SR-71 PROPULSION SYSTEM
P&W J58 ENGINE (JT11D-20)
PETER LAW

ONE OF THE BEST JET ENGINES EVER BUILT
Rolls-Royce Milestone Engines

Merlin

W2B Welland

Conway

Derwent

Trent
SR-71
GENERAL CHARACTERISTICS

- Two Place High-Altitude High-Speed Reconnaissance Aircraft
- Developed in Early 1960s By Kelly Johnson, Lockheed "Skunk Works"
  - In Burbank, California (Advanced Development Projects - ADP)
- Delta Wing Configuration
- Crew Of Two: Pilot And Reconnaissance Systems Officer (RSO)
  - Seated In Tandem Arrangement
- Inflight Refueling Capability - Crew Endurance is Limit
- Aircraft Length is 107 Feet, Wing Span Is 55 Feet, Height is 18 Feet
- Takeoff Weight is 140,000 Pounds; 80,000+ Pounds Of Fuel
- 93% Of Vehicle Structure And Skin is Titanium
- Aircraft Series Known As "Blackbirds"
SR-71 PERFORMANCE CHARACTERISTICS

- Cruising Altitude is between 74,000 and 85,000 feet
- Cruising Speed is Mach 3.2+, 2100+ MPH, 3100+ Feet/Sec
- Range is 3,000 miles, 15,000 miles with refueling
- Total Flight Time of all "Blackbird" aircraft: 53,000+ hours
- Total Time above Mach 3.0: 11,000+ hours (22 million miles)
- Powered by two Pratt & Whitney J58 Turbojet engines, each with the power of the Queen Mary
- Vehicle was designed with radar signature reduction techniques
# SR-71

## FLIGHT RECORDS

- **Sustained Speed In Level Flight**: 7/28/76, 2,193.16 mph
- **Sustained Altitude In Level Flight**: 7/28/76, 85,069 feet
- **New York To London**: 9/1/74, 1806.96 mph, 1 Hr 54 Min 32 Sec
- **London To Los Angeles**: 9/13/74, 1435.59 mph, 3 Hr 47 Min 39 Sec
- **USA Coast To Coast**: 3/6/90, 2124.51 mph, 1 Hr 7 Min 53.69 Sec
- **Los Angeles To Washington**: 3/6/90, 2144.83 mph, 1 Hr 4 Min 19.69 Sec
- **Kansas City To Washington**: 3/6/90, 2176.08 mph, 24 Min 58.53 Sec
- **St. Louis To Cincinnati**: 3/6/90, 2189.94 mph, 8 Min 31.93 Sec

NAA Official Data - 1992
SR-71

SURFACE TEMPERATURES

- CRUISE CONDITIONS
- MAX. ENG. TEMP.

NOTE
L DENOTES LOWER SURFACES
GENERAL COMMENTS ON SR-71 PROPULSION SYSTEM

• THE SR-71 WAS THE FINEST AIR BREATHING JET AIRCRAFT EVER DEVELOPED, BUILT, AND FLOWN. DESIGNED TO FLY AT MACH 3.2, WIND TUNNEL TESTED TO MACH 3.5, AND FLEW MISSIONS AT MACH 3.3+, AT ALTITUDES OF 86,000+ FEET.

• THE P&W J58 (JT11D-20) HAD THE POWER OF THE QUEEN MARY; STARTED LIFE WITH 30,000 POUNDS OF THRUST, AND ENDED WITH 34,000 POUNDS.


• THE IMPORTANT FEATURES OF EACH WILL BE BRIEFLY COVERED, AS EACH PART WAS CRITICAL FOR PROPER OPERATION OF THE INTEGRATED “PROPULSION SYSTEM”.

• AT MACH 3.2, 54% OF THE THRUST WAS PROVIDED BY THE INLET (DIFFERENTIAL PRESSURE BETWEEN EXTERNAL AND INTERNAL SURFACES OF THE INLET SPIKE), 17% BY THE ENGINE, AND 29% BY THE EJECTOR. ENGINE ACTED AS A GAS GENERATOR.

• ENGINE OPERATES FROM 4,000 RPM (IDLE) TO 7,400 RPM (MAX).
HIGH SPEED

CENTERBODY BLEED OVERBOARD
SUCK-IN DOORS CLOSED
TERTIARY DOORS CLOSED

SPIKE FULLY RETRACTED
BYPASS DOORS CLOSED OPEN AS REQUIRED TO POSITION SHOCK OR RESTART INLET
AFT SECONDARY BYPASS DOORS NORMALY CLOSED
EJECTOR FLAPS FULL OPEN

UNCLASSIFIED
THE ENGINE

• THE ENGINE IS THE PRATT AND WHITNEY JT11D-20, DESIGNATED “J58” BY THE MILITARY
  – ENGINE IS A SINGLE-SPOOL, AFTERBURNING TURBO-JET, WITH A 4<sup>th</sup>-STAGE BLEED BYPASS DUCTING AIR INTO THE AFTERBURNER
  – BLEED SYSTEM IS OPERATED AT HIGH MACH NUMBERS TO PROVIDE INCREASED COMPRESSOR STALL MARGIN
  – BLEED AIR RE-ENTERS THE ENGINE AHEAD OF THE AFTERBURNER WHERE THE AIR IS USED FOR COOLING AND INCREASED THRUST AUGMENTATION
  – BYPASS AIRFLOW IS 20% OF TOTAL FLOW INTO ENGINE
  – ENGINE RPM IS MAINTAINED BY MODULATING THE EXHAUST NOZZLE

• THIS ARRANGEMENT PROVIDES NEARLY CONSTANT AIRFLOW AT A GIVEN MACH NUMBER FROM BELOW MILITARY POWER TO MAXIMUM AB, WHICH IS VERY DESIRABLE WHEN OPERATING BEHIND A SUPersonic MIXED COMPRESSION INLET
J58 Installation in SR-71
J58 ENGINE SYSTEM

• FUEL CONSUMPTION AT A CRUISING MACH NUMBER IS APPROXIMATELY 8,000 GALLONS PER HOUR
• FUEL IS JP-7, WHICH HAS AN EXTREMELY LOW VAPOR PRESSURE AND A VERY HIGH FLASH POINT
• TO LIGHT THIS FUEL A SPECIAL IGNITION SYSTEM IS USED. A CHEMICAL – PYROPHORIC TRIETHYLBORANE (TEB), IGNITES THE MAIN ENGINE AND THE AFTERBURNER
• THE ENGINE OPERATES IN THE MOST HOSTILE ENVIRONMENT ANY ENGINE HAS EVER BEEN SUBJECTED TO:
  – AIR ENTERING THE COMBUSTOR REACHES 1400°F
  – TURBINE INLET TEMPERATURE IS 2000°F
  – TEMPERATURE IN AFTERBURNER SECTION REACHES 3200°F
• GROUND STARTING REQUIRES USING TWO 300 HP BUICK WILDCAT RACING ENGINES CONNECTED TO THE J58 STARTER DRIVE
• AT FULL AFTERBURNER POWER THE AFTERBURNER GLOWS CHERRY RED
JT11D-20 ENGINE - A SUCCESSFUL LEAP INTO THE TECHNICAL UNKNOWN

J-58 DEVELOPMENT WAS STARTED IN LATE 1956

BACKGROUND EXPERIENCE

EXPERIENCE AND TECHNOLOGY IS ALWAYS UTILIZED
DESIGN REQUIREMENTS WERE A LEAP INTO THE UNKNOWN

<table>
<thead>
<tr>
<th>Production Engine Experience (J57 and J75)</th>
<th>JT11D-20 Design Requirements</th>
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<tbody>
<tr>
<td><strong>MACH NUMBER</strong></td>
<td>2.0 FOR 15 MIN (J75 ONLY)</td>
</tr>
<tr>
<td><strong>CORRECTED AIRFLOW TURNDOWN RATIO</strong></td>
<td>90%</td>
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<tr>
<td><strong>ALTIMETRE</strong></td>
<td>55,000 FT</td>
</tr>
<tr>
<td><strong>COMPRESSOR INLET TEMPERATURE</strong></td>
<td>-40 °F TO 250 °F (J75 ONLY)</td>
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<tr>
<td><strong>COMBUSTOR EXIT TEMPERATURE</strong></td>
<td>1750 °F (TAKEOFF)</td>
</tr>
<tr>
<td></td>
<td>1550 °F (CONTINUOUS)</td>
</tr>
<tr>
<td><strong>MAXIMUM FUEL INLET TEMPERATURE</strong></td>
<td>110 - 130 °F</td>
</tr>
<tr>
<td><strong>MAXIMUM LUBRICANT INLET TEMPERATURE</strong></td>
<td>250 °F</td>
</tr>
<tr>
<td><strong>THRUST/WEIGHT RATIO</strong></td>
<td>4.0</td>
</tr>
<tr>
<td><strong>MILITARY OPERATION</strong></td>
<td>30-MIN TIME LIMIT</td>
</tr>
<tr>
<td><strong>AFTERBURNER OPERATION</strong></td>
<td>INTERMITTENT</td>
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INNOVATIONS ON THE JT11D-20 ENGINE

- VARIABLE CAMBER INLET VANE
- HIGH TEMPERATURE LUBRICANT
- FUEL USED AS HYDRAULIC FLUID
- VARIABLE GEOMETRY SPRAYBARS
- BLOW-IN-DOORS TO INCREASE TRANSONIC THRUST
- VARIABLE EXIT AREA
- DUAL TEMPERATURE SENSORS
- FUEL USED AS HEAT SINK
- AIRFLOW CONTROL
- COOLED TURBINE
- VARIABLE THROAT AREA TO CONTROL AIRFLOW
- BYPASS BLEED DUCTS TO VARY ENGINE CYCLE
- EJECTOR PART OF AIRFRAME STRUCTURE, PROVIDES THRUST AUGMENTATION AND LOW DRAG EXHAUST OF SURPLUS INLET AIR
HIGH TEMPERATURES REQUIRED NEW MATERIALS AND PROCESSES

- JT11D-20 ENGINE IS MADE FROM HIGH-TEMPERATURE NICKEL BASE ALLOYS EXCEPT FOR THE INLET GUIDE VANE, FIRST COMPRESSOR STAGE AND GEARBOX INTERNAL PARTS

| Material     |               |               |               |               |               |               |               |               |               |               |               |               |               |               |
|--------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| TITANIUM     |               |               |               |               |               |               |               |               |               |               |               |               |               |
| WASPALOY    |               |               |               |               |               |               |               |               |               |               |               |               |               |
| INCO 718     |               |               |               |               |               |               |               |               |               |               |               |               |               |
| HASTELLOY X  |               |               |               |               |               |               |               |               |               |               |               |               |               |
| ASTROLOY     |               |               |               |               |               |               |               |               |               |               |               |               |               |
| IN100/MAR-200DS |           |               |               |               |               |               |               |               |               |               |               |               |               |
| L605         |               |               |               |               |               |               |               |               |               |               |               |               |               |

![Jet engine diagram](image_url)
TOTAL PRESSURES IN THE ENGINE AND NACELLE DURING SUPERSONIC CRUISE

\[
\frac{\text{BURNER PRESSURE}}{\text{AMBIENT PRESSURE}} = 112 \\
\frac{\text{TURBINE DISCHARGE PRESSURE}}{\text{AMBIENT PRESSURE}} = 35.5 \\
\frac{\text{INLET PRESSURE}}{\text{AMBIENT PRESSURE}} = 38.8 \\
\frac{\text{EXHAUST PRESSURE}}{\text{AMBIENT PRESSURE}} = 31.2 \\
\frac{\text{EJECTOR SECONDARY PRESSURE}}{\text{AMBIENT PRESSURE}} = 9.1
\]
Figure 2-1. J58 Engine (Sheet 1 of 2)
FIGURE 2.1
SCHEMATIC DIAGRAM OF THE JT11D-20 ENGINE MOUNTED IN THE ALTITUDE TEST FACILITY
INLET REQUIREMENTS

• HIGH PRESSURE RECOVERY
• MINIMUM DRAG
• AIRFLOW CAPABILITY COMPATIBLE WITH ENGINE AIRFLOW REQUIREMENTS
• DUCT EXIT AIRFLOW DISTORTION ACCEPTABLE TO ENGINE
• AIRFLOW SUPPLY TO COOL ENGINE & OPERATE EJECTOR NOZZLE
• STABLE OPERATION
SR-71 AIR INLET DESIGN DRIVERS

• FUNCTIONAL REQUIREMENTS FOR THE ENGINE INLET
  – MATCH THE AIR FLOW CAPTURED BY THE INLET TO THE AIR FLOW REQUIRED BY THE ENGINE FOR ALL CONDITIONS
  – AT SUPersonic CRUISE, REDUCE THE VELOCITY OF THE CAPTURED AIR TO ABOUT 0.4 MACH REQUIRED AT THE ENGINE FACE
  – MAXIMIZE THE PRESSURE RECOVERY AT THE ENGINE FACE WHILE REDUCING VELOCITY
  – MINIMIZE THE TRANSIENT FLOW EFFECTS OF EXTERNAL DISTURBANCES

• NO FIXED INLET CONFIGURATION CAN SIMULTANEOUSLY SATISFY THESE REQUIREMENTS OVER THE ENTIRE FLIGHT ENVELOPE AND ENGINE OPERATING RANGES
  – VARIABLE INLET GEOMETRY IS REQUIRED
AXISYMMETRIC MIXED COMPRESSION INLET DESIGN CONCEPT

CENTERBODY SHOCK (CONICAL)

COWL LIP SHOCK

REFLECTED SHOCKS (OBLIQUE)

INLET THROAT STATION

TERMINAL SHOCK

ENGINE
INLET BLEED and BYPASS ARRANGEMENT

- Spike Bleed Exit
- Aft-Bypass Door Assembly
- Shock-Trap FlowTube
- Forward-Bypass Exit
- Forward-Bypass Door Opening
- Spike Support Structure
- Forward-Bypass Door Assembly
- Cowl Bleed (Shock Trap)
- Spike Bleed
- Translating Spike
SR-71 AIR INLET CHARACTERISTICS

- AXI-SYMMETRIC MIXED COMPRESSION INLET CHOSEN BECAUSE
  - LOWER WEIGHT, DRAG, AND SIGNATURE OF AXI-SYMMETRIC
  - DESIRED RANGE AND CRUISE PERFORMANCE REQUIRED PRESSURE RECOVERIES HIGHER THAN POSSIBLE WITH AN EXTERNAL COMPRESSION INLET AT MACH 3.0+

- MIXED COMPRESSION INLETS CAN ATTAIN HIGH PRESSURE RECOVERY ABOVE MACH 2.2
  - IF NORMAL SHOCK CAN BE KEPT AT THE DESIGN LOCATION JUST DOWNSTREAM OF THE MINIMUM CROSS SECTIONAL FLOW AREA (INLET THROAT)
  - IF NORMAL SHOCK CAN BE MAINTAINED NEAR THE DESIGN LOCATION DURING INTERNAL OR EXTERNAL FLOW PERTURBATIONS

- IF NORMAL SHOCK CANNOT BE MAINTAINED DOWNSTREAM OF THE THROAT ABOVE MACH 2.2
  - INLET IS SAID TO BE “UNSTARTED”
  - NORMAL SHOCK POPS OUT AND STABILIZES FORWARD OF THE INLET LIP
  - PRESSURE RECOVERY, AIR FLOW, AND THRUST DROP TO LOW LEVELS
  - DRAG INCREASES SIGNIFICANTLY
  - INLET MUST BE RESTARTED AS FAST AS POSSIBLE TO PREVENT ENGINE DAMAGE AND MINIMIZE AIRPLANE YAW TRANSIENT
INLET SYSTEM

– INLET HAS A TRANSLATING 26-DEGREE CONE WHICH ACTS AS THE INITIAL DECELERATION OR COMPRESSION SURFACE PRODUCING A SERIES OF SHOCK WAVES UP TO THE INLET THROAT

– THE SHOCK TRAIN ENDS WITH A FINAL TERMINAL OR NORMAL SHOCK FOLLOWED BY A SUBSONIC DIFFUSER

– THE PURPOSE OF THE INLET IS TO SUPPLY THE AIR REQUIRED BY THE ENGINE AT THE HIGHEST PRESSURE RECOVERY AND THE LOWEST DRAG, WITH A MINIMUM OF DISTORTION. THIS IS NOT AS SIMPLE AS IT SOUNDS!

• A TURBOJET ENGINE IS A CONSTANT VOLUME MACHINE. THIS MEANS THAT REGARDLESS OF FLIGHT SPEED – FROM M = 0 TO CRUISE SPEED – THE SPEED OR MACH NUMBER ENTERING THE ENGINE IS RELATIVELY CONSTANT, BETWEEN M = 0.3 AND 0.5
AIR INLET

• The SR-71 engine air inlet is a mixed external and internal compression, axi-symmetric inlet, with gradual isentropic compression approaching the throat.

• The boundary layer which builds up on the centerbody is removed ahead of the terminal shock through a porous bleed.

• This bleed passes overboard through louvers at the ends of the centerbody support struts.

• Forward bypass doors, located close to the throat match the inlet to the engine, bypassing air overboard.

• The cowl bleed is a “shock trap” ram bleed which supplies air through tubes across the by-pass door region into the engine secondary passage, where it is used for cooling, and fed through to the engine ejector.

• Aft by-pass flow joins the cowl bleed flow and passes through the engine ejector.

• This by-pass was installed to provide sufficient flow to permit engine operation at idle.

• During acceleration, aft by-pass is used to reduce the forward overboard by-pass with its attendant drag.
INLET SPIKE

• THE INLET SPIKES REGULATE THE AMOUNT OF AIR ENTERING THE INLET BY MOVING PROGRESSIVELY REARWARDS AS THE AIRCRAFT’S SPEED INCREASES
  – THE FULLY FORWARD POSITION WHICH THE SPIKE MAINTAINS UP TO MACH 1.4
  – THE SPIKE AT THE LIMIT OF ITS 26-INCH AFT TRANSLATION
  – THE CONFIGURATION OF THE INLET AT MACH 3 AND ABOVE

• AT THIS POINT THE CAPTURE AREA HAS INCREASED BY 112%, WHILE THE THROAT DIAMETER AT THE POINT OF MINIMUM CROSS-SECTION FURTHER DOWN THE INTAKE HAS DECREASED BY 54% IN ORDER TO HOLD THE TRI-SONIC SHOCKWAVE IN THE CORRECT POSITION

• AT MACH 2.2 THE INLET PRODUCES 13% OF THE OVERALL THRUST, THE ENGINE AND EJECTOR ACCOUNTING FOR 73% AND 14% RESPECTIVELY
  – THE CORRESPONDING FIGURES AT MAXIMUM CRUISING SPEED, MACH 3+ ARE 54%, 17%, AND 29%
  – MOST OF THE THRUST IS DEVELOPED BY THE INLET SPIKE
SR-71 INLET/EXHAUST AIRFLOW PATTERNS

Airflow Patterns

Centerbody Bleed
Suck-in Doors Open
Fwd Bypass Doors Open
Aft Bypass Doors Closed
Tertiary Doors Open Ejector Flaps Closed

Shock Trap Bleed Supplies Engine Cooling Air
Centerbody Bleed Overboard
Suck-in Doors Closed
Fwd Bypass Doors Closed
Aft Bypass Doors Closed
Tertiary Doors Open Ejector Flaps Closed
SR-71 INLET/EXHAUST AIRFLOW PATTERNS

- Shock Trap Bleed Supplies Engine Cooling Air
- Centerbody Bleed Overboard
- Suck-In Doors Closed
- Spike Forward
- Fwd Bypass Doors Open
  As Required to Position Inlet Shock
- Aft Bypass Doors Closed
- Tertiary Doors Open
  Ejector Flaps Closed
- Spike Retracting
- Centerbody Bleed Overboard
- Suck-In Doors Closed
- Fwd Bypass Doors Open
  As Required to Position Inlet Shock
- Aft Bypass Doors Position B
  Tertiary Doors Closed
  Ejector Flaps Opening
- Spike Retracted
- Centerbody Bleed Overboard
- Suck-In Doors Closed
- MACH 1.5
- FWD Bypass Doors Closed
  Will Open as Required to Position Inlet Shock
- Aft Bypass Doors Closed
  Tertiary Doors Closed
  Ejector Flaps Open
- MACH 2.5
- MACH 3.2
CENTERBODY BLEED ARRANGEMENT

- Support Strut
- Spike Bleed Exit Louvers (4 Locations)
- View Looking AFT
- Spike Bleed (Slotted Surface)
- Engine Face

Side View
FORWARD BYPASS

- Shock Trap Tubes
- Bypass Exit Louvers (6 Locations)
- Rotary Flush Sliding Doors
- Bypass Exit Louvers
- Forward Bypass Flow
- Aft Bypass Doors
- Engine Face

SECTION A-A
SECONDARY FLOW SYSTEMS
COWL BLEED AND AFT BYPASS

- Shock Trap Flow
- Shock Trap Tubes
- Aft Bypass Flow
- Aft Bypass Doors
- Engine Face
- Side View
- Engine Bay

To Ejector
INLET CONFIGURATION AND CONTROL

• THE INLET UTILIZES DAFICS COMPUTERS FOR CONTROL OF SPIKE AND BYPASS DOORS
• SPIKE MOVEMENT IS CONTROLLED BY MACH NUMBER, ANGLE OF ATTACK, ANGLE OF YAW, AND LOAD FACTOR
• THE TERMINAL SHOCK POSITION IS CONTROLLED AND REGULATED BY FORWARD AND AFT BYPASS DOORS WHICH MATCH THE INLET AIR SWALLOWING CAPABILITY TO THE ENGINE REQUIREMENT
• THE COMPRESSION RATIO AT CRUISE IS 40 TO 1
• AT CRUISE, EACH INLET SWALLOWS APPROXIMATELY 100,000 CUBIC FEET OF AIR PER SECOND – EQUIVALENT TO TWO MILLION PEOPLE BREATHING ON THE GROUND
• INLETS CANTED INBOARD 3.2° – EFFECT OF CHINE and FUSELAGE
• INLETS CANTED DOWN 5.6° – EFFECT OF ANGLE OF ATTACK AT CRUISE
SR-71 AIR INLET CONTROL SYSTEM FUNCTIONS

- **Forward ByPass Doors** are open with the gear down, close when landing gear retracts, but begin to open again at Mach 1.4 to dump excess flow captured by inlet.
- **Spike** is full forward at low Mach numbers and is progressively retracted for Mach numbers above 1.6.
- **Control System** positions spike as a function of Mach number with AOA, slideslip, and normal acceleration bias.
- **Normal Shock** moves downstream of the inlet throat (inlet starts) at approximately Mach 1.7.
- Above Mach 2.2, **bypass doors** modulate as required to keep normal shock at the design location.
- If an unstart occurs in one inlet above Mach 2.3, both spikes are driven to the forward position and the forward bypass doors are opened to obtain a restart and minimize yaw transients.
- **Aft bypass doors** are scheduled manually to provide cooling air to engine bay and ejector.
EJECTOR NOZZLE

• THE LAST PART OF THE PROPULSION SYSTEM IS THE EJECTOR
  – THE EJECTOR PERFORMS THE REVERSE FUNCTION OF THE INLET
  – IT ACCELERATES THE AIR COMING OUT OF THE TURBINE AT M = 0.4 UP TO M = 3.0+
  – THE EXIT VELOCITY MUST MATCH OR EXCEED THE FLIGHT SPEED, THEREFORE THE VARIABLE EXIT FLAPS. THEY STAY FULLY CLOSED UNTIL ABOUT M = 1.2, AND ARE FULLY OPEN AT ABOUT M = 2.4

• PRIMARY NOZZLE IS A RING OF BLOW-IN DOORS WHICH PROVIDE TERTIARY AIR TO FILL IN THE EJECTOR AT MACH NUMBERS BELOW 1.2
  – TERTIARY AIR IS PROVIDED BY SUCK-IN DOORS AROUND THE NACELLE, AUGMENTED BY THE COWL (SHOCK TRAP BLEED AND AFT BY-PASS BLEED)
  – MAIN EJECTOR IS SUPPORTED DOWNSTREAM ON STREAMLINED STRUTS AND A RING OF RENE 41 STEEL ALLOY ON WHICH ARE HINGED FREE-FLOATING TRAILING EDGE FLAPS OF HASTELLOY X
REFERENCES:


