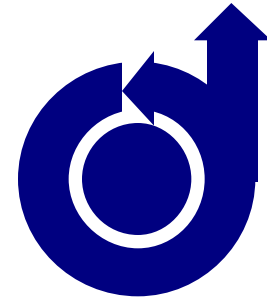


2000 International Powered Lift Conference



V/STOL Fighter Programs in Germany: 1956-1975

Mike Hirschberg

ANSER, Inc.

1 November 2000

Overview

- Overview
 - Pre-VJ 101C Concepts
 - VJ 101C
 - VJ 101C Follow-On Concepts
-
- Pre-VAK 191 Concepts
 - VAK 191
 - VAK 191 Follow-On Concepts
 - End Results



Supersonic fighter-interceptor



Transonic nuclear strike fighter

Historical Overview

- May 1955 Germany entered NATO
- The re-formed German Luftwaffe envisioned creation of core combat capability primarily consisting of V/STOL aircraft
 - Designed to free aircraft from dependency on large, vulnerable airfields
- Development started on 3 VTOL aircraft
 - High altitude supersonic fighter-interceptor
 - EWR VJ 101C
 - Low altitude nuclear strike fighter
 - VFW VAK 191B
 - Theater tactical airlift aircraft
 - Dornier Do 31

The EWR VJ 101C V/STOL Fighter



VJ 101 Requirements

- VJ = Vertikal Jäger = V/STOL Fighter
- Intended as replacement for Lockheed F-104G
 - Initial requirements Nov 1956
 - V/STOL requirements added Feb 1957

VJ 101 Specifications:

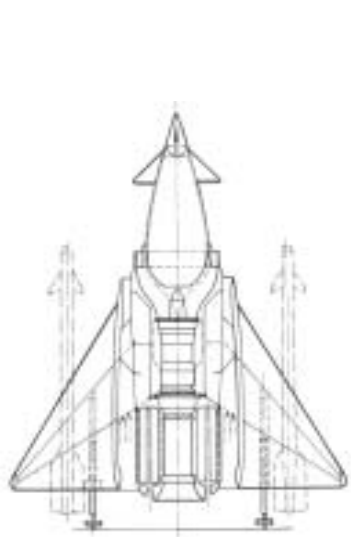
- Operational range: 54-270 nm
- Max altitude: 65,600-72,200 ft
- Maximum speed: Mach 2.5
- Vertical take-off with 25% reserve power
- Time to climb to 65,600 ft approx 90 sec

F-104G Characteristics:

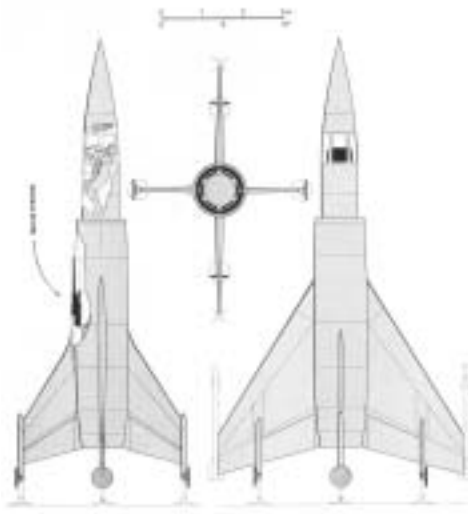
- Operational range: 260 - 648 nm
- Max altitude: 58,000 ft - 90,000 ft
- Maximum speed: Mach 2.2
- Take-off distance 3,000 ft
- Time to climb to 50,000 ft approx 140 s
- Payload of two air-to-air missiles and 20 mm cannon

Initial Tailsitter Designs

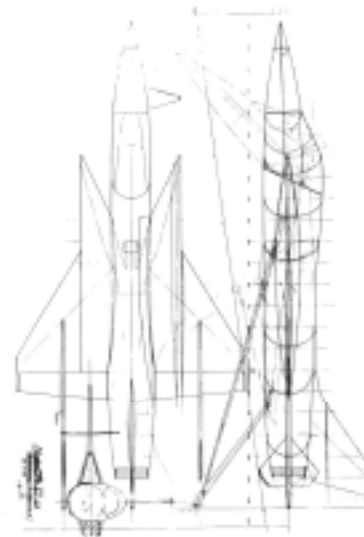
- After the war, almost no aircraft work in Germany
 - Many German engineers went abroad to work
 - Some on the French SNECMA Coléoptère
- Four companies responded to requirements with studies
 - Numerous concepts, each had tailsitter designs



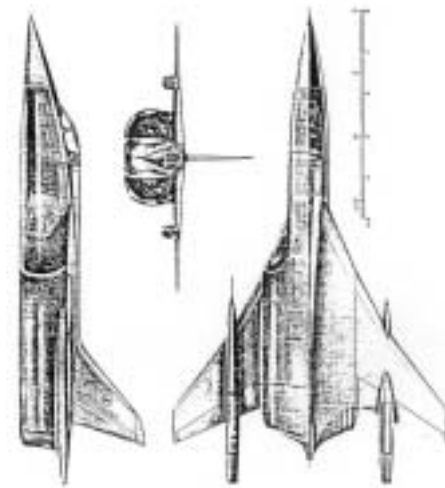
Bolkow P 110.1



Heinkel He 231

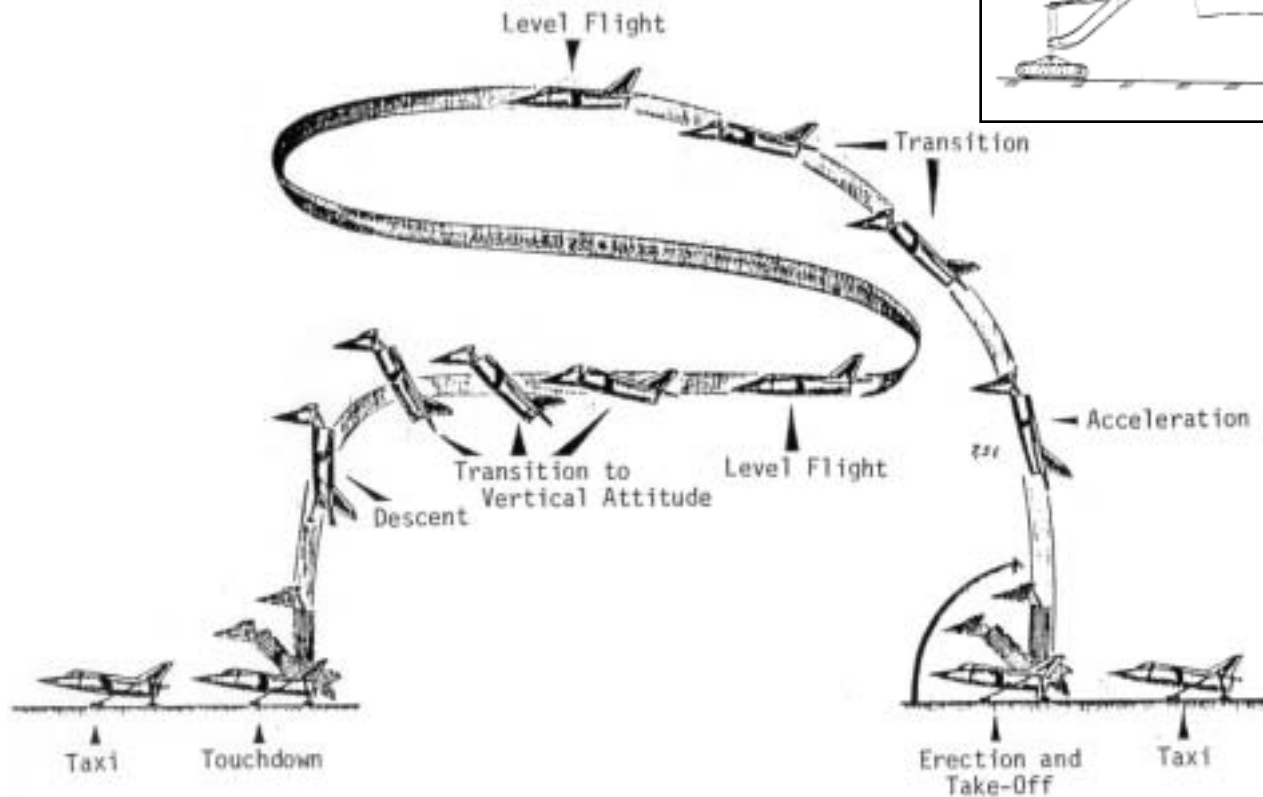
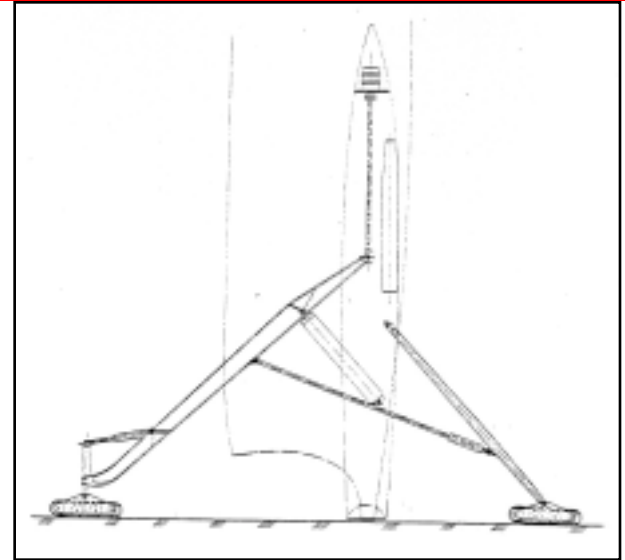
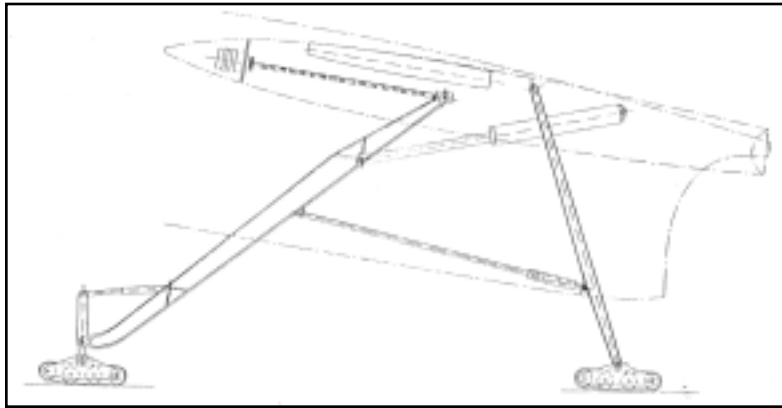


Messerschmitt Me X1-21

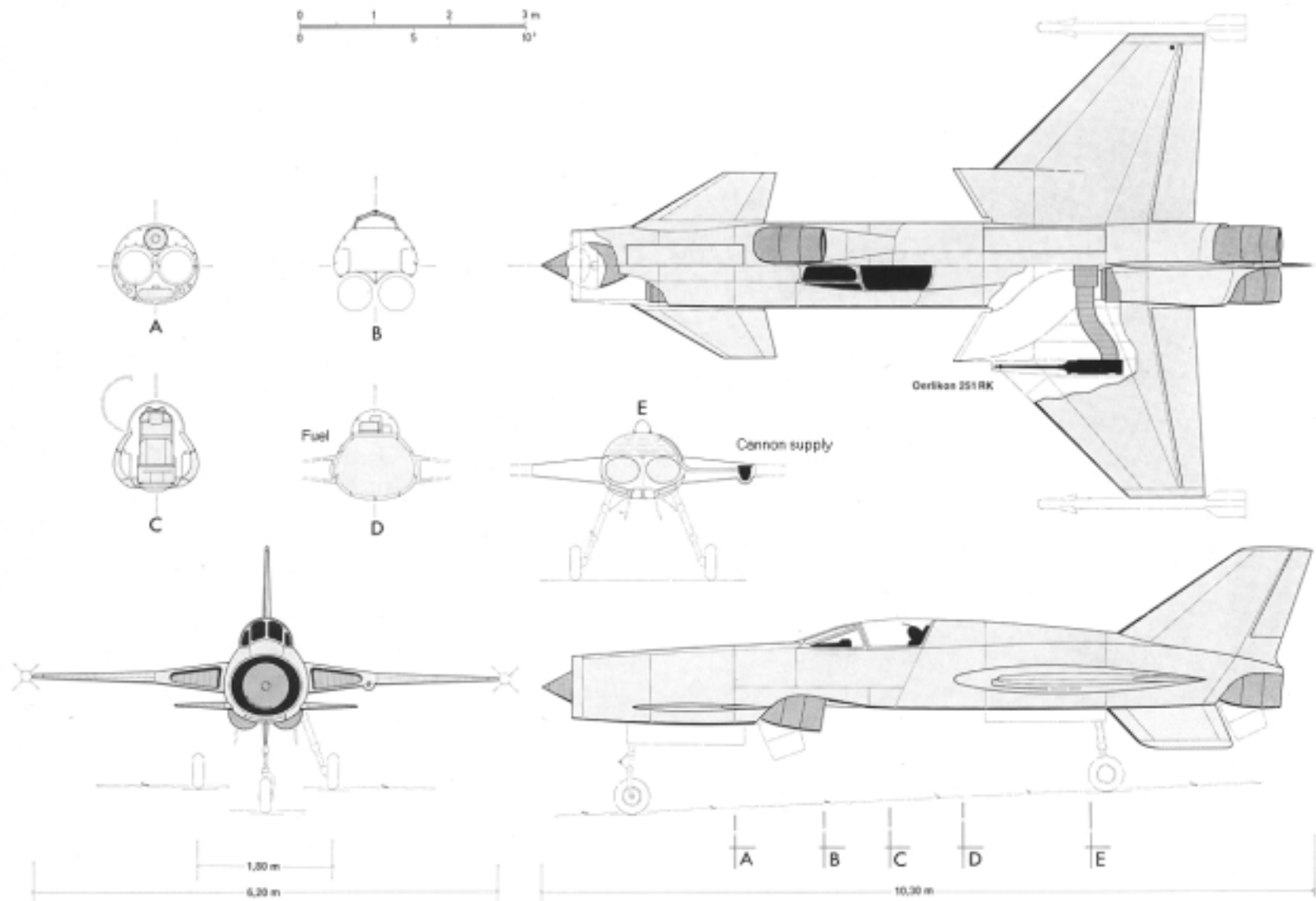


Focke Wulf Fw 860

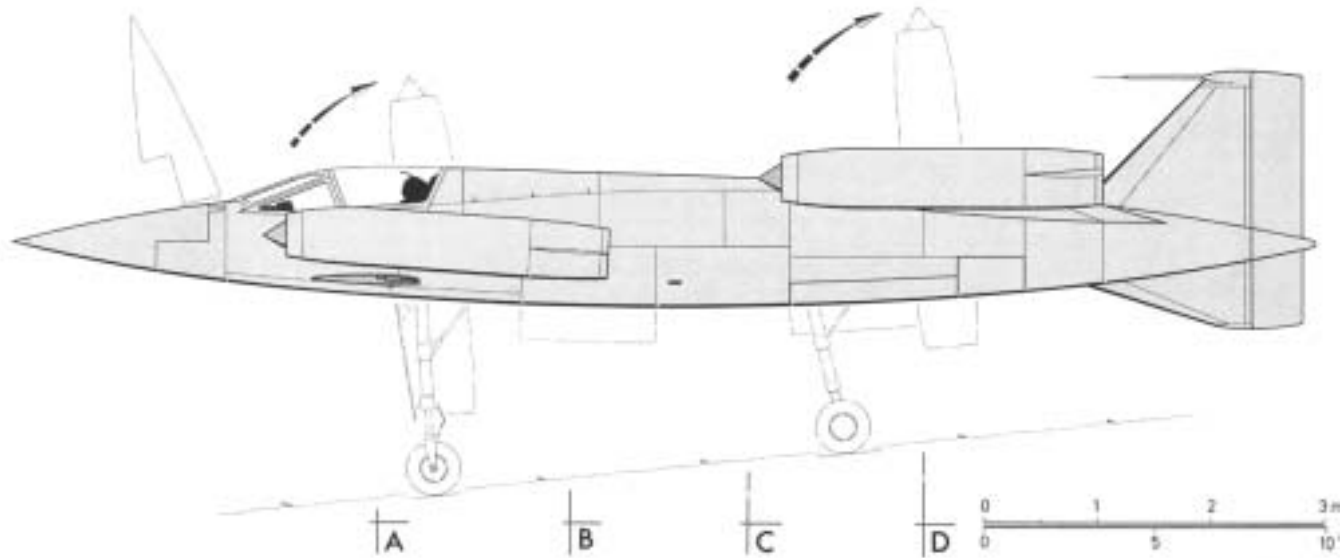
Focke-Wulf 860 Tailsitter Concept



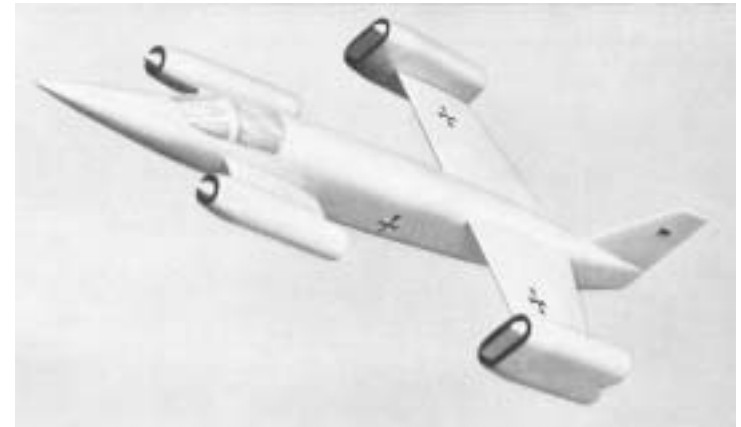
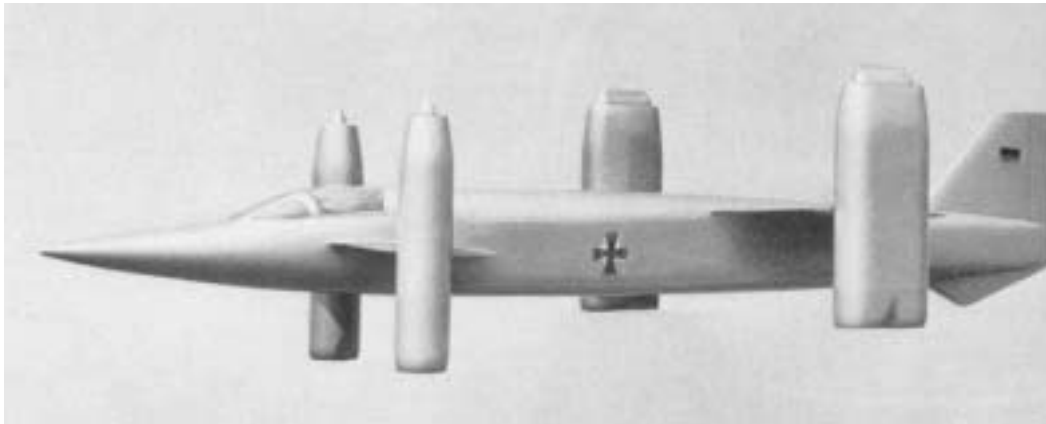
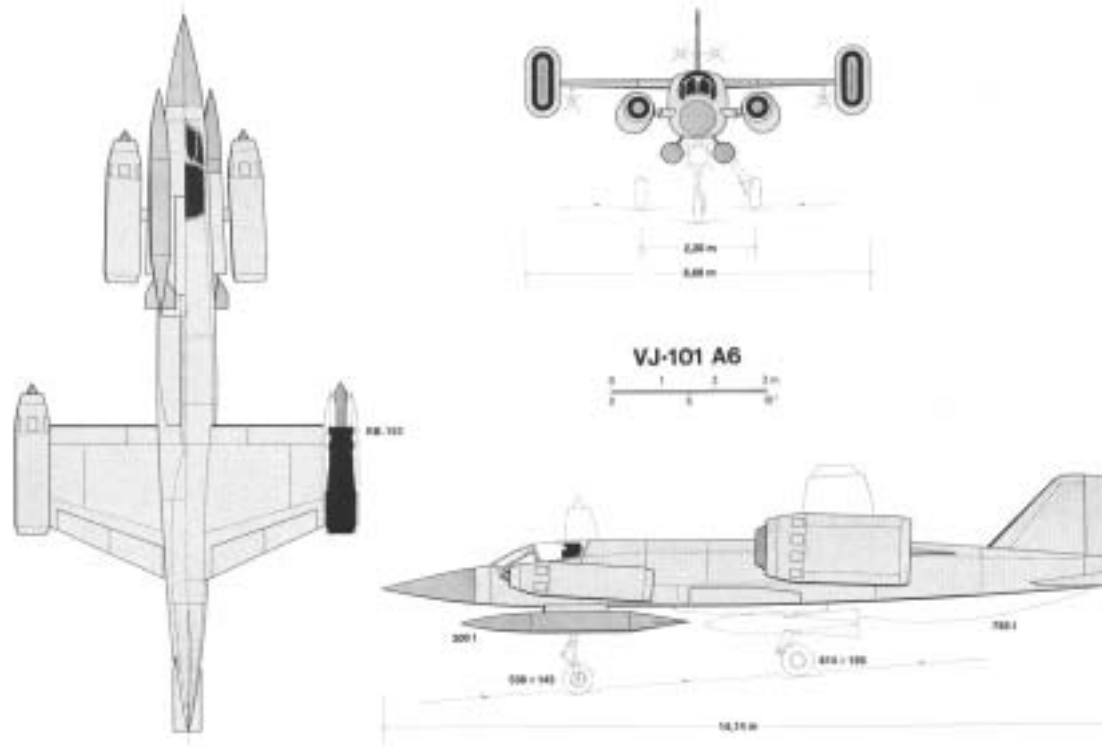
Heinkel He 231



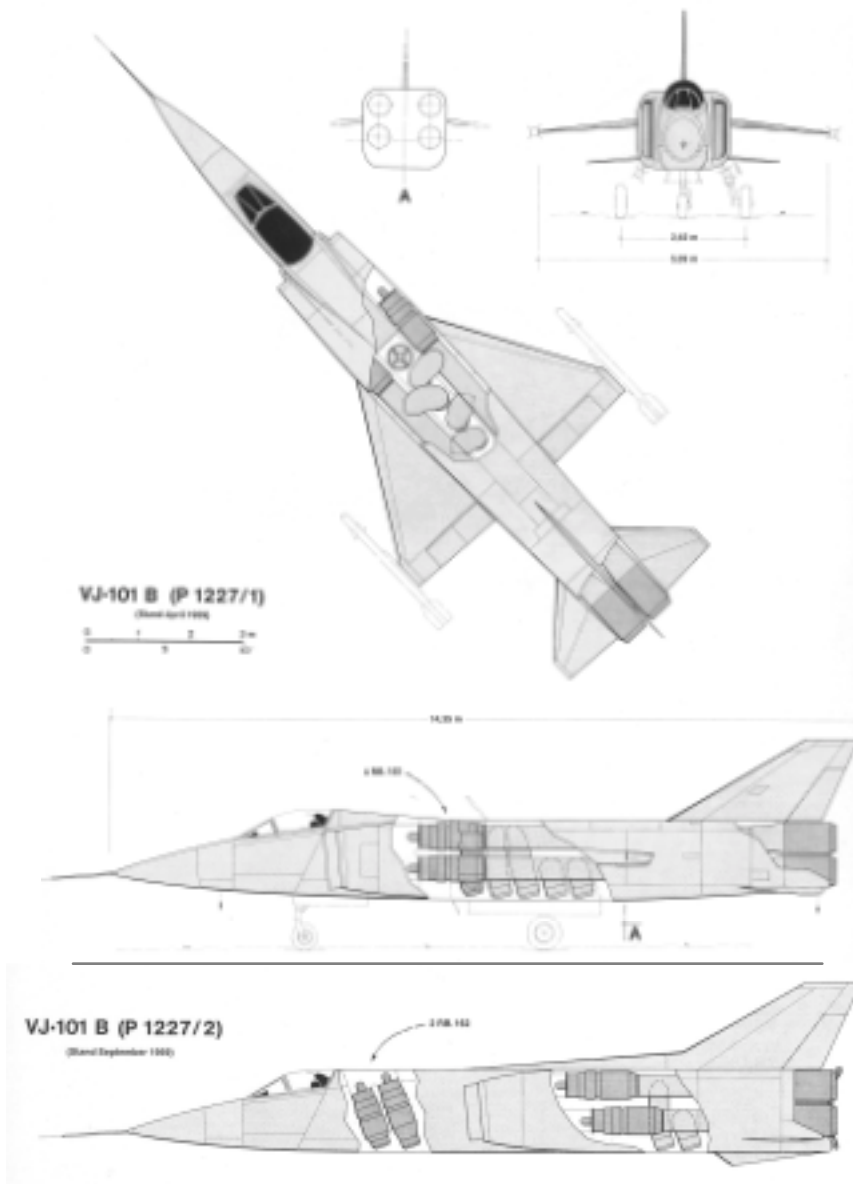
Heinkel He 231 (VJ 101A)



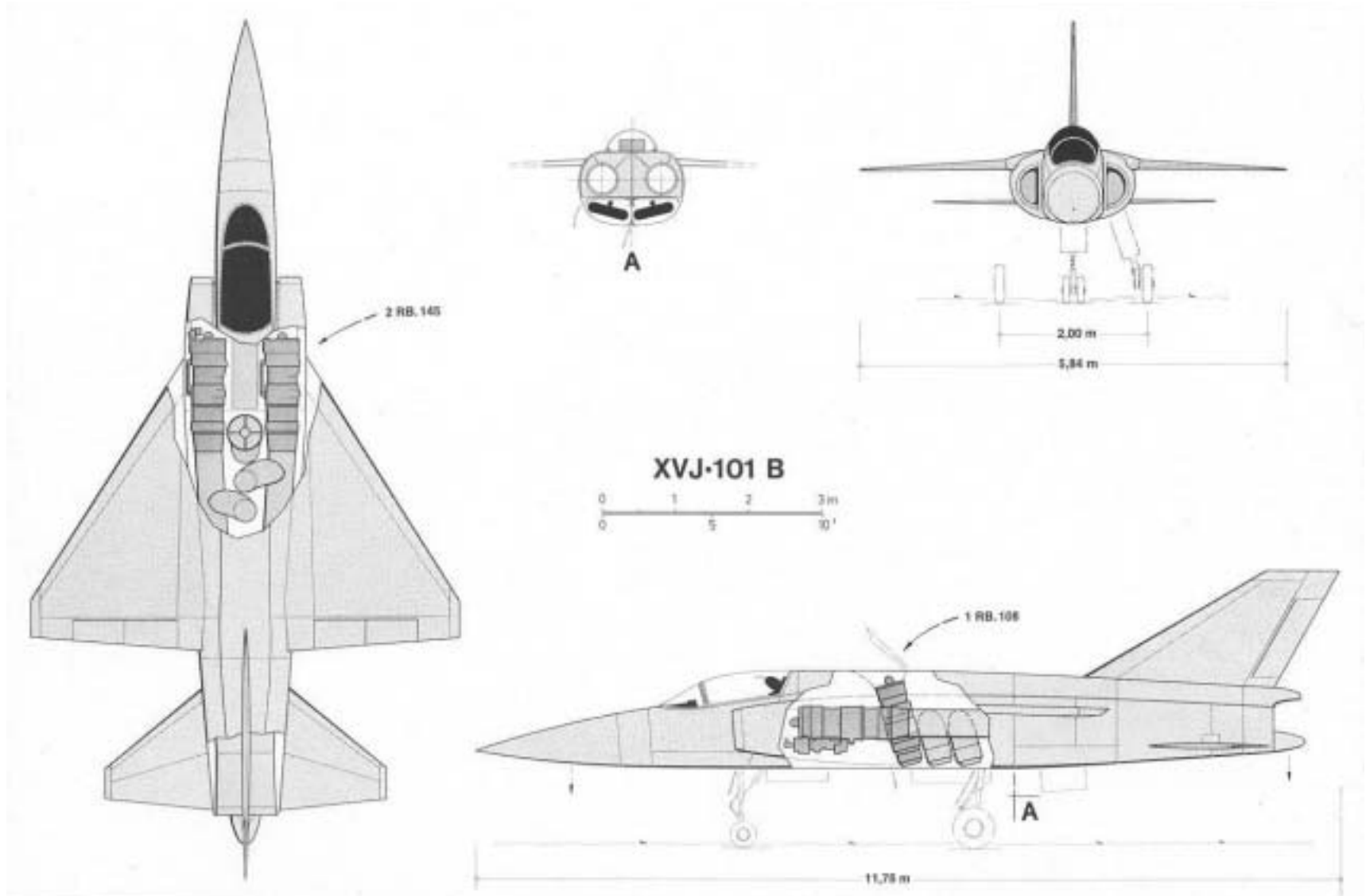
Heinkel VJ 101A6



Messerschmitt P 1227 (VJ 101B)

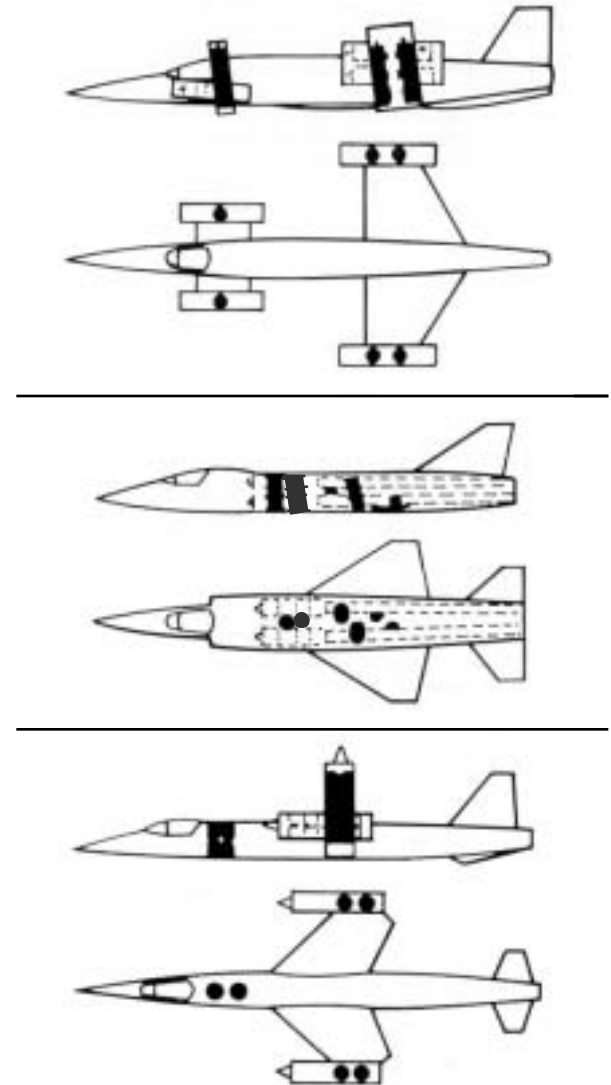


Messerschmitt XVJ 101B

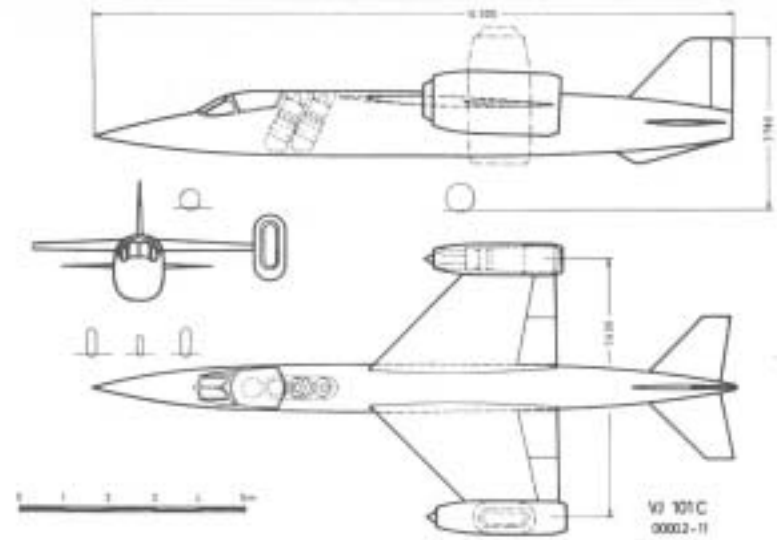
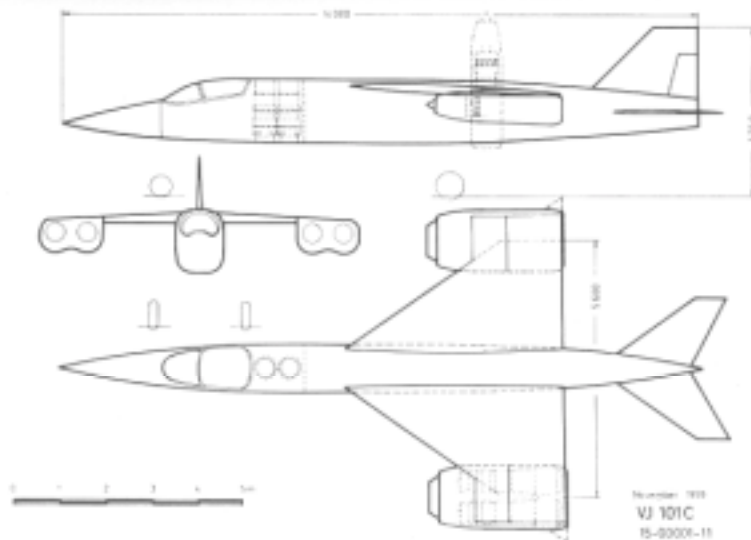
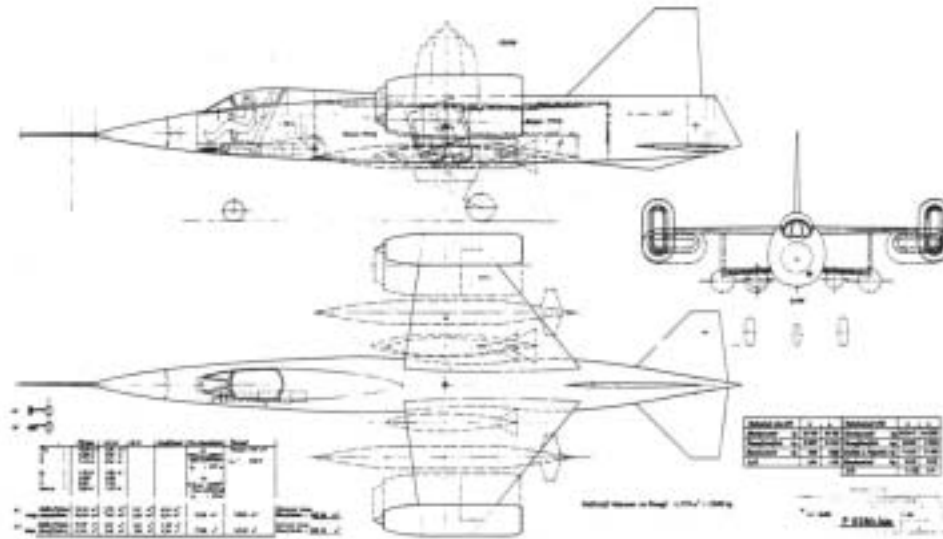


Design Convergence

- Defense Ministry encouraged competitors to develop a joint design
- Consortium founded in Feb 1959 of the (southern) German companies: Messerschmitt, Heinkel, and Bölkow known as Entwicklungsring-Süd (EWR-Süd)
- Combined solution reached in Sep 1959
 - Heinkel dropped canards
 - Messerschmitt accepted podded engines
- Lift plus lift/cruise propulsion concept with 2 lift engines and 4 lift/cruise engines
- EWR awarded contract in December 1959
- Extensive test program to validate design concept and reduce risk utilizing:
 - ground test rigs
 - hover test rigs
 - flight demonstrator aircraft



VJ 101C Evolution



VJ 101C Research Aircraft

Two supersonic single-seat VTOL research aircraft (X1 and X2) to support the VJ 101C development



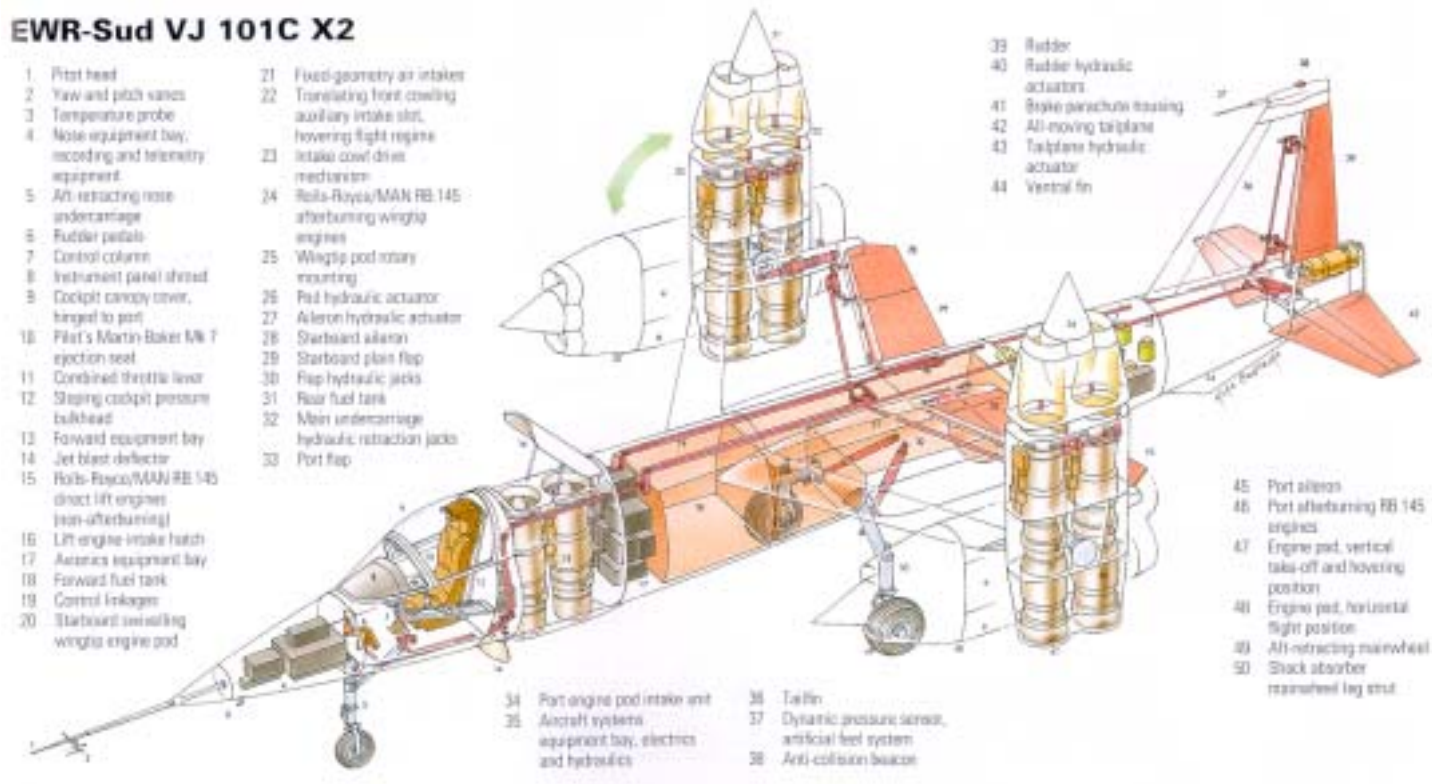
- X1 intended to focus on V/STOL aspects of the program



- X2 equipped with afterburning wingtip engines to expand the VJ 101C flight envelope beyond Mach 1

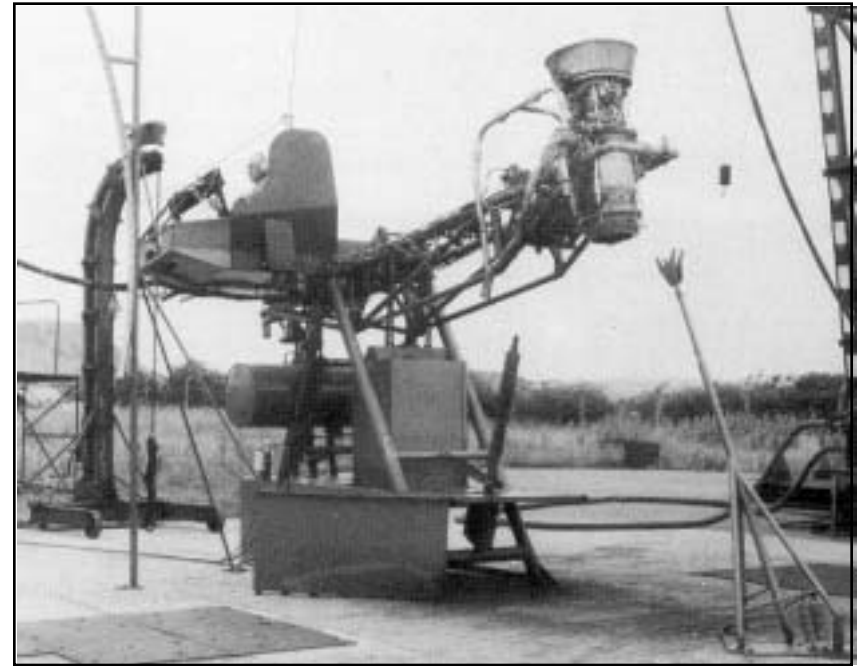
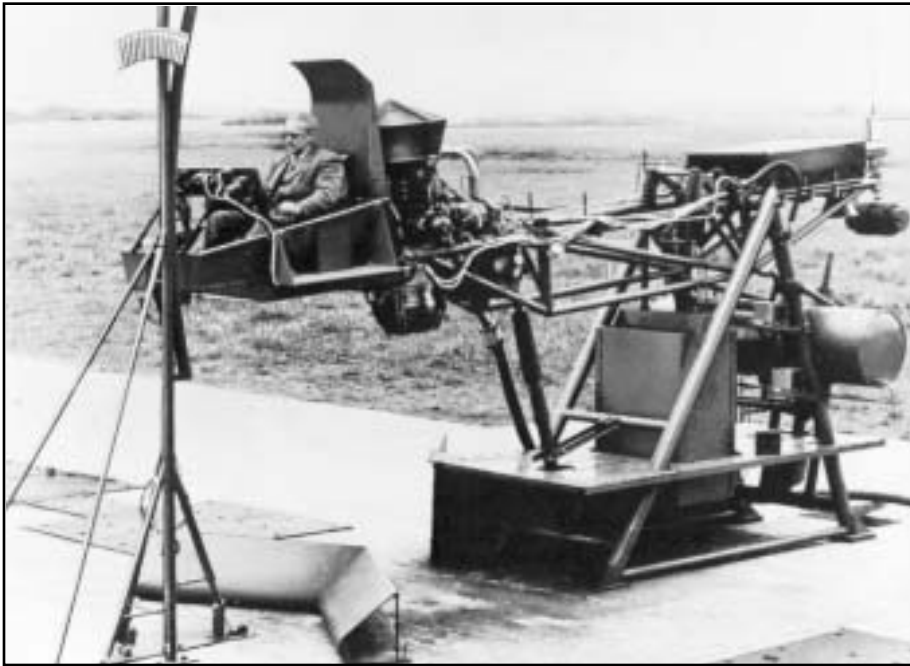
VJ 101C Propulsion System

EWR-Sud VJ 101C X2



- Lift plus lift/cruise propulsion concept
- Powered by 6 Rolls-Royce RB.145 turbojet engines
 - 2 engines mounted in tandem aft of cockpit
 - 4 engines carried in wingtip swiveling nacelles
- Wingtip engine nacelles capable of movement from full aft to 6 degrees forward of vertical

Ground Testbed



- Flight control experiments were conducted using ground test rig called the Wippe (“see-saw”)
- RB.108 lift engine could be used for pitch or roll
- Wippe used for initial development of thrust modulation stability augmentation system

VJ 101 Hover Rig



- Hover rig designed to simulate geometric layout of VJ 101C aircraft in hovering mode
 - Orientation of engines, cockpit, and landing gear designed to be as similar to actual aircraft as possible
 - Thrust to moment of inertia ratio equal to that of VJ 101C
 - Fitted with capability to swivel wingtip engines plus or minus 6 degrees from the vertical for yaw control
- Rig proved valuable for flight control system evaluation and initial pilot training

VJ 101C Hover Performance



- Initial hover tests conducted in captive mode using telescoping pylon enabling vertical motion as well as pitch, roll, and yaw motion
- Free-flight hover conducted in April 1963 after successful completion of tethered testing
- Initially tested with a fixed landing gear
- Aircraft thrust-modulated flight control system and attitude control approach demonstrated to be effective

Vertical Takeoff and Landing Techniques



- Vertical Takeoff
 - Jump technique minimized adverse near-field hot gas effects
 - Far-field gas ingestion effects reduced by tilting the aircraft forward after jump takeoff
- Vertical Landing
 - After slowing aircraft, landing gear/flaps lowered and lift engines started
 - As forward airspeed continued to decrease wingtip nacelles tilted toward 90 degree position, followed by vertical landing

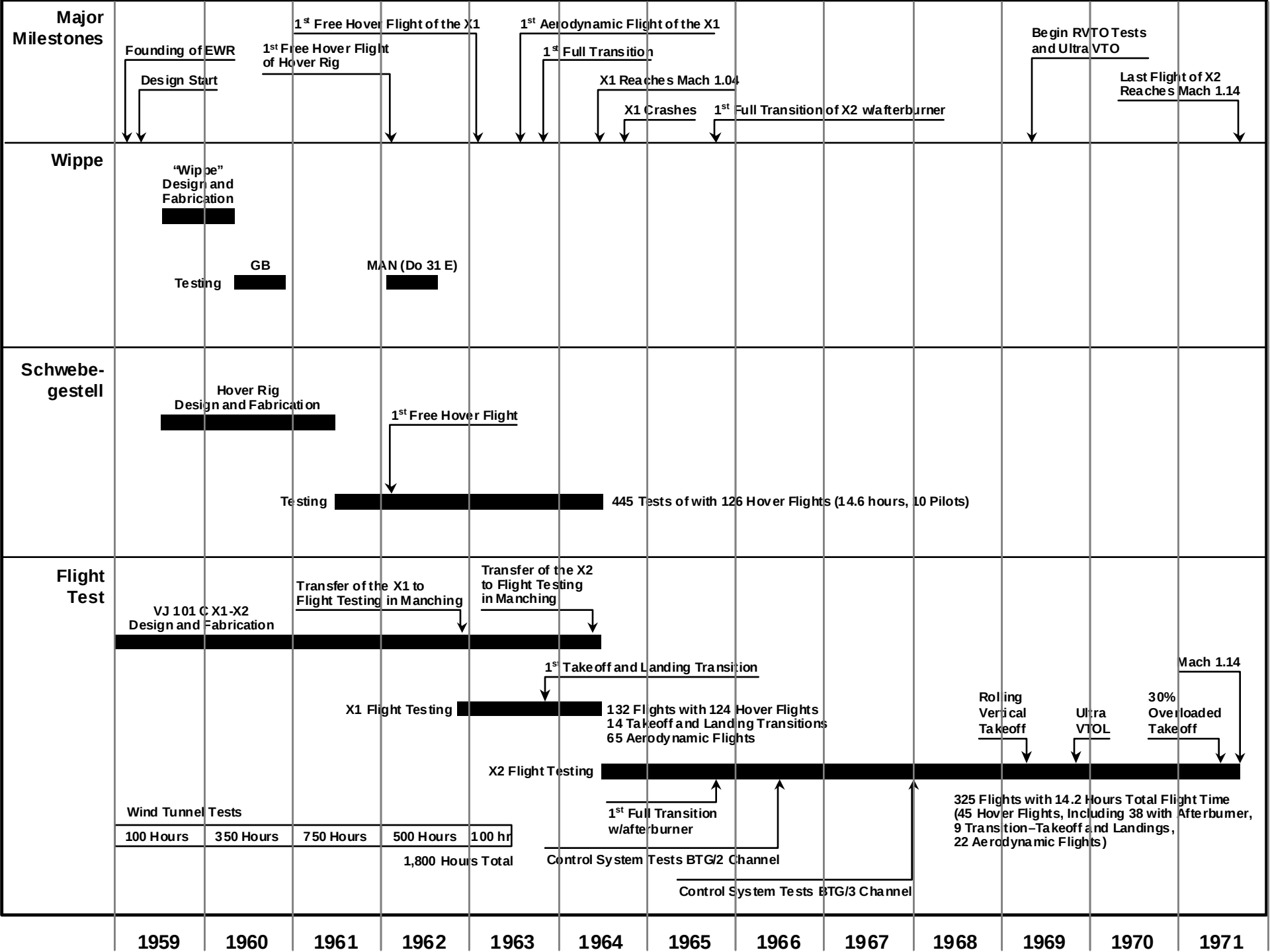
Afterburner Usage Effects



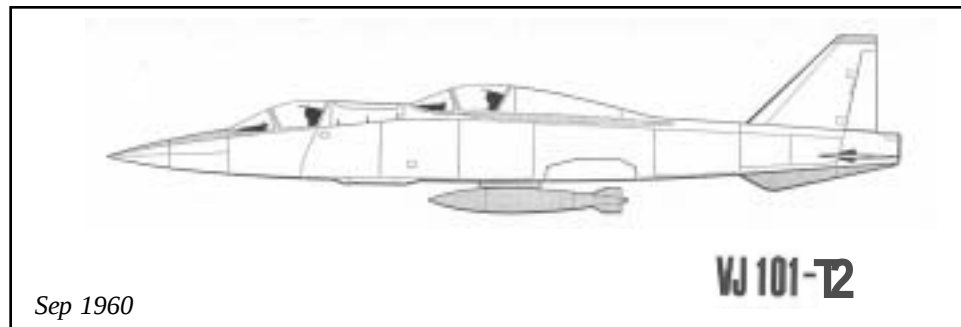
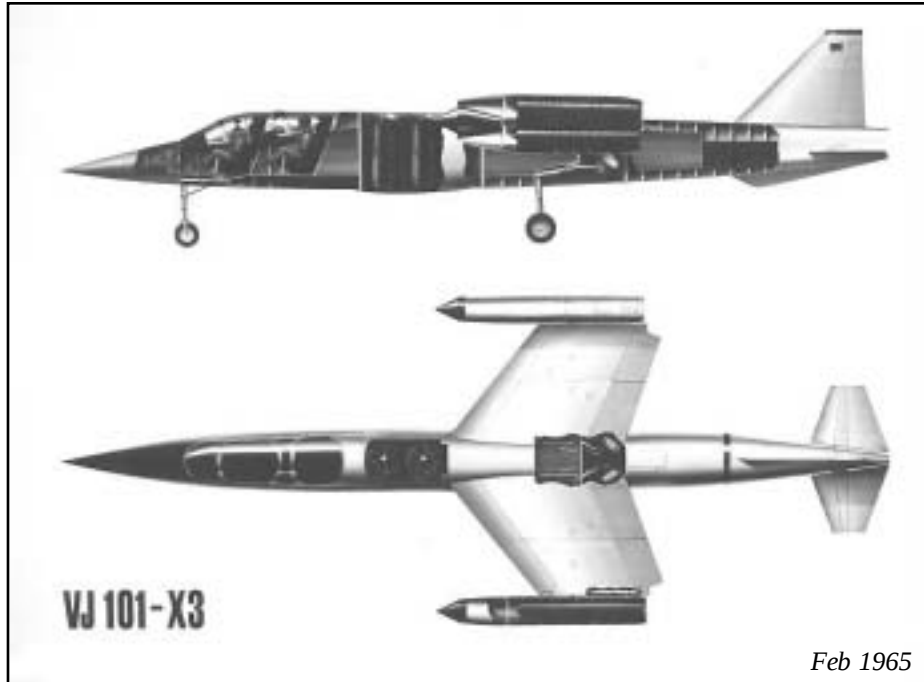
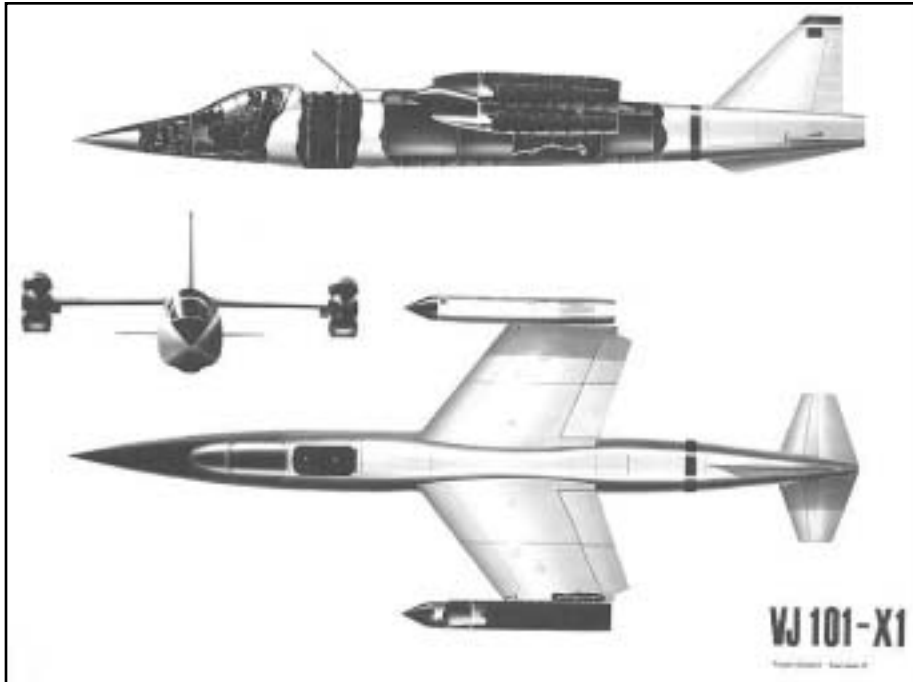
- Use of afterburning during vertical takeoffs and landings found to have adverse effects:
 - Extensive runway damage
 - Very high temperature exhaust gases reflected onto aircraft skin and tires
- Short takeoff run technique developed to minimize adverse effects of afterburner usage

VJ 101C Crashes

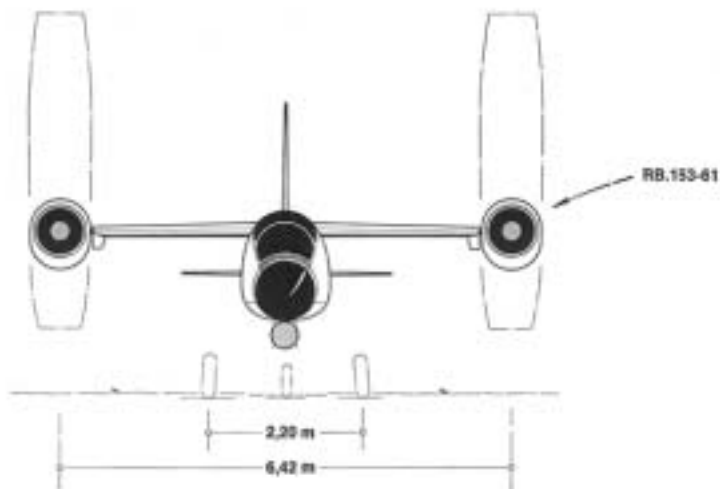
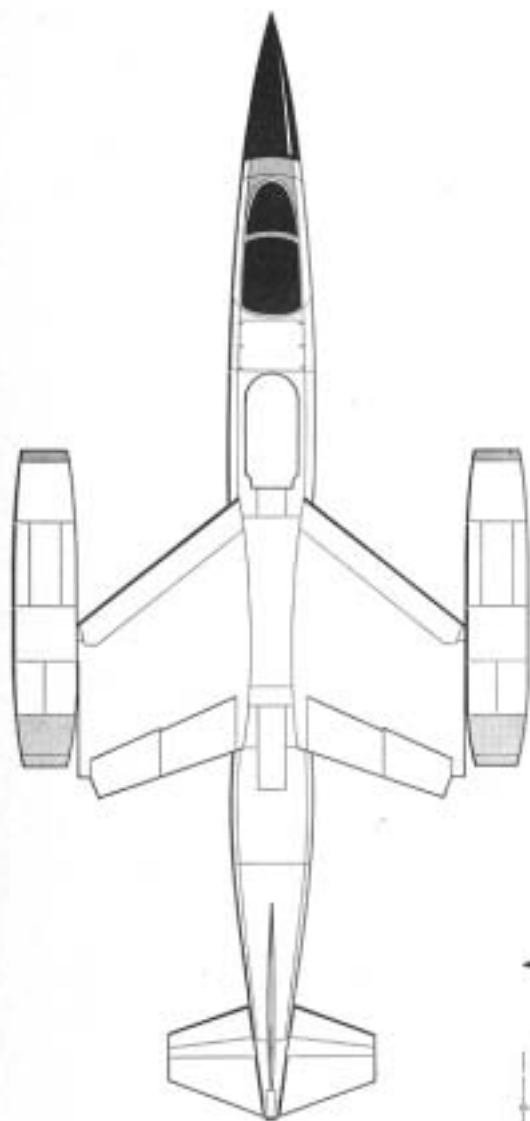
- VJ 101C X1 was destroyed on 14 Sept 1964
 - Uncommanded roll during a conventional take-off
 - Roll rate gyro was installed with reverse polarity
 - Lost on the 132nd flight
 - 124 hover flights
 - 14 transitions
 - First supersonic V/STOL -- Mach 1.08 without afterburner
- VJ 101C X2 suffered a hard landing in 1967
 - Ingested hot engine gases while taking off from a raised platform
 - Failure of the landing gear and serious damage to the aircraft
 - Rebuilt to flying status
 - Flew a total of 325 flights
 - 45 hover flights including 38 with afterburner
 - 9 transitions
 - Mach 1.14 highest test speed



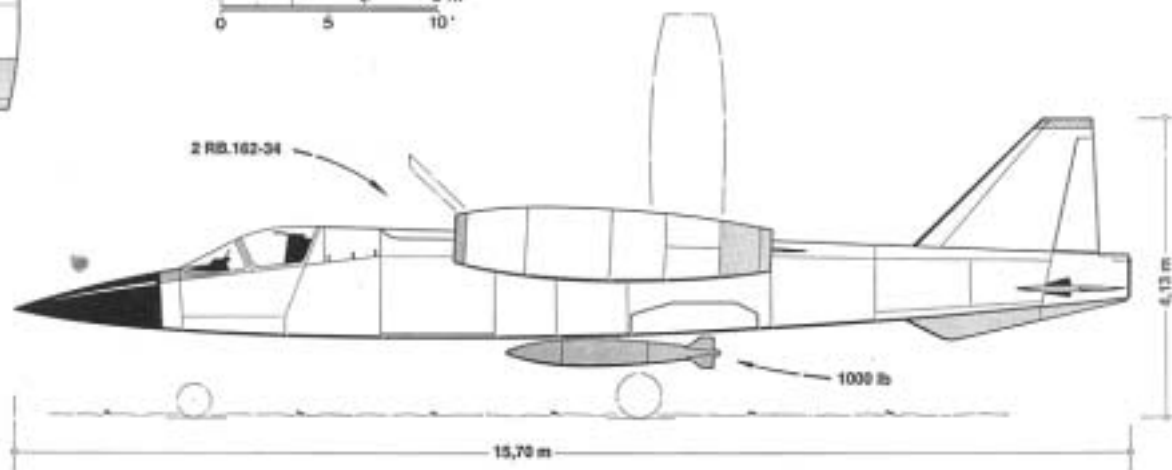
VJ 101C Two Seaters



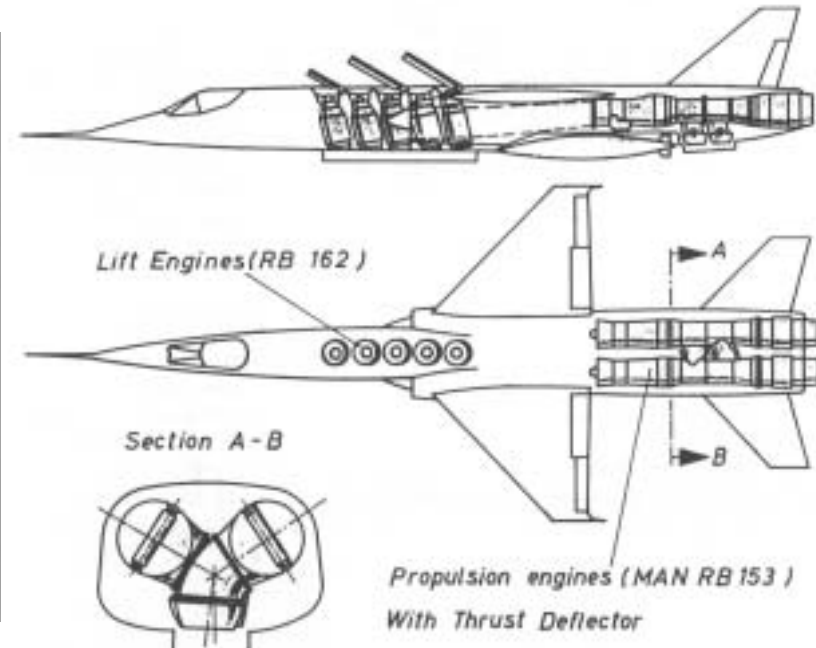
VJ 101 X4A



VJ-101 X4A

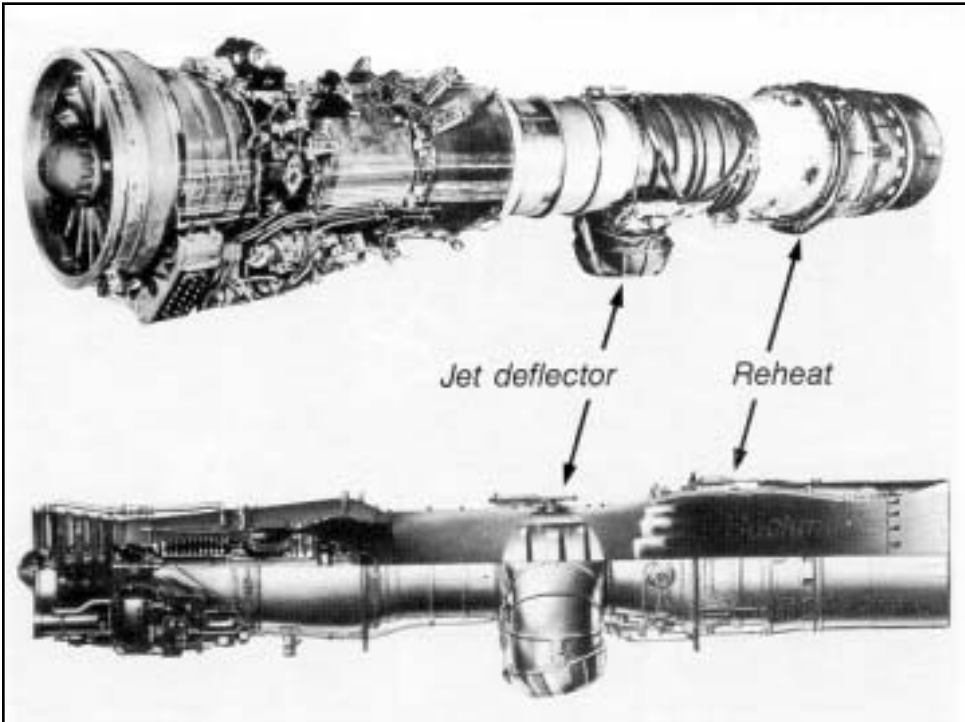


VJ 101D Design Concept



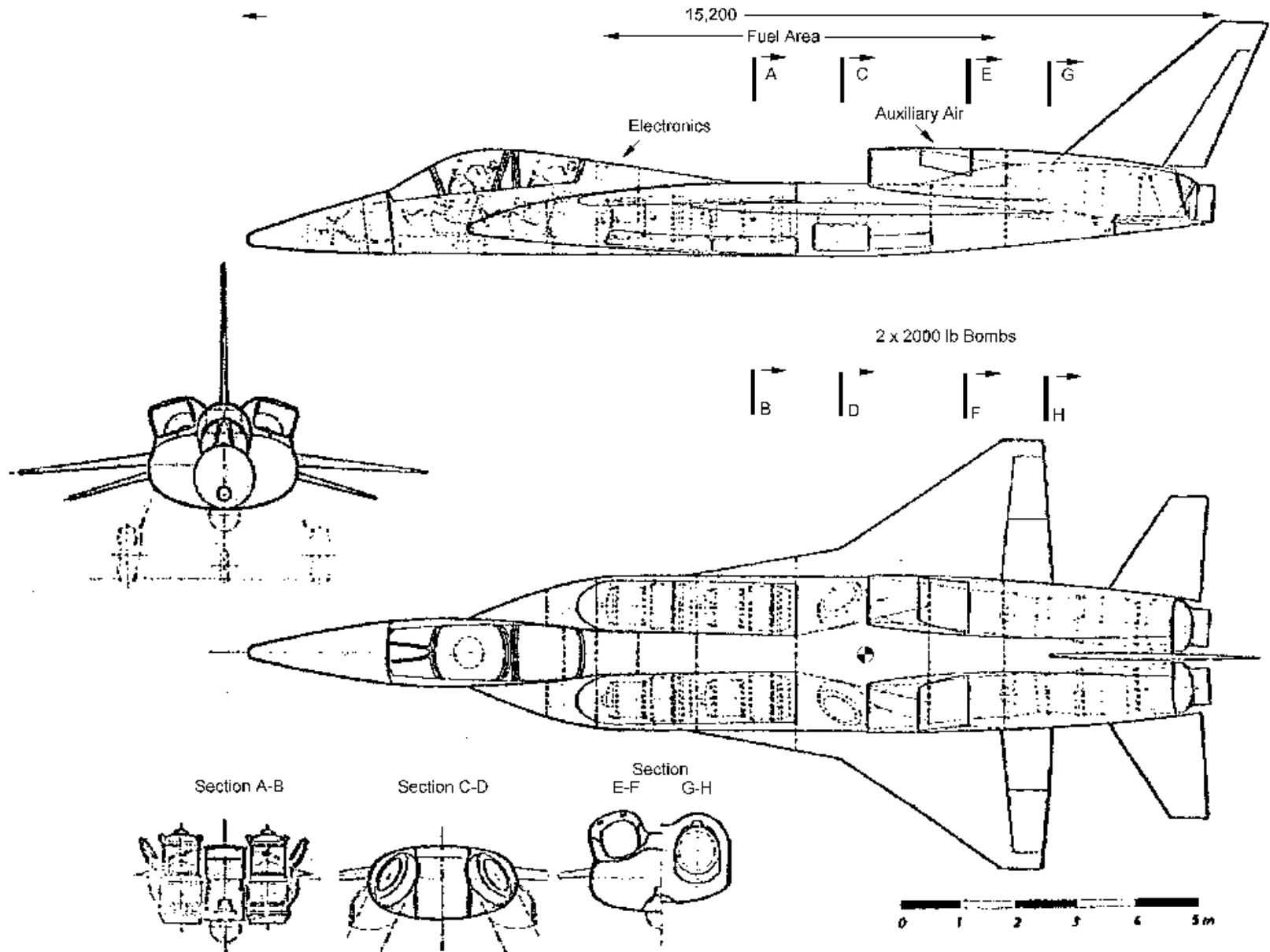
- VJ 101D represented major design shift away from VJ 101C demonstrator aircraft due to a NATO shift in strategy in mid-1961
- Primary VJ 101 combat role redefined to that of a low altitude VTOL strike fighter with supersonic high altitude capability
- Aircraft reconfigured with 2 fuselage mounted lift/cruise engines along with 5 lift engines in tandem
 - Rolls-Royce/MAN RB.153 lift/cruise engines in aft fuselage
 - Rolls-Royce RB.162 lift engines in forward fuselage

VJ 101D Propulsion System

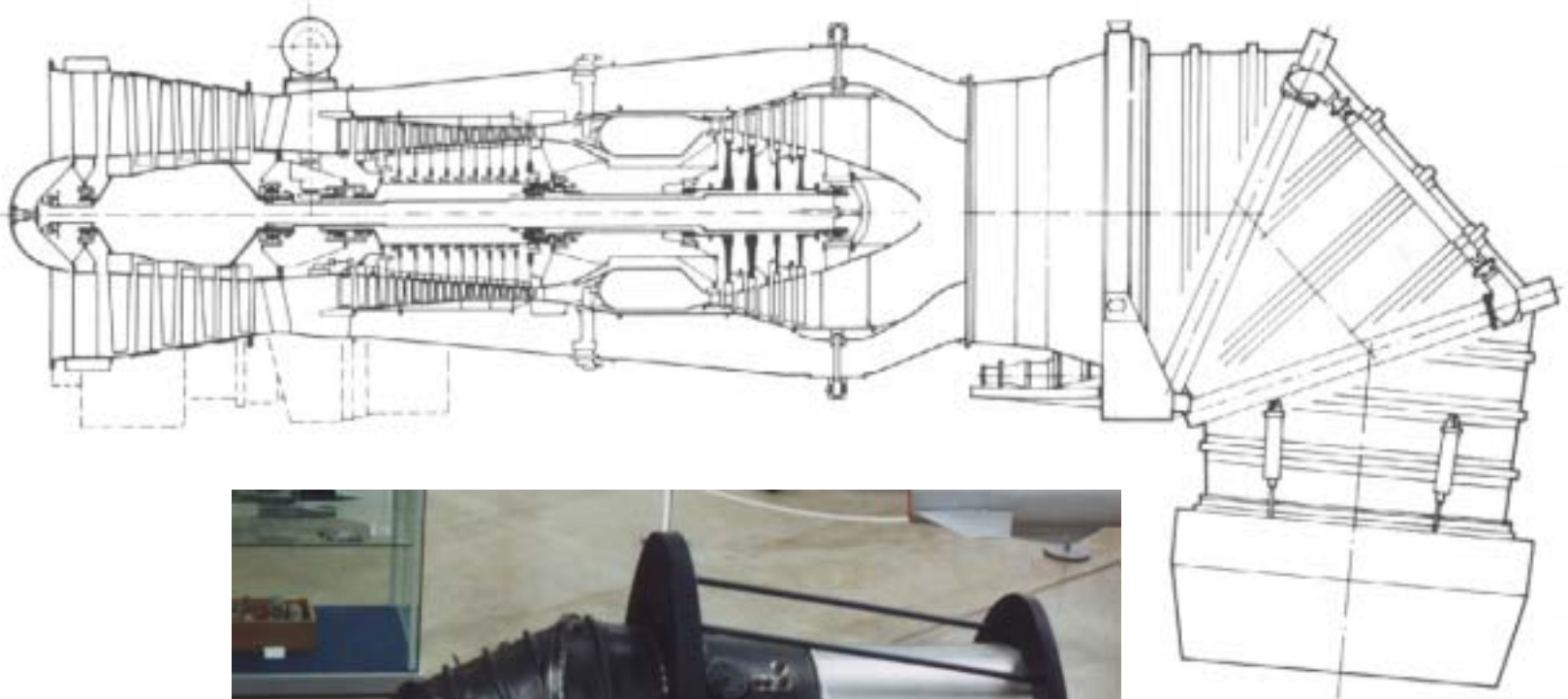


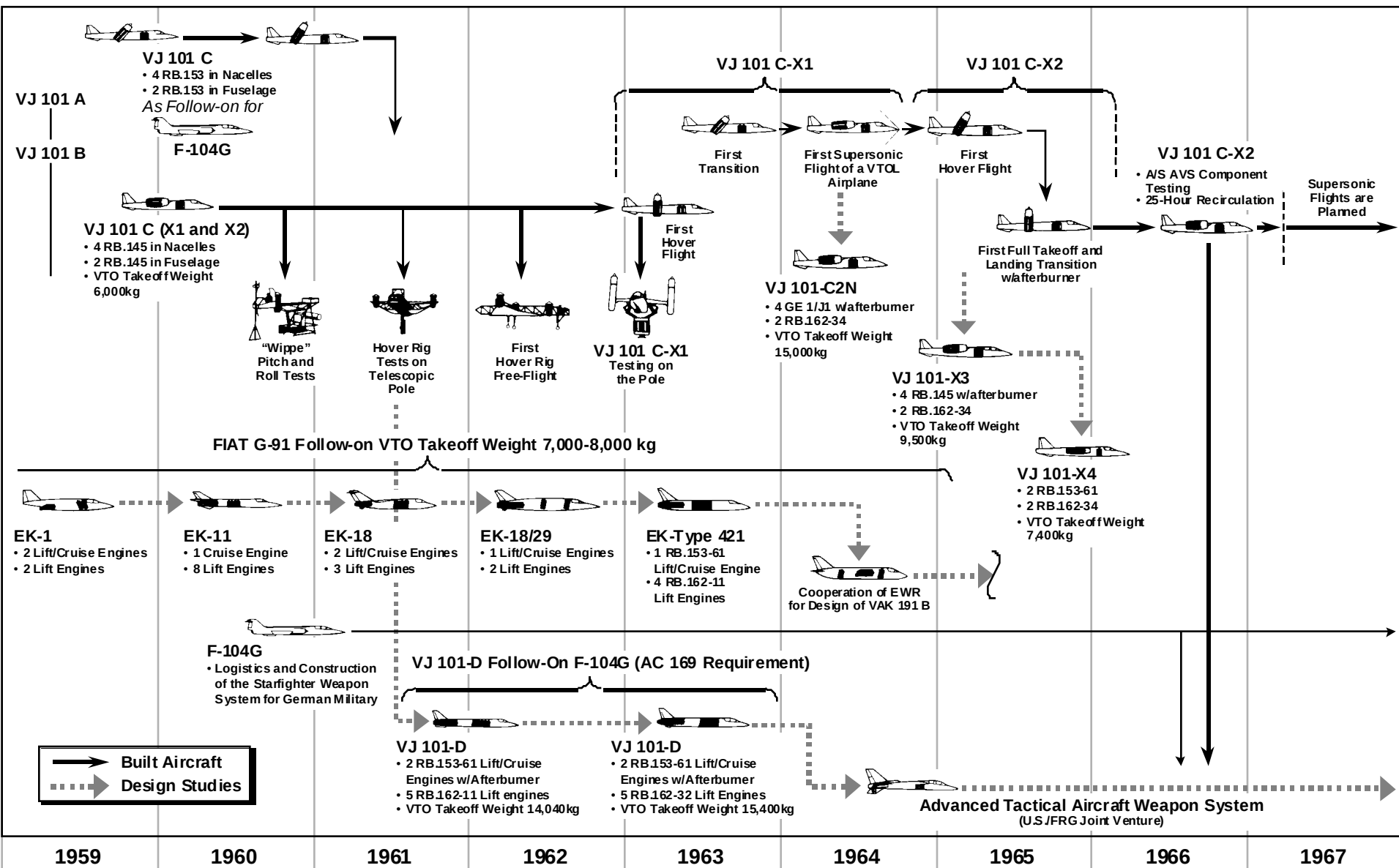
- Deflector nozzles with 15° swivel
- 6,850 lb thrust (30.5 kN)
- 11,750 lb in afterburner (52.3 kN)
- 6 engines were built
- Total running time 1,502 hours

VJ 101E



VJ 101E Propulsion System





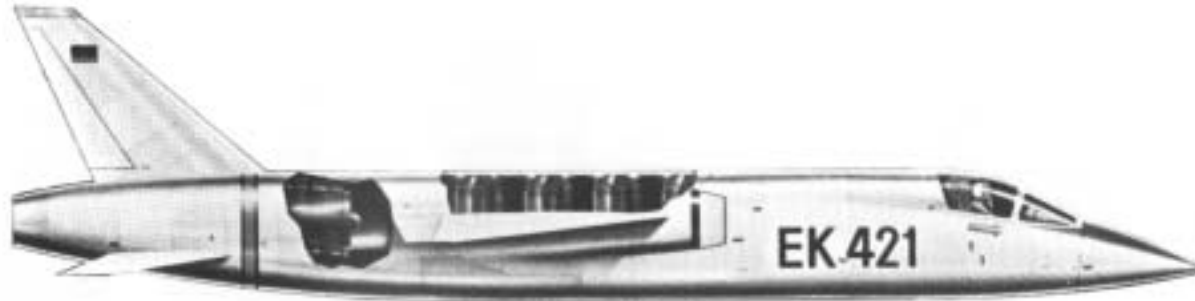
The VFW VAK 191 V/STOL Strike Fighter



VAK 191B Nuclear Strike Fighter

- VAK 191B optimized as single-mission design to deliver a nuclear weapon
- High speed low altitude profile taking off and landing vertically from dispersed sites
- Design sized to be as small as possible to meet mission requirements
- Propulsion concept included vectored thrust lift/cruise engine plus 2 vertical lift engines
- VAK = Vertikalstartendes Aufklärungs und Kampfflugzeug (V/STOL Reconnaissance and Strike Aircraft)

VAK 191B Overview



- Program began in 1962 to replace Fiat G.91 ground attack fighter with VTOL aircraft optimized for nuclear strike role
- Development undertaken by multi-national team led by a (northern) German consortium known as Vereinigte Flugtechnische Werke (VFW), which included Focke-Wulf, Heinkel and Weser
 - Formed December 1963
- Change in NATO policy from nuclear retaliation to flexible response drastically altered aircraft requirements
- Competing designs submitted by Hawker, EWR and Fiat

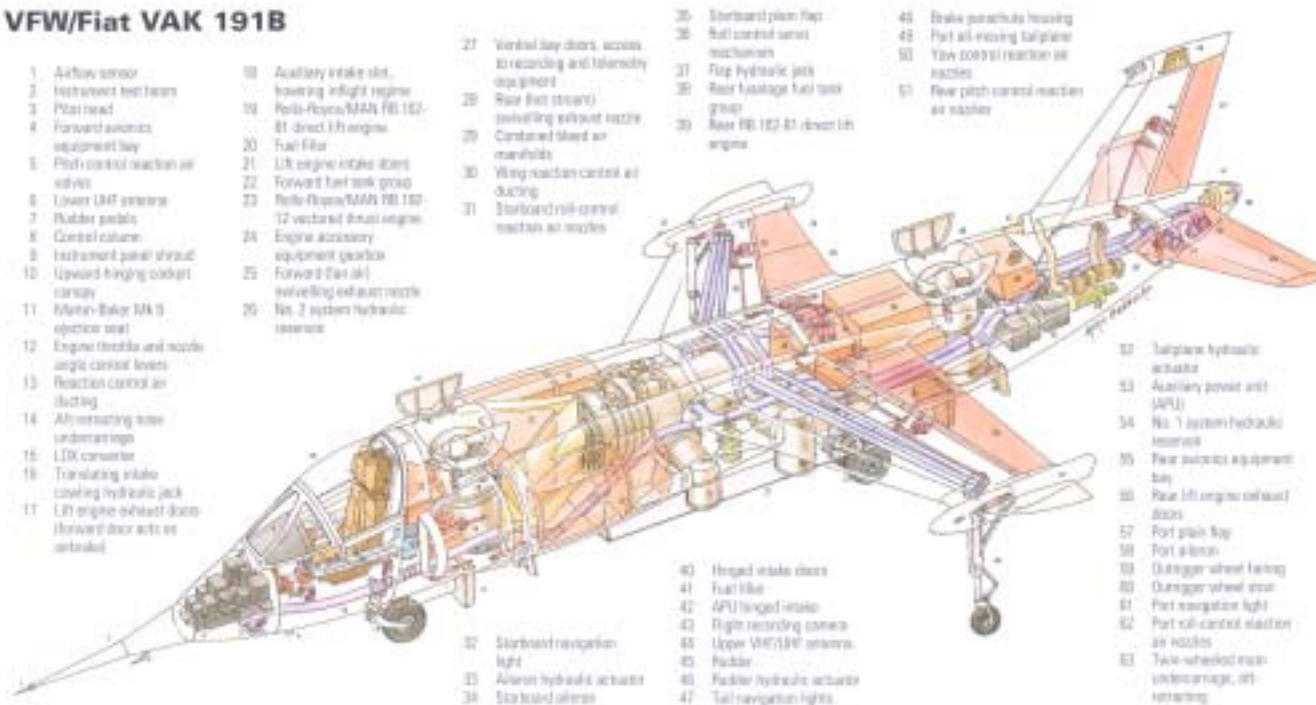
VAK 191B Project Focus Shift



- After change in NATO strategy project refocused as experimental V/STOL technology demonstrator
- 3 VAK 191B aircraft flown during flight test program from 1970-1972, further tested from 1974-75
- Many V/STOL and other advanced aircraft technologies, such as fly-by-wire (FBW) flight control systems, were successfully demonstrated

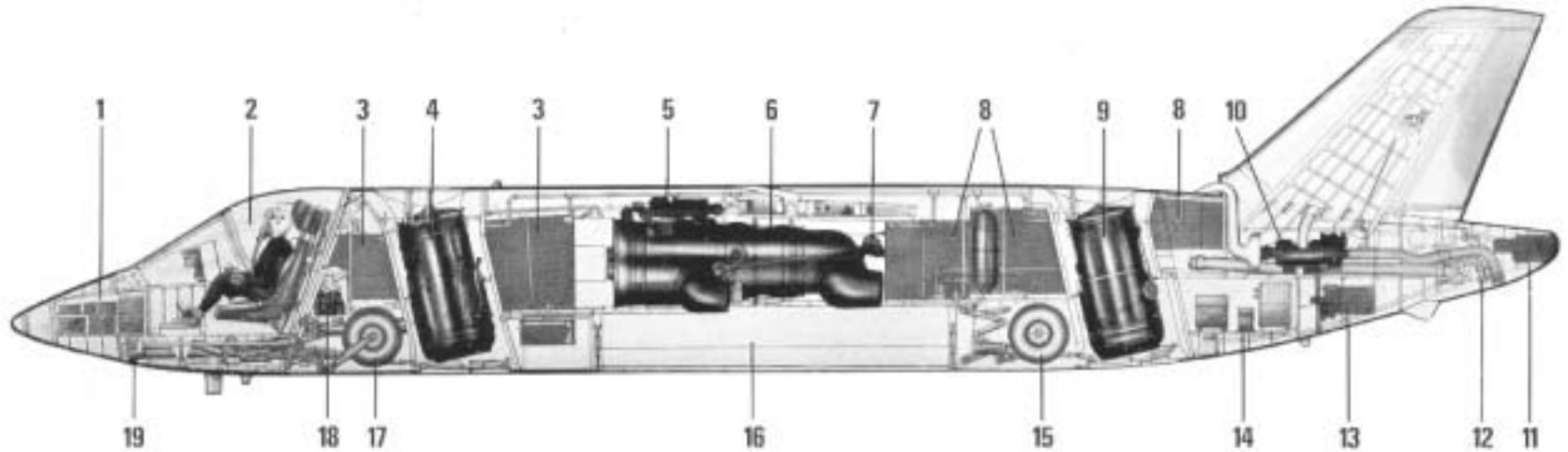
VAK 191B Concept

VFW/Fiat VAK 191B



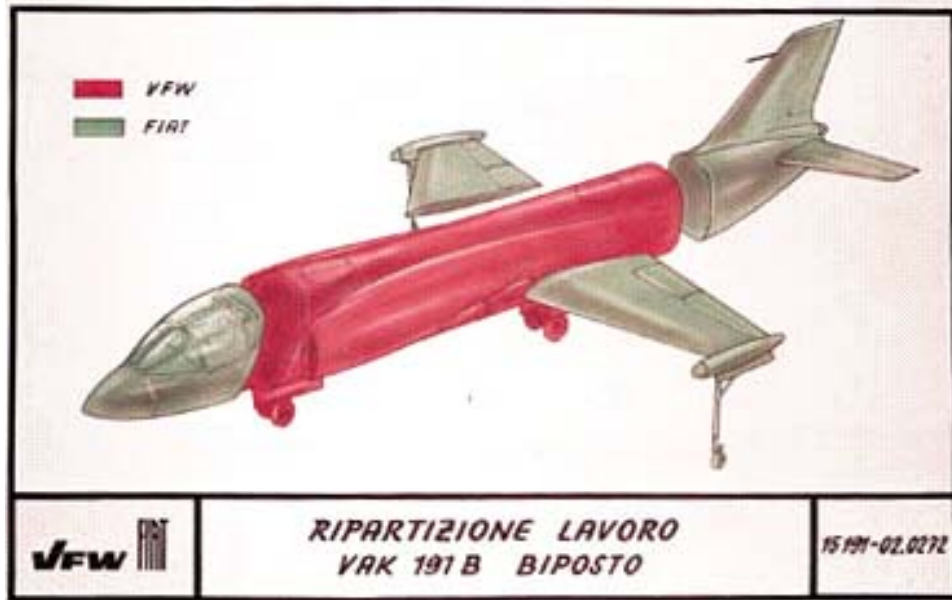
- Rolls-Royce and MTU teamed for propulsion
- German design team reasoned it was inefficient to design a VTOL aircraft with a single large vectored thrust engine
 - unnecessarily heavy/oversized for cruise
 - uneconomical operation
 - high aircraft drag resulting from large inlet area

NATO VAK 191 Requirement

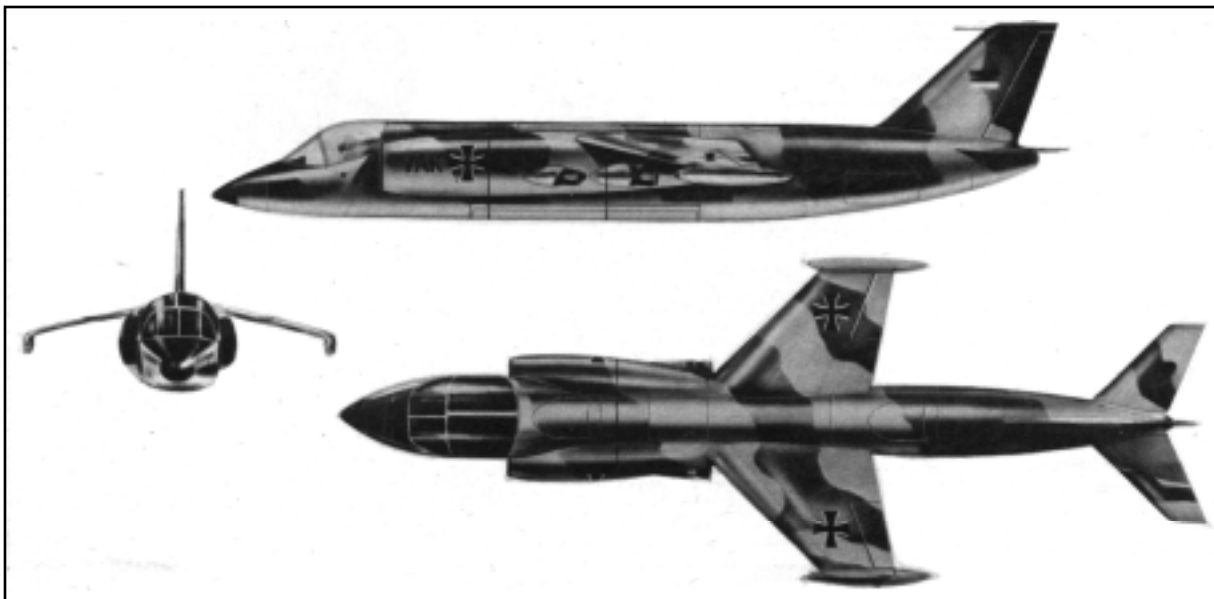


- Fiat G.91 Replacement
 - UK, Italy, Germany
- Formal NATO VAK 191 specifications:
 - Delivery of a single nuclear weapon at Mach 0.92 and low altitude
 - Low-low mission profile with a combat radius of 320 km (180 nm)
 - VTOL operations from dispersed hardened sites
 - Supersonic dash capability (Mach 1.2-1.4) at medium to high altitudes
 - 15,000-16,000 lb gross takeoff weight

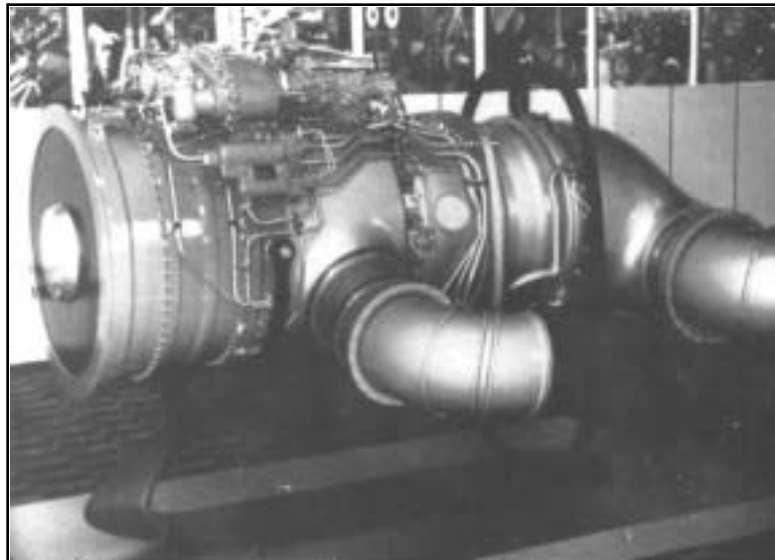
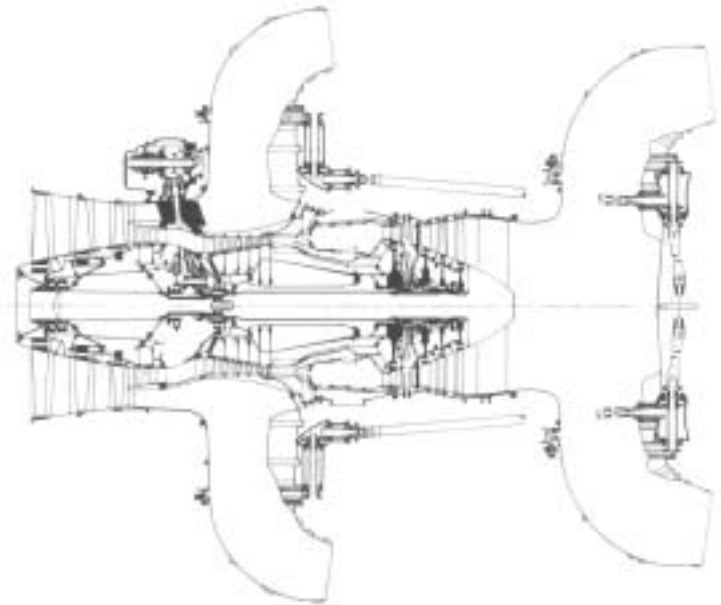
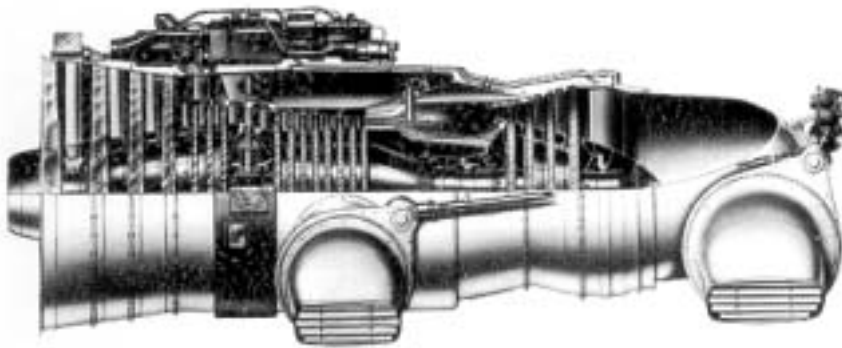
Fiat Involvement



- Originally Italy had a 40% stake in the program
- Fiat major subcontractor
- Two-seat trainer planned but cancelled in 1966
- Italy withdrew in 1967
- Fiat remained a partner



RR/MTU RB.193-12 Lift/Cruise Engine



Dimensions:

Length overall:	101.4 in	2.6 m
Fan diameter:	34.3 in	0.87 m

Weights:

Basic Engine:	1,742 lbs	790 kg
Installed Engine:	2,315 lbs	1050 kg

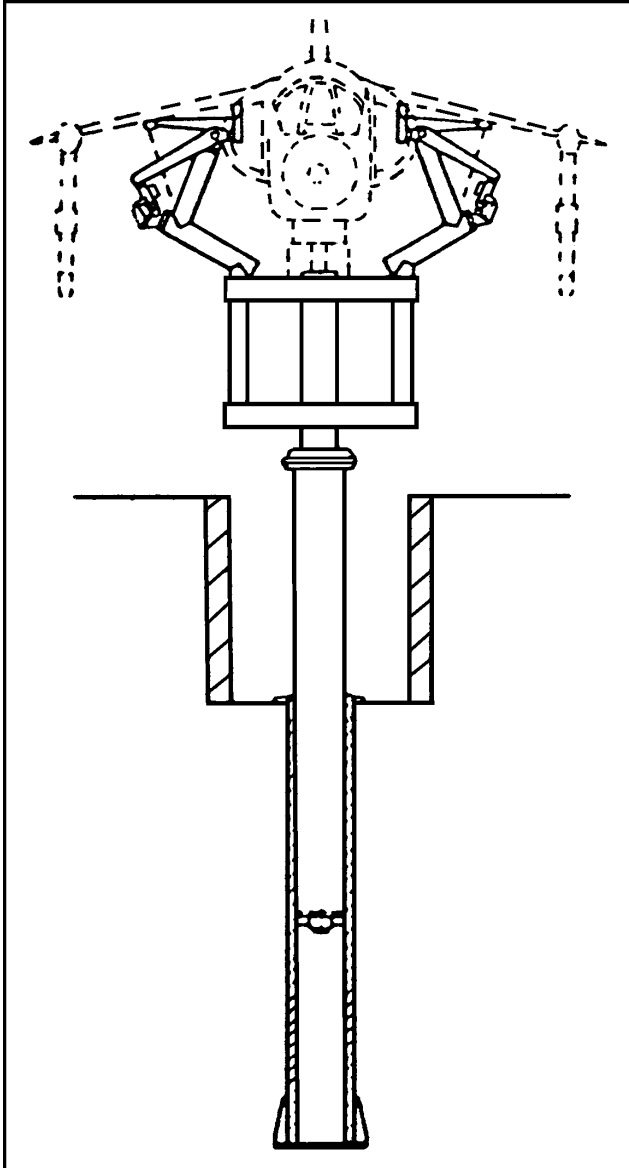
Maximum Thrust:	10,163 lbs	45 kN
------------------------	------------	-------

SG-1262 Hovering Rig



- Open-girder fuselage powered by 5 Rolls-Royce RB.108 lift-engines of 2,200 lb static thrust each.
 - 3 center engines simulated vertical thrust produced by lift/cruise engine of VAK 191B
 - 2 front/rear engines simulated aircraft lift engines
- Control accomplished via vertically-thrusting “puffer-jets”

Ground and Captive Testing



- VAK 191B program made use of extensive hardware development testing and preflight preparation phase including:
 - Wind tunnel testing
 - 5 engine hover rig capable of free-flight to evaluate FBW flight control system
 - Captive testing of VAK 191B with a telescoping (pedestal-mounted) test apparatus

Hover Performance



- Good precision and low pilot workload when out-of-ground-effect due to attitude-command FBW flight control systems
- Hover in-ground-effect unsteady resulting from recirculation and hot gas ingestion
- Non-linear pitch-attitude control response due to mixing of lift engines thrust modulation with reaction bleed air forces

Short Takeoff Performance



- Short rolling takeoffs accomplished by starting lift engines during takeoff roll
- Short takeoff performance of VAK 191B considered poor because of small wing and high lift engine ram drag
- Procedure resulted in high pilot workload and was not deemed operationally suitable

Conventional Takeoff and Landing



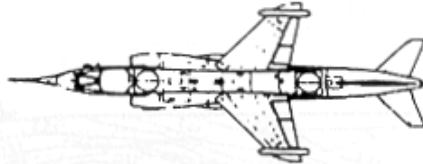
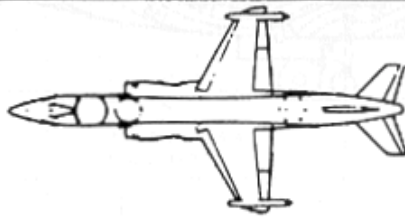
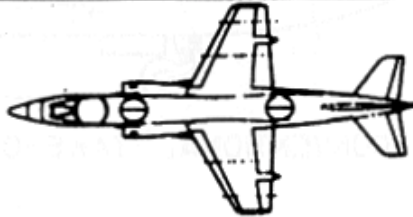
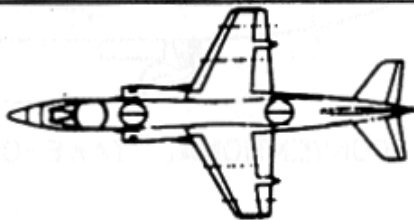
- Takeoff
 - Aircraft design based on VTOL operation only
 - Small wing area and high wing loading required takeoff speeds near 230 kts
 - Rotation of aircraft difficult because of landing gear arrangement and small tailplane
- Landing
 - One emergency conventional landing successfully made, but well above max landing gear design speed (190 vs 160 kt)

Transition Flight Performance



- High required transition speeds (over 200 kts)
- Acceleration in upper transition speed range barely adequate at nominal gross weights
- High induced drag associated with small low aspect ratio swept wing
- High momentum drag due to flow turning through lift engines

NATO Strategy Shift

 VAK 191 B V/STOL EXPERIMENTAL AIRCRAFT			
MK 1	 1 x RB 193-12 (10 200 lb) 2 x RB 162-90 (11 740 lb)	MK 3	 1 x RB 193-30 (13 360 lb) 2 x XJ-99 (14 400 lb)
	 1 x RB 193-30 (13 360 lb) 2 x RB 162-91 (12 300 lb)		 1 x RB 193-30/P (18 300 lb) 2 x XJ-99 (14 400 lb)

- Change in NATO strategy from massive nuclear retaliation to flexible response
- NATO strike aircraft needed robust conventional weapons capability
- Nuclear role deleted and VTOL capability de-emphasized from G.91 replacement requirement

VAK 191B Mk. 2

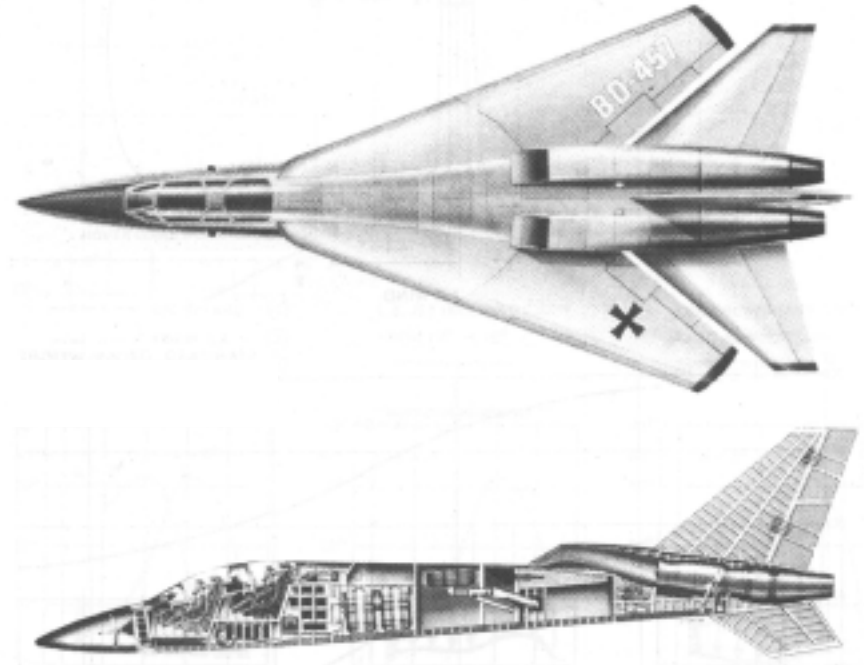


- VFW proposed VAK 191B Mk. 2 variant to create more flexible design with good weapons payload and high maneuverability
- VAK 191B Mk. 2 featured:
 - 50% increase in wing area
 - Up-rating of lift/cruise engine thrust by 30%
 - Up-rating of lift engine thrust by 5%
 - Addition of 4 underwing ordnance pylons

VAK 191B Observations

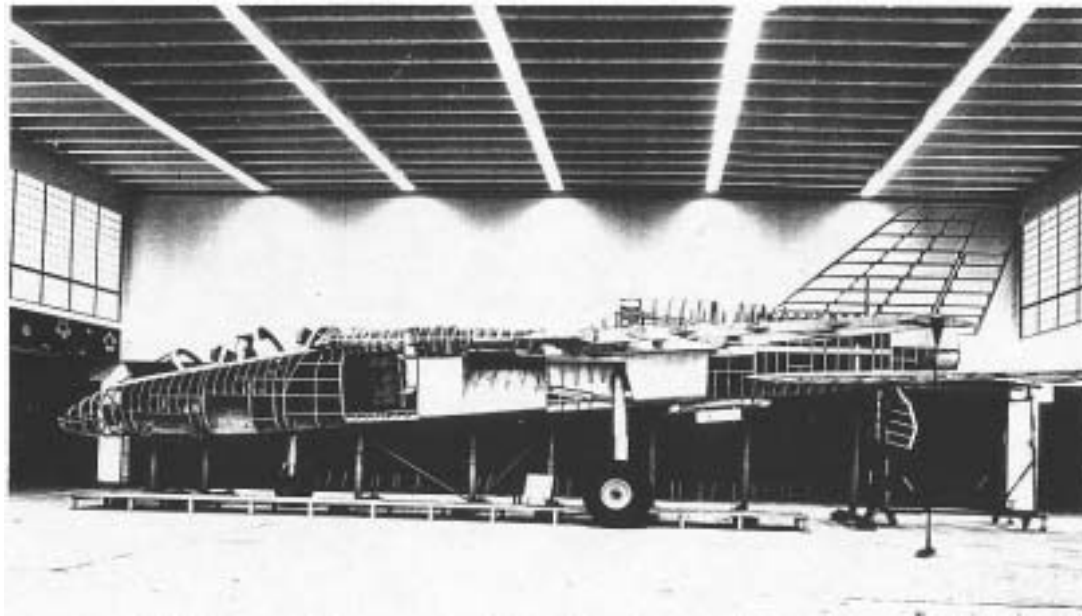
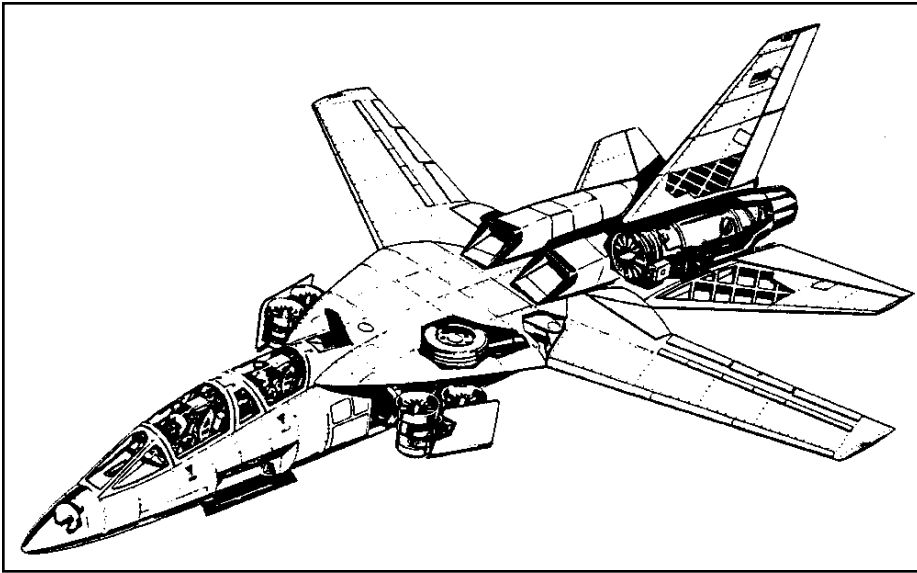
- VAK 191B designed as smallest VTOL aircraft capable of flying a single nuclear strike mission
- Design concept resulted in an aircraft with severely limited flexibility for other missions
- Design was not amenable to growth without carrying high risk of an uncontrollable weight spiral
- Aircraft had poor thrust-to-weight ratio and high wing loading resulting in seriously limited use for conventional ground attack missions
- VAK 191B was a useful demonstrator in proving feasibility of advanced technologies
 - Fly-By-Wire
 - 4,000 psi hydraulic system
 - APU

Aftermath: AVS Program

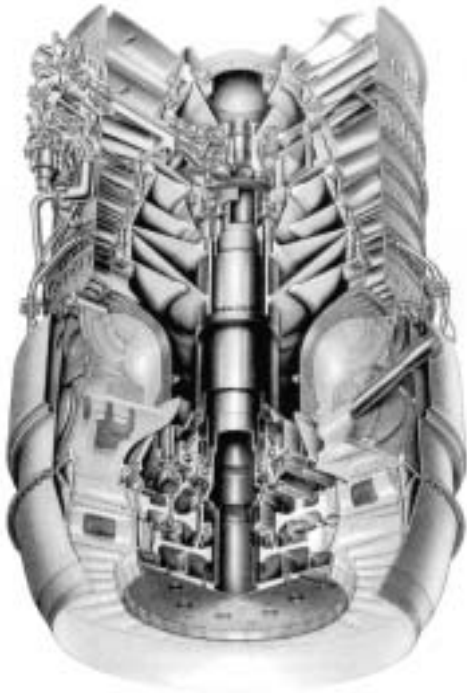


- Advanced V/STOL Tactical Fighter Weapons System (AVS)
- Design study for an F-104G successor with V/STOL capability
- Joint German / US project with EWR / Boeing then EWR / Fairchild Hiller Republic
- Program ran from 1964-68

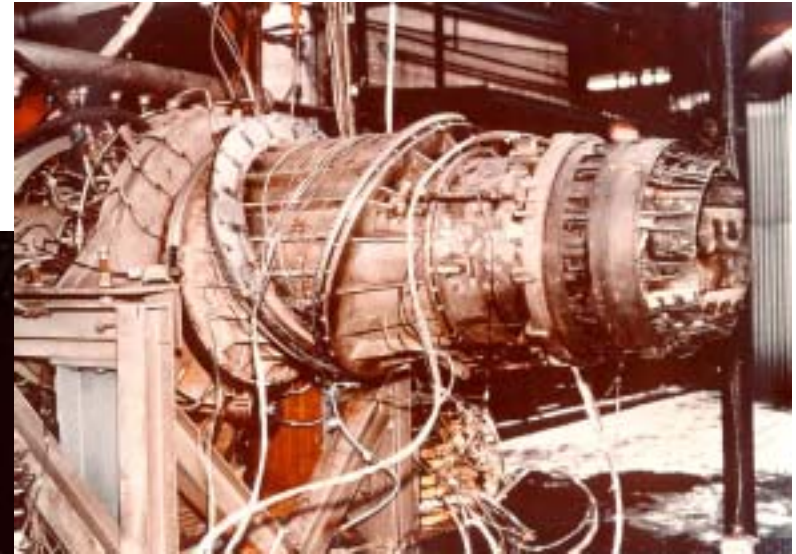
AVS



Aftermath: AVS Propulsion System



- Rolls-Royce Allison XJ99 Lift Engine
 - Development 1965-1971
 - Engine tests in 1968
 - 8690 lb thrust (39 kN)
 - 17.6 T/W



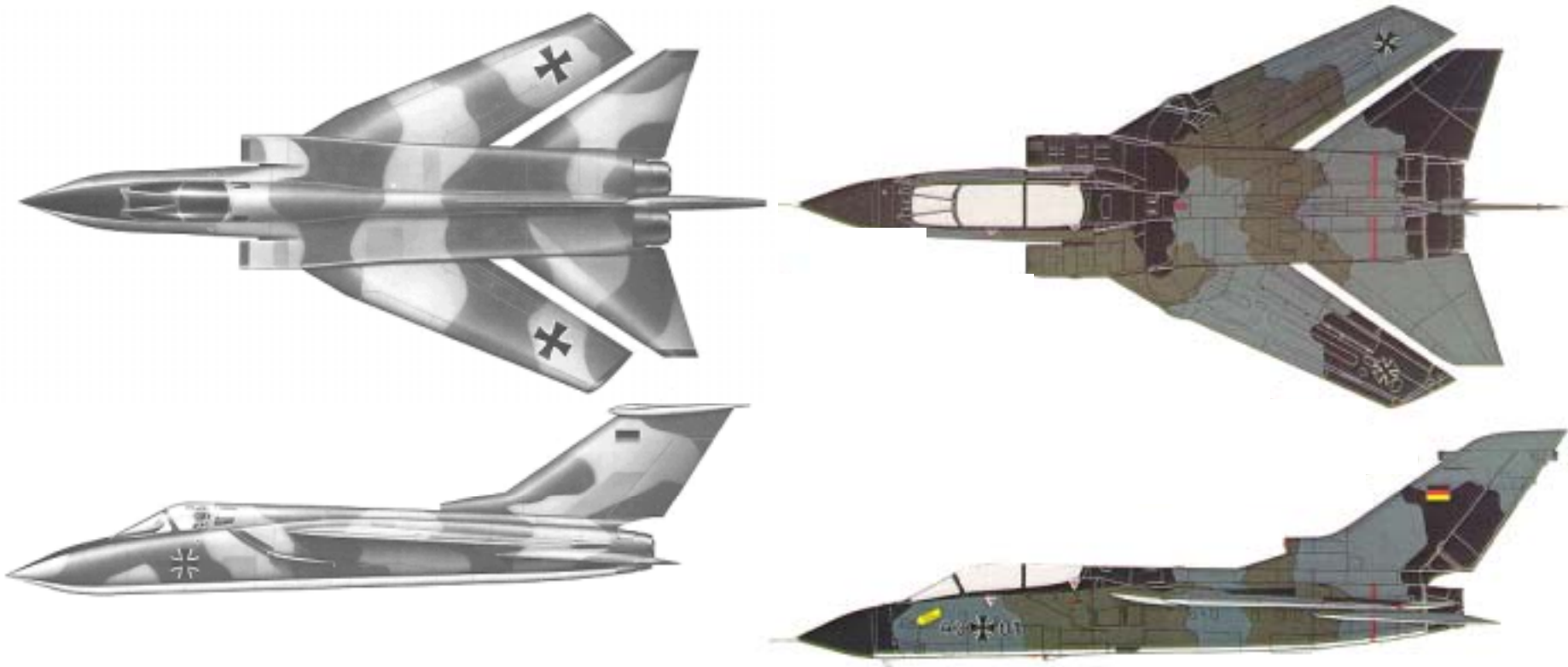
- Lift/Cruise engine with three-bearing swivel nozzle
- Nozzle tests conducted
 - Half-scale actuated
 - Full-scale non-actuated
 - Afterburner operations

Aftermath: EWR A 400 Design Study

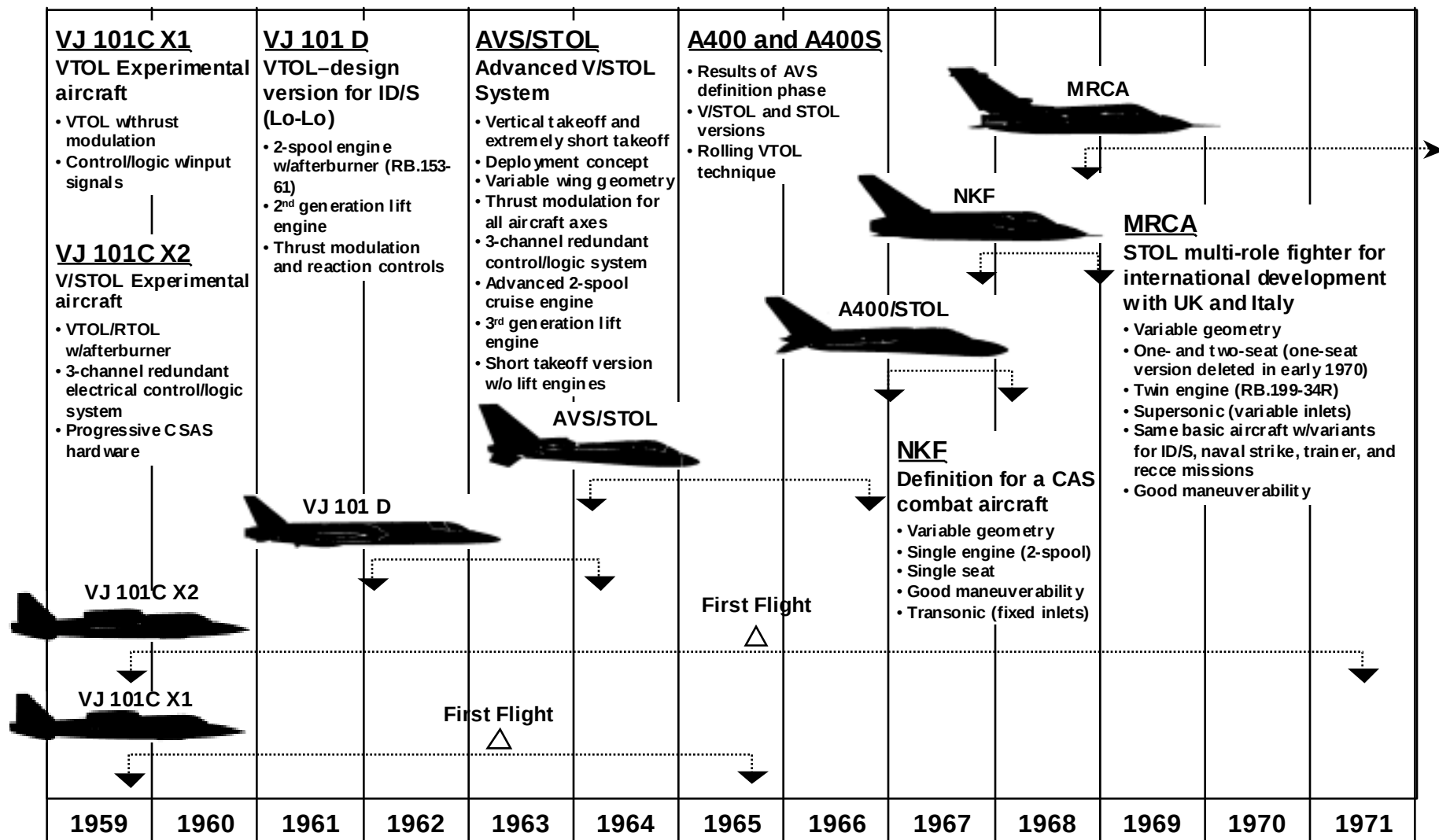


- EWR design studies 1965-1968
- STOL and V/STOL versions (with lift engines)

Aftermath: Panavia Tornado



- Multi-Role Combat Aircraft (MRCA)
- Germany/Italy/UK program initiated in 1968
- First flight August 1974 with full-scale development March 1976
- Nearly 1000 aircraft built through end of production in 1993



Summary

- In the 1960s and early 1970s, the German Luftwaffe developed three V/STOL aircraft
 - High altitude supersonic fighter-interceptor
 - EWR VJ 101C
 - Low altitude nuclear strike fighter
 - VFW VAK 191B
 - Theater tactical airlift aircraft -- subject of a future paper!
 - Dornier Do 31
- All fell victim to challenging and changing requirements