

XB-70, SR-71, & TU-144

Large Supersonic Transports



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XB-70 Valkyrie



- Intended Role: High-Altitude Supersonic Bomber
- After U-2 bombing: Production Program Cancelled
 - New Role: Research Test Bed for Large Supersonic Transport
 - Capable of sustained, long-range supersonic flights

The original role of the XB-70 was to be a high-altitude supersonic bomber, to be escorted by the XF-108 Rapier, a proposed supersonic fighter which was developed by North American Aviation in parallel with the XB-70. The Rapier was also intended as a defensive aircraft to counter an anticipated Russian bomber with capabilities similar to the XB-70.

Once the U-2 aircraft flown by Gary Powers was downed, the viability of the XB-70 was questioned and the program was changed to a research program. The XB-70 Valkyrie seemed to be a perfect testbed for SST research. It was the same size as the projected SST designs, and used similar structural materials, such as brazed stainless steel honeycomb and titanium. Only two XB-70 aircraft were manufactured once the production program was cancelled.

The Flight Research Center had several SST studies underway in the early 1960's. Its Douglas F5D-1 was used for landing studies, a North American F-100C was modified to simulate SST handling qualities, a North American A-5A was used to develop ways an SST would operate in the air traffic control system, and a Lockheed JetStar was modified as an in-flight SST simulator. But the XB-70A was the first transport-sized aircraft capable of sustained, long-range supersonic flight. Its research programs had a significant impact on American SST efforts at the time and could influence the design of future large, supersonic aircraft.

Timeline of XB-70 Research Flights

1st Aircraft

- September 21, 1964: Maiden Flight
- 1964-1965: Airworthiness Tests
- Troubles with construction, leaks, and landing gear
- May 7, 1965: All 6 engines damaged beyond repair
- October 14, 1965: Mach 3+ flight
 - More troubles with honeycomb construction
 - Poor Directional Stability over Mach 2.5
 - Speed Limit (Mach 2.5) imposed on this aircraft

1st Aircraft:

The first XB-70 made its maiden flight on September 21, 1964 from Palmdale to Edwards Air Force Base, Calif. Tests of the XB-70's airworthiness occurred throughout 1964 and 1965 by North American and Air Force test pilots. The first aircraft would be found to suffer from weaknesses in the honeycomb construction, primarily due to inexperience with fabrication of this new material. Construction of the honeycombed panels was much more difficult than anticipated by the designers. The first aircraft was also continually troubled by hydraulic leaks, fuel leaks, and problems with the aircraft's unusually complicated landing gear.

In flight on May 7th, 1965, the divider separating the left and right halves of the engine inlet broke off and was ingested into the engines, damaging all six beyond repair.

On October 14, 1965, on the first flight exceeding a speed of Mach 3, the stress again damaged the honeycomb construction, leaving two feet (600 mm) of the leading edge of the left wing missing. Also, the first XB-70 was found to have poor directional stability above Mach 2.5. The construction problems along with the stability issues resulted in the imposition of a speed limit of Mach 2.5 on the first aircraft.

Despite the problems, the early flights provided data on a number of issues facing SST designers. These included aircraft noise, operational problems, control system design, comparison of wind tunnel predictions with actual flight data, and high-altitude, clear-air turbulence.

Timeline of XB-70 Research Flights

2nd Aircraft

- Added 5 degrees of dihedral and fixed honeycomb construction – Much better handling
- July 17, 1965: Maiden flight of 2nd Aircraft
- January 3, 1966: First Mach 3 flight
- May 19, 1966: 2400 miles in 91 min., Mach 3 for 33 min.
- June 8, 1966: Collision with F-104 at photo shoot
 - Destruction of 2nd XB-70
 - Deaths of 2 pilots

2nd Aircraft:

The honeycomb construction deficiencies were almost completely solved on the second aircraft and 5 degrees dihedral was added. The changes resulted in much better handling.

The first flight of the second aircraft was on July 17, 1965.

The second XB-70 achieved Mach 3 for the first time on Jan. 3, 1966

On May 19th, 1966 aircraft number two flew 2,400 miles (3,840 km) in 91 minutes, attaining Mach 3 for 33 minutes of that flight.

A joint agreement was signed between NASA and the Air Force to use the second XB-70A prototype for high-speed research flights in support of the SST program, selected due to its better aerodynamics, inlet controls, and a much superior instrument package, compared to the first aircraft. The NASA research flights were to begin in mid-June, once the North American Aviation Phase I tests of the vehicle's airworthiness were completed. The flights were to evaluate the aircraft on typical SST flight profiles, and to study the problems of sonic booms on overland flights.

On June 8, 1966, however, it crashed following a mid-air collision with an F-104 that occurred while the aircraft were flying in close formation for a photo shoot.

The destruction of the second XB-70 and deaths of 2 pilots had major consequences for the research program. The second XB-70 had been selected for the Phase II tests, which were to be conducted jointly by NASA and the Air Force. With this aircraft now destroyed, only the first aircraft was available. Given the aircraft's shortcomings, the Air Force began to doubt that it would be able to meet the Phase II test goals.

Timeline of XB-70 Research Flights

After the Crash...

- November 3, 1966: 1st Aircraft flies again
- November 1966 – January 1967
 - 11 Flights for National Sonic Boom Program
- Grounded for Maintenance and Turned over to NASA
- April 1967 – March 1968: 12 flights
 - Measure structural response to turbulence
 - Determine Handling Qualities during Landings
 - Investigate Boundary Layer Noise, inlet performance, structural dynamics
- Fitted for the Identically Located Acceleration and Force (ILAF) experiment
- SR-71 was far more advanced technology – ended XB-70
- February 4, 1969: final XB-70 flight
 - Subsonic structural dynamics test & ferry flight
 - Landed at Wright-Patterson Air Force Base for display at the Air Force Museum

After the Crash:

The first XB-70 was undergoing maintenance and modifications at the time of the accident to its sister ship. It did not fly again until Nov. 3, 1966. The first aircraft with its limited abilities continued research, making 33 more research flights. A top speed of Mach 2.57 was the highest attained during the remainder of the XB-70 program.

11 flights were made between Nov 1966 and Jan 1967. These flights were made as part of the National Sonic Boom Program. The XB-70 flew at differing altitudes, Mach numbers, and weights over an instrumented test range at Edwards. The "boom carpet" area was determined and the overpressure measured on two specially constructed housing units. The tests showed that a large aircraft, such as the XB-70 or the projected SST, could generate overpressures high enough to cause damage. Moreover, when the XB-70 made a turn, its shock waves converged, and often doubled the overpressure on the ground.

Following these tests, the XB-70 was grounded for maintenance that lasted 2 1/2 months. The Air Force had concluded by that point that the XB-70 program should be turned over to NASA as soon as possible.

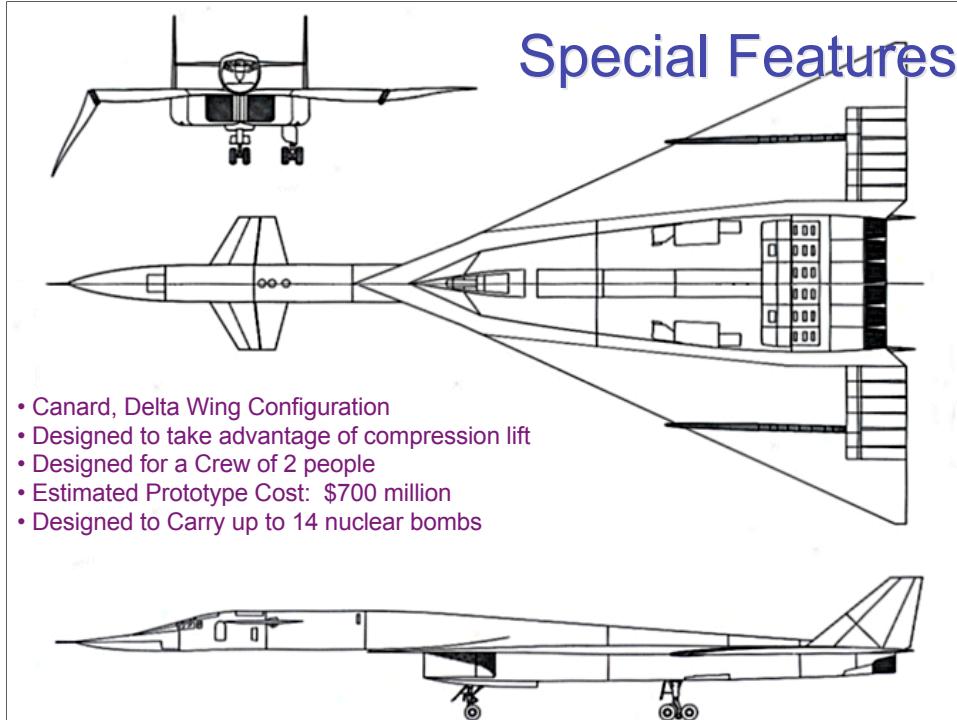
The first NASA XB-70 flight occurred on April 25, 1967, by Fulton and Cotton. By the end of March 1968, another 12 research flights had been completed. The flights acquired data to correlate with an Ames ground-based SST simulator and the JetStar in-flight SST simulator at FRC. Other XB-70 research goals were to measure its structural response to turbulence; determine the aircraft's handling qualities during landings; and investigate boundary layer noise, inlet performance, and structural dynamics, including fuselage bending and canard flight loads.

The XB-70 underwent modifications after a final flight on March 21, 1968. The XB-70 was fitted with two small vanes for the Identically Located Acceleration and Force (ILAF) experiment. The vanes rotated 12 degrees at a rate of up to 8 cycles per second. This induced a structural vibration in the XB-70 at a known frequency and amplitude. The XB-70's accelerometers detected the disturbances, then signaled the aircraft's stability augmentation system to damp out the motion. When XB-70 research flights resumed on June 11, 1968, the ILAF proved its ability to reduce the effects of turbulence and atmospheric temperature changes.

Despite the accomplishments of the XB-70, time was running out for the research program. NASA had reached an agreement with the Air Force to fly research missions with a pair of YF-12As and a "YF-12C," which was actually an SR-71. These represented a far more advanced technology than that of the XB-70. In all, the two XB-70s had logged 1 hour and 48 minutes of Mach 3 flight time. A YF-12 could log this much Mach 3 time in a single flight.

The final XB-70 research flight occurred on Feb. 4, 1969. Fulton and Sturmfahl made a subsonic structural dynamics test and ferry flight. The XB-70 took off from Edwards and flew to Wright-Patterson Air Force Base, Ohio, where the aircraft was put on display at the Air Force Museum. The first XB-70 made 83 flights totaling 160 hours and 16 minutes, while the second XB-70 logged 46 flights in its brief life, totaling 92 hours and 22 minutes.

Special Features

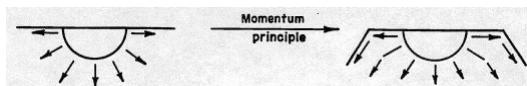


SPECIAL FEATURES:

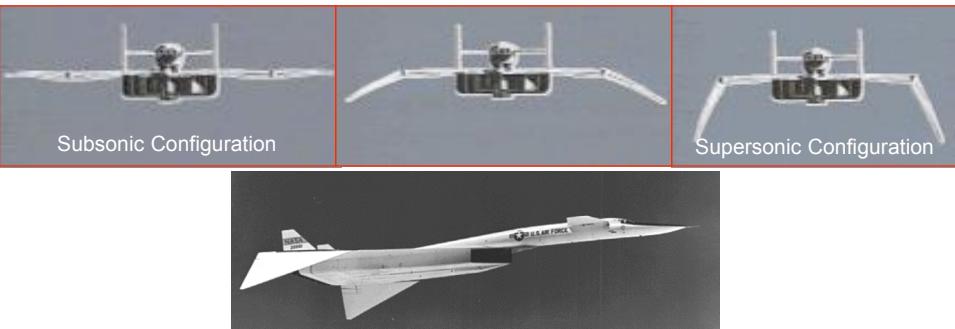
- A canard delta wing configuration, built largely of stainless steel honeycomb sandwich panels and titanium.
- Designed to Take advantage of Compression Lift (Discussed in more detail on the next slide)
- Designed for a crew of 2 people
- Estimated Prototype cost: \$700 million
- Designed to carry up to 14 nuclear bombs

Compression Lift

- At supersonic speeds, the shock wave supports part of aircraft weight
 - Shifts momentum of shock wave under wing downward, generating lift



- On XB-70, deflect wingtips up to 65°
 - Improves directional stability with greater vertical surface area
 - Reduces trim drag at supersonic speeds by reducing the area aft of the CG
 - "Traps" the shock wave caused by compression wedge at center of wing



It was designed to make use of a phenomenon called "compression lift," achieved when the shock wave generated by the airplane flying at supersonic speeds supports part of the airplane's weight. The XB-70 and it is the only airplane of its size to ever feature drooping wingtips. For improved stability at supersonic speeds, the Valkyrie could drop its wingtips as much as 65 degrees. Drooping the wingtips also strengthened the compression lift effect — with the wingtips drooped downwards, the shock wave caused by the compression wedge at the center of the wing would be further trapped under the wings, rather than simply flowing out past the end of the wings. There is a popular belief that this helps the XB-70 have the highest lift-to-drag ratio on a manned aircraft. While it does improve the performance, the ratio still is not as high as on most sailplanes.

At supersonic speeds, adequate cruise lift-to-drag ratio could be developed with less wingspan, so the outer panels were folded down. Deflected, they reduced drag as the wingtips interacted with the inlet shock wave in the lower surface flow field. Lowering the wingtips also reduced the area behind the airplane center of gravity (cg). This phenomenon was important because as Mach number increased, the center of pressure moved rearward, so less area aft of the cg caused a reduction of trim drag. The outer panels also provided more vertical surface to improve directional stability.

The resulting shape used a delta wing on a slab-sided fuselage that contained the six jet engines that powered the aircraft. The outer wing panels were hinged. During take off, landing, and subsonic flight, they remained in the horizontal position. This feature increased the amount of lift produced, improving the lift-to-drag ratio. Once the aircraft was supersonic, the wing panels would be hinged downward. Changing the position of the wing panels reduced the drag caused by the wingtips interacted with the inlet shock wave. The repositioned wingtips also reduced the area behind the airplane's center of gravity, which reduced trim drag. The downturned outer panels also provided more vertical surface to improve directional stability at high Mach numbers. Attached to the delta was a long, thin forward fuselage. Behind the cockpit were two large canards, which acted as control surfaces.

Geometric Parameters

Wing Dimensions

- Area = 6297.8 ft²
- Span = 105 ft
- Aspect Ratio = 1.751
- Taper Ratio = 0.019
- Dihedral = 0°
- Root Chord = 117.76 ft
- Tip Chord = 2.19 ft
- MAC = 78.532 ft
- y_{MAC} = 17.82 ft
- LE Sweep = 65.57°
- TE Sweep = 0°
- Root Incidence = 0°
- Tip Incidence = -2.60°
- Inboard t/c = 2%
- Outboard t/c = 2.5%

Canard Dimensions

- Area = 415.59 ft²
- Span = 28.81 ft
- Aspect Ratio = 1.997
- Taper Ratio = 0.388
- Dihedral = 0°
- Root Chord = 20.79 ft
- Tip Chord = 8.06 ft
- MAC = 15.36 ft
- y_{MAC} = 6.14 ft
- LE Sweep = 31.70°
- TE Sweep = -14.91°
- Root Incidence = 0°
- Tip Incidence = 6°
- Root t/c = 2.5%
- Tip t/c = 2.52%

Wing Dimension Notes:

- Dihedral of zero degrees is for the 1st XB-70 built. For the second aircraft built, the dihedral was adjusted to 5 degrees.
- The wing is a delta wing and has a large amount of leading edge sweep. This is beneficial for increasing the drag rise mach number
- The wing tips are twisted down 2.60 degrees
- The wing airfoil is a hexagonal airfoil and the sectional thickness of the airfoil varies from 2% of the chord at the wing root to 2.5% of the chord at the wing tip.

Canard Dimension Notes:

- The leading edge of the canard is swept aft 31.70 degrees and the trailing edge is swept forward 14.91 degrees
- The canard tips are twisted up six degrees from the canard root.
- The canard airfoil is a hexagonal airfoil and the sectional thickness of the airfoil varies from 2.5% of the chord at the canard root to 2.52% of the chord at the canard tip.

Geometric Parameters

Vertical Tail Dimensions Fuselage Dimensions

- | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none">– Area = 233.96 ft²– Span = 15 ft– Aspect Ratio = 1– Taper Ratio = 0.3– Root Chord = 23.08 ft– Tip Chord = 6.92 ft– MAC = 197.40 ft– z_{MAC} = 6.15 ft– LE Sweep = 51.77°– TE Sweep = 10.89°– Root t/c = 3.75%– Tip t/c = 2.5%– Cant Angle = 0° | <ul style="list-style-type: none">– Length = 185.75 ft– Max Depth = 8.91 ft<ul style="list-style-type: none">• x-position = 73.15 ft– Max Breadth = 8.33 ft<ul style="list-style-type: none">• x-position = 71.25 ft– Side Area = 939.72 ft²– Planform Area = 1184.78 ft²– Tail Scrape Angle = 12.67° |
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Wetted Surface Areas

- Fuselage = 2850.0 ft²
- Duct = 3430.6 ft²
- Wing = 9307.7 ft²
- 2 Vertical Tails = 937.7 ft²
- Canard = 532.5 ft²
- *Total* = 17058.2 ft²

Tail Dimension Notes:

-The vertical tail airfoil is a hexagonal airfoil and the sectional thickness of the airfoil varies from 3.75% of the chord at the tail root to 2.5% of the chord at the tail tip.

Fuselage Dimension Notes:

- the length of the fuselage does not include the length of the pitot tube at the nose of the aircraft
- The x-positions noted for the positions of max depth and breadth are measured aft from the nose of the aircraft
- Side area is the 2d area of the aircraft if looking at it from the side.
- Planform area is the 2d area of the aircraft if looking at it from the top.

Wetted Surface Areas:

- Provided from NACA TP-1516 (Arnaiz)

Other Design Parameters

Weights

- Empty Weight = 300,000 lb
- Typical Loaded Weight = 534,700 lb
- Max Takeoff Weight = 542,000lb
- Max Payload = 200,000 lb
- *Wing Loading* = 84.93 lb/ft²

Propulsion

- 6 YJ-93-GE-3 engines
- 28,000 lbf of thrust each
- $T/W = 0.314 \text{ lbf/lb}$

Aircraft Performance

- Cruise
 - 2,000 mph at 72,000ft (Mach 3)
 - Cruise Cl = 0.16445
 - $Cd_0 = 0.007692$
- Max Speed
 - 2,056 mph at 73,000ft (Mach 3.1)
- Other Parameters
 - Combat Range = 3726.2 nm
 - Typical Range = 3725 nm
 - Service Ceiling = 77,350 ft

Aircraft Performance Notes:

- Base drag calculated using friction.m code

XB-70 References

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SR-71 Blackbird



NASA Dryden Flight Research Center Photo Collection
<http://www.dfrc.nasa.gov/gallery/photo/index.html>
NASA Photo: EC92-7013-4 Date: 1992 Photo by: NASA

Three SR-71s on Ramp

Background

- Originally designed as an Interceptor
- The CIA saw the need for a replacement to the U-2 spy plane
- CIA wanted a high-speed/high-altitude aircraft with a low radar signature



[1]

The Airforce had originally called for a supersonic Interceptor/fighter and work began on the A-12 Oxcart as a result. The CIA then saw the need for a new supersonic reconnaissance aircraft that could safely get through Russia's improved air defenses. Thus, the CIA needed a high-speed/high-altitude aircraft and it had to be as hard to detect as possible by radar.

Predecessor

A-12 Oxcart

- Supersonic Interceptor/fighter aircraft
- 18 A-12s were built
- Max speed of Mach 3.0

Specs:

Length: 102 ft
Wingspan: 55 ft
Height: 18 ft
Wing area: 1,795 ft₂
Empty weight: 67,500 lb
Loaded weight: 117,000 lb
Powerplant: 2_ Pratt & Whitney J58-1 continuous bleed-afterburning turbojets, 32,500 lbf each



[2]

Designed by Kelly Johnson's "Skunk Works"

The SR-71 design was based on the A-12 "Oxcart." The Oxcart was a supersonic interceptor/fighter/reconnaissance aircraft. Eighteen Oxcarts were built in the '60s and were flown by the CIA in reconnaissance missions over Cuba and Korea (North Korea). It was later retired in 1968 when the SR-71 became operational.

Operational History

- First flight: December 22, 1964
- Entered service in January, 1966
- Service Record:
 - 3,551 Mission Sorties Flown
 - 17,300 Total Sorties Flown
 - 11,008 Mission Flight Hours
 - 53,490 Total Flight Hours
 - 2,752 hours Mach 3 Time (Missions)
 - 11,675 hours Mach 3 Time (Total)

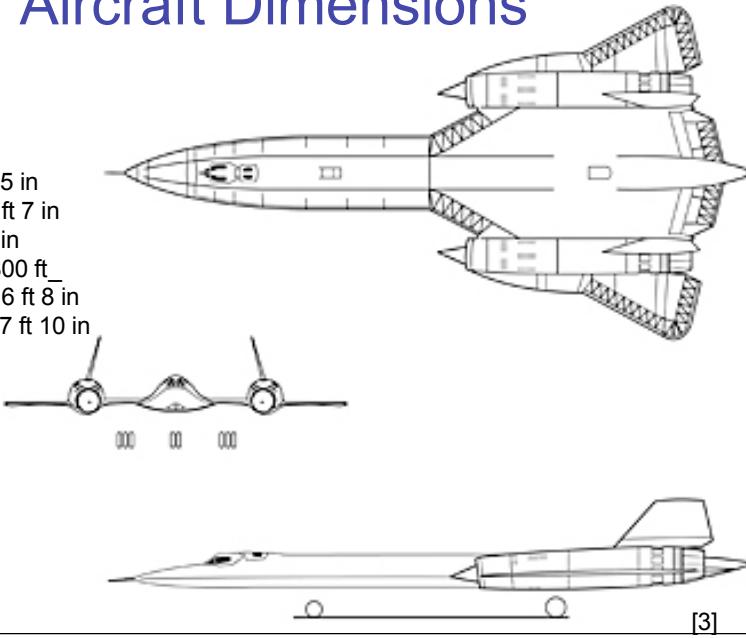
NASA Dryden Flight Research Center Photo Collection
<http://www.dfrc.nasa.gov/gallery/photo/index.html>
NASA Photo: EC90-0047-08 Date: 1990 Photo by: NASA

SR-71 Landing with Drag Chute

The first flight of the SR-71 was in December 22, 1964 and it first entered into service in January, 1966. Thirty-two SR-71s were manufactured of which two were trainers and one was a hybrid designated as SR-71C.

Aircraft Dimensions

- **Crew:** 1 or 2
- **Length:** 107 ft 5 in
- **Wingspan:** 55 ft 7 in
- **Height:** 18 ft 6 in
- **Wing area:** 1,800 ft²
- **Wheel track:** 16 ft 8 in
- **Wheel base:** 37 ft 10 in



Wing: Tail-less delta wing, LE angle of 60 degrees, TE angle of -10 degrees.

Fuselage: Blended forward wing/fuselage called a “chine”.

Vertical Tails: Two canted all moving vertical tails.

Other Design Parameters

Weights:

- **Empty weight:** 67,500 lb
- **Loaded weight:** 170,000 lb
- **MGTW:** 172,000 lb

Propulsion:

- **Power plant:** 2_ Pratt & Whitney J58-1 continuous-bleed afterburning turbojets, 32,500 lbf each
- **Thrust/weight:** 0.382:1

Performance:

- **Maximum speed:** Mach 3.35 at 80,000 ft
- **Range:** 2,900 nautical miles combat, 3,200 nautical miles ferry
- **Service ceiling:** 85,000 ft operational, 100,000 ft maximum
- **Climb rate:** 11,810 ft/min
- **Wing loading:** 94 lb/ft₂

Dryden Flight Research Center EC99-45065-6 Photographed 1999
SR-71A NASA/Dryden Jim Ross

The SR-71 still holds the record for fastest speed at Mach 3.35 and highest maintainable cruise altitude of 83,000 ft. The two power-plants produce a net of 65,000 lbf of thrust.

Fuselage

- Fuselage is a blended body (wing/fuselage)
- The wing portion is called the “chine”
- The chine acts as a fixed canard surface
- During cruise the chine produces enough lift to reduce the forward bending moment of the fuselage in half

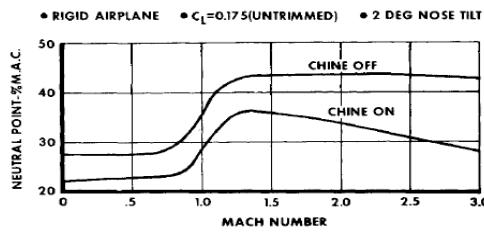


Fig. 5 Effect of chines on neutral point. [4]

The chine aside from reducing the forward bending moment of the fuselage also reduces trim drag. Without the chine at supersonic speed the aircraft has a large SM, does trim drag will be high. Since the chine acts as a canard it destabilizes the airplane, therefore, the elevator can operate at a lower alpha-trim which means the trim drag will be lower.

Thermodynamics

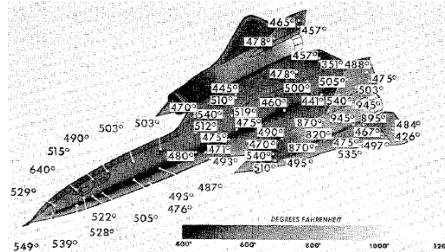


Fig. 15 SR-71 surface temperature cruise Mach. [4]

- During cruise the temperature distribution varies from 400°F to 640°F around the aircraft frame
 - The external temperatures around the afterburner and ejector are around 900-1100°F
 - 93% of the aircraft is built out of titanium alloys to withstand the high temperatures
 - Most of the titanium used in the SR-71 came from Russia
 - On the ground the fuselage panels fit loosely to allow them to expand at the high temperatures during cruise
 - Due to the loosely fit fuselage panels and the lack of a fuel sealing system that can operate at the wide temperature ranges the aircraft leaked fuel during takeoff
 - To keep the cockpit at 60°F air had to be pumped in at -40°F

Due to the high operational temperatures during cruise the SR-71 had to be made out of titanium. Metal expansion due to the heat was not fixed. Rather, there was not a way around it. To account for heat expansion of the titanium the fuselage panels were fitted loosely. Thus, when the aircraft would heat up the panels would have room to expand and fit tightly. This created a problem when the aircraft was cool. The fuel tanks did not have a good sealing system. During takeoff and before warming up the aircraft would leak its fuel. Thus, pilots would takeoff and dash out to warm up to stop the fuel leakage and then refuel in mid-air to start its mission. The fuel was also used as a coolant in the aircraft. Fueled would be pumped around the chine and then fed into the engines. On a side note it is ironic that the titanium used to build the SR-71 came from the Soviet Union, the country it was designed to spy on.

M-21

- SR-71 was modified and used to carry a drone
- The drone was completely autonomous and unmanned
- Designed to fly faster and higher than the SR-71
- Its mission to fly over target area, fly to rendezvous point and drop data package which would be picked up in mid-air by a C-130 aircraft
- Once mission was complete the drone would self-destruct
- During the fourth flight test the drone crashed into the M-21 destroying both aircraft
- Program was cancelled after the crash



The M-21 was designed to launch a drone into enemy hot spots where the drone would collect data and drop the package, containing the data, into a rendezvous point where a C-130 was waiting to pick-up the data package in mid-air. During the fourth flight test, which was during cruise speeds, the shock wave of the M-21 interfered with the drone causing it to crash into the mother ship destroying both airplanes and killing the launch control officer.

Miscellaneous

- JP-7 fuel especially formulated to have a high flash point, has fluorocarbons to increase lubricity, and a cesium compound A-50 to reduce the exhaust's radar signature
- Operating cost range of \$24-27,000/hr
- Due to cruise altitude of 80,000ft the pilots had to wear pressurized suits, similar to astronauts suits



The JP-7 fuel was originally developed for the Oxcart. It is extremely expensive to make and it's a major contributor to the high operating cost of the SR-71. Instead of pressurizing the cockpit it was decided that the pilots should wear pressurized suits, which they would need in case it was necessary for them to eject at a high altitude.

What's in a Name?

- Originally called the R-12
- Was to be officially renamed as RS-71
- Then USAF Chief of Staff lobbied to have the R-12 designated as the SR-71
- President Lyndon Johnson's speech was changed to read SR-71
- The media transcript however, still read RS-71 which lead to the believe that the President had misread the name
- 29,000 blue prints had to be altered to read "SR-71" along with numerous flight crew handbooks

Before the disclosure of the SR-71 program to the public there was a naming controversy that arose from naming the R-12 to RS-71, reconnaissance striker. Then Chief of Staff of the Airforce did not like that designation and thus convinced President Lyndon Johnson to disclose the program as the SR-71. When President Johnson gave his speech the transcripts given to the media still had the old name of RS-71. Thus, the media thought the President had simply misread the name of the aircraft.

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Tupolev TU-144

Russian Supersonic Transport



During the height of the cold war, in order to keep up with the Anglo-French Concorde, the Soviet Union began work on developing a supersonic transport aircraft (SST), which became the Tupolev TU-144. With the help of some espionage, Russia was able to develop their SST 3 months earlier, which was faster and bigger than the Concorde.

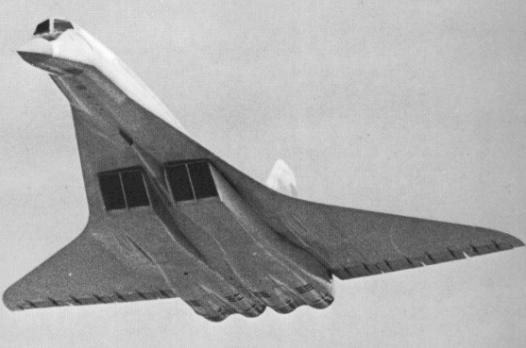
The program was roaring ahead at full force when during the 1973 Paris Airshow, where the Concorde and TU-144 were set to square off. Unfortunately, the TU-144 suffered a catastrophic crash that would keep it out of flying outside the Soviet Union.

The TU-144 ran mail, cargo, and passenger flights until a crash in 1978 ended all commercial activities. This lead the TU-144 to become a research aircraft, where it helped train Soviet Cosmonauts for the Soviet Space Shuttle. It was eventually used by NASA for SST research.

Currently only a handful of TU-144's are on display, and the rest have either been scrapped or are in storage in a factory

Timeline of TU-144

Prototype Aircraft



- December 31, 1968: Maiden Flight
- June 5, 1969: Reached Mach 1.0
- May 26, 1970: First Civil Aircraft to Reach Mach 2.0
- July 15, 1970: Reached Max Speed of Mach 2.35
- 1969: Displayed to World in Moscow
- 1971: Participated in XXIX Paris Airshow where it met the Concorde for the First Time
- Problems
 - Enhanced Vibration Levels
 - Tail Fuselage Heating by 4 Engines

Prototype Aircraft:

The 1st TU-144 made its maiden flight on December 31, 1968, which was 3 months before the Concorde. This aircraft used 4 Kuznetsov NK-144 engines which produced 44000 lbs of thrust using the Afterburner. The afterburner had to be used to maintain supersonic speeds. The engines were arranged 4 across so that they were right next to each other. This caused vibration problems and resulted in the heating of the aft fuselage area. This problem would be fixed in the next design.

One of the features on the TU-144 was the drooping nose, that dropped down 12 degrees for take off, and 17 degrees for landing, in order to increase visibility at the high angles of attack needed for low speed flight.

This prototype was also the first SST to reach Mach 2.0, and reached a max speed of Mach 2.35. It was displayed to the world for the first time in 1969, and in 1971, it participated in the XXIX Paris Airshow, where it competed with the Concorde for the first time.

This aircraft was manufactured at the Opty plant near Moscow, and then shipped for final Assembly to Zhukovsky.

Timeline of Tu-144

Pre-Production Aircraft

- Design Modified to fix Detected Problems and Increase Supersonic Range
 - Upgraded and Separated Engines into two pods, reducing Vibration and Heating Problems
 - Innovative Landing Gear Placed Between Engine Pods
 - Added Canards for Improved Low Speed Stability
 - Modified Wing Geometry and Increased Surface Area
- June 1, 1971: Maiden flight of Pre-Production Aircraft



Pre-Production Aircraft:

This was the second TU-144 built and was designated a TU-144S. The design changed from the first prototype with an upgrade of engines to the Kuznetsov NK-144F which had a much better fuel consumption, thus greatly increasing range. The engines were also moved further outboard such that there were 2 pods each containing two engines, just outboard of the fuselage. This fixed the vibration and fuselage heating problems that the prototype had. The movement of the engines resulted in a more complicated landing gear system where the main gear retracted up into the nacelles of each engine pod.

Also a retractable canard was added to be used during low-speed flight. The canard is not a control surface, but a lifting surface forward of the center of gravity so that the aircraft can takeoff and land at lower approach angles.

The wing was also modified to improve aerodynamic efficiency, and the wing area was also increased. The fuselage was made longer, and larger in order to accommodate 150 passengers. The takeoff weight was also increased.

This aircraft was manufactured at the Opty plant near Moscow, and then shipped for final Assembly to Zhukovsky.

Timeline of TU-144

First Production Aircraft

TU-144S

- Design Modified to Improve Wing Aerodynamics, Increase Wing Area and Take Off Weight,
- March 20, 1972: Maiden Flight of First Production Aircraft
- 1973: Flew to Paris to Participate in XXX Paris Airshow



Paris Airshow Crash

- Flight Began with Low Pass by Crowd and Then Climb to 1200 m
- Aircraft Lost Power and Entered a Dive
- Crew Tried to Recover, pulled 4.5 to 5 G's until Left Wing Broke Apart (Canard Failure Could be a Factor)
- Evasive Maneuvers from French Mirage
- All 6 Crew Members and 8 People on the Ground were Killed

First Production Aircraft:

This was the first production TU-144S, and had some small modifications from the pre-production aircraft. The wing was tweaked to increase aerodynamic efficiency, as well as an increase in wing area. The take off weight was also increased.

In 1973, this aircraft went to the XXX Paris Air Show to fly off against the Concorde. The Concorde flew first and demonstrated an impressive performance. When the TU-144 took off, it did a low pass by the crowd several times at low speed, and then pulled up into a quick climb to 3900 ft. The aircraft then lost power so the pilots put the aircraft into a dive to try and restart their flamed out engines. As the pilots tried to pull out of the dive, they pulled some extreme maneuvers between 4.5 to 5 G's. This ultimately led to the left wing failing and breaking apart. The aircraft crashed in a fireball into the village of Goussainville. All 6 crew members and 8 people on the ground were killed, as well as 25 people on the ground were injured.

The investigation yielded no conclusion on what caused the crash, but there are several theories developed to try and explain it. One theory is that as the aircraft went into a steep climb, the aircraft lost power due to a low quantity of fuel that resulted in a fuel pressure drop. This caused the engines to flame out.

Another theory is that the pilots pushed the plane too hard while trying to compete with the Concorde, and they pushed it outside of its flight envelope causing the engine to flame out.

One of the other popular theories is that a French Mirage Fighter was in the area, with surveillance equipment. The mirage was trying to take pictures of the canards of the TU-144 in flight. The theory goes that when the TU-144 climbed up to altitude, the pilots saw the mirage and took evasive action to avoid a collision, resulting in the engine flame out.

While in the dive, a TV camera mounted in the cockpit for a French TV station, fell onto the controls, causing precious seconds to be lost while trying to recover the aircraft.

Whatever the cause of the crash, the TU-144 would never operate any commercial flights outside the Soviet Union.

Timeline of TU-144

After the Crash...

- **December 26, 1976:** TU-144S put into Service for Mail and Cargo Flights From Moscow to Alma Alta, Kazakhstan
- **November 1, 1977:** TU-144S Begins Passenger Service
- **April 27, 1978:** First Flight of TU-144D
 - D Model has new Koliesov RD-36-51A Engines
- **May 23, 1978:** TU-144D model Crashes During Test Flights
 - Fuel Line Broke, 8 Tons of Fuel Flooded into the Right Wing
 - Engine 3 Caught Fire, Forced Emergency Landing in a Field with Landing Gear Still Up
 - Nose Cone Collapsed, Killing 2 Crew Members, and Plane Became Engulfed in a Fireball
 - Stops All TU-144 Commercial Flights Indefinately
- **1981:** TU-144D Received Air-Worthiness Certificate and Prepares to Begin Commercial Flights
- **1983:** ALL TU-144 Production Ordered to Stop, and Begin Converting Aircraft to Flying
 - Holds 14 Speed and Altitude Records for Commercial Aircraft
 - 1985-1986 Used As Training Flights for Russian Space Shuttle Program
- **1993-1999:** 27 Flights as Joint Project with NASA
 - Upgraded Engines to Kuznetsov NK-321 and became TU-144LL

After the Crash:

After the Paris Air Show crash, several tests were run, and 3 years later the TU-144S entered regular service, carrying mail and cargo to Alma Alta, Kazakhstan. A year later in 1977, it begins passenger service to Alma Alta as well.

On April 27, 1978, the first TU-144D model made its maiden flight. This aircraft had new and improved engines that allowed the aircraft to cruise supersonically without afterburner. The aircraft would reach supersonic cruise speed with afterburner, but then shut off the afterburner when at cruise. The engines were Koliesov RD-36-51A's that produced 51000 lbs of thrust with afterburner and enough thrust without afterburner to maintain supersonic cruise.

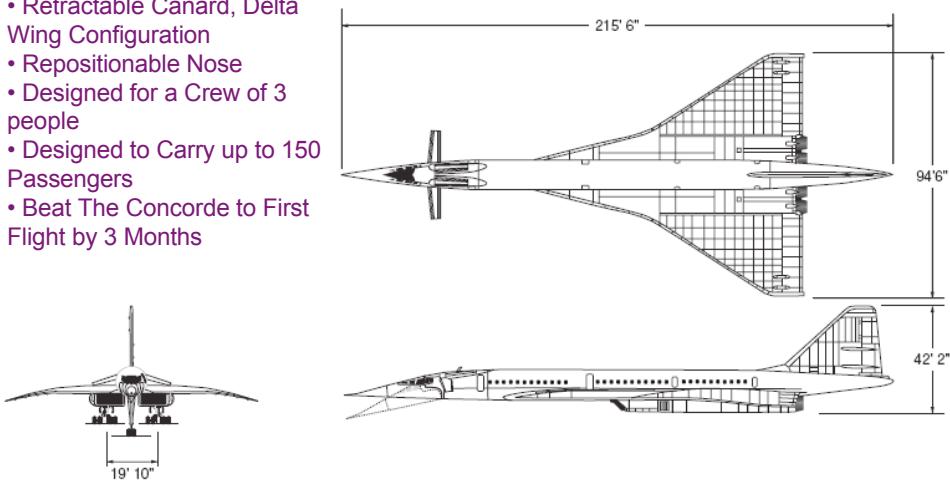
May 23, 1978, almost one month after its first flight, a fuel line in the aircraft ruptured and spilled nearly 8 tons of fuel into the wing. Engine number 3 caught fire in flight, causing the pilots to shut off engine 4. As the tried to head back to the airfield, engine number 2 failed and forced the pilots to attempt a belly landing in a nearby field. The nose cone of the aircraft collapsed killing two crew members, and the aircraft caught fire. 6 other crew members were injured. The crew members were later commended for their bravery and efforts in trying to save the aircraft.

All TU-144 aircraft were grounded after the accident. In 1981 the TU-144D received its Air-Worthiness Certificate, and preparations began to return to commercial service. However, the TU-144 would never fly commercially again. Due to funding, in 1983 all production of the TU-144 was ordered to a halt, and existing aircraft were to be retrofitted into flying test beds. The TU-144 then participated in various research projects, and set 14 speed and altitude records for commercial aircraft. The TU-144 was used for training flights for Russian Cosmonauts while developing the Russian Space Shuttle. In 1989 all flights of the TU-144 was halted due to funding.

In 1993 NASA entered a joint project for SST aircraft. They retrofitted one of the TU-144D with Kuznetsov NK-321 engines. These engines were almost 5 ft longer than the RD-36-51A's, so extensive modification was down to the inlet and nacelle. The NK-321 engines could produce 33000 lbs of thrust dry and 55000 lbs of thrust with afterburner on. This aircraft configuration became the TU-144LL. It flew 27 flights before the TU-144 was retired from service for ever.

Special Features

- Retractable Canard, Delta Wing Configuration
- Repositionable Nose
- Designed for a Crew of 3 people
- Designed to Carry up to 150 Passengers
- Beat The Concorde to First Flight by 3 Months



SPECIAL FEATURES:

- The TU-144 used a retractable Canard that was used as a lifting surface forward of the center of gravity to decrease the approach angles required during take off and landing.
- It utilized a double Delta wing configuration to decrease drag rise at high speeds, and to generate vortex lift at low speeds.
- Nose drooped down to for take off and landing to increase visibilites at the high angles of attack needed to generate lift
- Designed to Carry 150 passengers seated in 5 across in 30 rows.
- Flown by a crew of 3 people
- Pushed through development and beat the Concorde its first flight by three months.

Geometric Parameters

Wing

- Dimensions
 - Area = 5457 ft²
 - Span = 94.5 ft
 - Aspect Ratio = 1.66
 - Taper Ratio = 0.122
 - Root Chord = 104.583 ft
 - Tip Chord = 2.19 ft
 - MAC = 76.417 ft
 - $x_{MAC} = 98.667$ ft
 - Fwd LE Sweep = 76°
 - Main LE Sweep = 57 °
 - TE Sweep = 0°
- Control Surfaces
 - 4 Elevons Outboard of Engines on Each Wing

Vertical Tail

- Dimensions
 - Area = 717.8 ft²
 - Span = 28.5 ft
 - Aspect Ratio = 1.13
 - Taper Ratio = 0.233
 - Root Chord = 40.7 ft
 - Tip Chord = 9.5 ft
 - LE Sweep = 47.4°
 - TE Sweep = 1.43°
- Control Surfaces
 - 2 Rudder Elements

Wing Notes:

- The wing is a double delta with the forward inboard sections of the wing swept at a leading edge angle of 76 degrees, and the main aft section of the wing is swept at 57 degrees.
- The wing spans 94.5 ft while the root chord is 104.58 ft, and has an aspect ratio of 1.66, and a wing area of 5457 ft²
- There are 4 elevons outboard of the engines on each wing which provide both pitch and roll control.

Vertical Tail Notes:

- The TU-144 has a large vertical stabilizer that has a span of 28.5 ft and an area of 717.8
- The vertical tail has a 2 element rudder to provide yaw control.

Geometric Parameters

Fuselage

- Dimensions
 - Length = 215.5 ft
 - Cabin Width = 11.25 ft
 - Cabin Height = 11.42 ft
 - Total Height (Gear Retracted) = 42.17 ft
 - Total Height from Ground = 47.25 ft
 - Carried a Total of 150 passengers

Nose Cone

- Nose Cone Droops Down 11° for Take off and 17° for Landing to Increase Visibility from Cockpit
- When the Nose is in the Up Position, a Visor is Raised over the Windshield



Fuselage Notes:

- The Fuselage is 215.5 ft long with a width of 11.25 ft and a height of 11.42 ft. The Vertical stabilizer reaches 47.25 ft above the ground
- The nose of the aircraft droops down 11 degrees during take off and 17 degrees during landing, to increase visibility for the pilot as the aircraft has to fly at a high angle of attack at low speed
- When the nose is in the up position a visor covers the windshield to protect it from the temperature and pressures at high supersonic speed

Geometric Parameters

Canards

- Dimensions
 - Area = 179.63 ft²
 - Span = 17.49 ft
 - Aspect Ratio = 1.70
 - Taper Ratio = 0.6875
 - Root Chord = 6.08 ft
 - Tip Chord = 4.183 ft
- Canards were Retracted During Cruise and Extended for Low Speed Flight
- Canards are not Control Surfaces
- Canards Contained Leading Edge and Trailing Edge Flaps
- Canards were used only in Low Speed Flight as an Additional Lifting Surface in Front of the CG.



Canards Notes:

The TU-144 has retractable canards that are flush with the fuselage at high speed and extend out at low speeds. The canards extend to a span of 17.49 ft, and has an area of 179.63 square ft. The canards are equipped with both trailing edge and leading edge flaps.

The canards are not used as a control surface, but as another lifting surface, that acts in front of the center of gravity. Since the wing is designed to have the aerodynamic center further aft for supersonic flight, and the aerodynamic center moves forward for low speed flight, the canards are used to help balance it out. This also allows the aircraft to fly at a lower angle of attack due to an increase in lift.

Other Design Parameters

Weights

- Empty Weight = 187,395 lb
- Max Takeoff Weight = 396,830lb
- Max Payload = 209,435 lb
- Wing Loading = 72.72 lb/ft²
- CG varies between 40 and 42%

Aircraft Performance

- Cruise = 1,350 kts (Mach 2.35)
 - Cruise CL = 0.080
- Service Ceiling = 60,000 ft
- Typical Range = 3515 nm

Propulsion

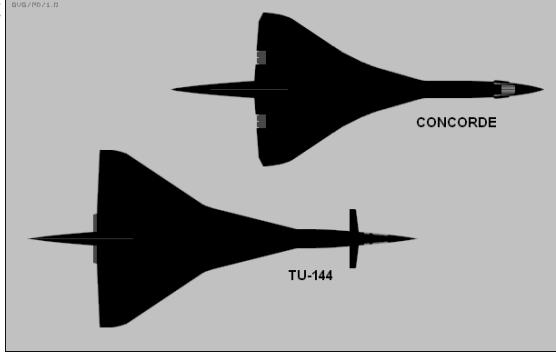
- TU-144 (Prototype)
 - 4 Kuznetsov NK-144 Engines
 - 44000 lb Thrust w/ A/B
- TU-144S
 - 4 Kuznetsov NK-144A Engines
 - 44000 lb Thrust w/ A/B
- TU-144D
 - 4 Koliesov RD-36-51A Engines
 - 51000 lb Thrust w/ AB
 - Able to Cruise without use of A/B
- TU-144LL
 - 4 Kuznetsov NK-321 Engines
 - 55000 lb Thrust w/ A/B
 - 31000 lb Thrust Dry

Aircraft Performance Notes:

- The TU-144 was designed to carry 150 passengers or 209,435 lbs of payload. It has an empty weight of 187,395 lb and a max take off weight of 396,830 lbs. This gives the aircraft a maximum wing loading of 72.72 lb/ft². The center of gravity was usually between 40% to 42% of the length of the aircraft.
- The cruise speed was pretty much the max speed of the aircraft which was Mach 2.35. It had a Ceiling of 60000ft and a Range of 3515 nm.
- One of the biggest issues with a SST is the massive amount of fuel that it consumes. So as new and improved engines that had a better specific fuel consumption was developed, they were added on to the TU-144. With the Addition of the Koliesov RD-36-51 engines, the afterburner no longer had to be used while cruising supersonically, this greatly reduced fuel consumption.

TU-144 vs Concorde

- **Background**
 - Developed During the Height of the Cold War
 - KGB Stole Blueprints of Concorde
 - TU-144 Completed First Flight 3 Months Earlier
- **Similarities**
 - Delta Wing
 - 4 A/B Engines in 2 Separate Nacelles
 - Drooping Nose
 - Flight Crew of 3
- **Differences**
 - TU-144 is Large and Longer, Allowing for 5 Abreast Seating Instead of 4
 - Tu-144 Max Speed of Mach 2.35 as Opposed to Concorde's Mach 2.02
 - Tu-144 Wing Planform is a Double Delta, while Concorde has an ogival curve
 - Engine Placement on TU-144 was more in board and Tu-144 had all Elevons outboard of Engines
 - TU-144 had more Complex Landing Gear Assembly, Retracting into Engine Nacelle
 - TU-144 had Retractable Canards



During the cold war it was a matter of pride for the Soviet Union to produce a SST when they discovered that the Concorde was really going to be built. Unfortunately for the Soviet Union, they were behind the curve on SST technology and the Concorde had a head start. In order to keep up, the KGB stole the blue prints to the Concorde. The Russians didn't copy the Concorde, but were able to use the information stolen to catch up in technology, get inspiration and avoid the dead ends that the English and French had already been through. This allowed the Soviet Union to develop their aircraft quicker and have the first flight test 3 months before the Concorde. While at first glance the TU-144 might look like a copy of the Concorde, one must remember the mission of each aircraft is identical, so a lot of the design is already chosen by the mission. One of the early American designs looked very similar to the Concorde as well. Looking closer the TU-144 has a number of differences, and is an entirely different aircraft. These differences are:

- TU-144 is Large and Longer, Allowing for 5 Abreast Seating Instead of 4
- Tu-144 Max Speed of Mach 2.35 as Opposed to Concorde's Mach 2.02
- Tu-144 Wing Planform is a Double Delta, while Concorde has an ogival curve
- Engine Placement on TU-144 was more in board and Tu-144 had all Elevons outboard of Engines
- TU-144 had more Complex Landing Gear Assembly, Retracting into Engine Nacelle
- TU-144 had Retractable Canards

Fate of TU-144

- **17 Aircraft were produced**

- 3 Prototype Aircraft
 - 1 TU-144
 - 2 TU-144S (1 Production TU-144S was used to Test Engines for TU-144D)
- 14 Production Aircraft
 - 8 TU-144S
 - 6 TU-144D (1 TU-144D Converted to TU-144LL)

- **Currently**

- 6 Aircraft were Scrapped
- 4 Stored in Production Factory
- 4 On Display at Museums
- 3 Unknown Whereabouts



As the TU-144 went out of service, most were either scrapped for parts or left somewhere to rot and fall into disrepair. Of the 17 aircraft produced only 4 are maintained on display in museum around the world.

TU-144 References

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2. "The Rise and Fall of the SST." <http://www.vectorsite.net/avsst.html>
3. "TU-144" <http://www.tupolev.ru/English>Show.asp?SectionID=148&Page=1>
4. Rivers et al. "A Qualitative Piloted Evaluation of the Tupolev TU-144 Supersonic Transport," NASA TM-2000-209850. <http://ntrs.nasa.gov/>, 2000.
5. Curry, Timothy J. "Estimation of Handling Qualities of the Tupolev TU-144 Supersonic Transport From Flight Test Data," NASA CR-2000-210290. <http://ntrs.nasa.gov/>, 2000.

VIDEO OF TU-144 CRASH:

http://perso.wanadoo.es/tu144sst/accidents/pictures/TU-144_crash.wmv

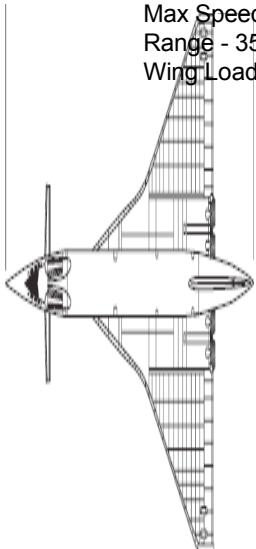
Comparison of the 3 Aircraft

TU-144, 215ft

Max Speed – Mach 2.35

Range - 3515 nm

Wing Loading - 72.72 lb/ft²



All images are to scale

XB-70, 185ft

Max Speed – Mach 3.1

Range - 3725 nm

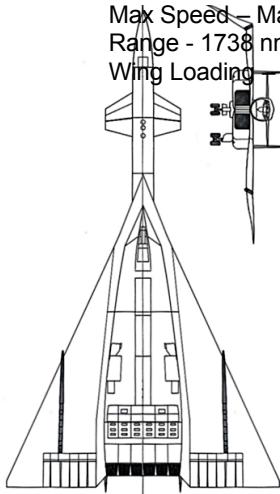
Wing Loading - 84.93 lb/ft²

SR-71, 107ft

Max Speed – Mach 3.2

Range - 1738 nm

Wing Loading - 94 lb/ft²



The images of the aircraft are to scale.