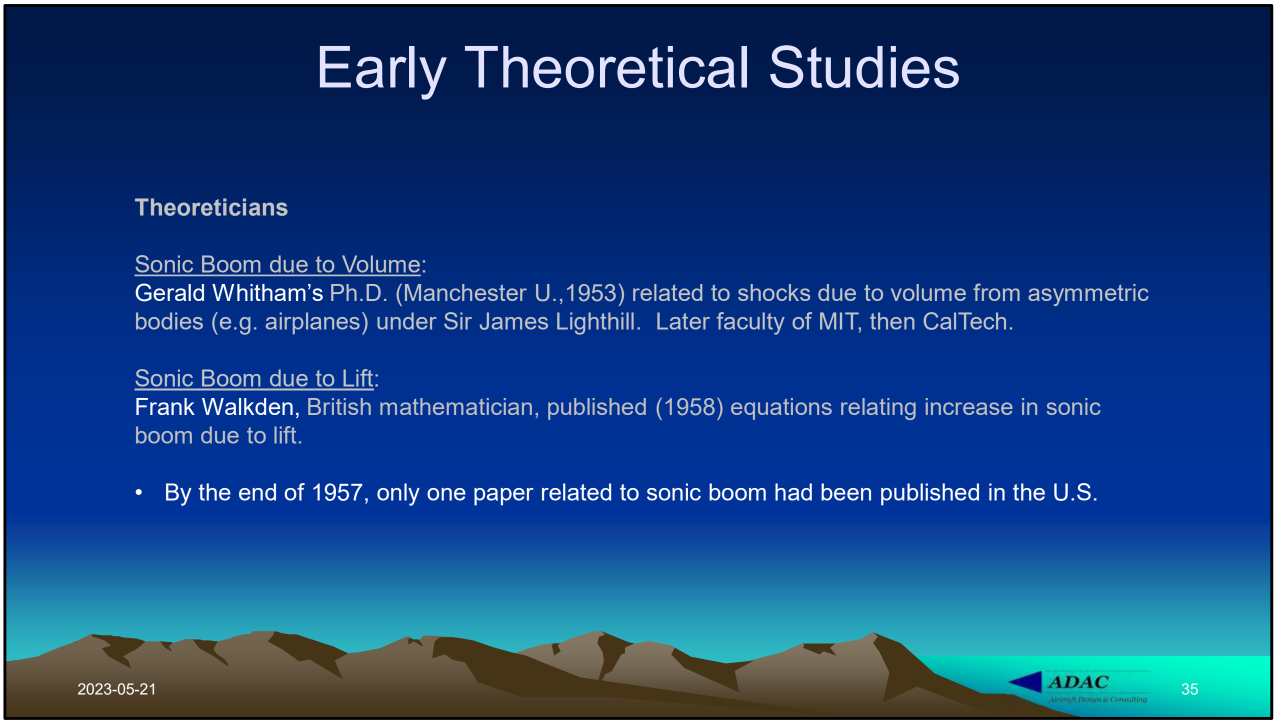
"There is a strange phenomenon connected with these diving stunts which I want to mention. Assuming that the airplane approaches the observer at subsonic speed, makes a dive reaching supersonic speed, then recovers from the dive and continues in flight again at subsonic speed. In that case the observer 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."

2023-05-21

ADAC

34

Strangely, in the U.S. there was little interest in understanding both the cause and effect of the sonic boom. Schlieren was invented in 1894. Von Kármán knew that that Ernst Mach (1838-1916) used Schlieren for studies of supersonic flow (See "Aerodynamics", p. 106). So why were shock waves not associated with the sonic boom?



Strangely, in the U.S. there was little interest in understanding both the cause and effect of the sonic boom

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 picked up in the late 1960s

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

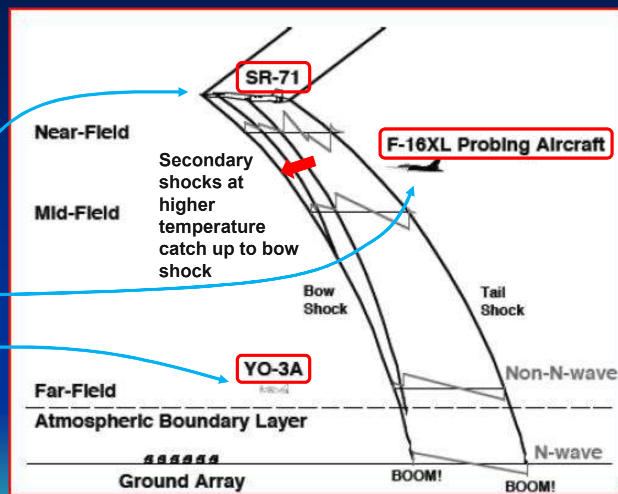
Good research summary:
Dominic Maglieri, et al., Sonic Boom, Six Decades of Research, NASA/SP-2014-622

Sonic boom research picked up in the late 1960s

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

2023-05-21

ADAC Aircraft Design & Consulting

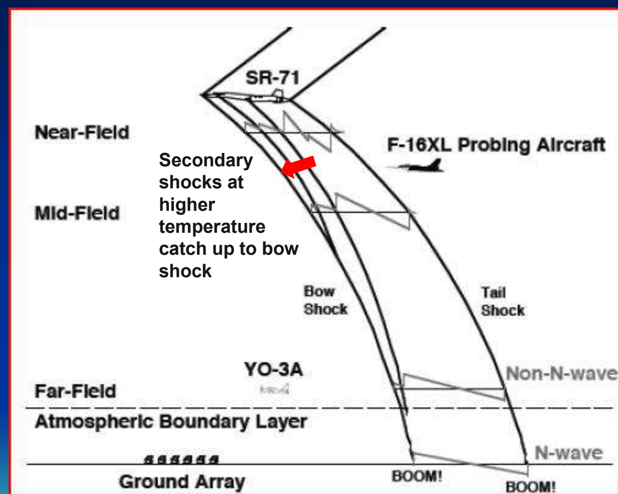
38

Minor shocks on the aft section of the body drift rearward toward the tail shock. Note refraction of the shock wave as it descends into higher temperatures (and higher speed of sound) at lower altitudes

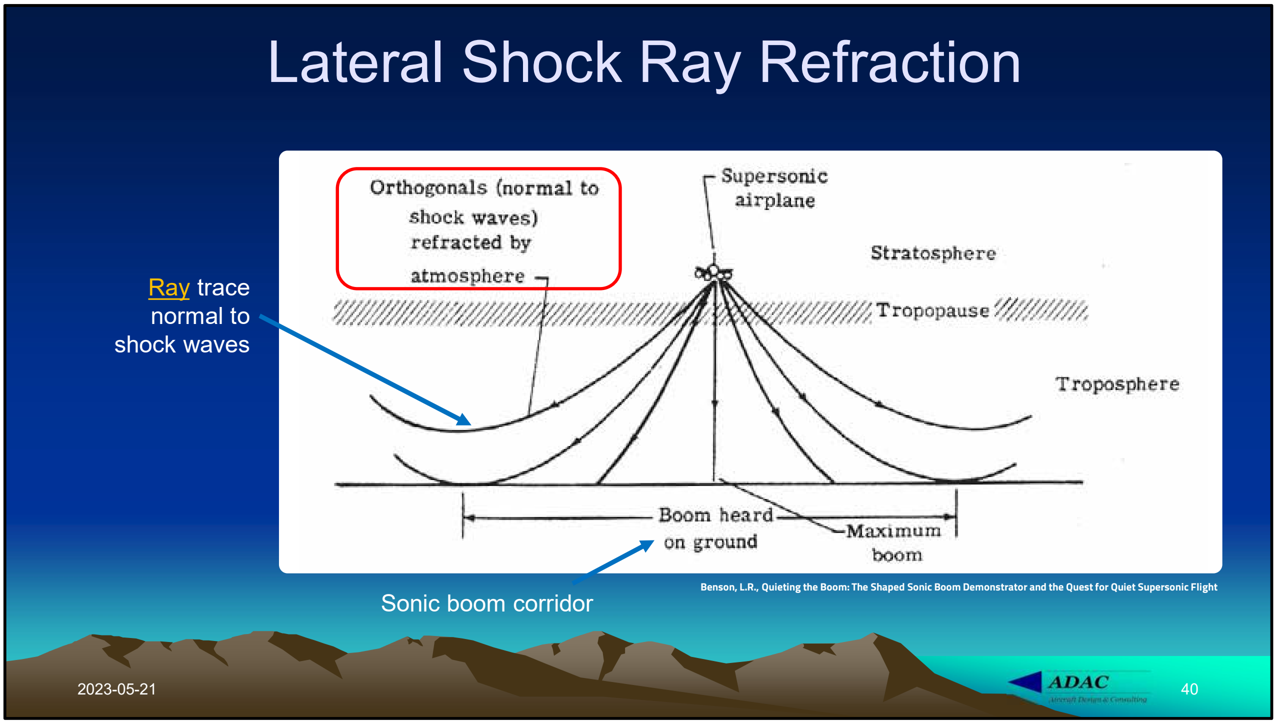
Longitudinal Shock Wave Refraction

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

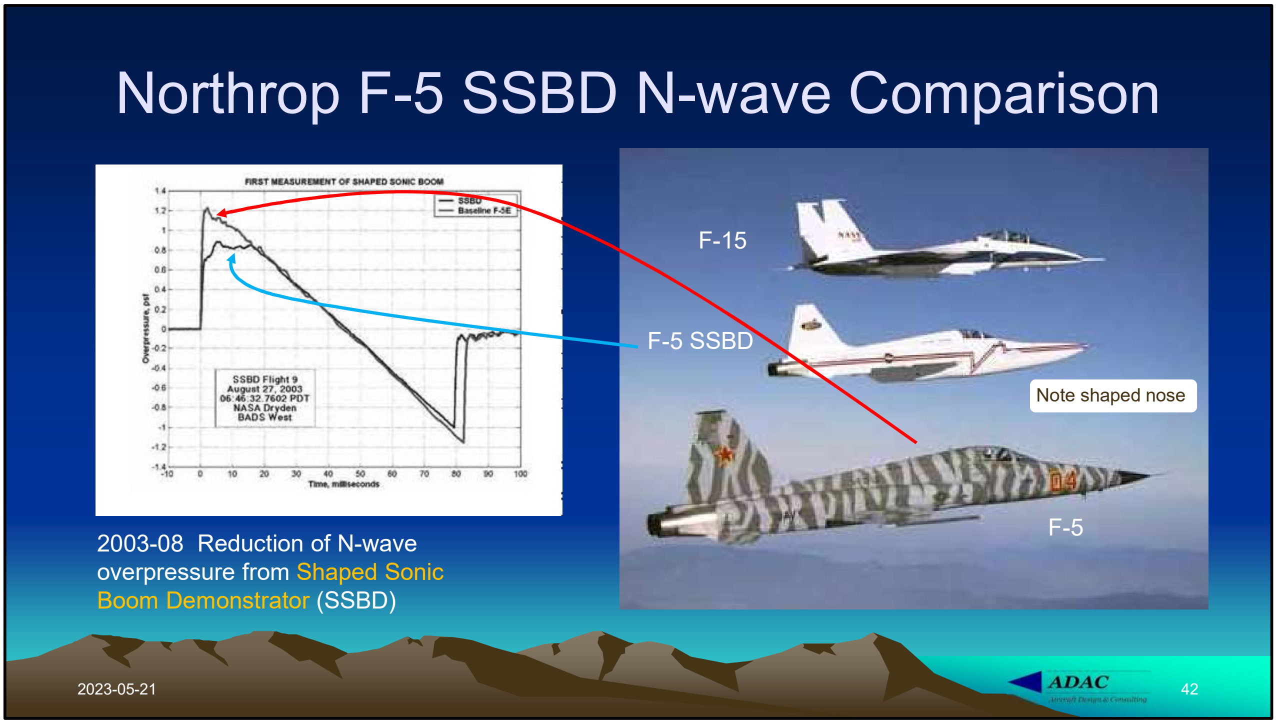
Then
- shock wave does not reach the ground



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



We don’t usually think of sound in terms of rays, but this illustrates how sonic boom may not be heard laterally due to refraction of sound waves

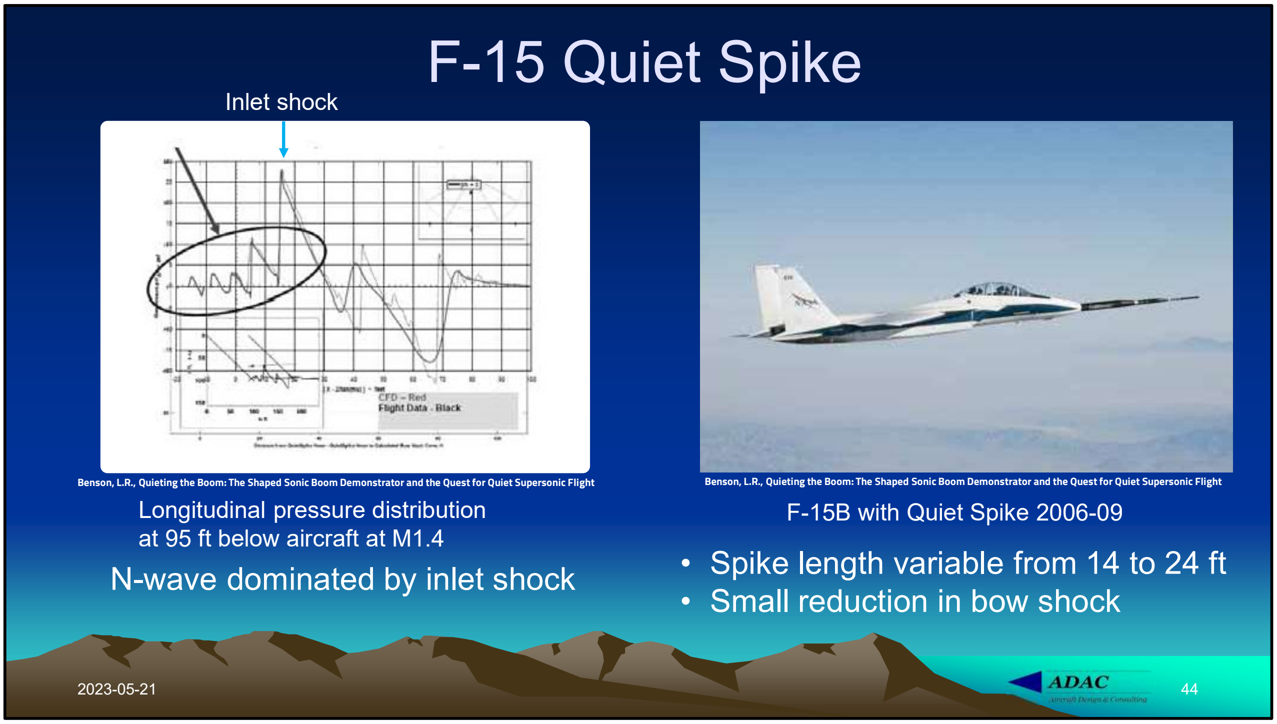


SSBD at 32,000 ft. Although somewhat counter-intuitive, the blunt nose should spread out the peak shock. And it did, but only by a small amount. The volume distribution no longer approximated a Sears-Haack body (if it was ever close), so wave drag due to volume undoubtedly increased

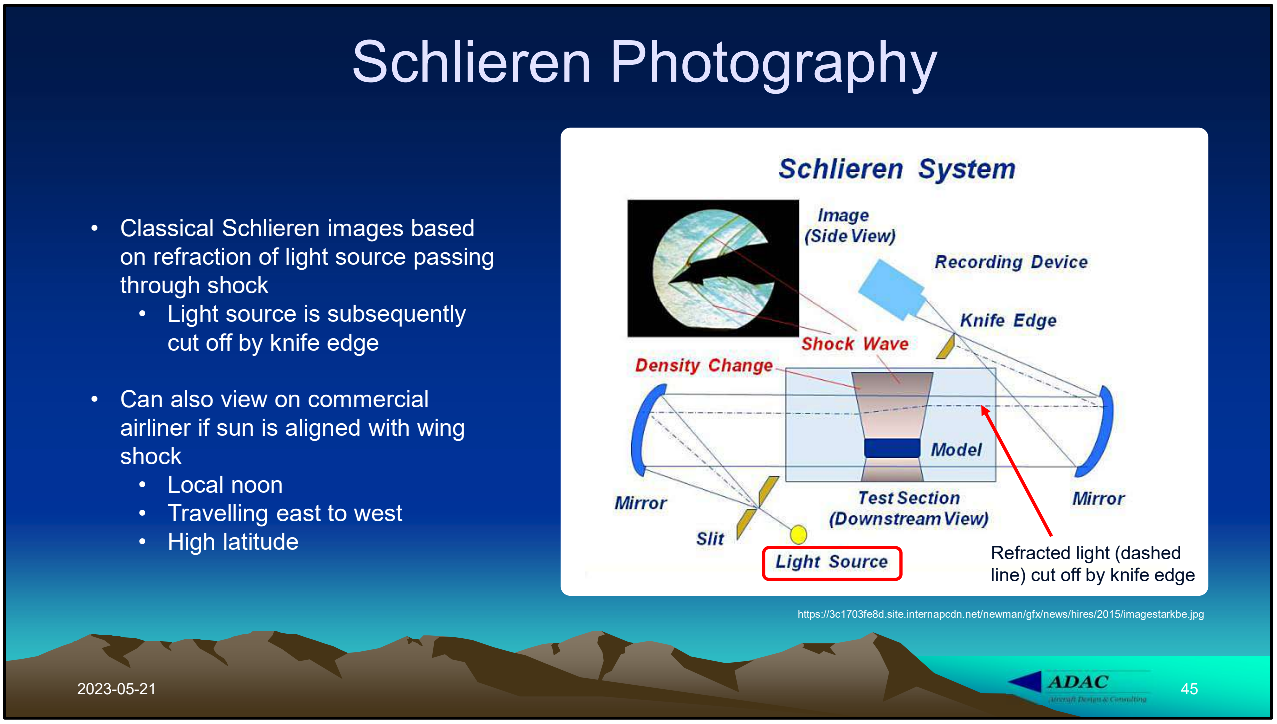
Shaped Sonic Boom Demonstrator

Roy Martin
Chief Test Pilot
Northrop Grumman

Roy Martin was chief test pilot at NGC



The small reduction in bow shock was overwhelmed by the inlet shock

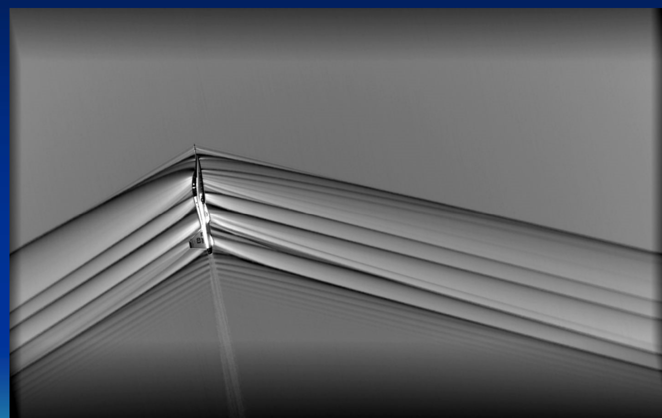


Schlieren photography was invented in 1894 by August Toepler (https://en.wikipedia.org/wiki/Schlieren_photography#:~:text=Schlieren%20photography%20is%20a%20process,flow%20of%20air%20around%20objects.) The first supersonic wind tunnel was built at the National Physical Laboratory in the UK in 1922.

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



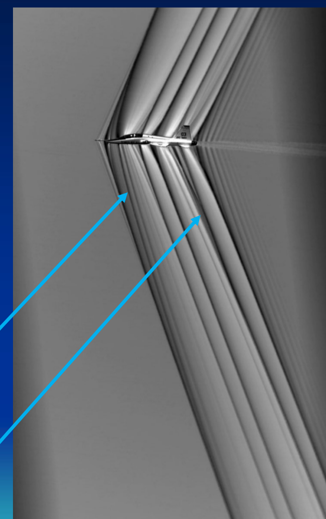
https://arstechnica.com/science/2019/03/nasa-visualizes-supersonic-shockwaves-in-a-new-awe-inspiring-way/

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

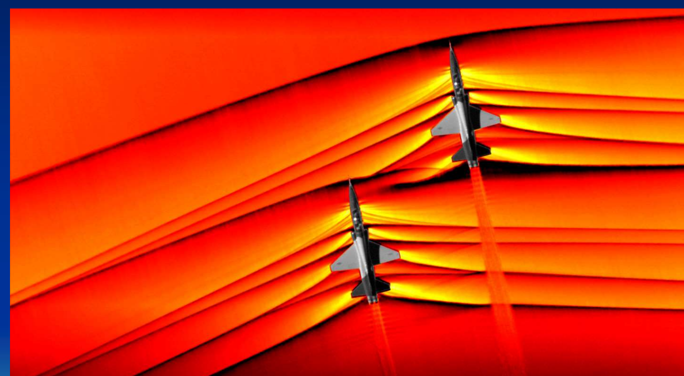


Forward shock waves coalescing with bow shock

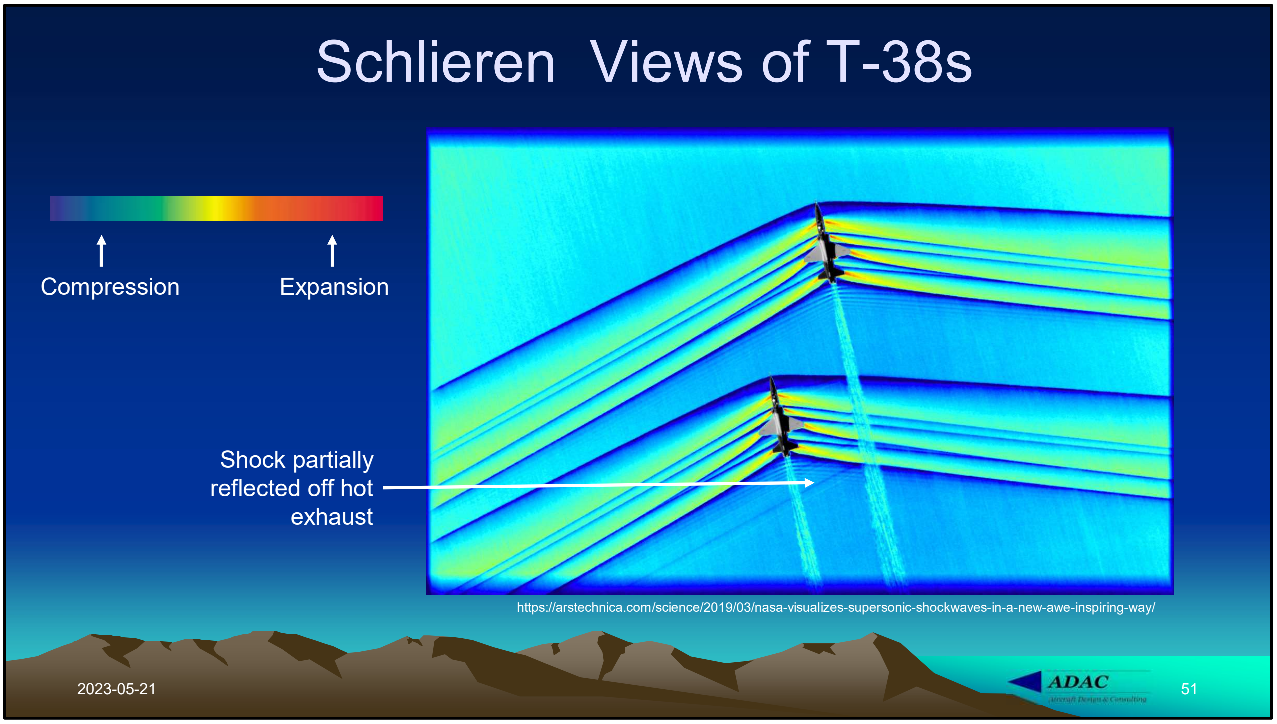
Aft-body shock waves coalescing and migrating towards aft shock

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/



Reflection of sound by the hot exhaust was used by the Lockheed CL-1611 with over/under engines. Directly below the flight path at takeoff, the sound of the upper jet flow was shielded by the lower jet as the aircraft passed over the FAR Part 36 takeoff microphone.

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.

2023-05-21

ADAC

Aircraft Design & Consulting

53

The statement applies for M > 1.15 or thereabouts

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

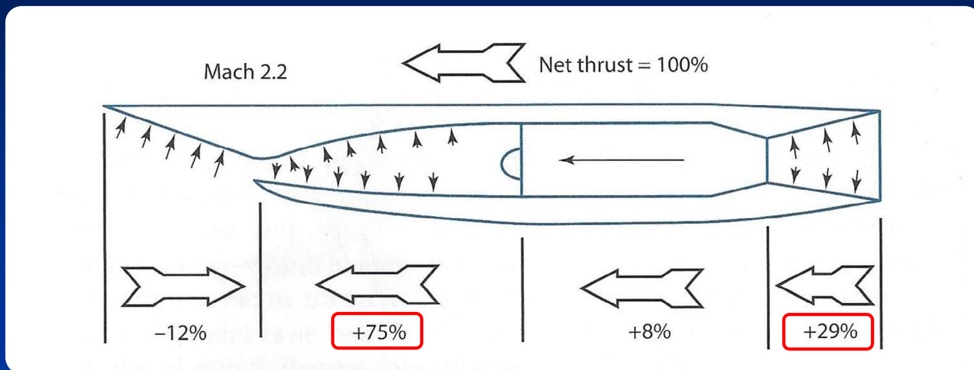
Current:

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

Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design

Nacelle Thrust – Drag Accounting



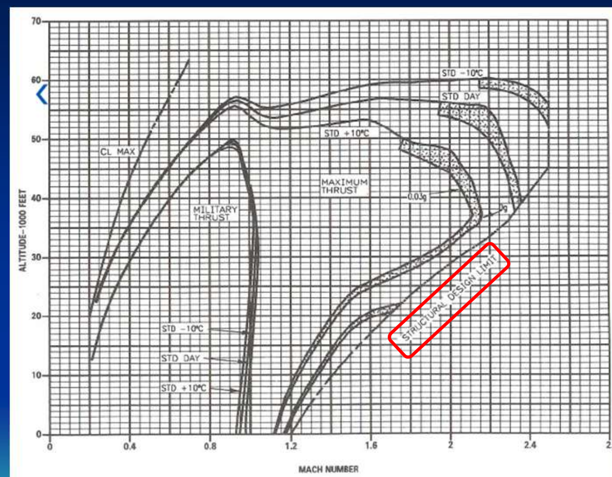
North American A-5 with GE J79 turbojets

Source: Raymer Fig 13.2

The majority of thrust is from the subsonic diffuser

The inlet diffuser is doing most of the work in pushing the aircraft along

Dynamic Pressure Performance Constraint

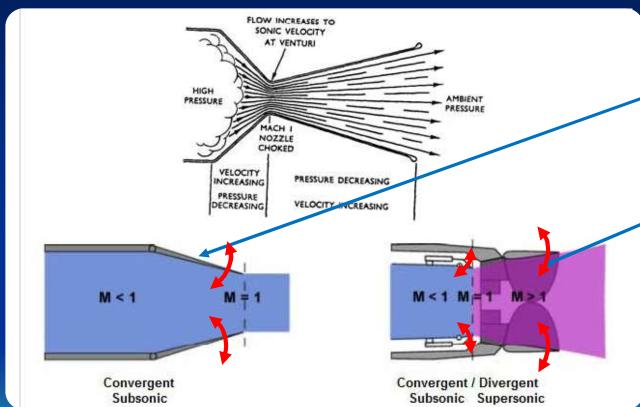


- F-15C, gross weight 38,000 lb
- 2x F100-PW120

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

Note the q-limited structural design limit due to inlet pressure

Nozzle Efficiency

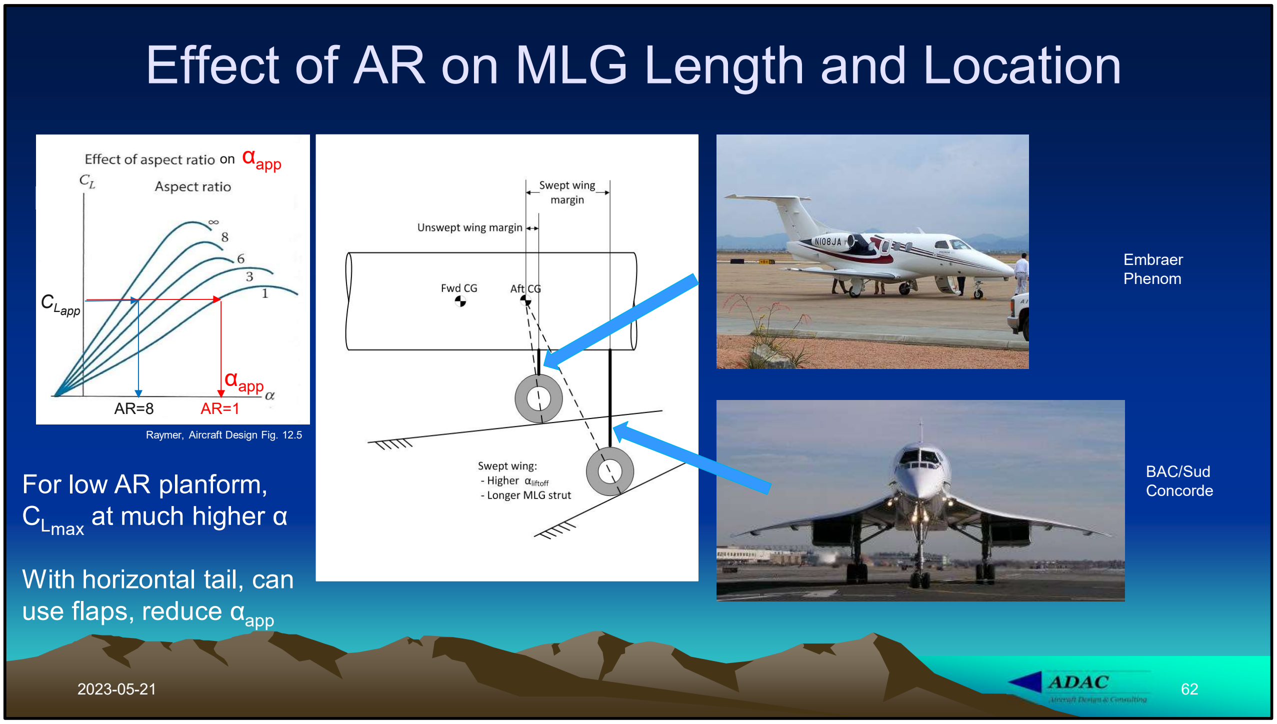


- For convergent nozzle, control thrust by changing nozzle throat area
- Gain additional thrust by adding divergent section to nozzle

Concorde had a con/di nozzle to maximize efficiency

Topics

- Challenges of Supersonic Flight
  - Wave Drag
  - Sonic Boom
  - Propulsion
  - Configuration Design



Location of MLG as a %MAC is function of gear length and required rotation and approach angle of attack. Concorde had long and heavy landing gear, which resulted in a severe economic penalty

Landing gear must be strong

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

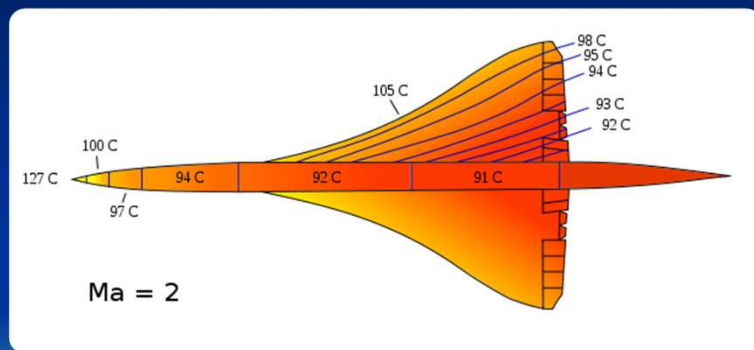
Monarch A320 landing at BHX r/w 33

Landing gear must be very strong, both for vertical loads and, in the case of crosswind landings, lateral loads. BHX is Birmingham International

High winds are common in the UK, and the BHX runway is almost at right angles to the prevailing wind direction. It's the perfect location to get photos like this one.

Aerodynamic Heating

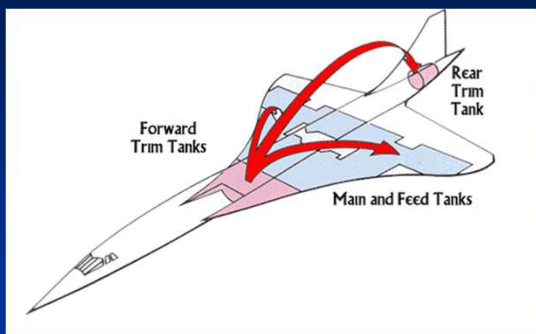
At M 2.2, T_{max} is 150 C
Difficult to certify for number of lifetime flight cycles (needs structural life of 30,000 hrs)



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

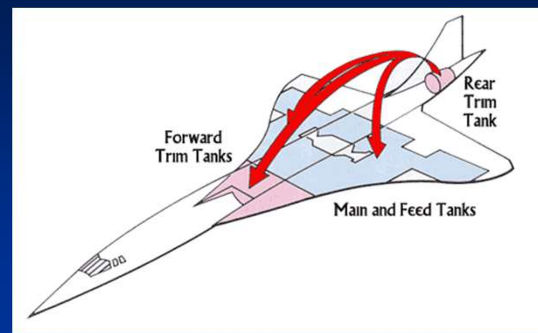
The nose and wing leading edge reach the highest temperatures

Center of Gravity Control



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)



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

- Before and during deceleration, flight engineer moves fuel forward. After landing, more fuel pumped forward

2023-05-21

ADAC

66

The center of lift moves aft during acceleration to supersonic flight, and because there is no horizontal stabilizer, c.g. management is just about the only way to trim the aircraft

Flight Deck Visibility

Lower nose to provide adequate visibility at takeoff and landing

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

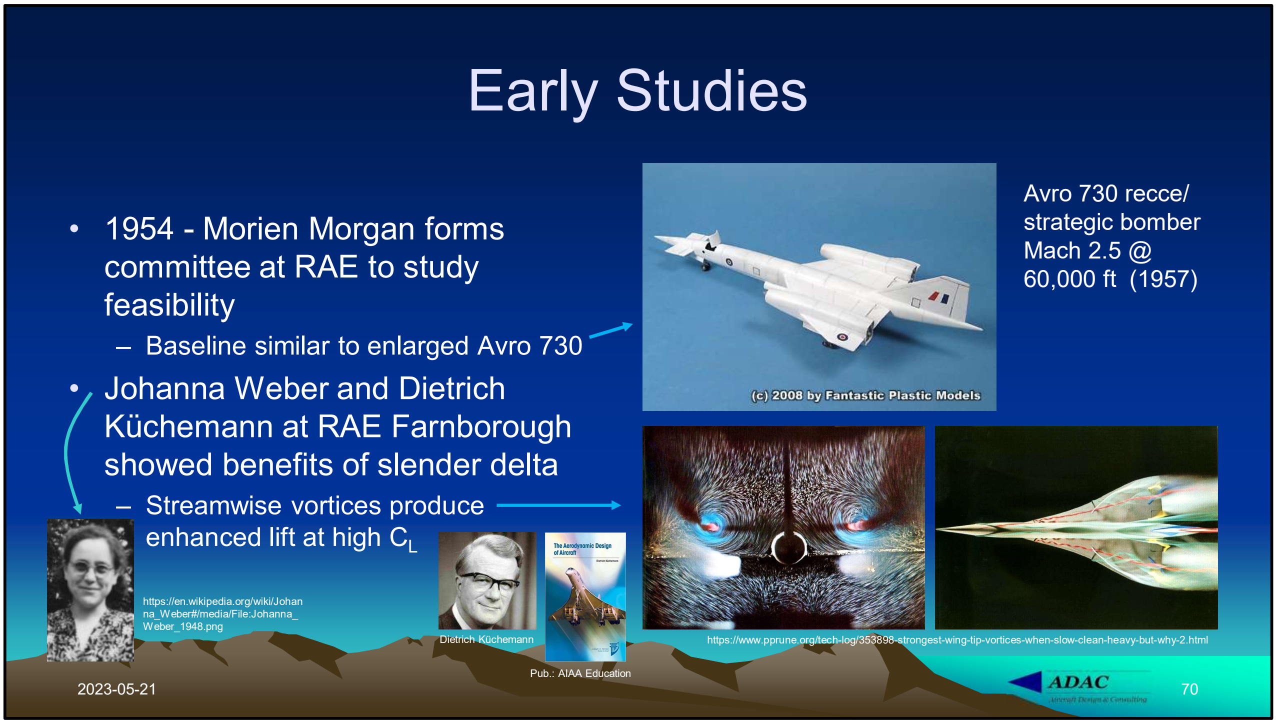
De Havilland DH 108 Swallow

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

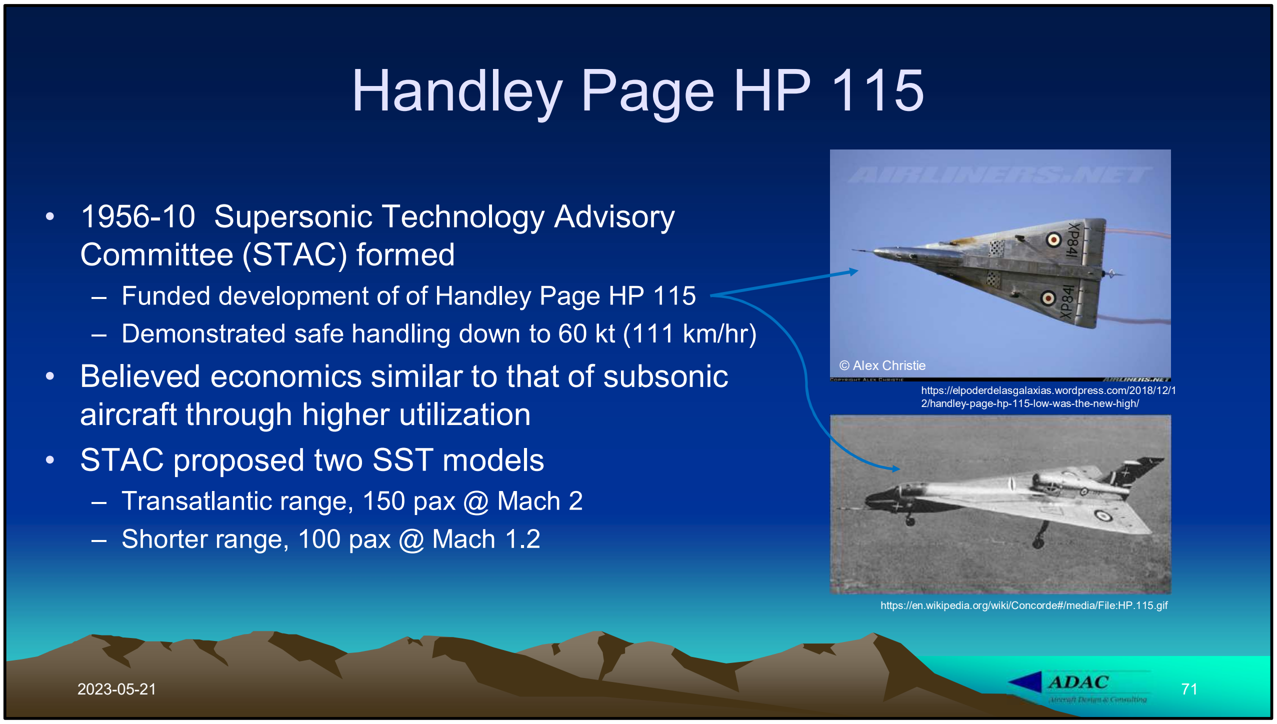
https://www.baesystems.com/en/heritage/de-havilland-dh108-swallow

2023-05-21 ADAC Aircraft Design & Consulting 69

The first British aircraft to fly faster than the speed of sound was the DH 108 Swallow on 9 September 1948. De Havilland's three sons were all killed flying, two as test pilots, one in a wartime air collision.



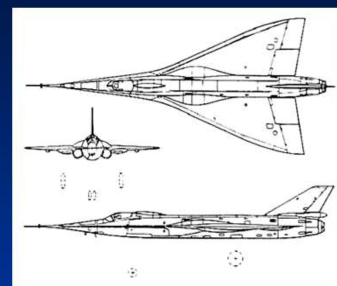
Weber was a mathematician and aerodynamicist, and worked with Dr. Küchemann in Germany, and both moved to RAE Farnborough in 1945. Dr. Küchemann's book "The Aerodynamic Design of Aircraft" was republished by the AIAA in 2012 due to popular demand.



HP 115 was designed to test the low-speed (note fixed landing gear) handling characteristics of a low aspect ratio wing. STAC assumptions on reduced DOC from higher utilization proved overly optimistic, made worse by the oil price shock of October 1973 and second price rise in mid-1979. Concorde entered service in January 1976.

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

2023-05-21

ADAC Aircraft Design & Consulting

72

The FD2 held the world speed record of 1,132 mph (1,822 km/h) from 1956-03-10, but it lasted for only a bit over a year.

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

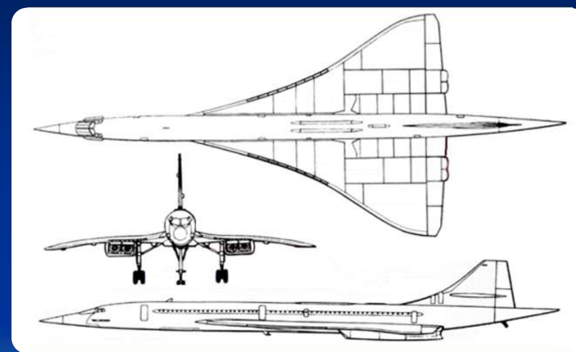
2023-05-21 ADAC Aircraft Design & Consulting 73

At various times, both French and UK governments wanted to cancel the program, but never simultaneously, so it continued in spite of lack of enthusiasm of either government.

Concorde Specifications

- 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

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



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

2023-05-21

ADAC Aircraft Design & Consulting

74

Data from http://www.aerospaceweb.org/aircraft/jetliner/concorde/ SNECMA = Société nationale d’études et de construction de moteurs d’aviation

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

Pictures of the fire were never made public, but they show an airfield fire truck parked in a large pool of aviation fuel that had leaked from the Vulcan. When the fire spread to the pool of fuel the fire truck itself was soon destroyed

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)

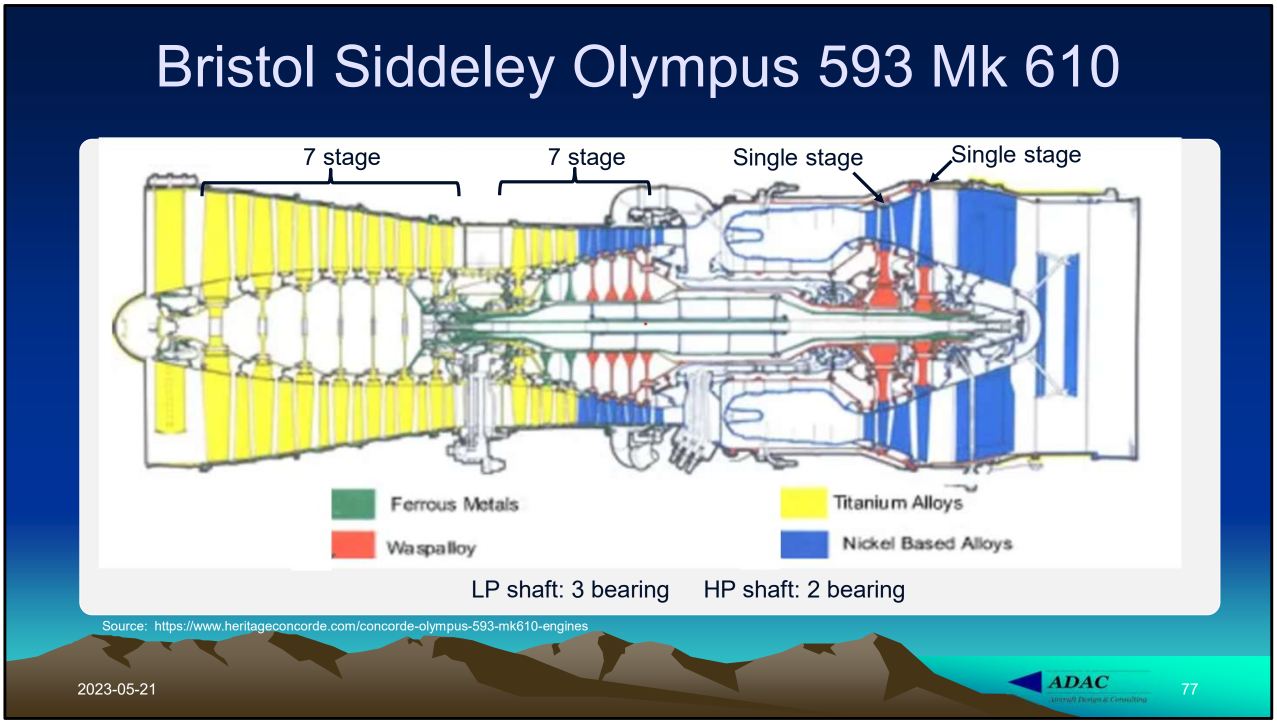
Vulcan flying test bed (FTB) with spray rig for icing test

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

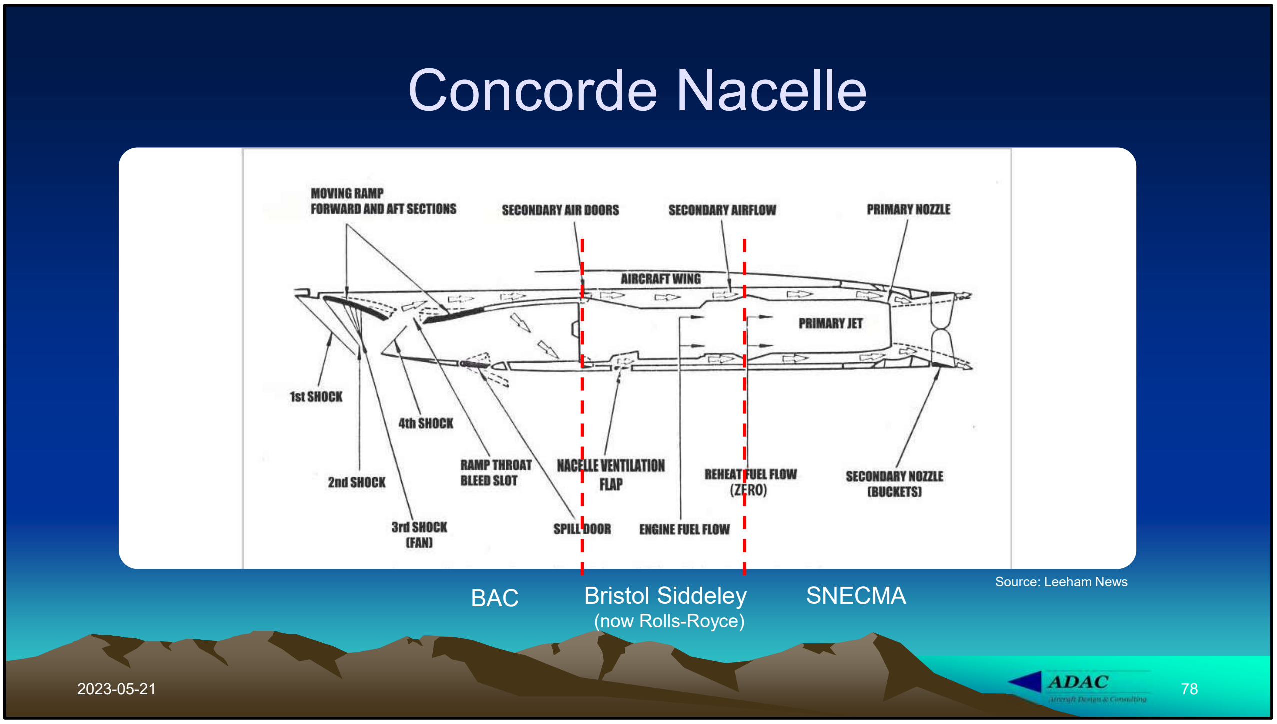
Bristol Siddeley Olympus 593

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

Inlet delivers pressure ratio at compressor face of 7.3:1 at M2.0 (Wikipedia) with engine OPR of 11.3:1 for total PR of 82:1. I did a small amount of work on the FTB. Needless to say, as an apprentice I did nothing useful.



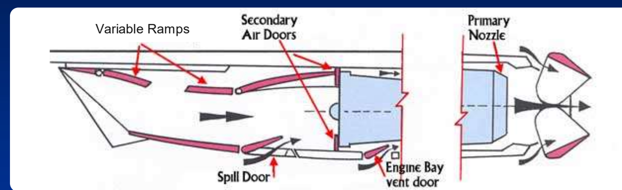
By today's design standards, it was very unusual to have a single-stage LP turbine. The compressor case one piece each for LP and HP. During machining, strange wave marks appeared on the machined surfaces, due, it turned out, to "ringing" of the casing. The solution was to wrap the areas that were not being machined in soft blankets.



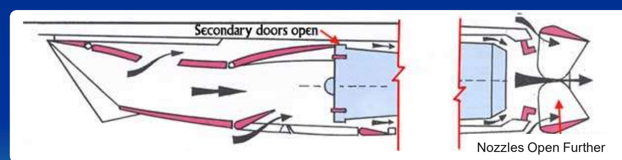
SNECMA = Société National d'Études et de Construction de Moteurs d'Aviation. In the engine test cell, the English-speaking engineers working on the forward end of the nacelle seemed to get along with the French-speaking engineers at the aft end of the nacelle

Concorde Engine Airflow Control

- Takeoff
  - Maximum airflow
- Initial climb noise abatement



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



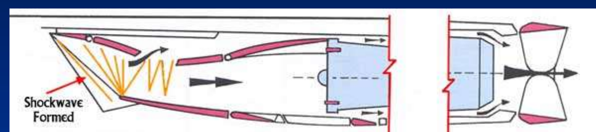
Source: http://www.concordesst.com/powerplant.html#

2023-05-21 79

The nacelle had many doors to control airflow to the engine. In the early days of operations, some of these doors were controlled manually.

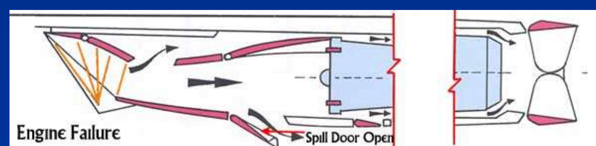
Concorde Engine Airflow Control

- Supersonic cruise
  - Mostly external compression



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

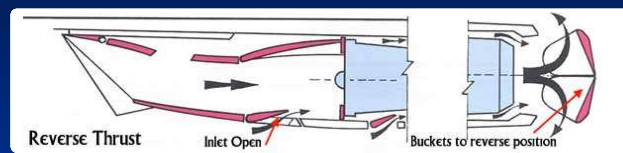
- Engine failure
  - Spill air to enable inlet restart



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

2023-05-21 ADAC 81

In early Concorde operations, intakes were controlled manually by the flight engineer. Later the system was computer-controlled.

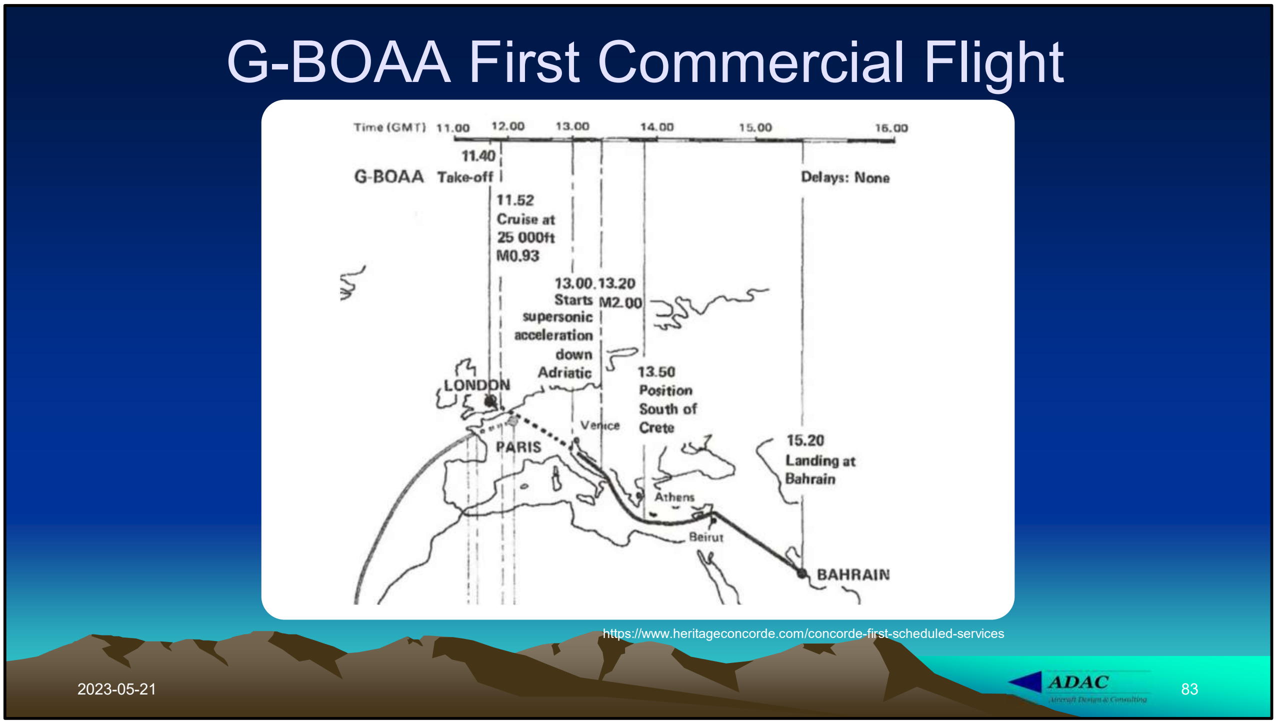
Operational History

- 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/

On takeoff from CDG, Concorde ran over a metal strip on the runway that had fallen off the CO DC-10 that had just taken off. The metal strip ruptured a tire, which hit the fuel tank and caused pressure wave to overwhelm a fuel tank valve, which proceeded to leak.



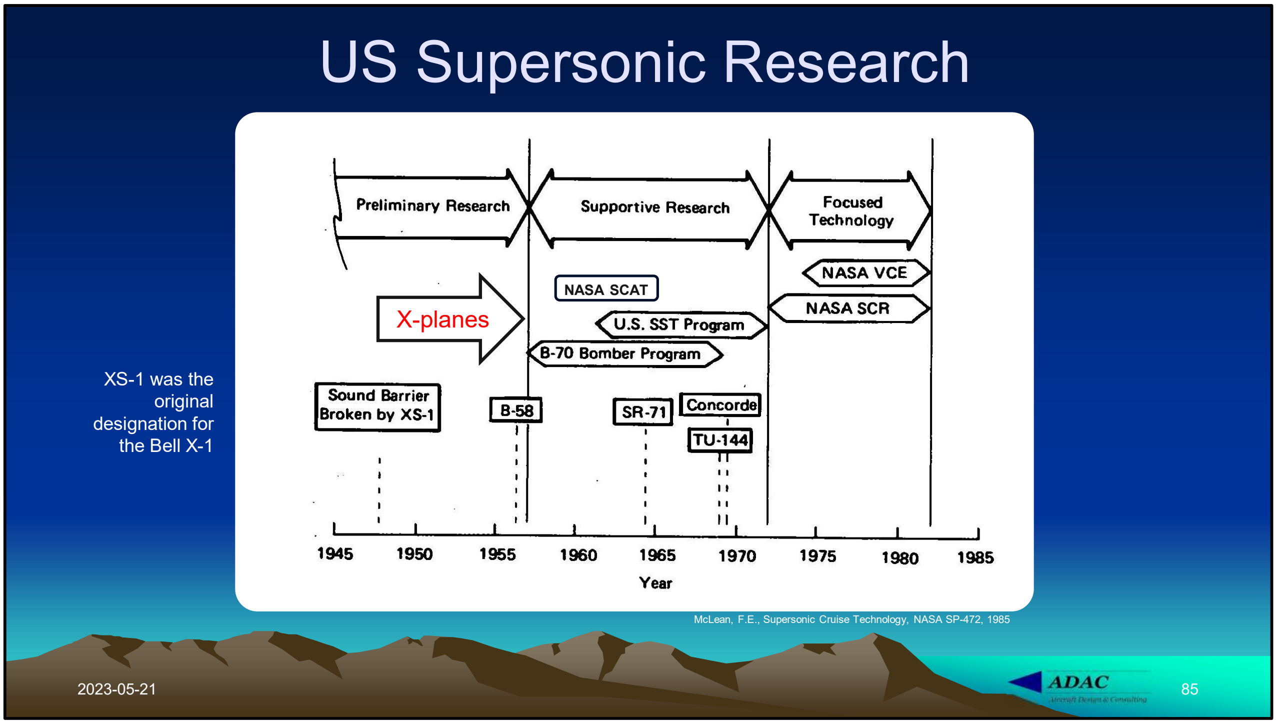
The flight could be operated supersonically only over water or unpopulated areas. This route was probably selected so that the aircraft could land at a nearby airfield in case of an unexpected problem

Tupolev Tu-144

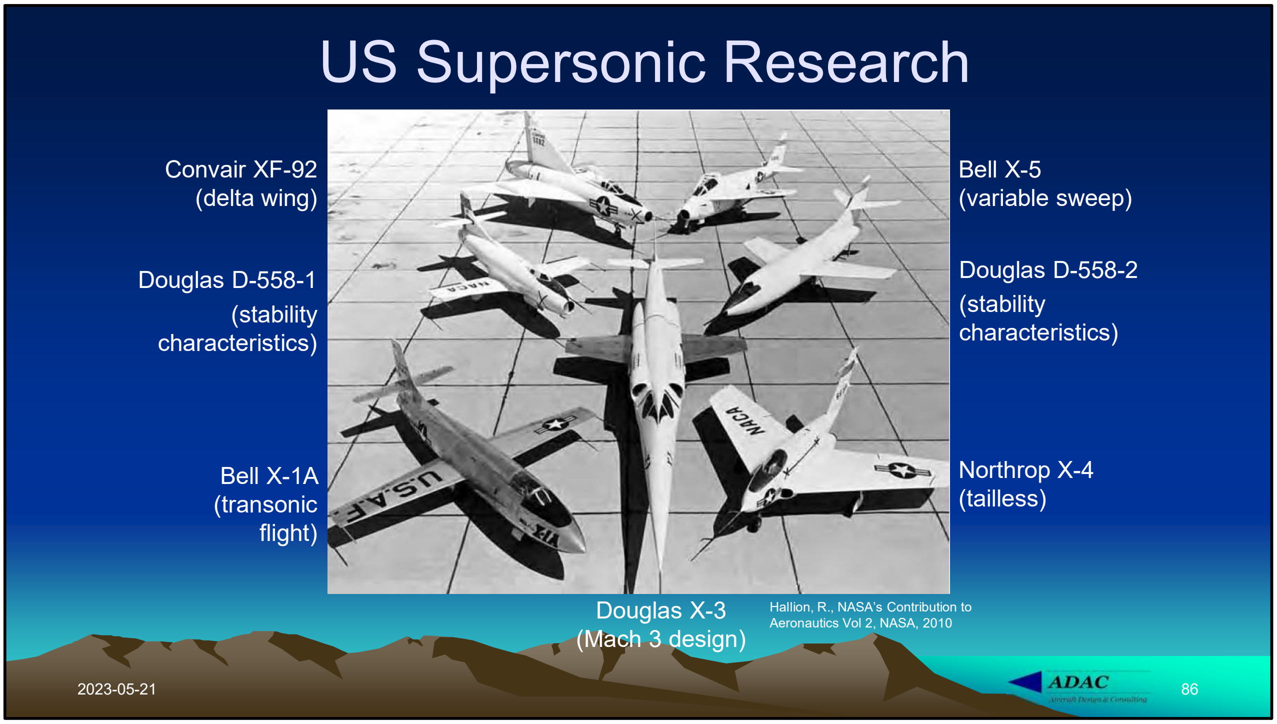
- 1968-12-31 First flight
- 1973 Crash at Paris Airshow
- 1977-11-01 Entry into service
- 1978-04 Crash on test flight during delivery
  - Retired from pax service
- 1999 Retired from service
- Number built 16

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

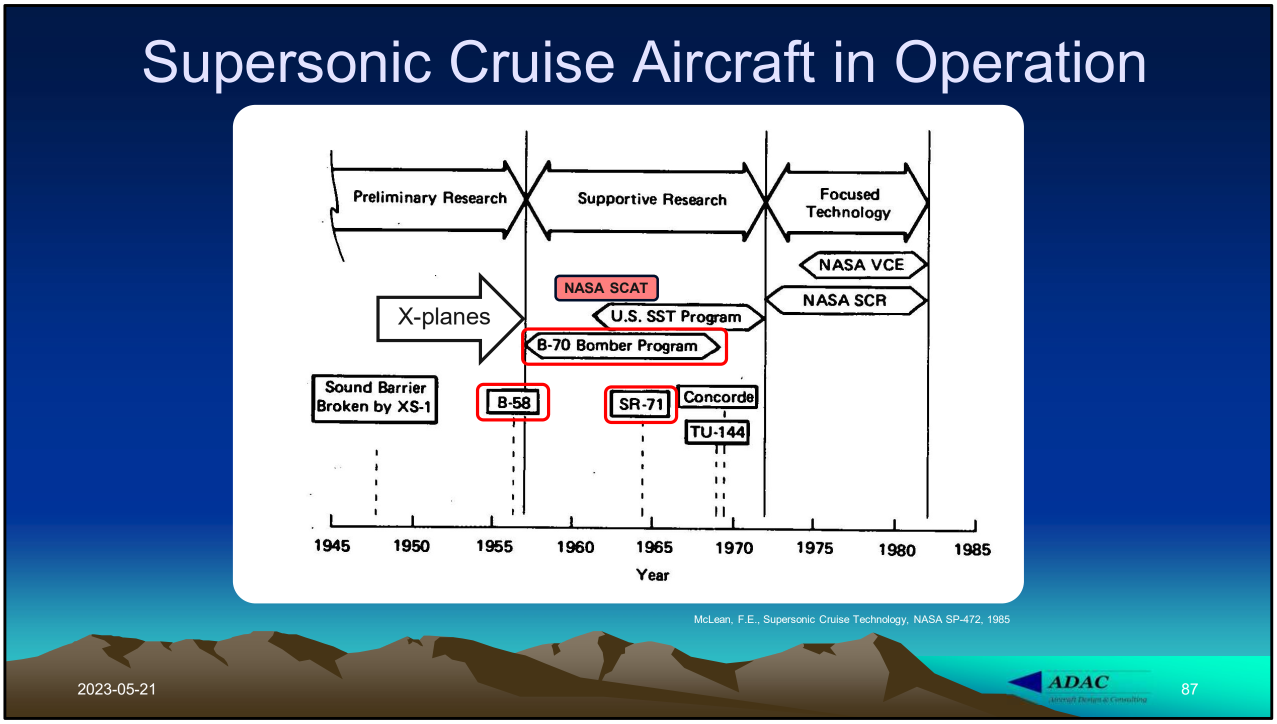
globalsecurity.org



The US had much more experience in supersonic operations than the Europeans, mostly through X-planes. Ed McLean was the SCR program manager until about 1978



The US had extensive experience in high-subsonic and supersonic aircraft operations. Most were not supersonic. Convair XF-92 could reach M1.05. D-558-2 was supersonic under rocket power. Bell X-1A also supersonic



Both the Convair B-58 Hustler and Lockheed SR-71 were operational supersonic cruise aircraft

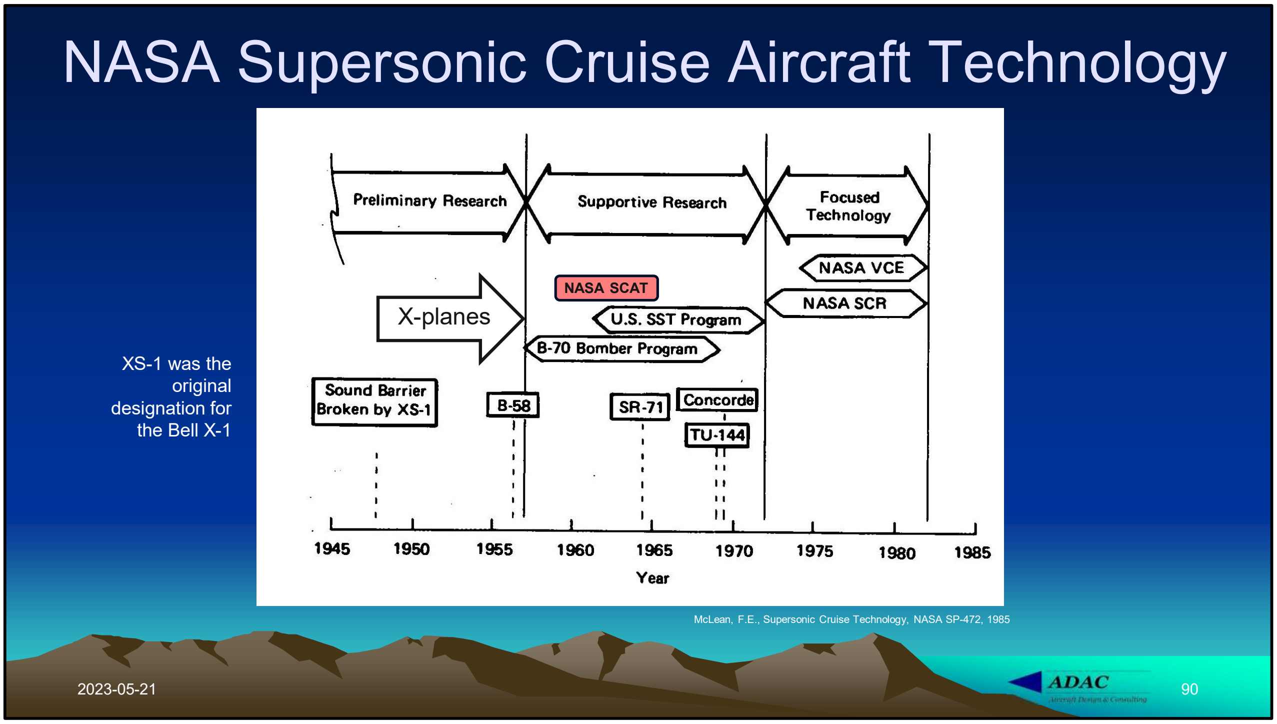
First Gen. Supersonic Cruise Aircraft

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

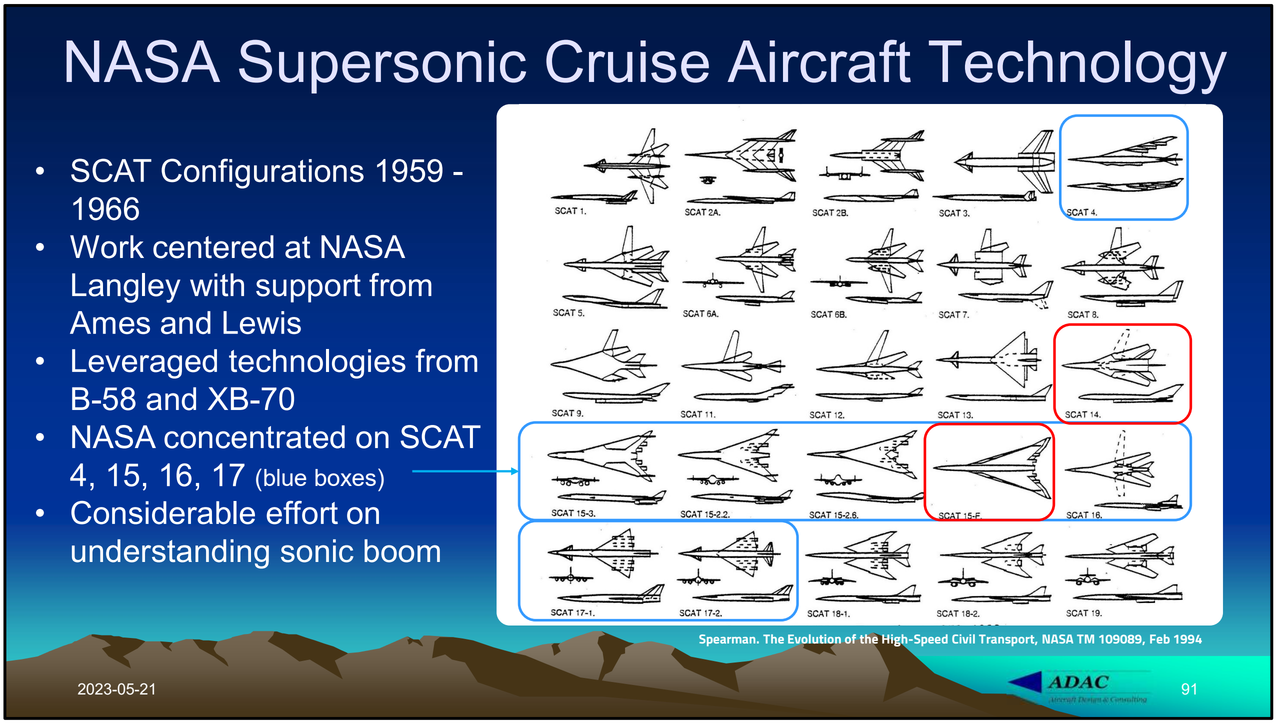
North American XB-70
M_{max}: 3.1
Range: 6,901 km (3,725 nmi)
TOGW: 246,000 kg (542,000 lb)

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

Lockheed A-12 first flight April 26, 1962. Existence of YF-12A announced by President Johnson in 1966



SCAT=Supersonic Commercial Air Transport. Ed McLean led the NASA Supersonic Cruise Research program until ~1980 when Neil Driver took over

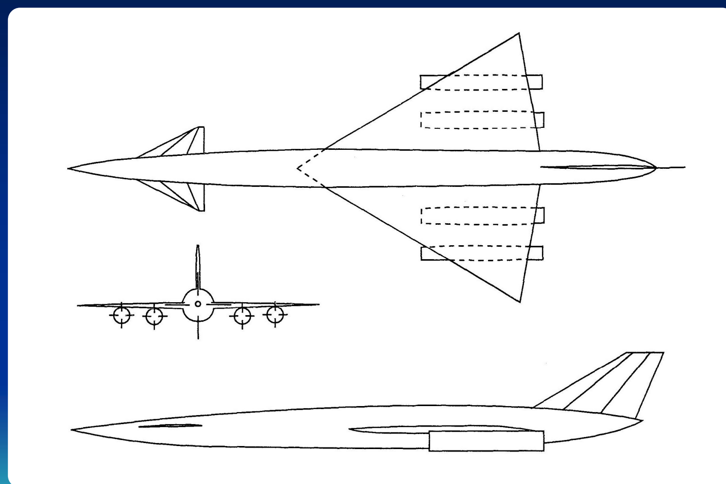


SCAT 14 used by Boeing in its successful bid for government contract. SCAT 15-F later emerged as preferred concept in SCR

Lockheed Evaluation of SCAT 17-1

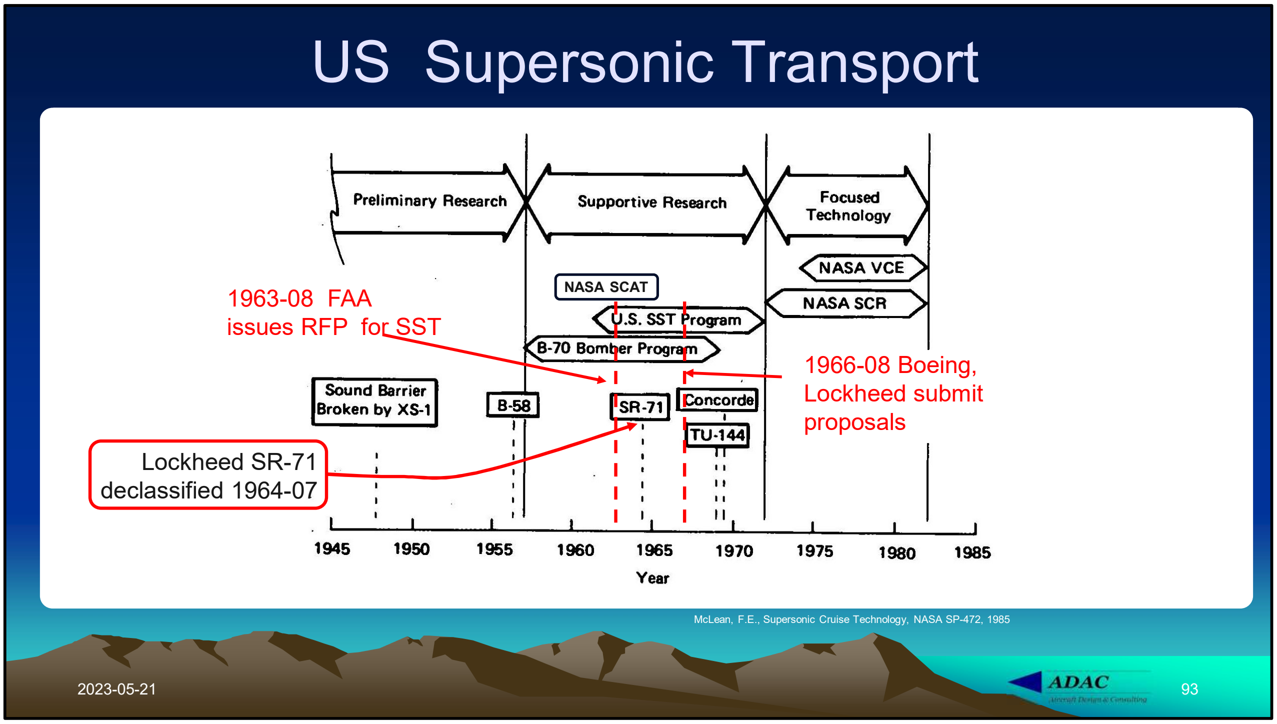
1963-02 Selected by NASA for evaluation under contract to Lockheed

Evolved as SCAT 17-2

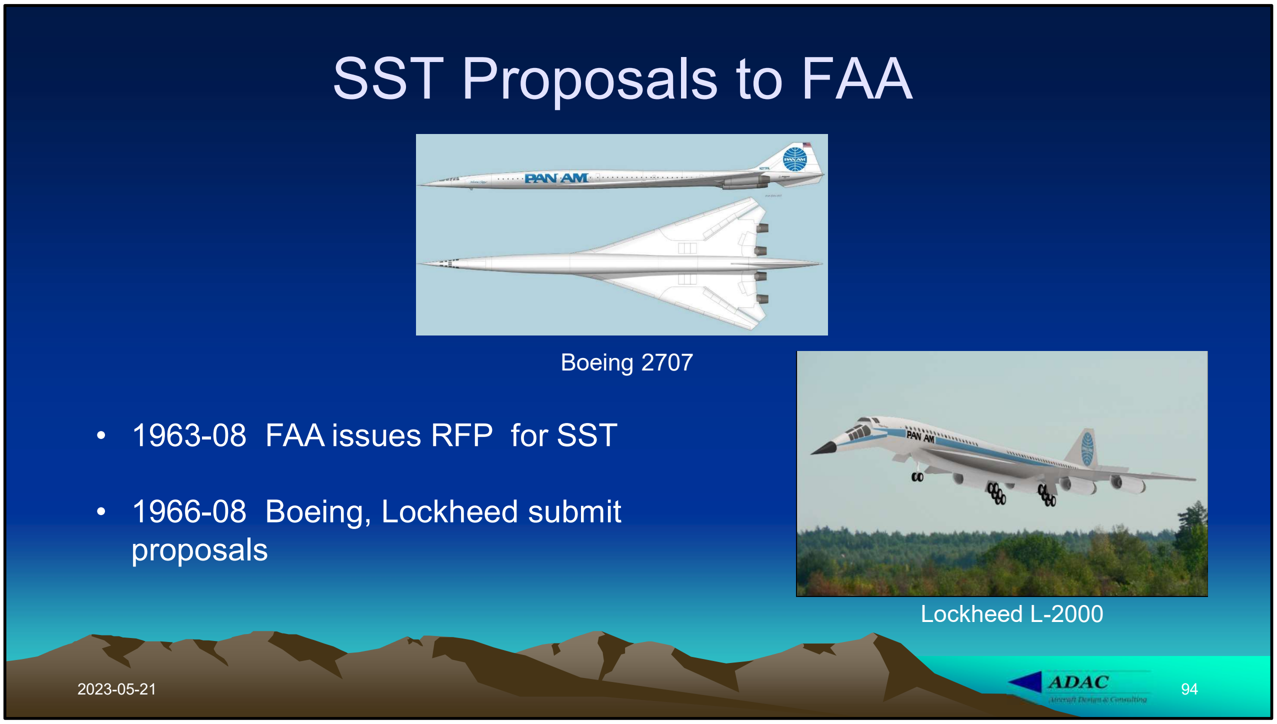


Proceedings of NASA Conference on Supersonic-Transport Feasibility Studies and Supporting Research - September 17-19,1963. NASA TM-905, 1963.

Lockheed A-12 first flight April 26, 1962. Existence of YF-12A announced by President Johnson in 1966



Note SR-71 was declassified 1964-07



Lockheed A-12 first flight 1962-04-26. Existence of YF-12A announced by President Johnson in 1964-02-29 (although he purposely mis-identified it as the “A-11”)

Boeing 2707

globalsecurity.org

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

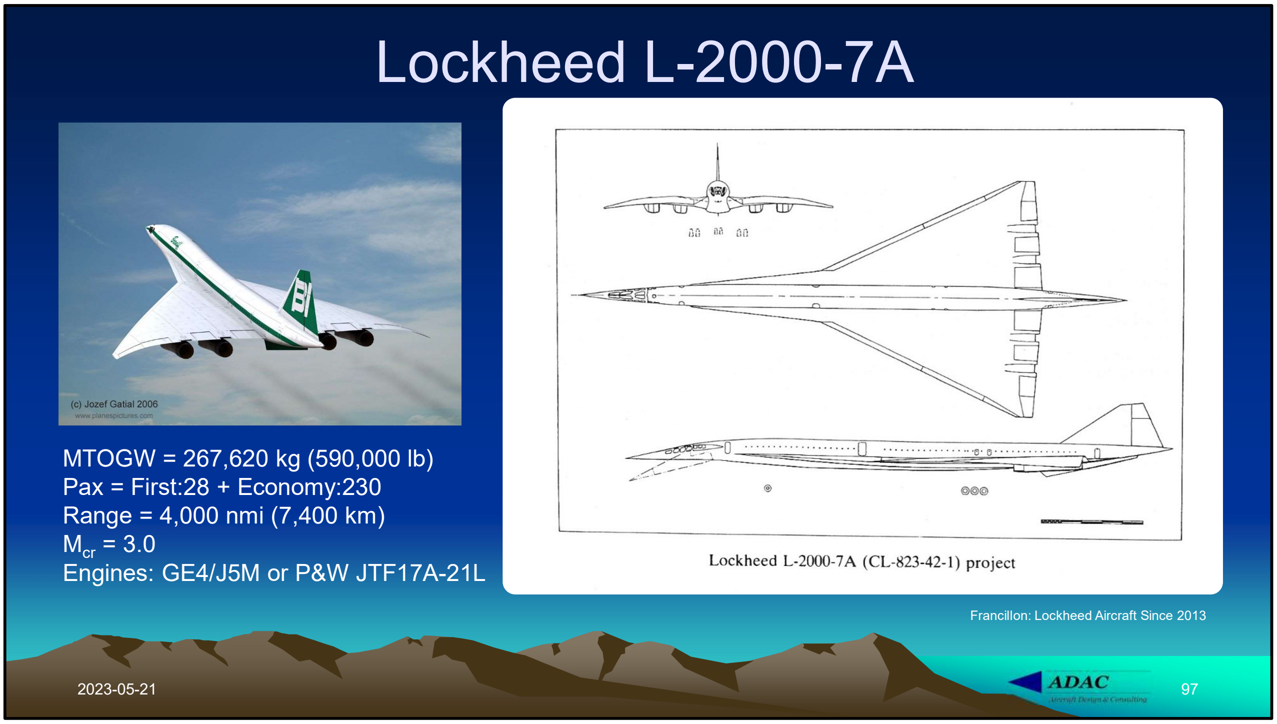
Variable-geometry Configurations

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)

Variable geometry used on several other military aircraft



The L-2000 was a conventional double-delta wing. M_{cr} of 3.0 implies Ti structure, which is difficult to work

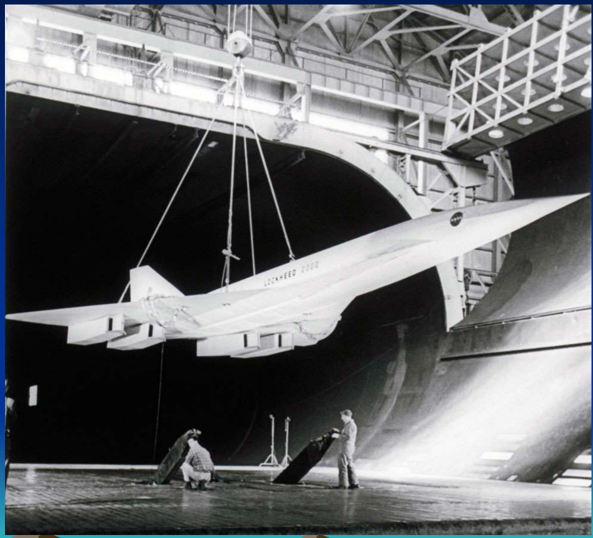
L-2000 Mockup

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

The 40 x 80 ft wind tunnel opened in 1944-06

Boeing 2707-200

Subscale model of variable geometry configuration

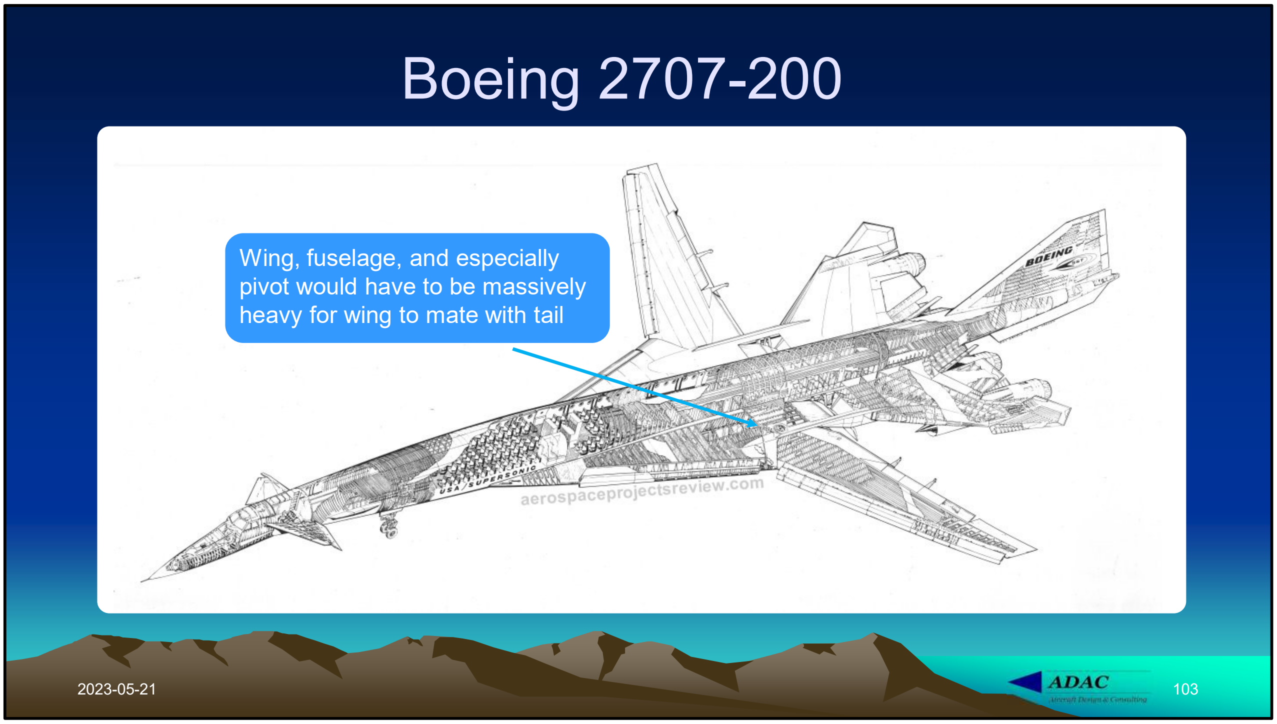
https://i.redd.it/1m77uj18u8m51.jpg

Boeing 2707-200

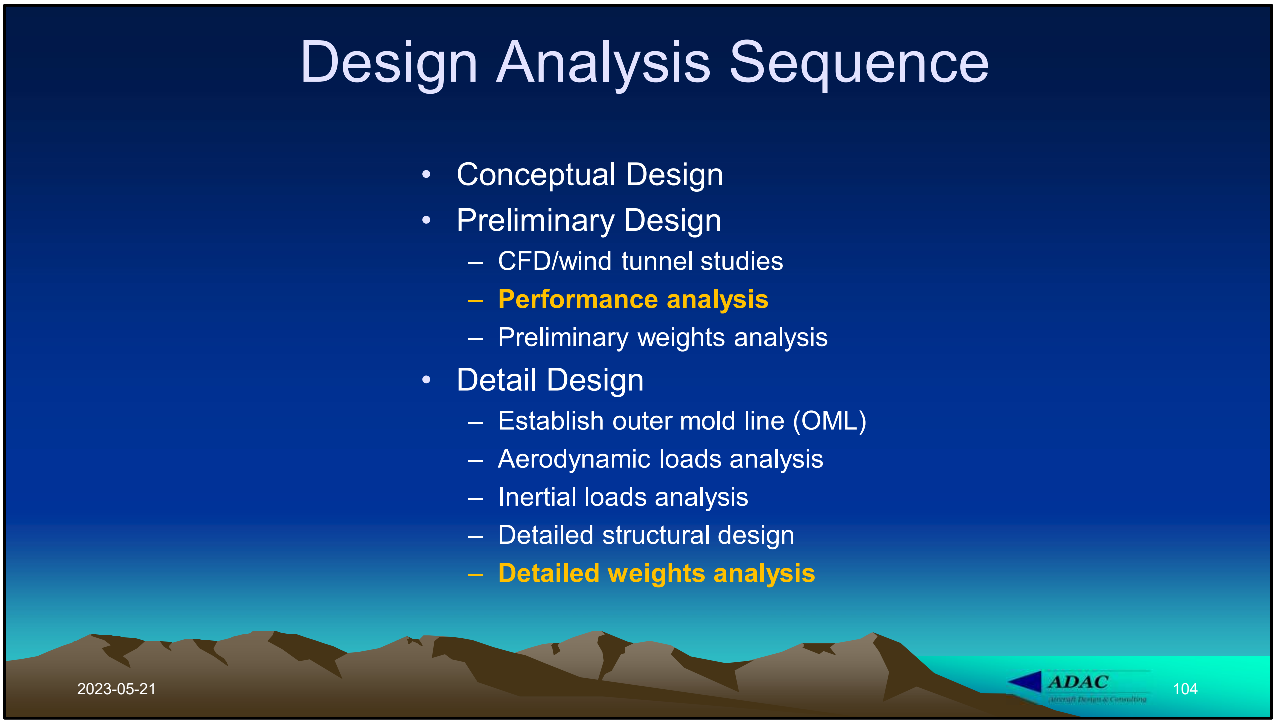
1967-01-01 FAA selects Boeing design

© Gaël Élégoët www.airsoc.com

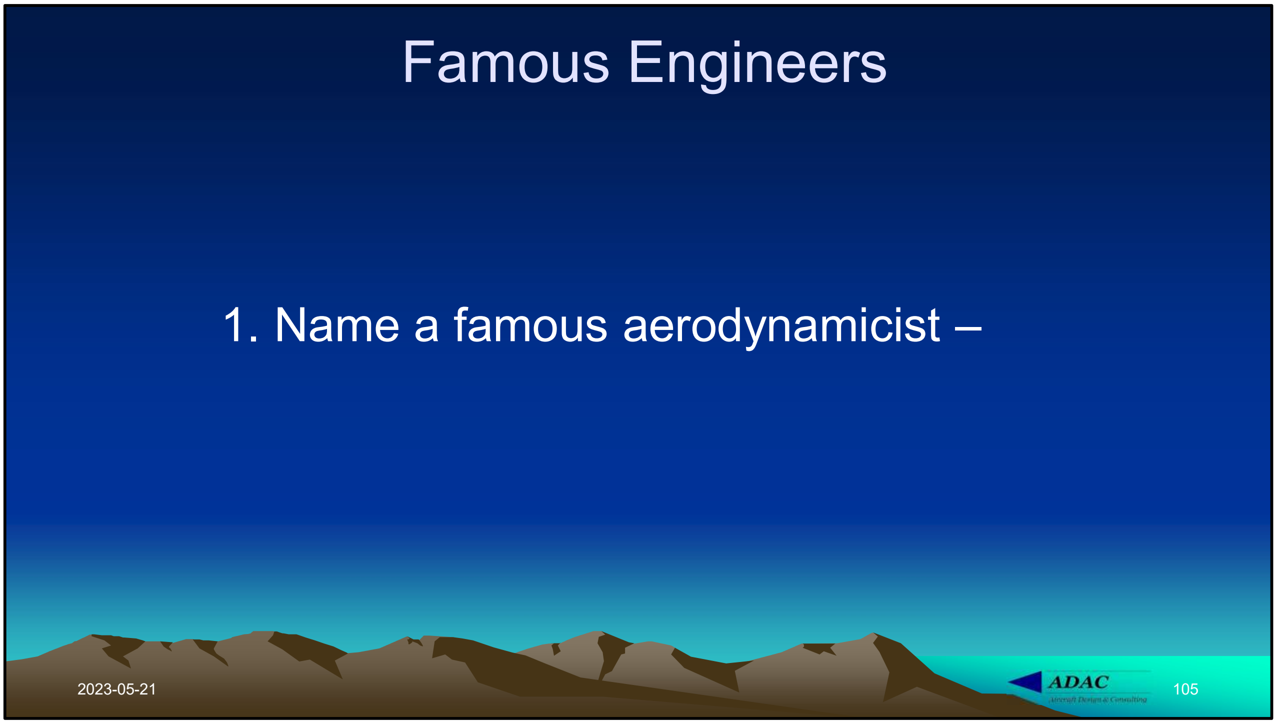
Much to everyone's surprise, the FAA selected Boeing, even though the existence of the SR-71 had proven Lockheed's capability to design a Mach 3 airplane. The FAA probably didn't have enough expertise for evaluation of submitted configurations, especially with respect to weight.



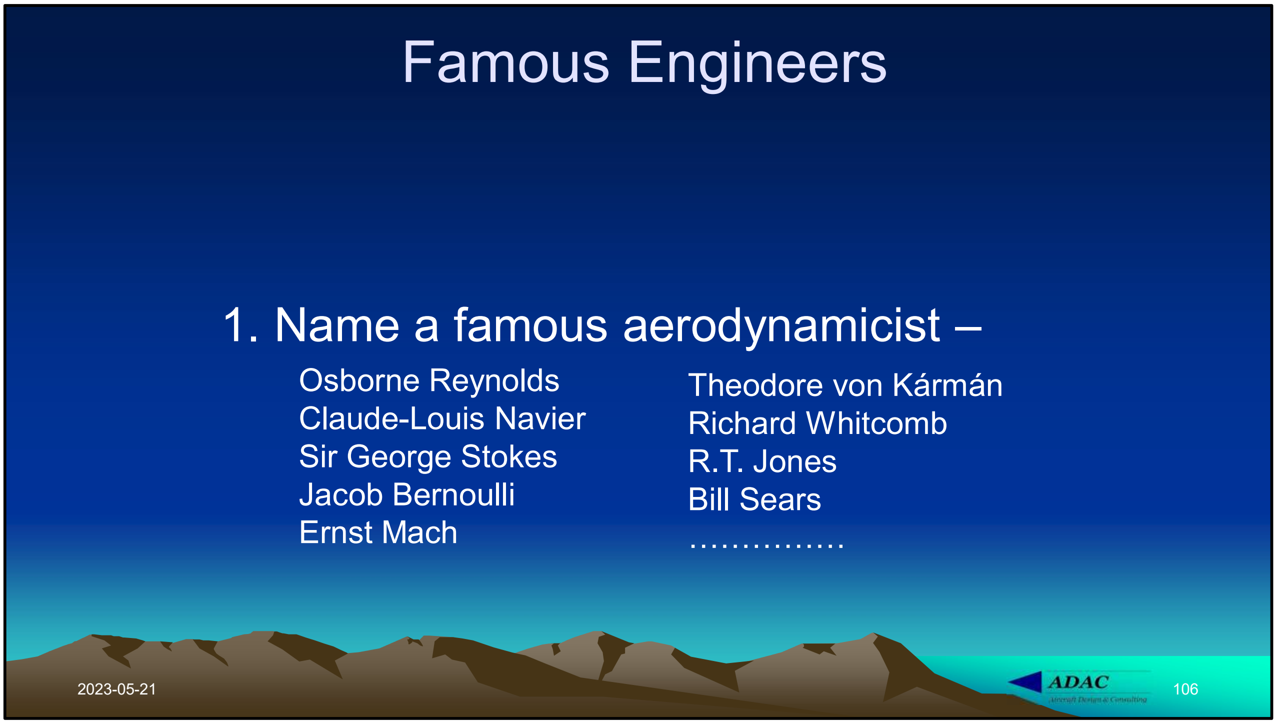
Boeing had trouble mating the wing with the horizontal stabilizer in a static rig test. They had doubts if they could possibly do it under dynamic loading conditions



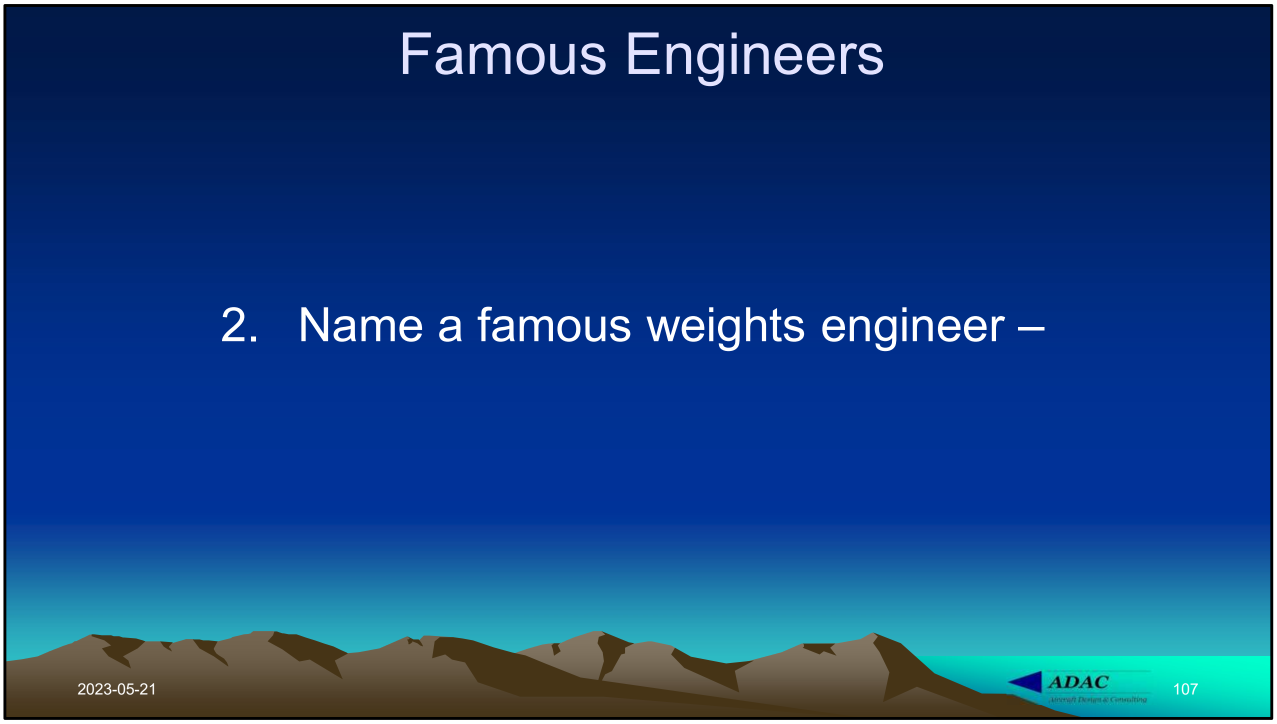
Weight estimation is especially difficult for a novel configuration, and meaningful weight analysis could not be done until the detail design stage. Solid modelling and software-based volume (and thus mass) estimation makes life easier for mass properties engineers



Osborne Reynolds, Claude-Louis Navier, Sir George Stokes, Jacoob Bernoulli, Ernst Mach, Richard Whitcomb, R.T. Jones, Theodore von Kármán, Bill Sears



We all know the names of famous aerodynamicists

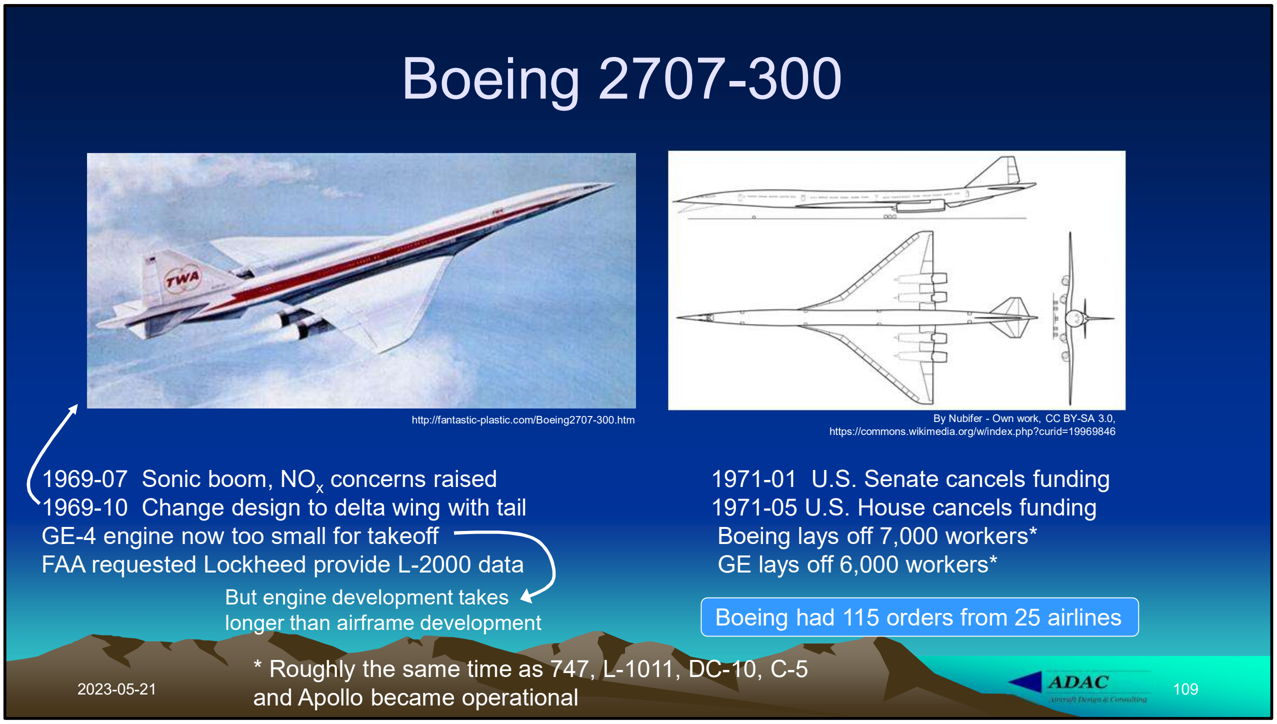


Nobody can name a famous mass properties engineer

Boeing 2707-300

Model of fixed geometry configuration in 1970

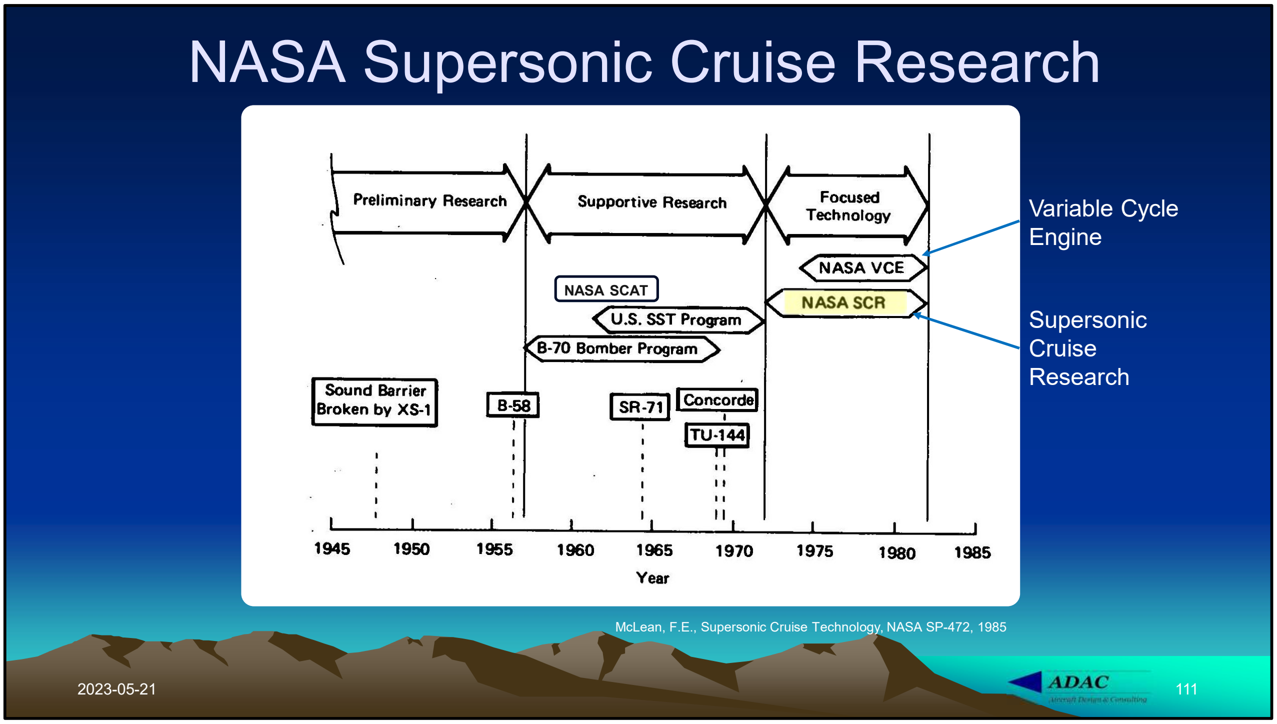
https://secure.boeingimages.com/archive/Boeing-SST-Mockup-Press-Show-1970-2JRSXLJQRFHB.html



For FAA's request for Lockheed to supply data, see LM Newsletter 2020-07. Engine development takes longer than airplane development, and with a fixed wing design, Boeing now did not have an engine to meet requirements. Boeing management was only too happy to cancel the program and accept a US government termination payment.

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 continued studies for a 2nd generation SST through the Supersonic Cruise Research program. The title had no mention of a supersonic transport, so as not to dissuade the US Congress from funding it

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

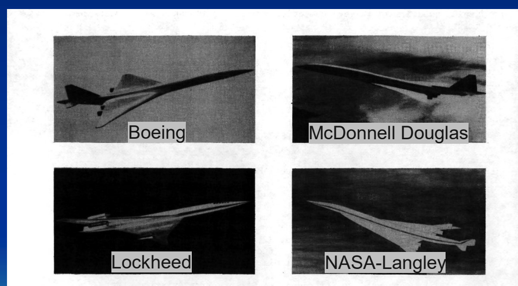


Figure 1.- Advanced supersonic cruise aircraft configurations.

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)

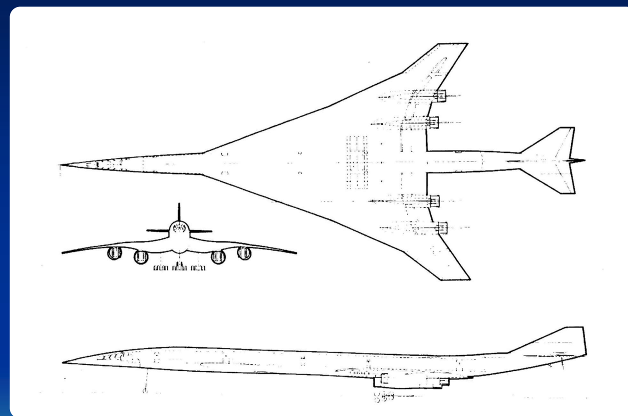
Lawrence Benson "Quieting The Boom"

Neil Driver took over as manager of SCR program in 1978, or thereabouts. Vince Mascitti was specialist in acoustics and sonic boom, and also kept the rest of us in good humor with his jokes. When Neil disagreed with one of our viewgraph slides, he would call out "That's bullshit".

Lockheed CL1627-1 Common Case Study

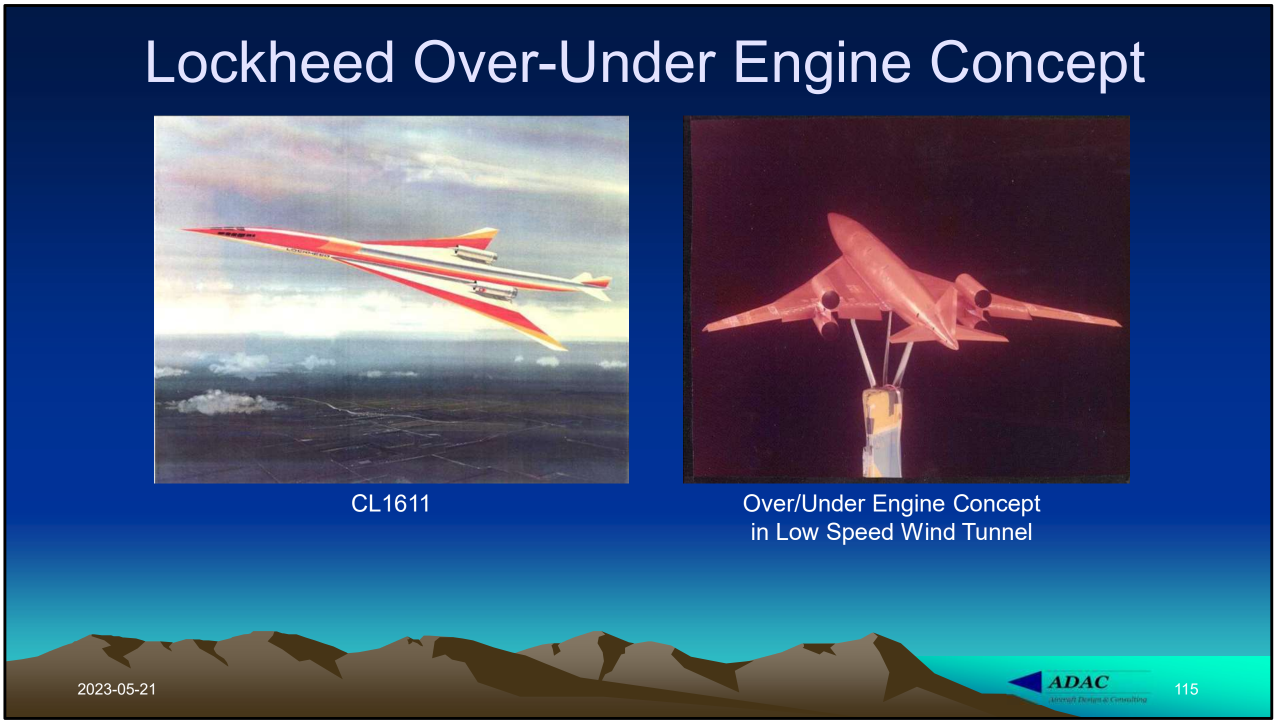
Study performed for the International Civil Aviation Organization (ICAO) by
- United States
- United Kingdom
- France
- Soviet Union

- 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)

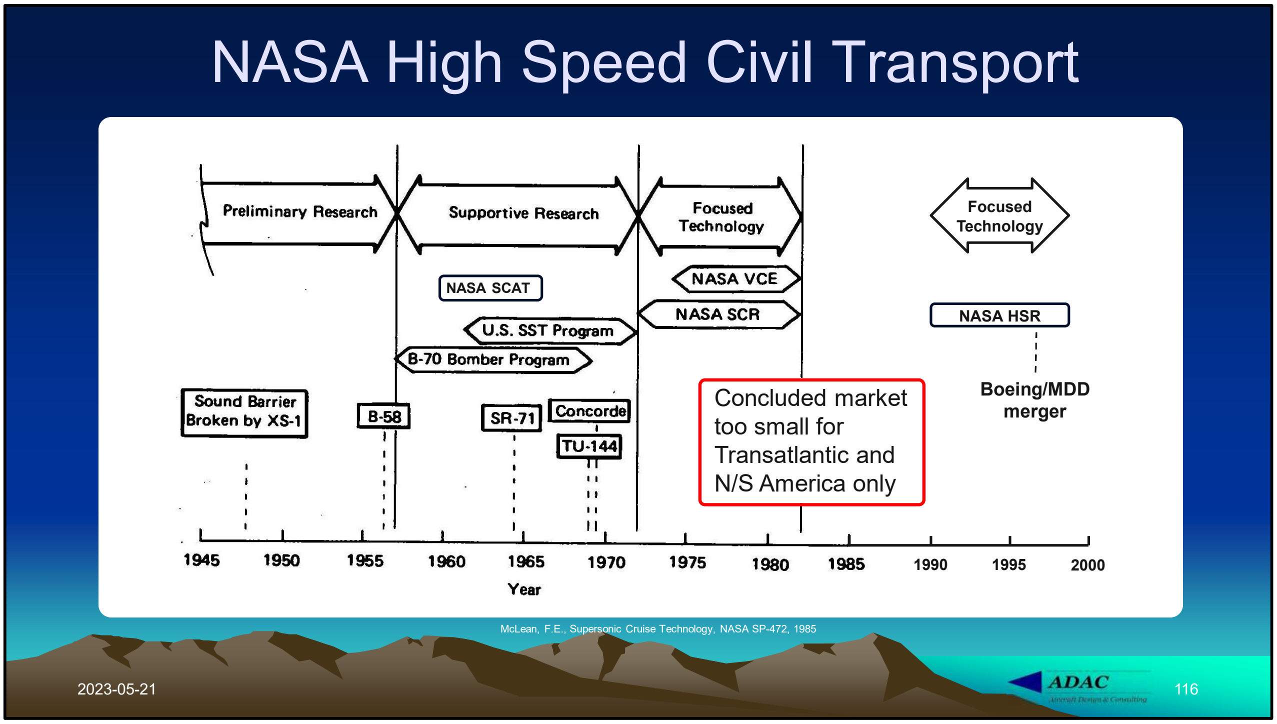


Clauss, J.S., Hays, A.P., Wilson, J.R., The Common Case Study, NASA CR-158935, 1978

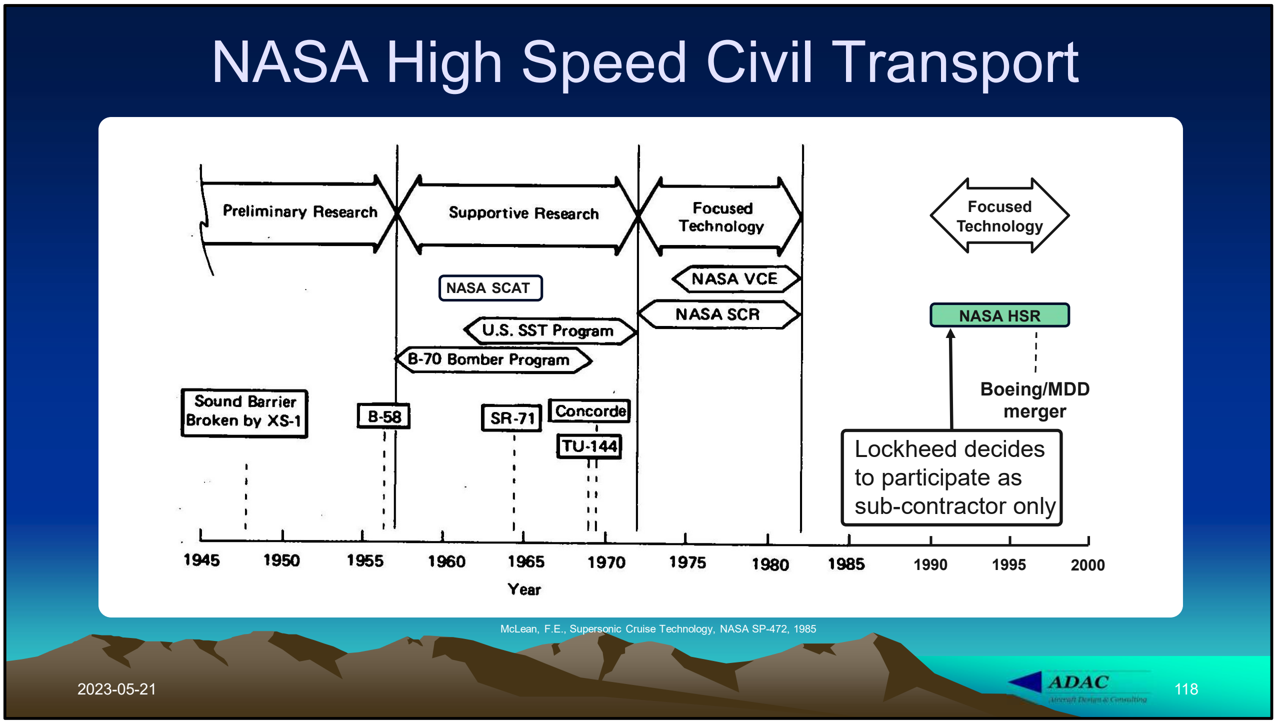
Lockheed preferred the over-under engine layout, but ICAO requested a conventional engine layout with 4 engines under the wing



The over/under nacelle concept provided more space for trailing edge flaps, would reduce wing structural weight because upper and lower nacelles shared a common structural rail in the wing, and also reduced takeoff noise directly under the flight path by acoustically shielding the upper engine exhaust noise by the lower engine exhaust. The disadvantage was that upper nacelles received airflow at a Mach number that was higher than the actual flight value, resulting in slightly lower inlet recovery.



In 1982 a market study by Lockheed showed that the market was too small for Transatlantic and North/South America only. TransPac would require a refuelling stop in Anchorage or Hawaii.



Phase 1 focused on several environmental concerns: NOx emissions which can deplete the ozone layer, community noise, sonic boom noise, and high-altitude radiation. Tests relevant to each concern were carried out. A U-2 spy plane, renamed to the ER-2, was used to measure high-altitude emissions from a Concorde jet, and to measure the radiation environment at high altitudes. New engine nozzle technologies were tested to reduce takeoff and landing noise. Sonic boom mitigation technologies were tested using an SR-71 Blackbird, but were considered to be economically unviable; instead, HSCT would be limited to subsonic speeds over land. (Source: Wikipedia)

Phase 2 demonstrated several key technologies' economic viability. Two F-16XLs were used to test supersonic laminar flow control and to validate advanced CFD design methods. Instead of using the droop nose like that on the Concorde, an "external vision" system would have replaced the cockpit windows entirely with computer-generated graphics made available to the pilots on cockpit displays. Finally, a variety of materials were designed and tested against the very high temperature of Mach 2.4 flight, with titanium and a unique variety of carbon fiber being leading candidates for different areas of the craft. (Source: Wikipedia)

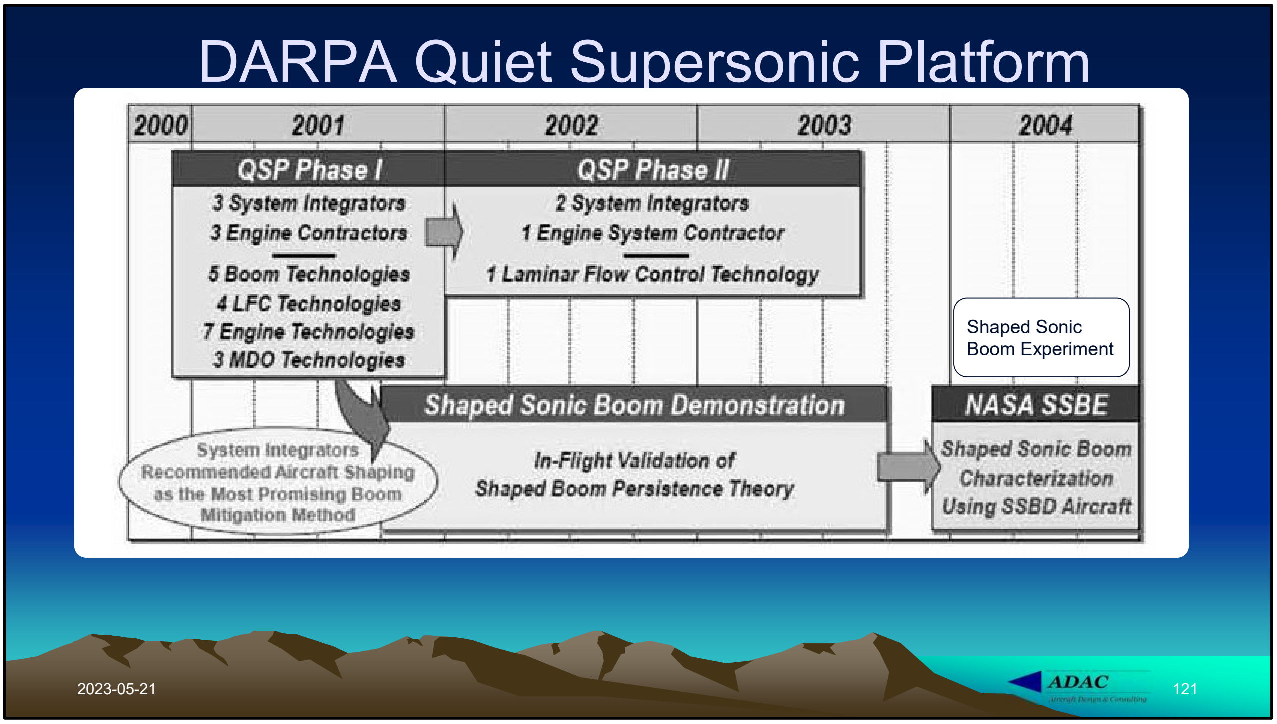
Lockheed/NASA NLF SST Concept

C. 1994

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

Primary benefit from improved takeoff and landing performance

Lockheed determined that the decrease in cruise drag was small, and that the primary benefit came from decreased thrust/weight and wing loading resulting from improved takeoff and landing performance.



"Quiet Supersonic" is an oxymoron

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

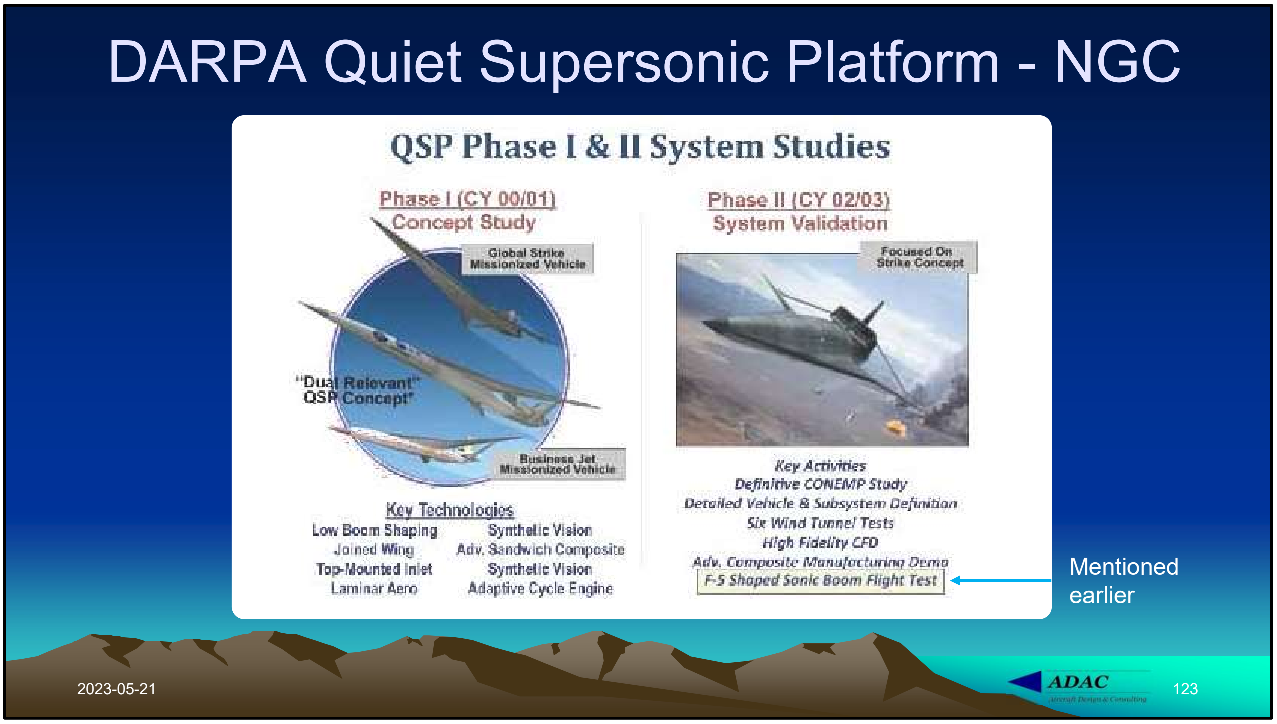
https://www.globalsecurity.org/military/systems/aircraft/qsp.htm

2023-05-21

ADAC

122

The DARPA goals were wildly optimistic and impossible to achieve



Joined wing concept of Julian Wolkovitch

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

For transpac, passengers will still be sitting in a small seat for 6 hours. This shows the joined wing concept that Julian Wolkovich had been promoting for many years. This enables thinner wing sections. For config shown here, would need large Vtail for Vmc requirement. For similar design with canard, see also 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

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

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

Sonic boom 1% of Concorde? Impossible. Material source: https://en.wikipedia.org/wiki/SAI_Quiet_Supersonic_Transport#:~:text=Supersonic%20Aerospace%20International%2C%20LLC%20(SAI,Gulfstream%20Aerospace%20founder%20Allen%20Paulson.

Lockheed Martin 2^{nd} 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

2023-05-21 ADAC Aircraft Design & Consulting 126

The referenced article claims NYC-LAX in 2.5 hours, but it would be impossible to reduce the sonic boom to an acceptable level and still carry 80 pax.

Lockheed Martin 2nd Gen. SST

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

Source: Aviation Week

2023-05-21

ADAC

Aircraft Design & Consulting

127

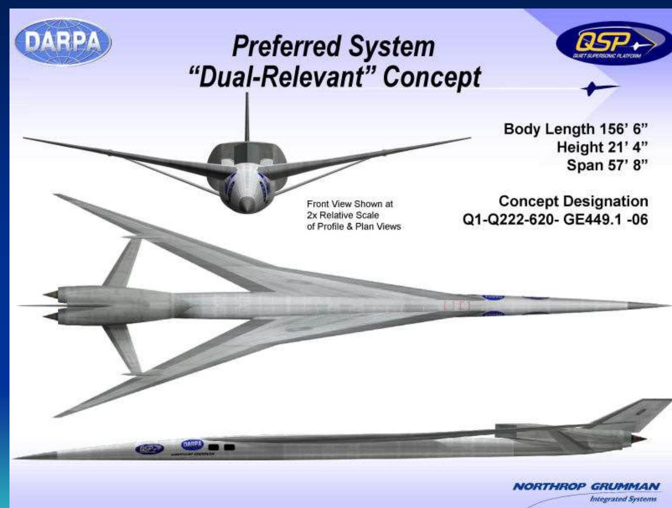
In wealth spectrum, looking for people who can’t afford their own bizjet, but whose time is very valuable. Are there enough people? UAL is abandoning first class. Presumably using gr-epoxy so limited to approx. M 1.6. Can you use high-temp composites?

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

2023-05-21 ADAC Aircraft Design & Consulting 129

With a thin wing, where are the fuel tanks for 6,000 nm range?

Lockheed Martin 40 pax SST

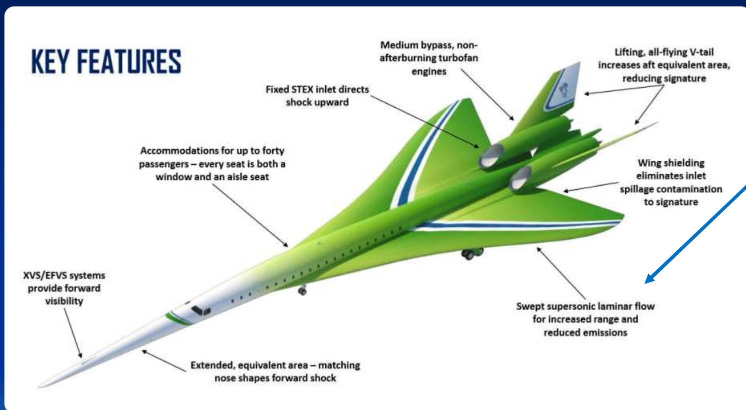
- M 1.8
- Threshold range = 7780 km (4,200 nmi)
- Goal range = 9820 km (5,300 nmi)
- TOFL = 3,200 m (10,500 ft)
- Length = 69 m (225 ft)
- Estimated boom = 75 PLdB* (Concorde boom = 105 PLdB)

* Perceived Loudness in decibels

https://www.lockheedmartin.com

Perceived Loudness is a measure of sonic boom loudness and will be explained shortly. 75 PLdB is goal of X-59. How can a passenger-carrying aircraft match that.? Range must be > 4,500 nmi, otherwise market is too small

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

Cannot fly supersonically JFK-LHR (2,991 nmi), so where <u>can</u> it fly supersonically?

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

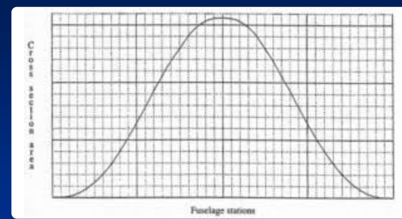
- NASA/Lockheed X-59
- Supersonic Bizjets
- Supersonic Transports

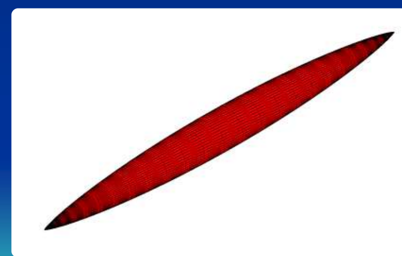
Sears-Haack Body

- 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



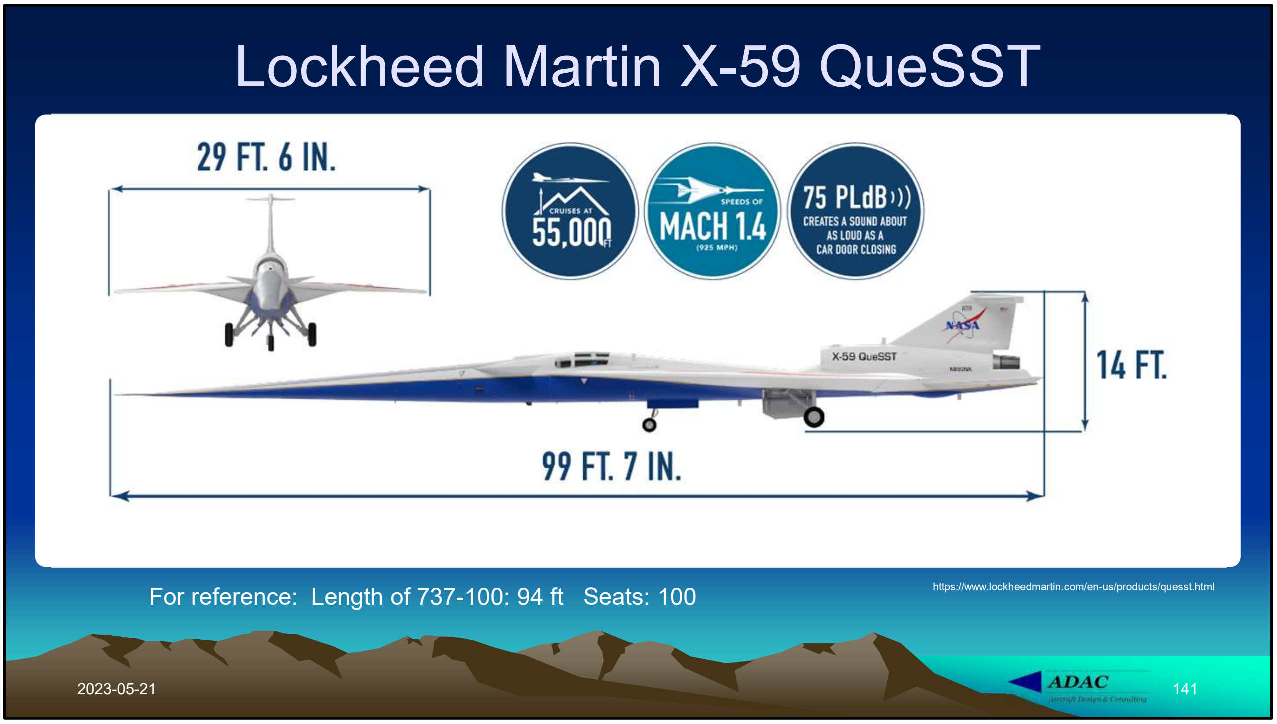


Lockheed Martin X-59 QueSST

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

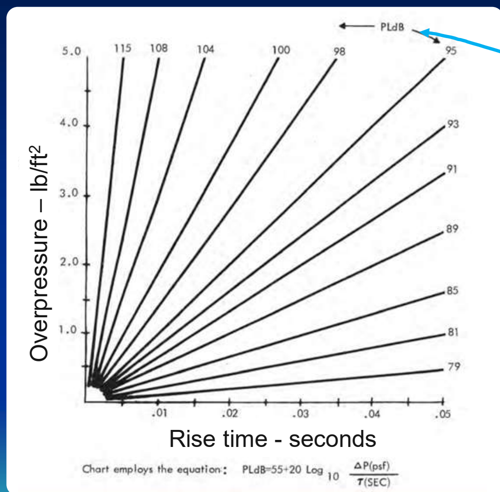
2018 LM awarded contract to design, build and fly Low Boom Flight Demonstrator (LBFD)
2021-22 planned first flight (now 2023 first flight)
2023 planned operational

One goal of the program is to convince the US Congress to relax the ban on supersonic overland commercial operations



One goal of the program is to convince the US Congress to relax the ban on supersonic overland commercial operations.
Source of 737-100 length https://www.airliners.net/aircraft-data/boeing-737-100200/91

Perceived Loudness in dB (PLdB)



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

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

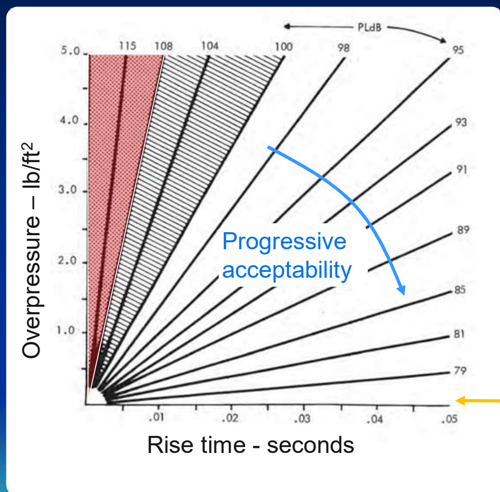
ΔP = overpressure

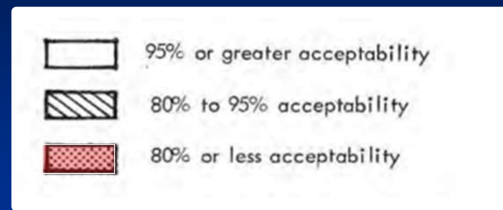
τ = rise time

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)





Lockheed claims X-59 PLdB of 75

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

2023-05-21

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

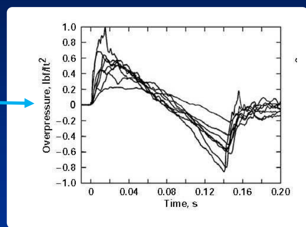
Lockheed Martin X-59 Cockpit

- 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

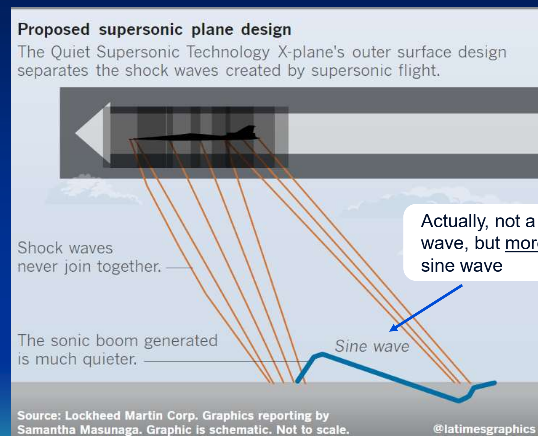
Instead of sonic boom N-wave



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

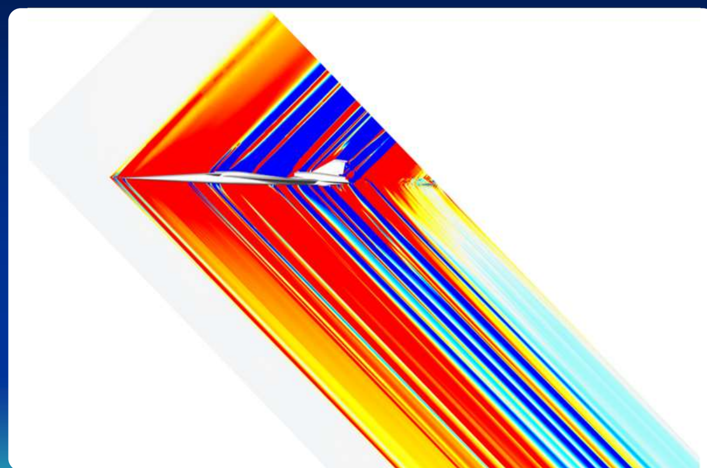


Actually, not a sine wave, but more like a sine wave

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

Remember two important range requirements: 3,000 nmi for transatlantic and 4,500 nmi for transpac

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

For boomless cruise, see NASA report Quieting the Boom, p.56, which says that it might be possible up to M 1.15

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.

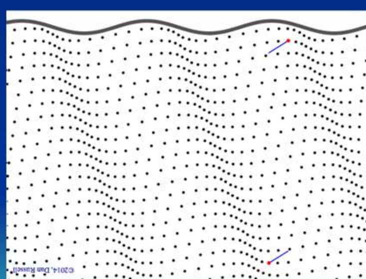
Aerion AS-2

- 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)

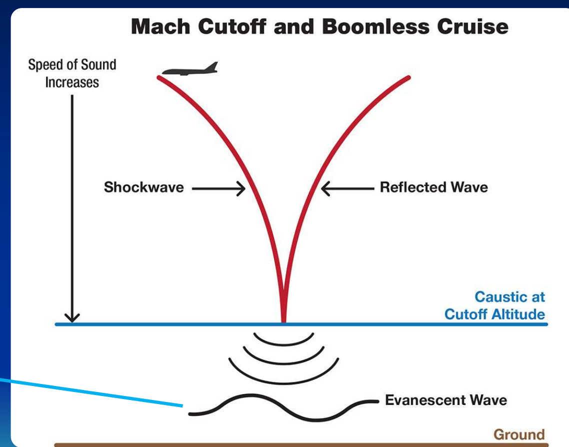
Source: Aerion

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



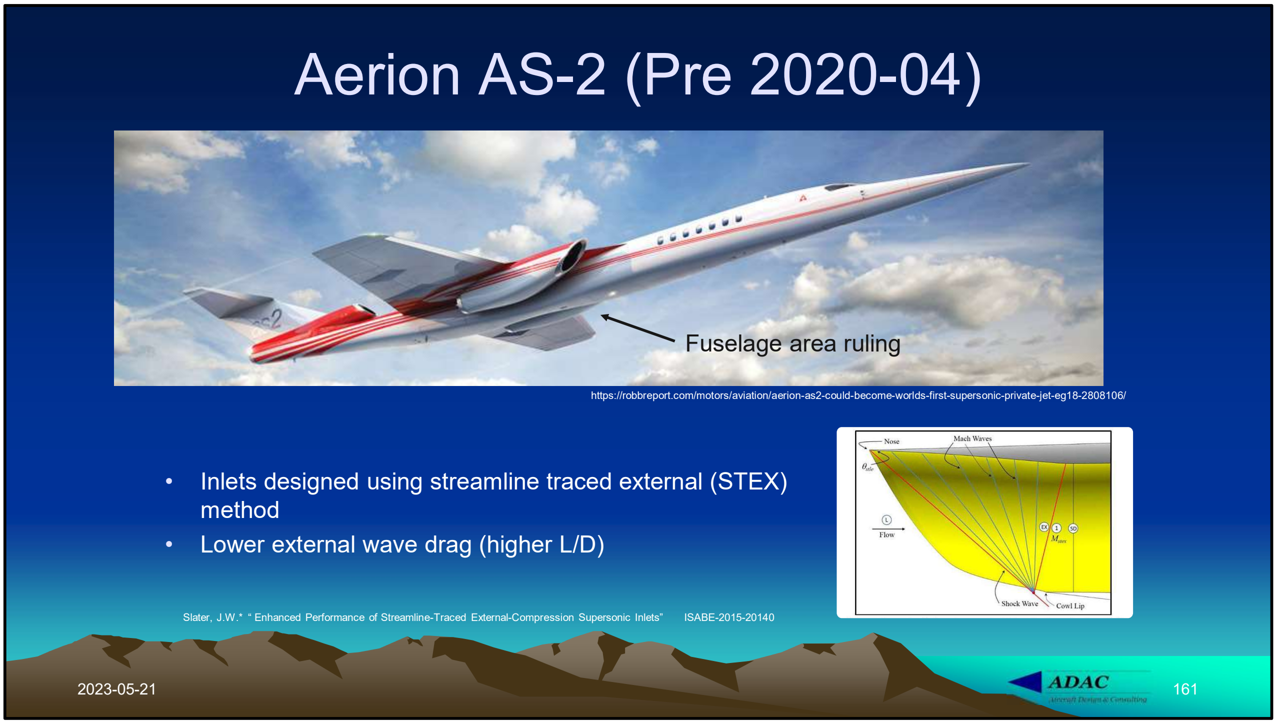
Aerion.com

For boomless cruise, see NASA report Quieting the Boom, p.56, which says that it might be possible up to M 1.15

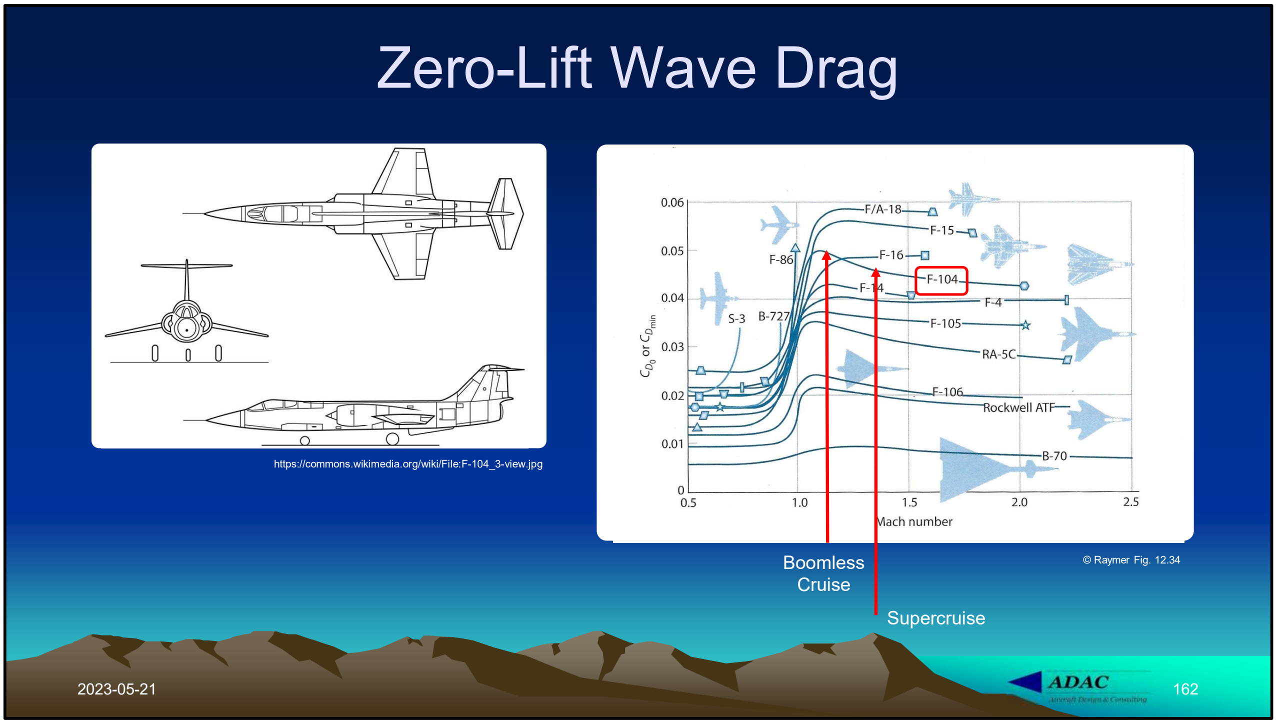
Aerion AS-2 (Pre 2020-04)

- 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/



Results indicate the integrated axisymmetric spike design offers higher inlet pressure recovery, lower fan distortion, and reduced sonic boom. The vehicle with the streamline-traced inlet exhibits lower external wave drag, which translates to a higher lift-to-drag ratio and increased range capability. "Inlet Trade Study for a Low-Boom Aircraft Demonstrator" Christopher M. Heath∗ and John W. Slater† NASA John H. Glenn Research Center at Lewis Field, Cleveland, Ohio 44135 And Sriram K. Rallabhandi‡ National Institute of Aerospace, Hampton, Virginia 23666



It is very difficult to design a low-drag configuration at the Mach number for boomless cruise

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

Pressure ratio data from Bjorn’s Corner Part 10

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

Pressure ratio data from Bjorn's Corner Part 10

Aerion Program Shuts Down

2021-05-24

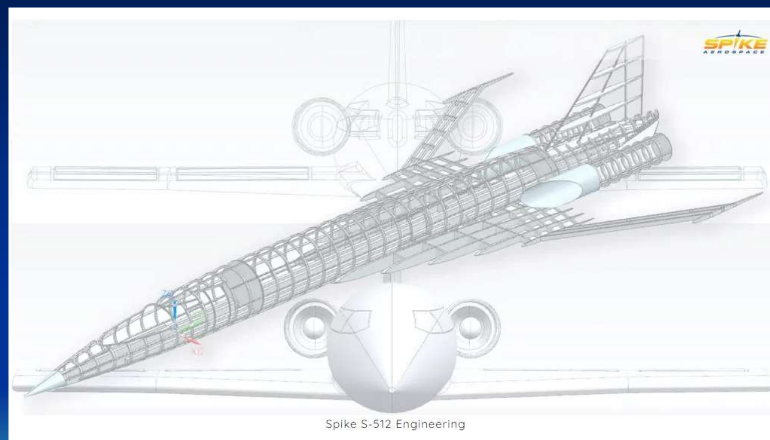
> *"The AS2 supersonic business jet program meets all market, technical, regulatory and sustainability requirements, and the market for a new supersonic segment of general aviation has been validated with $11.2 billion in sales backlog for the AS2.*
>
> *"However, in the current financial environment, 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 hasn't raised any money after 10 years of existence, although it has 22 employees (https://www.datanyze.com/companies/spike-aerospace/357669190)! The numbers on this slide are, to put it nicely, speculative.
https://tracxn.com/d/companies/spike-aerospace/__lhiHaGkG0M97t6zBrYiUe4nxyR4F0uvylQGpZYliqmk

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/

This claims for this configuration are divorced from reality

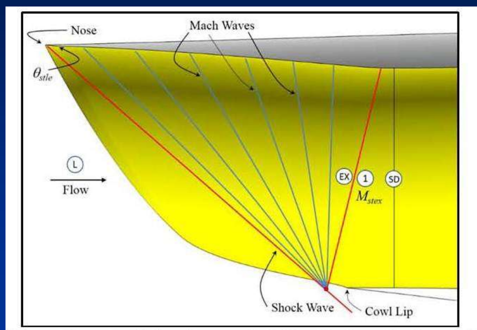
Spike Aerospace S-512

- Synthetic exterior display

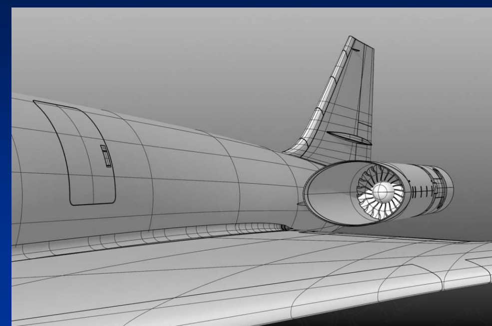
http://www.spikeaerospace.com/spike-images/

Intriguing concept, but is it feasible?

Spike Aerospace S-512 STEX Inlet



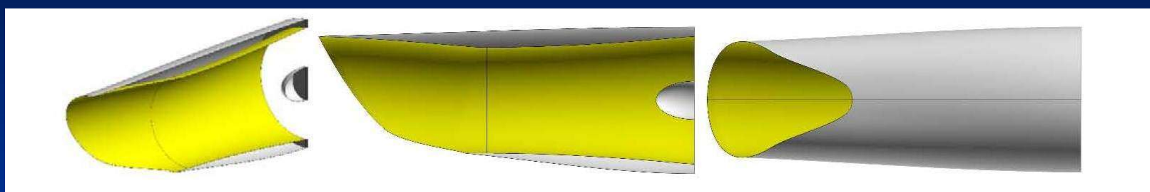
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160010068.pdf
Slater, J.W., "SUPIN: A Computational Tool for Supersonic Inlet Design"



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

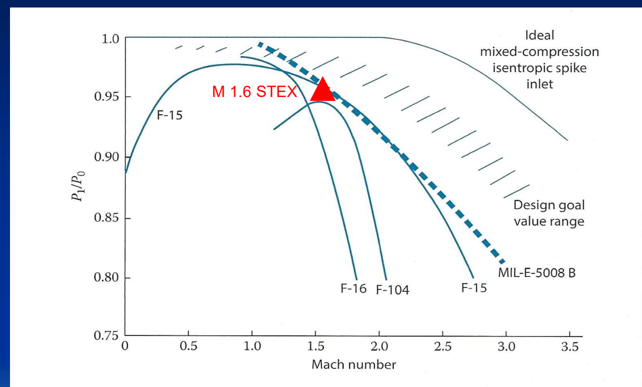


https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160010068.pdf
Slater, J.W., "SUPIN: A Computational Tool for Supersonic Inlet Design"

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

From the Spike website, Dr. Agrawal appears to be the head of engineering. It’s a bit of a mystery why he is endorsing a set of performance requirements that are highly unlikely to be met

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)

Cockpit visibility at TO and Landing? Total funding based on https://tracxn.com/d/companies/boom-supersonic/__4kTumlmSWdPzDsD6fbqFwRMEU5v-e-eFlKVTkqxhaWA

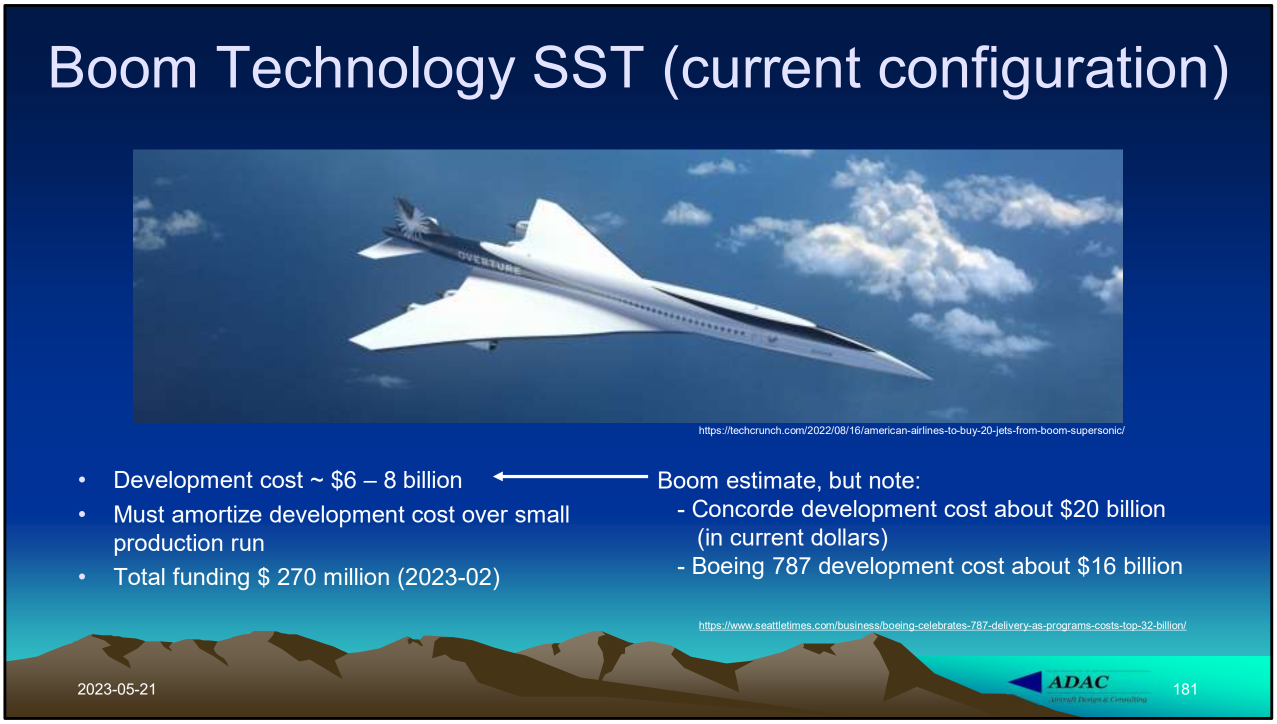
Boom Technology SST

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)

Visibility at TO and Landing? See
https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_90-106A.pdf
Turbulent BL about 1 ft thick at nacelle lip



For Boom development cost, see https://www.linkedin.com/pulse/boom-aerospace-bust-brent-wouters/?trk=pulse-article

For Concorde development cost, see https://en.wikipedia.org/wiki/Concorde#cite_note-10. Other estimates of total program cost exceeded £2 billion. *New Design Concepts for High Speed Air Transport* edited by H. Sobieczky (1997)

Quote:

"The program's cost, through March 1976, was put at between 1.5 and 2.1 billion in 1976 pounds sterling, or between 3.6 and 5.1 billion in 1977 U.S. dollars (yearly weighted exchange rates)." Say development cost was $4.1 billion (1977$) or $20 billion in 2023$ using https://www.in2013dollars.com/us/inflation/1977?amount=4.10

In 2011, estimate of 787 development cost was about $16B: 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”

2023-05-21 ADAC Aircraft Design & Consulting 182

For comparison seat pitch on UA A320 first class is 39”, 757 Polaris class is 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

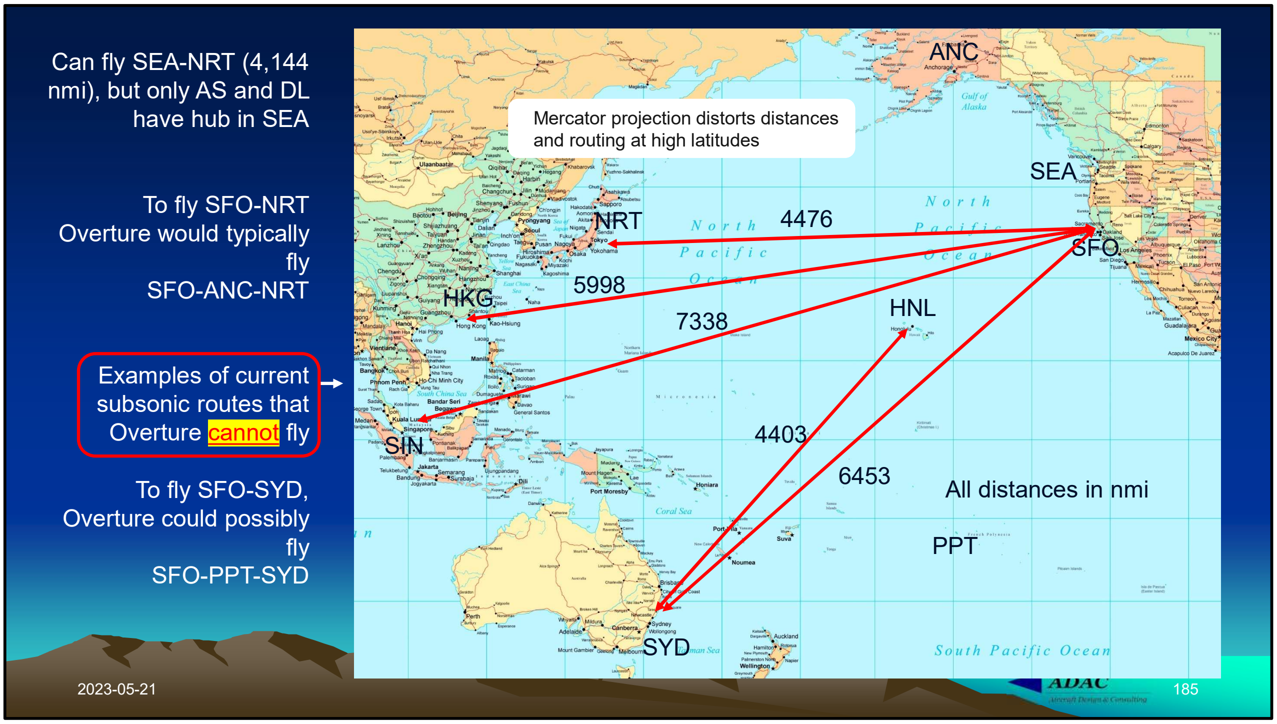
2023-05-21

ADAC

183

UA has probably set stringent requirements that Boom is unlikely to meet, but it makes UA appear to be forward-thinking. AA has also ordered 20 aircraft (https://techcrunch.com/2022/08/16/american-airlines-to-buy-20-jets-from-boom-supersonic/)

Price of $200 million is low. As of 2024-05, a 787-9 list price is $265 million, but it can be discounted as low as $143 million https://airinsight.com/wp-content/uploads/2016/02/247wallst-com.pdf



SFO-HNL 2084 nmi, HNL-GUM 3303 nmi, GUM-SYD 3261 nmi. SFO-PPT 3639 nmi. PPT-SYD 3308 nmi Runway length at PPT 3,420 m (11,220 ft). UA closed its SEA crew base in 2015 and does not fly non-stop SEA-NRT. Routes shown here are all UA, except HNL-SYD, which is flown by HA

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/

2023-05-21 ADAC Aircraft Design & Consulting 187

Most data from Wikipedia. It’s not obvious what will be learned from this flight test model. Apart from wing planform, there is very little in common with full-scale aircraft

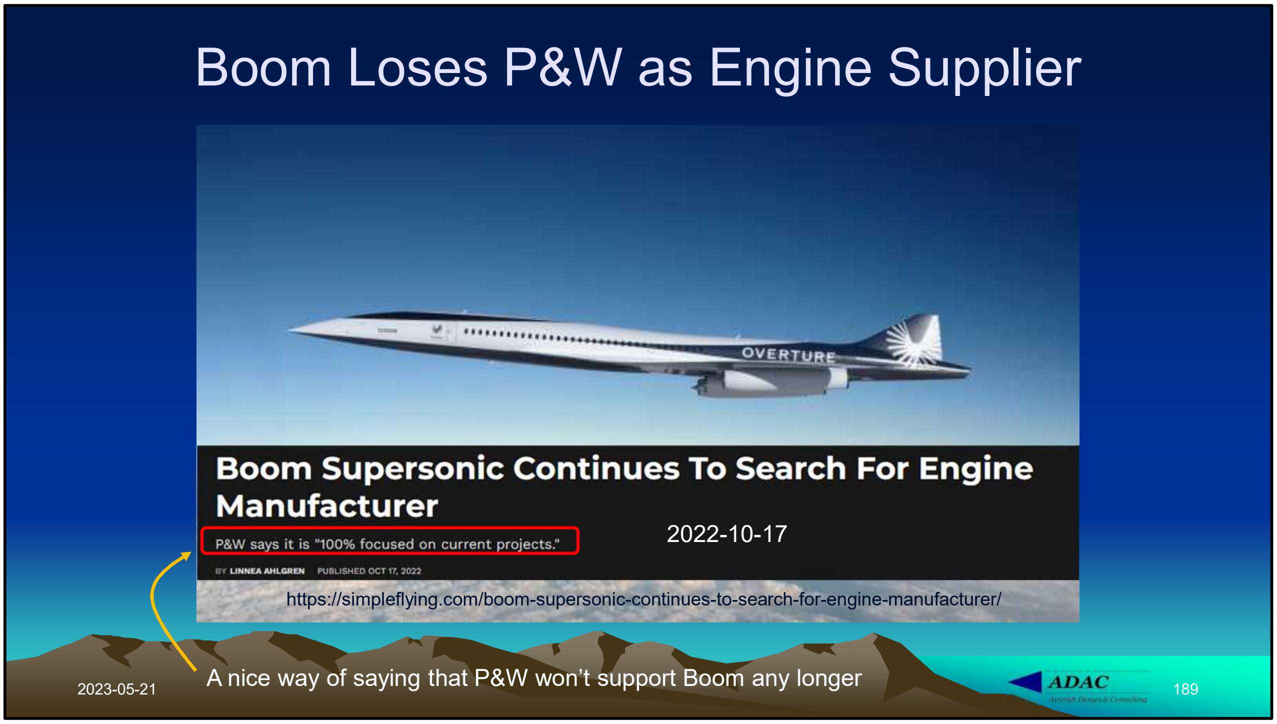
Boom Technology XB-1

https://boomsupersonic.com/

Current Overture configuration has axisymmetric inlets

https://boomsupersonic.com/xb-1

- Ground testing

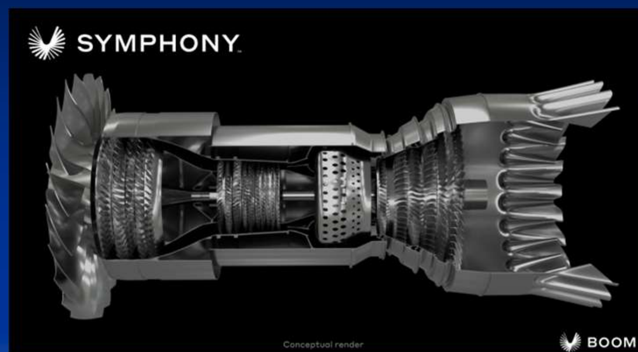


Similar to Aerion's loss of GE support for development of propulsion system for AS-2, Boom lost support from P&W

New Engine Developers

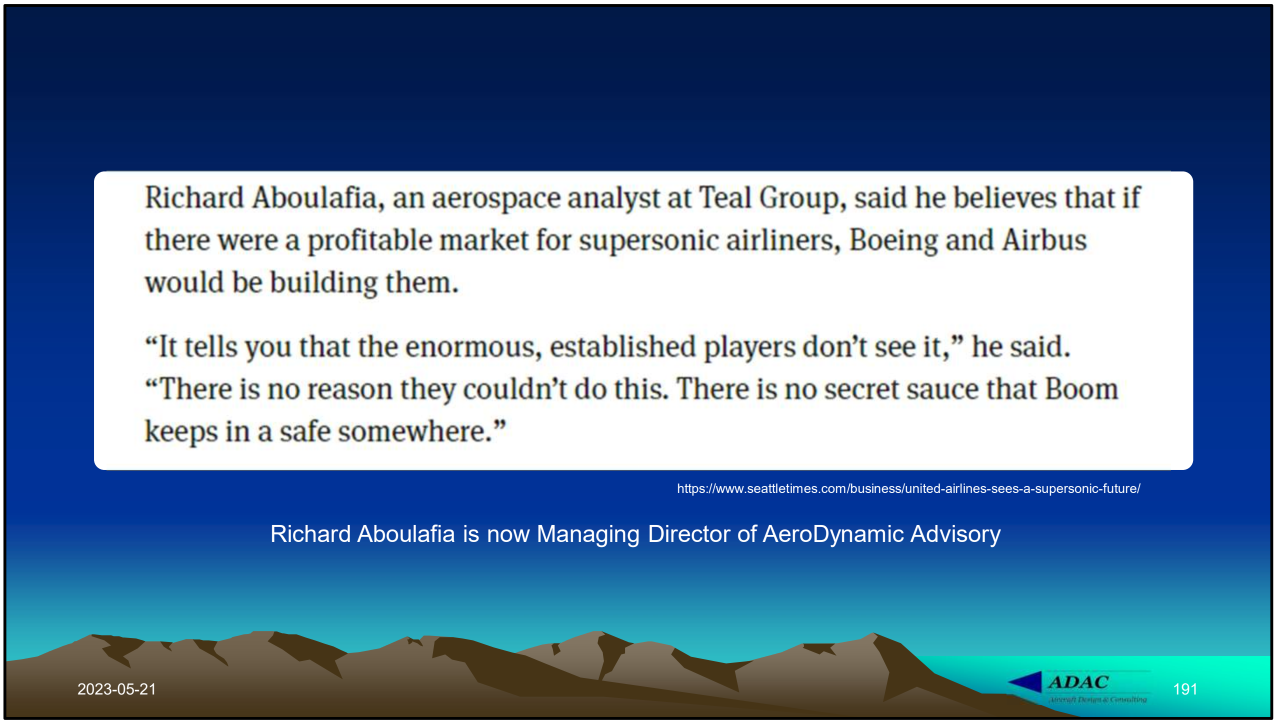
2022-12-13 "Boom Supersonic, the company behind what is touted to be the next supersonic passenger aircraft – Overture – has finally secured an engine maker to deliver the powerplants for its jet."

"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/

Florida Turbine Technologies has never made any jet engine larger than those for cruise missiles and UAVs (https://www.kratosdefense.com/about/divisions/turbine-technologies)



Richard Aboulafia is a well-respected industry analyst.

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/

2023-05-21 ADAC Aircraft Design & Consulting 192

The Exosonic website https://exosonic.com/ makes claims that are obviously impossible, such as flying LAX-JFK subsonically in 3 hours. JFK-LAX is 2151 nmi. Speed of sound at 36,000 ft is 573 kt.

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

Shaping the Future of Aerospace

Orange County Section

Thanks for your interest

An expanded and annotated pdf of this presentation is available
at www.adac.aero/class-presentations