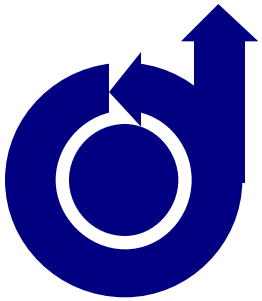
2000 International Powered Lift Conference



# 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

Supersonic fighter-interceptor

- Pre-VAK 191 Concepts
- VAK 191
- VAK 191 Follow-On Concepts
- End Results

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:

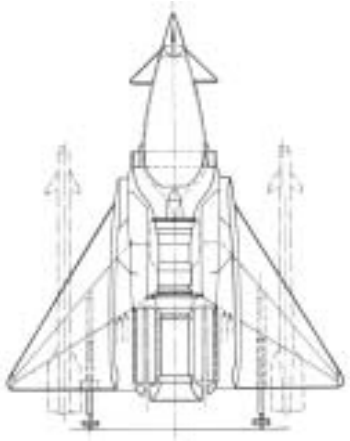
- Operational range: 54-270 nm
- Max altitude: 65,600-72,200 ft
- Maximum speed: Mach 2.5
- Vertical take-off with 25% reserve power
- Time to climb to 65,600 ft approx 90 sec

F-104G Characteristics:

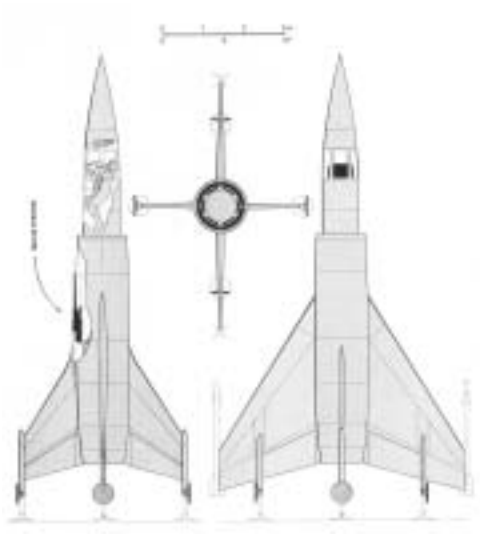
- Operational range: 260 - 648 nm
- Max altitude: 58,000 ft - 90,000 ft
- Maximum speed: Mach 2.2
- Take-off distance 3,000 ft3
- Time to climb to 50,000 ft approx 140 s
- Payload of two air-to-air missiles and 20 mm cannon

# 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

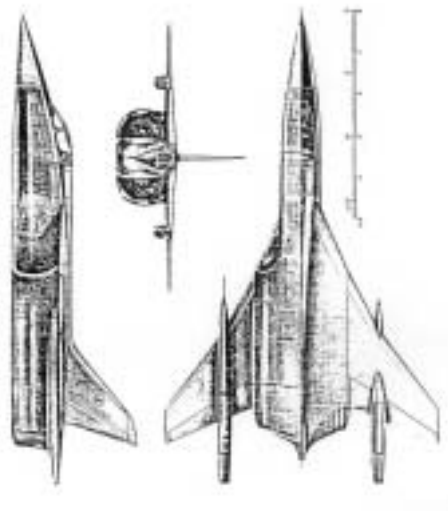


Bolköw P 110.1



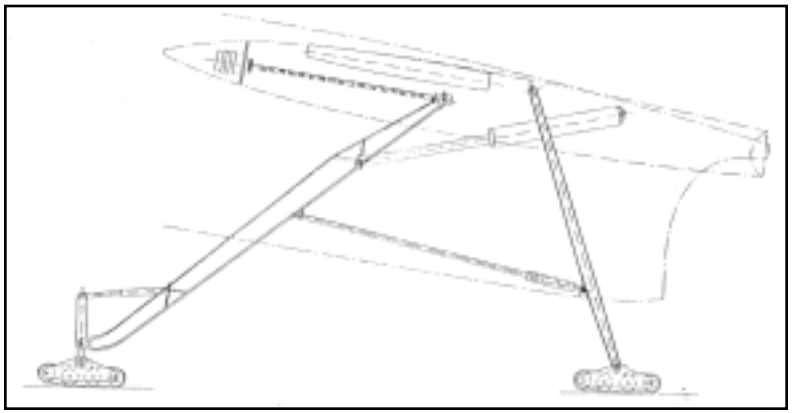
Heinkel He 231

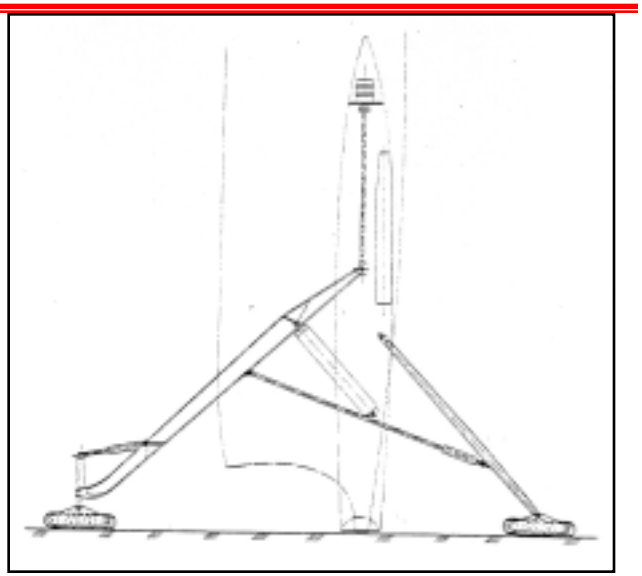
Messerschmitt Me X1-21

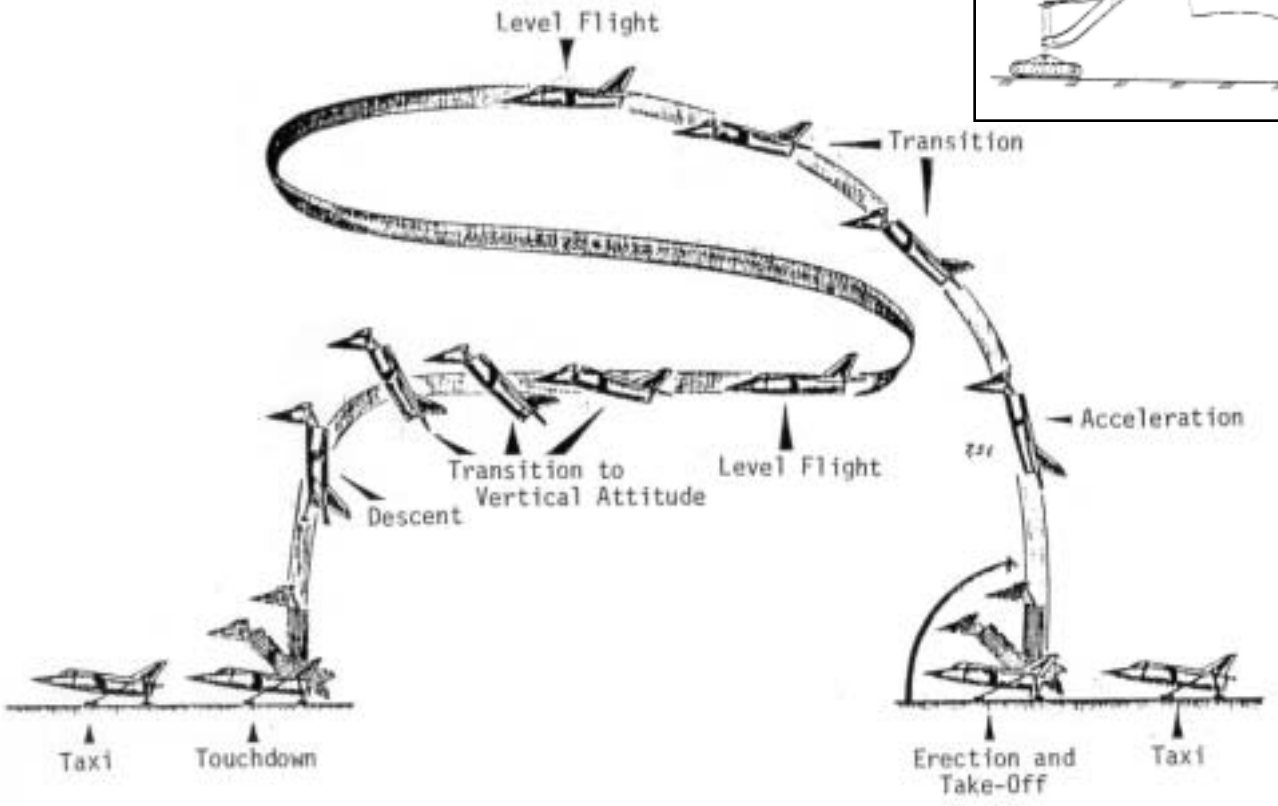


Focke Wulf Fw 860

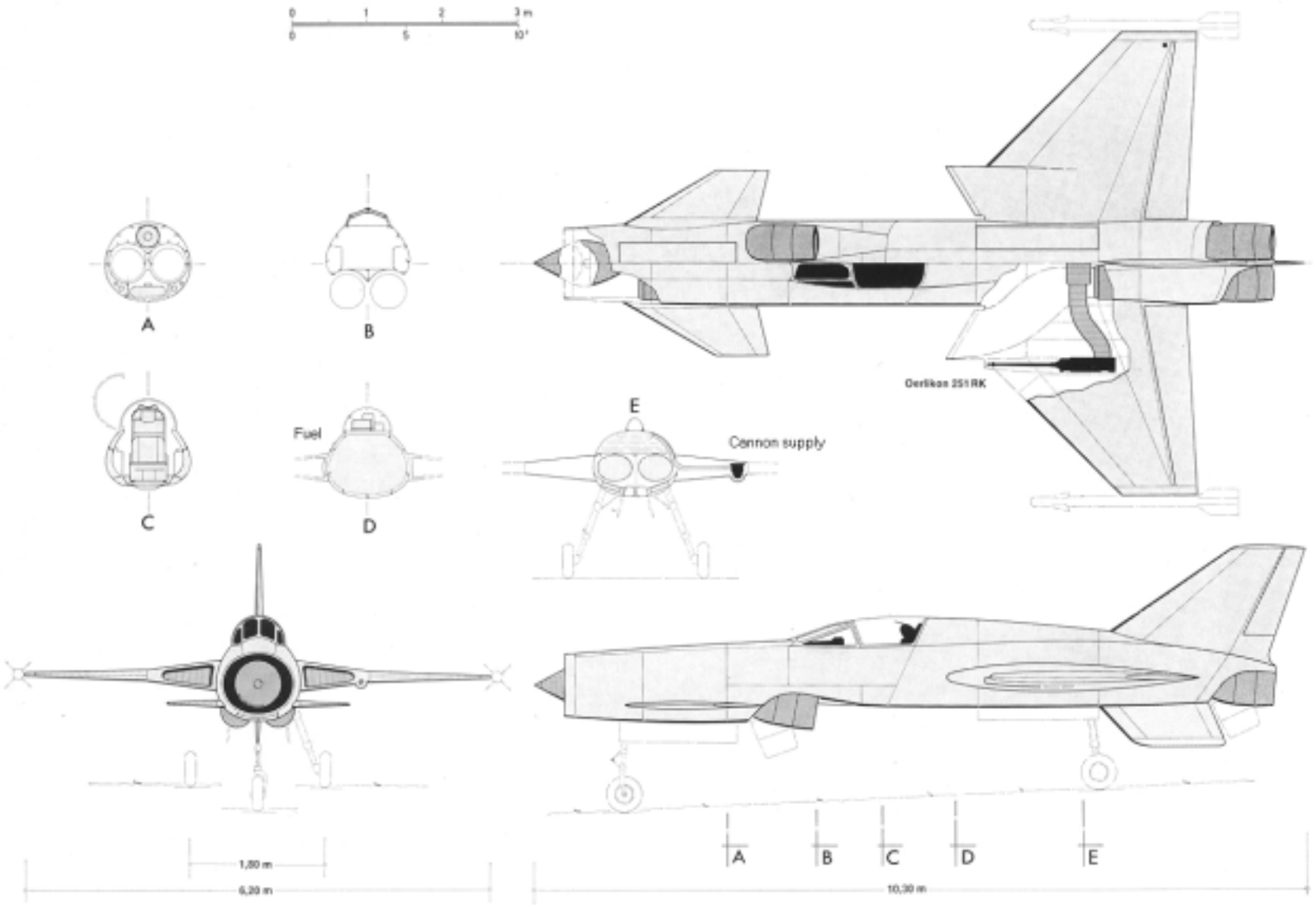
# Focke-Wulf 860 Tailsitter Concept



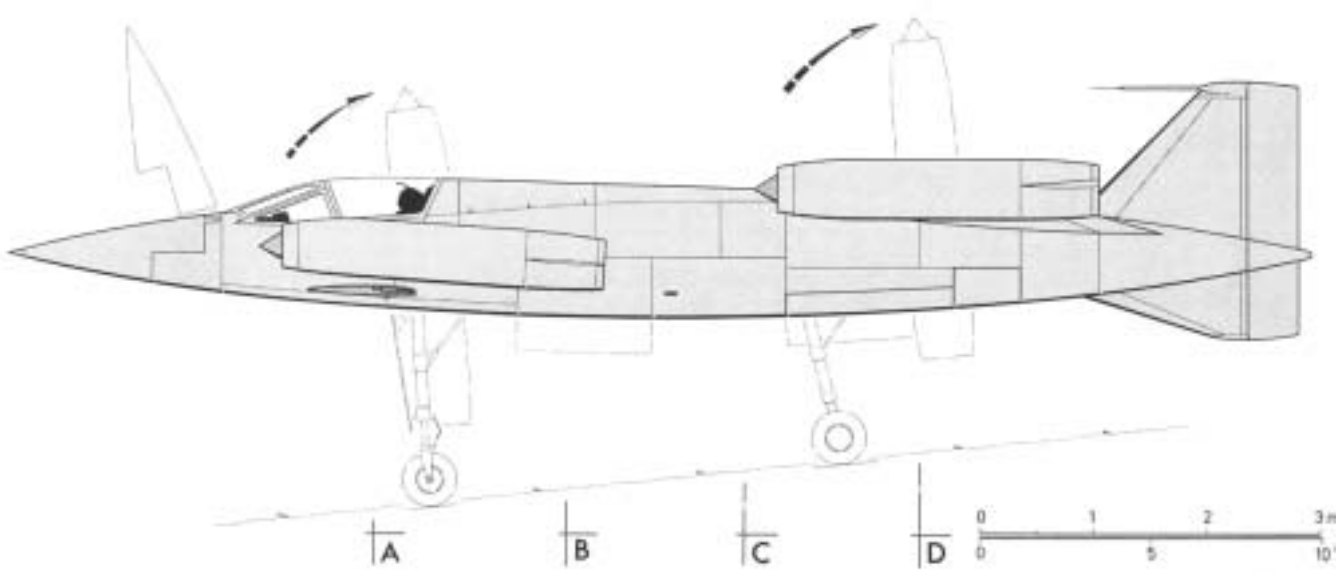




# Heinkel He 231

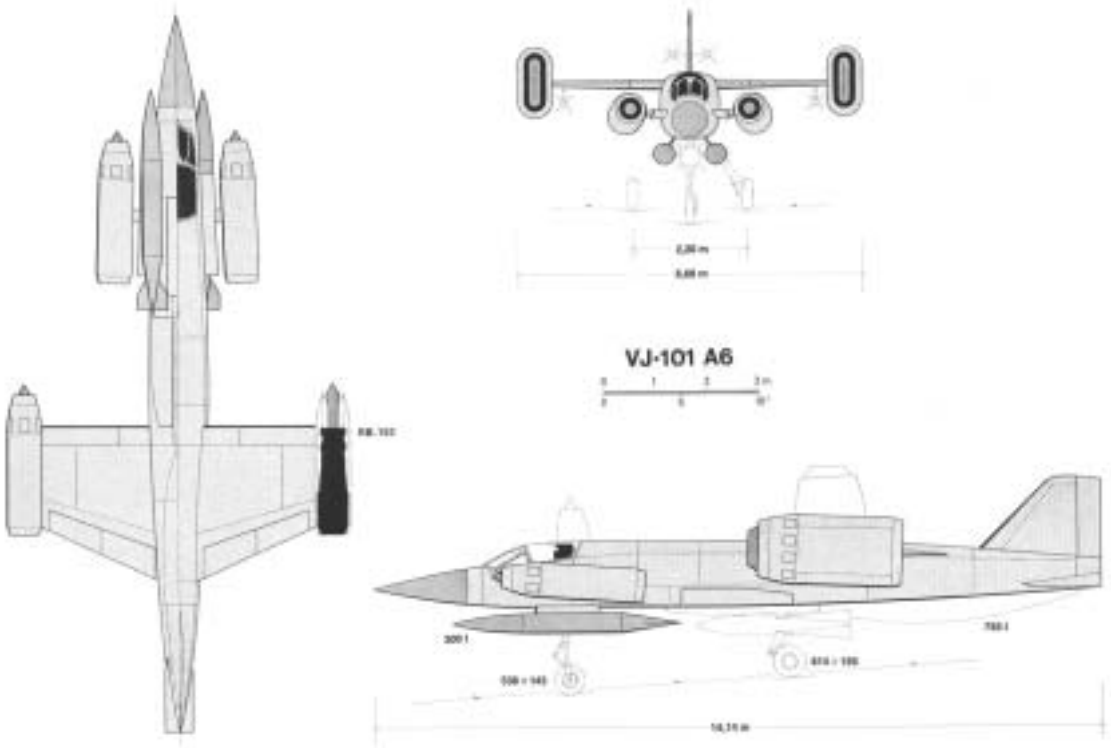


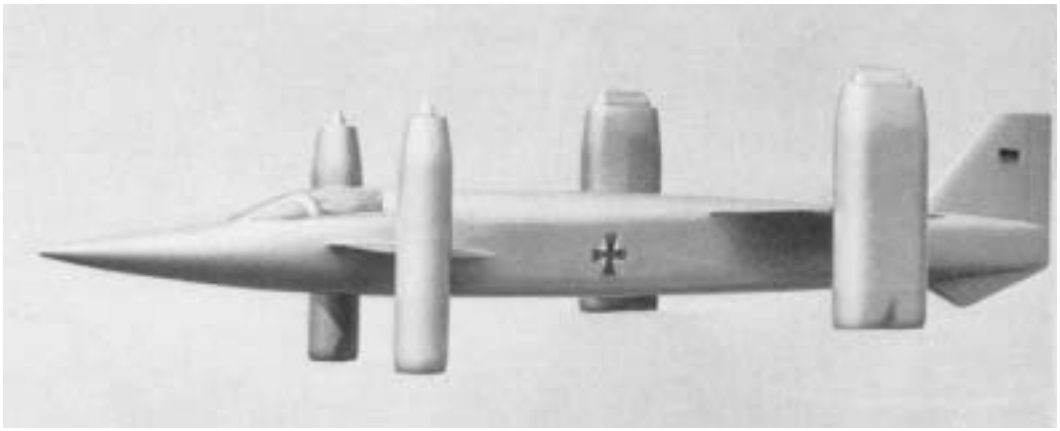
# Heinkel He 231 (VJ 101A)

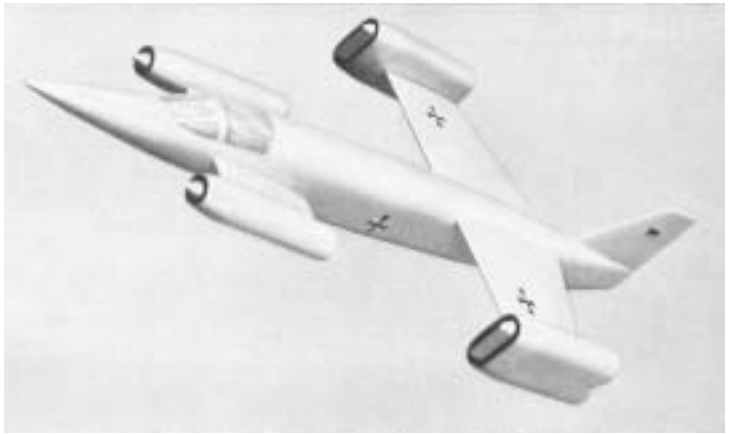




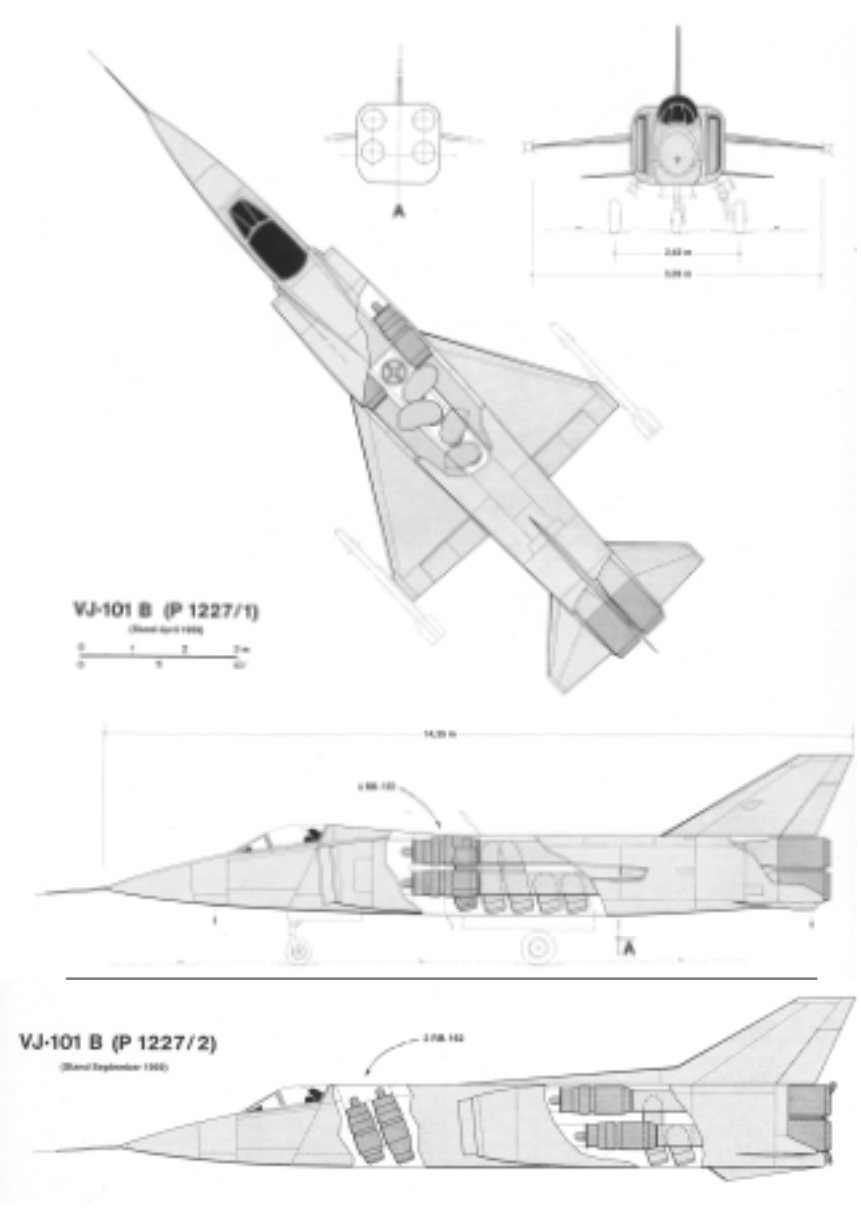
# Heinkel VJ 101A6



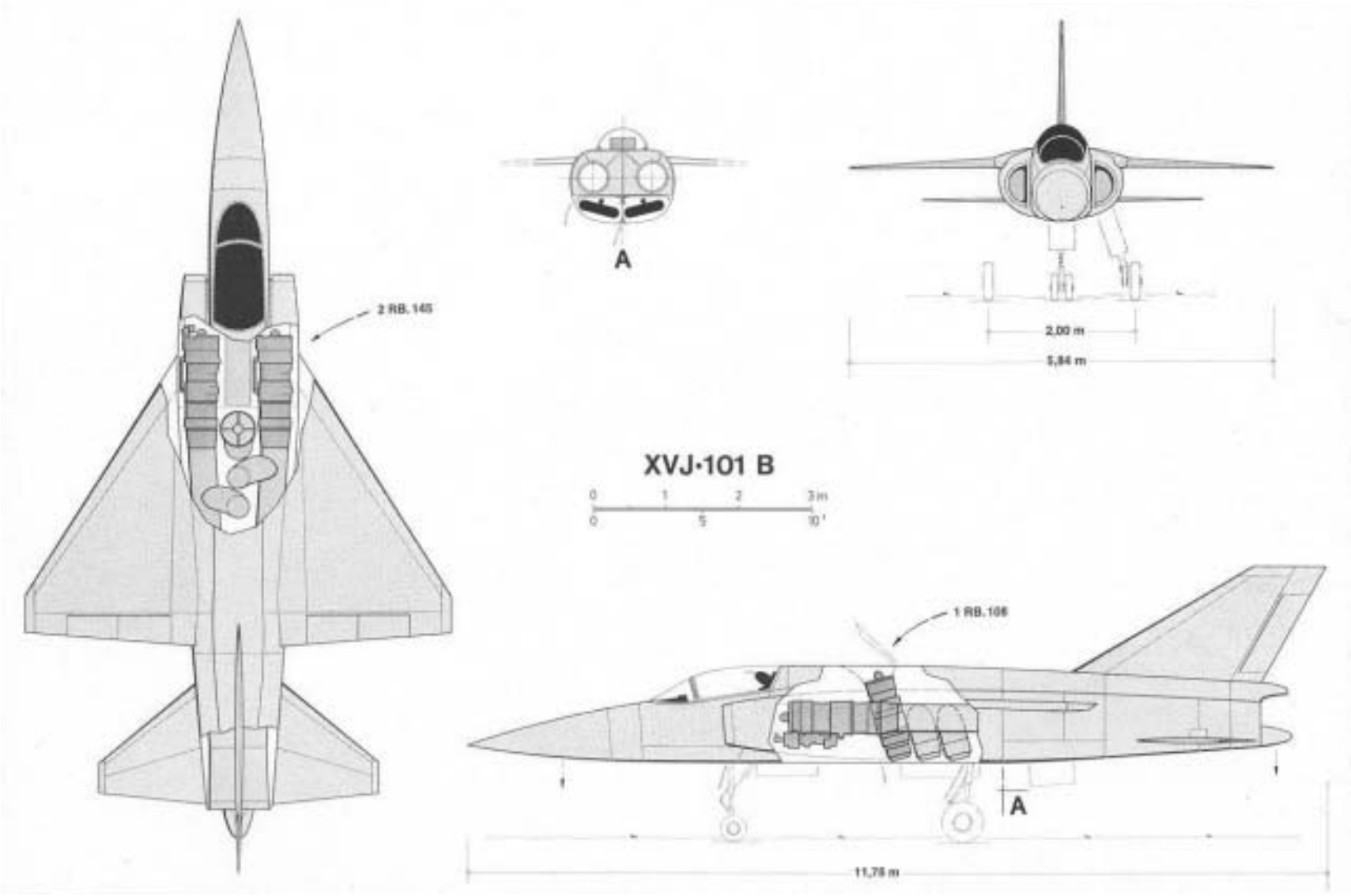





# Messerschmitt P 1227 (VJ 101B)

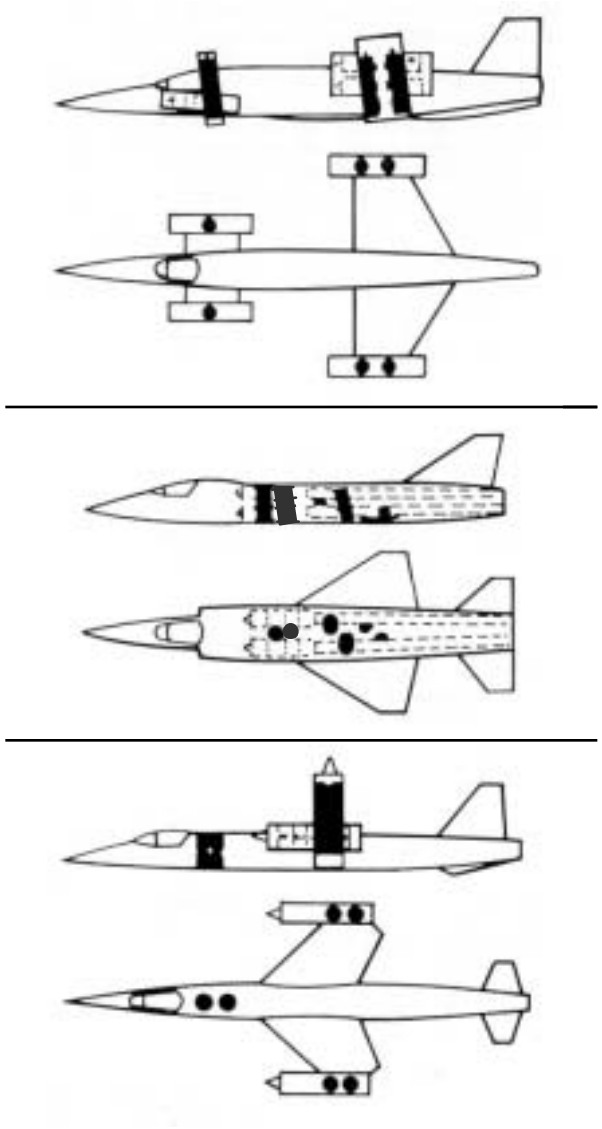



# Messerschmitt XVJ 101B

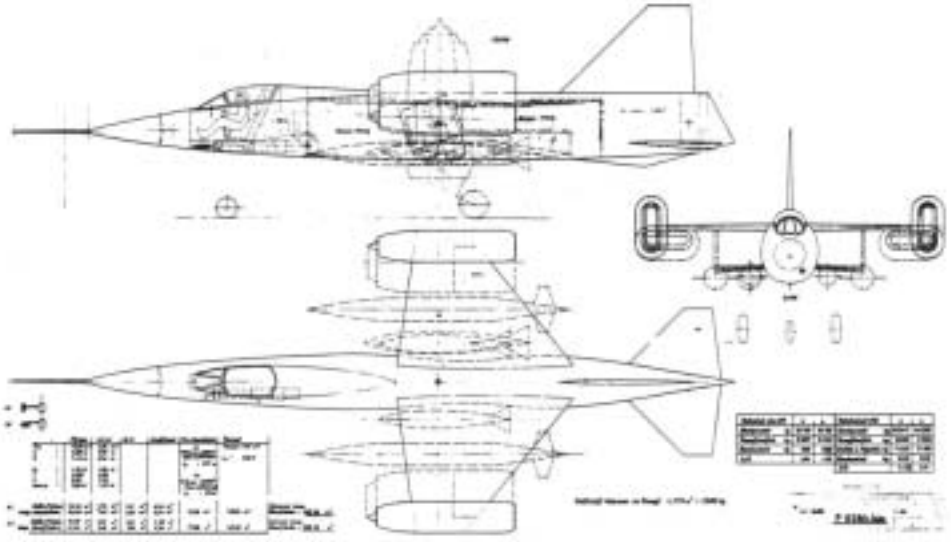


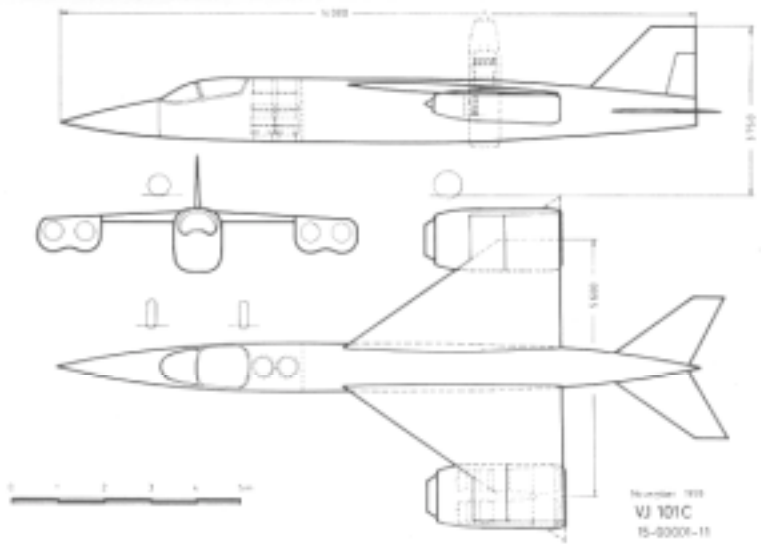
# Design Convergence

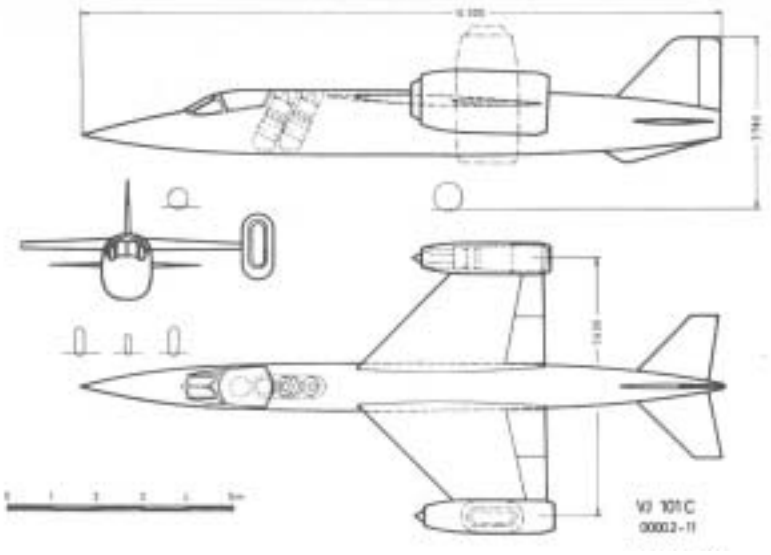
- Defense Ministry encouraged competitors to develop a joint design
- Consortium founded in Feb 1959 of the (southern) German companies: Messerschmitt, Heinkel, and Bölkow known as Entwicklungsring-Süd (EWR-Süd)
- Combined solution reached in Sep 1959
  - Heinkel dropped canards
  - Messerschmitt accepted 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





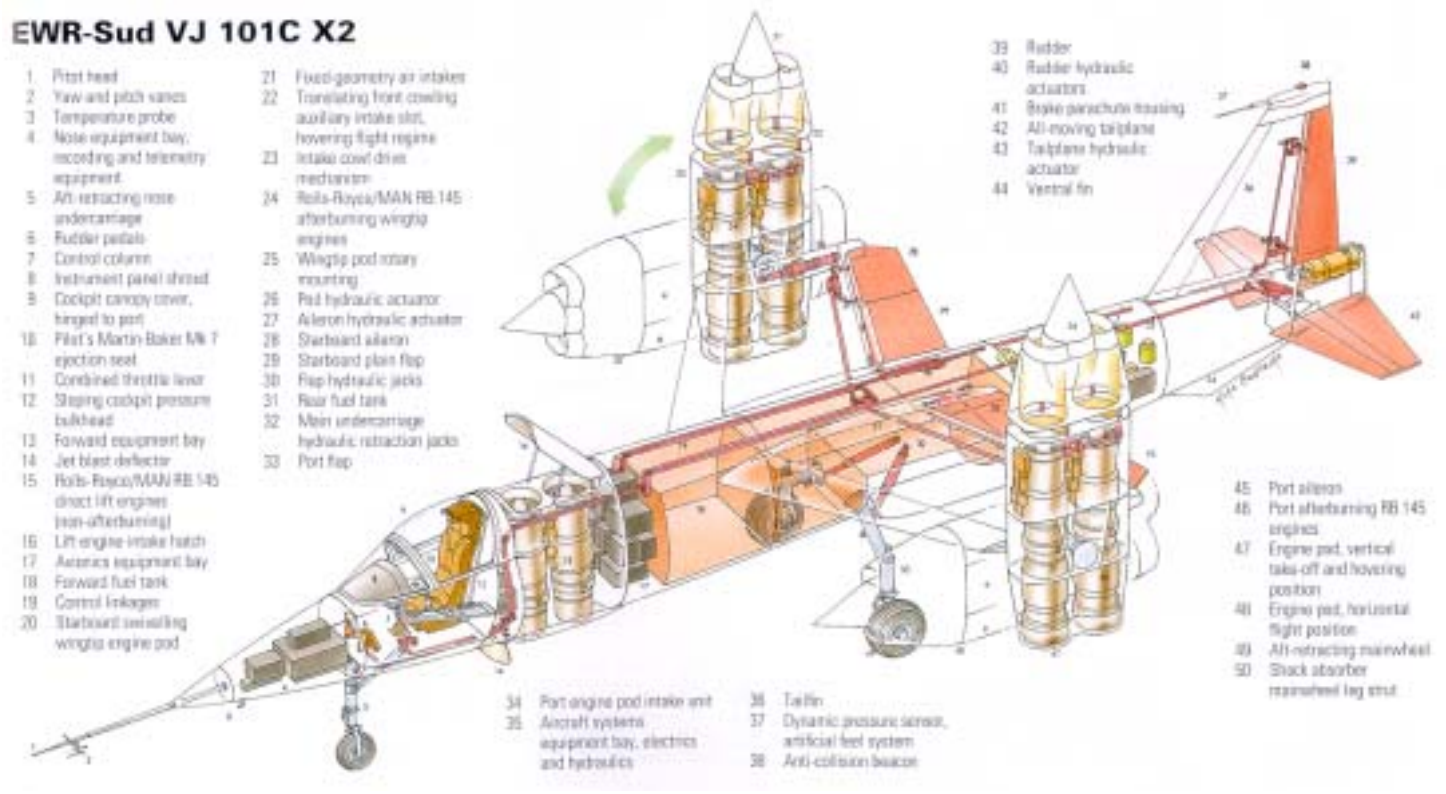
# VJ 101C Research Aircraft

*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

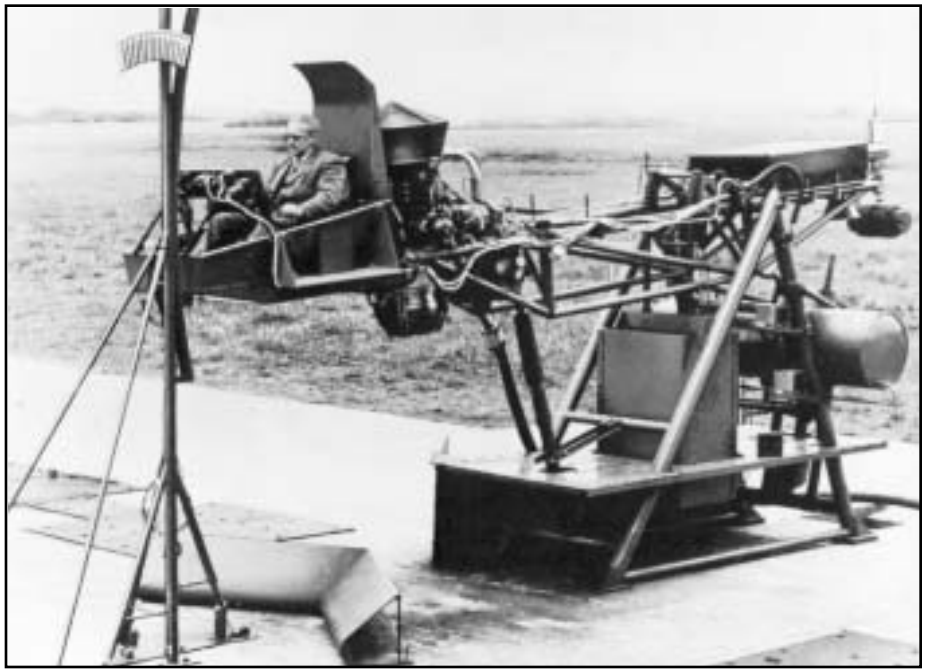
- X2 equipped with afterburning wingtip engines to expand the VJ 101C flight envelope beyond Mach 1

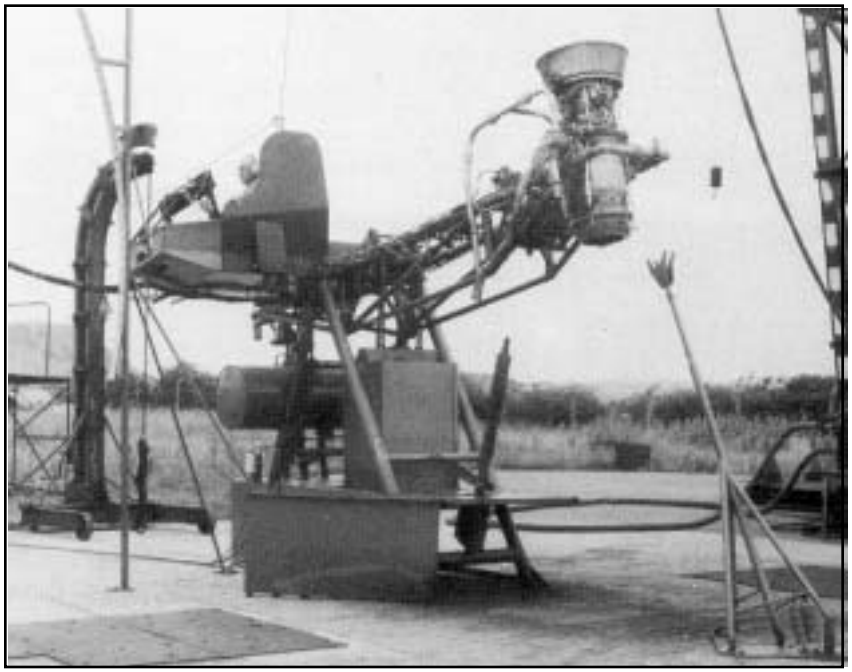
# VJ 101C Propulsion System




- 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

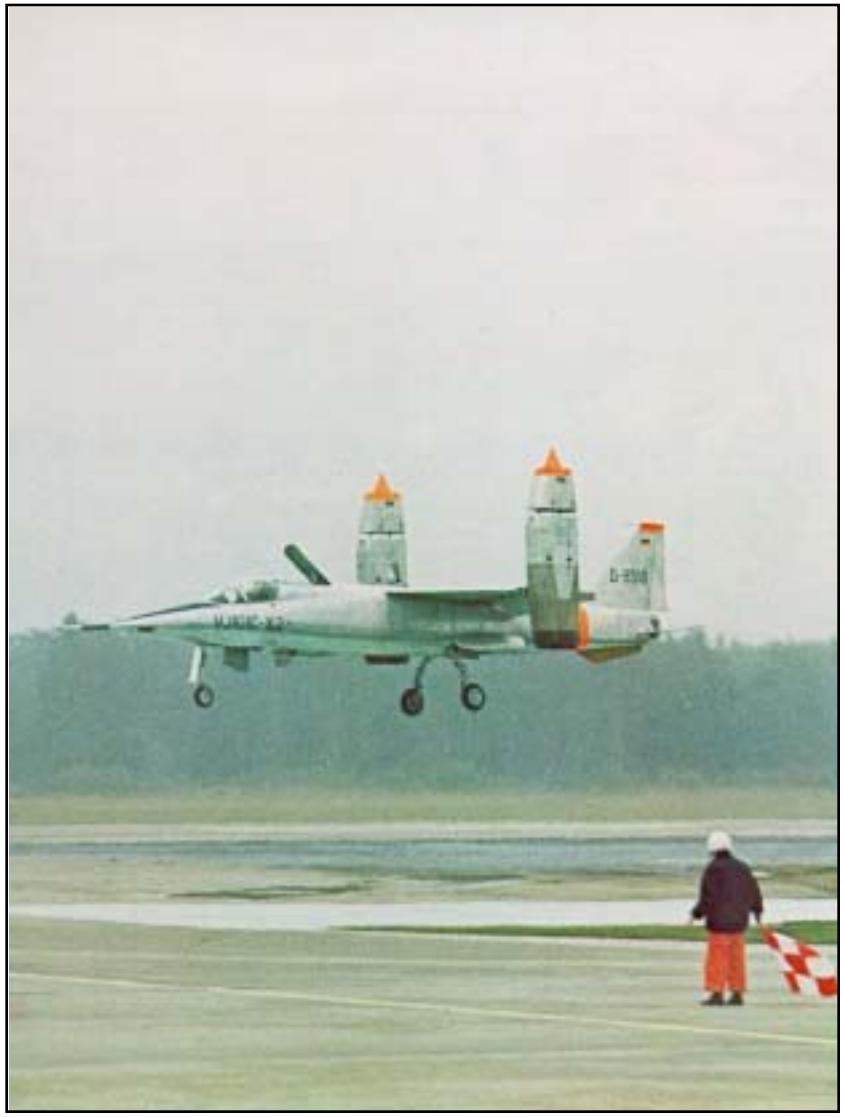
# VJ 101 Hover Rig

- 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



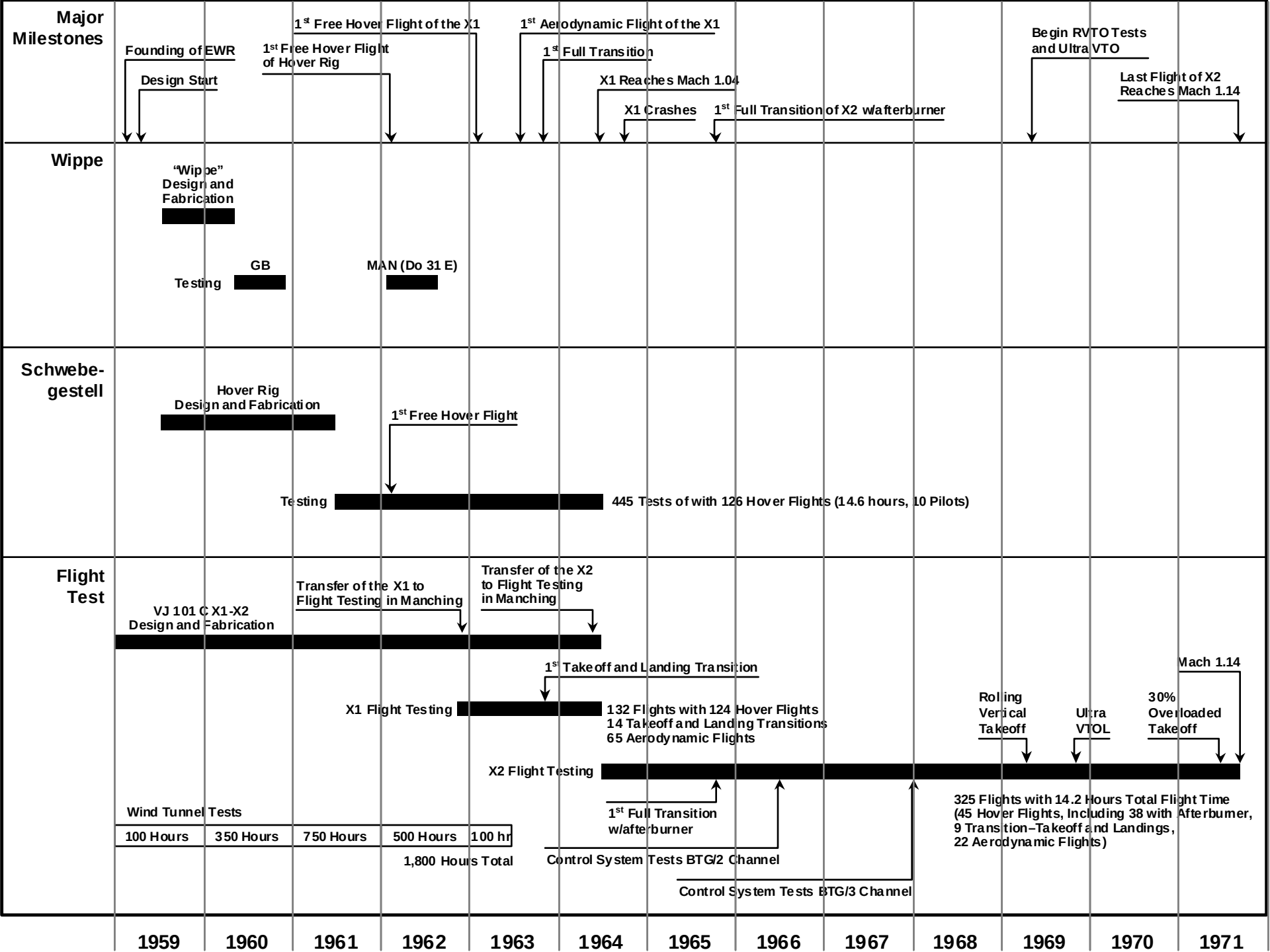
- Vertical Takeoff
  - Jump technique minimized adverse near-field hot gas effects
  - Far-field gas ingestion effects reduced by tilting the aircraft forward after jump takeoff
- Vertical Landing
  - After slowing aircraft, landing gear/flaps lowered and lift engines started
  - As forward airspeed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

# Afterburner Usage Effects

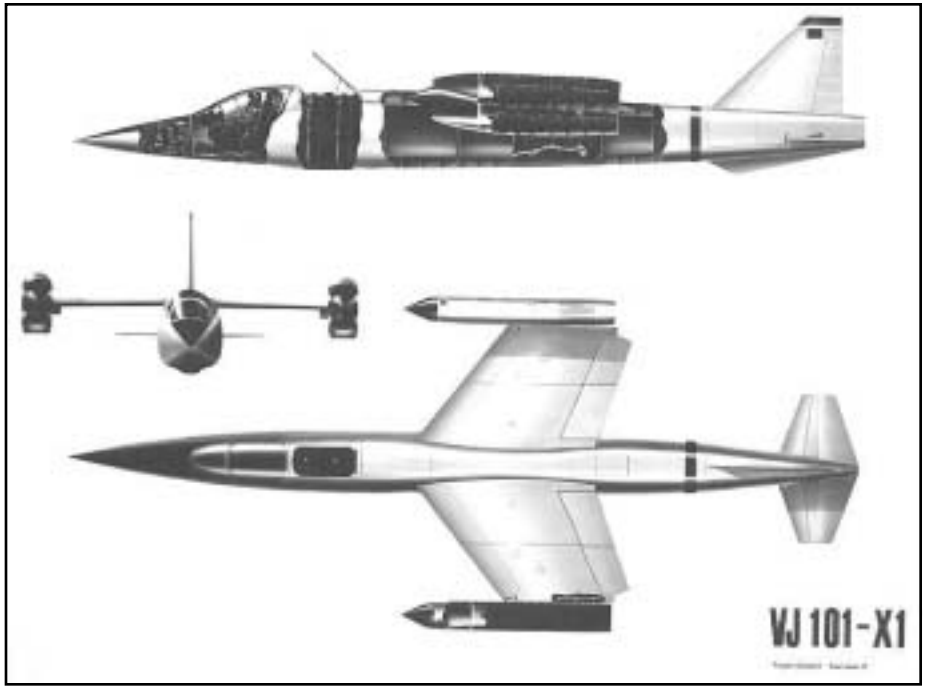
- Use of afterburning during vertical takeoffs and landings found to have adverse effects:
  - Extensive runway damage
  - Very high temperature exhaust gases reflected onto aircraft skin and tires
- Short takeoff run technique developed to minimize adverse effects of afterburner usage

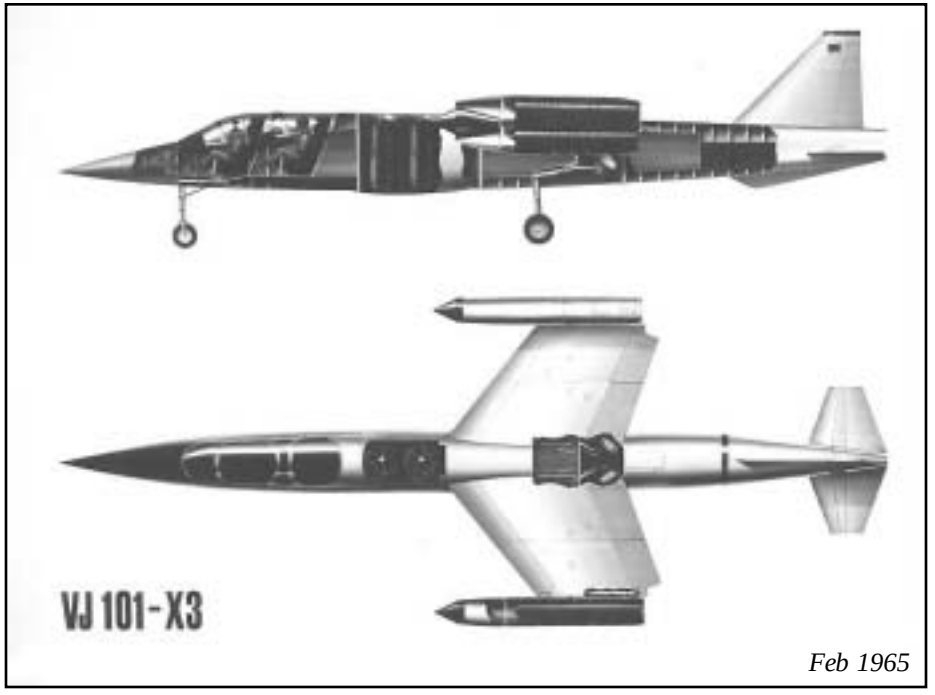
# VJ 101C Crashes

- 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

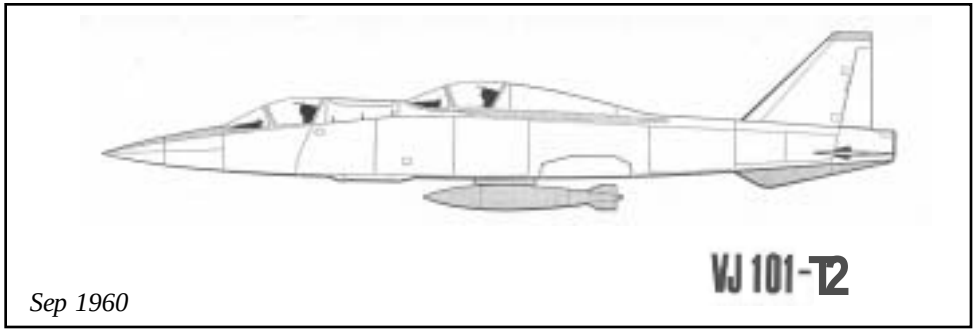

Major Milestones
Founding of EWR
Design Start
1st Free Hover Flight of Hover Rig
1st Free Hover Flight of the X1
1st Aerodynamic Flight of the X1
1st Full Transition
X1 Reaches Mach 1.04
X1 Crashes
1st Full Transition of X2 w/afterburner
Begin RVTO Tests and Ultra VTO
Last Flight of X2 Reaches Mach 1.14
Wippe
"Wippe" Design and Fabrication
GB
Testing
MAN (Do 31 E)
Schwebe-gestell
Hover Rig Design and Fabrication
1st Free Hover Flight
Testing
445 Tests of with 126 Hover Flights (14.6 hours, 10 Pilots)
Flight Test
VJ 101 C X1-X2 Design and Fabrication
Transfer of the X1 to Flight Testing in Manching
Transfer of the X2 to Flight Testing in Manching
1st Takeoff and Landing Transition
X1 Flight Testing
132 Flights with 124 Hover Flights
14 Takeoff and Landing Transitions
65 Aerodynamic Flights
Rolling Vertical Takeoff
Ultra VTOL
30% Overloaded Takeoff
Mach 1.14
X2 Flight Testing
1st Full Transition w/afterburner
325 Flights with 14.2 Hours Total Flight Time
(45 Hover Flights, Including 38 with Afterburner,
9 Transition–Takeoff and Landings,
22 Aerodynamic Flights)
Wind Tunnel Tests
100 Hours
350 Hours
750 Hours
500 Hours
100 hr
1,800 Hours Total
Control System Tests BTG/2 Channel
Control System Tests BTG/3 Channel
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971

# VJ 101C Two Seaters



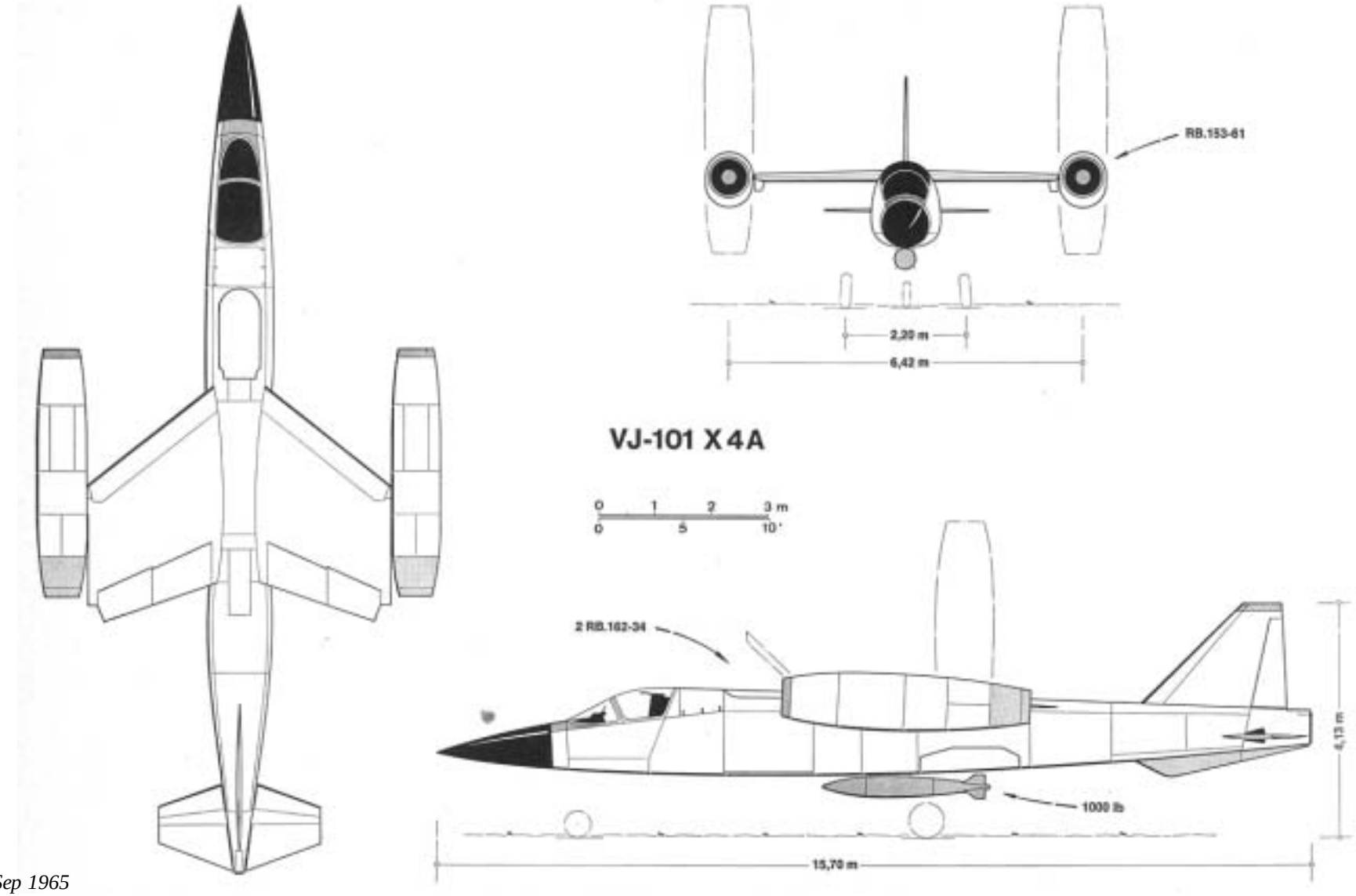




*Feb 1965*



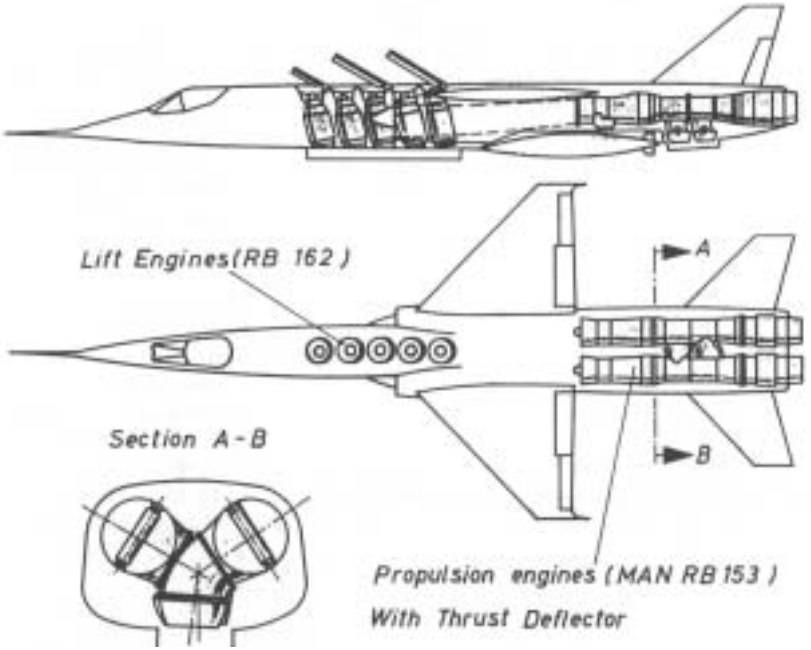

*Sep 1960*

# VJ 101 X4A



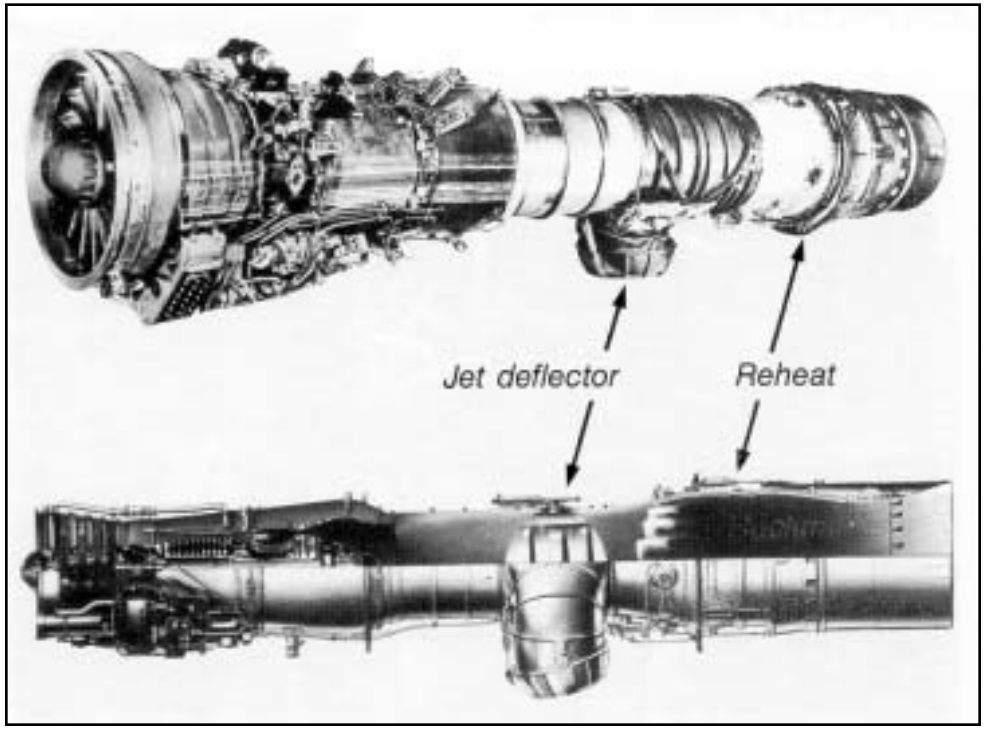

*Sep 1965*

# VJ 101D Design Concept

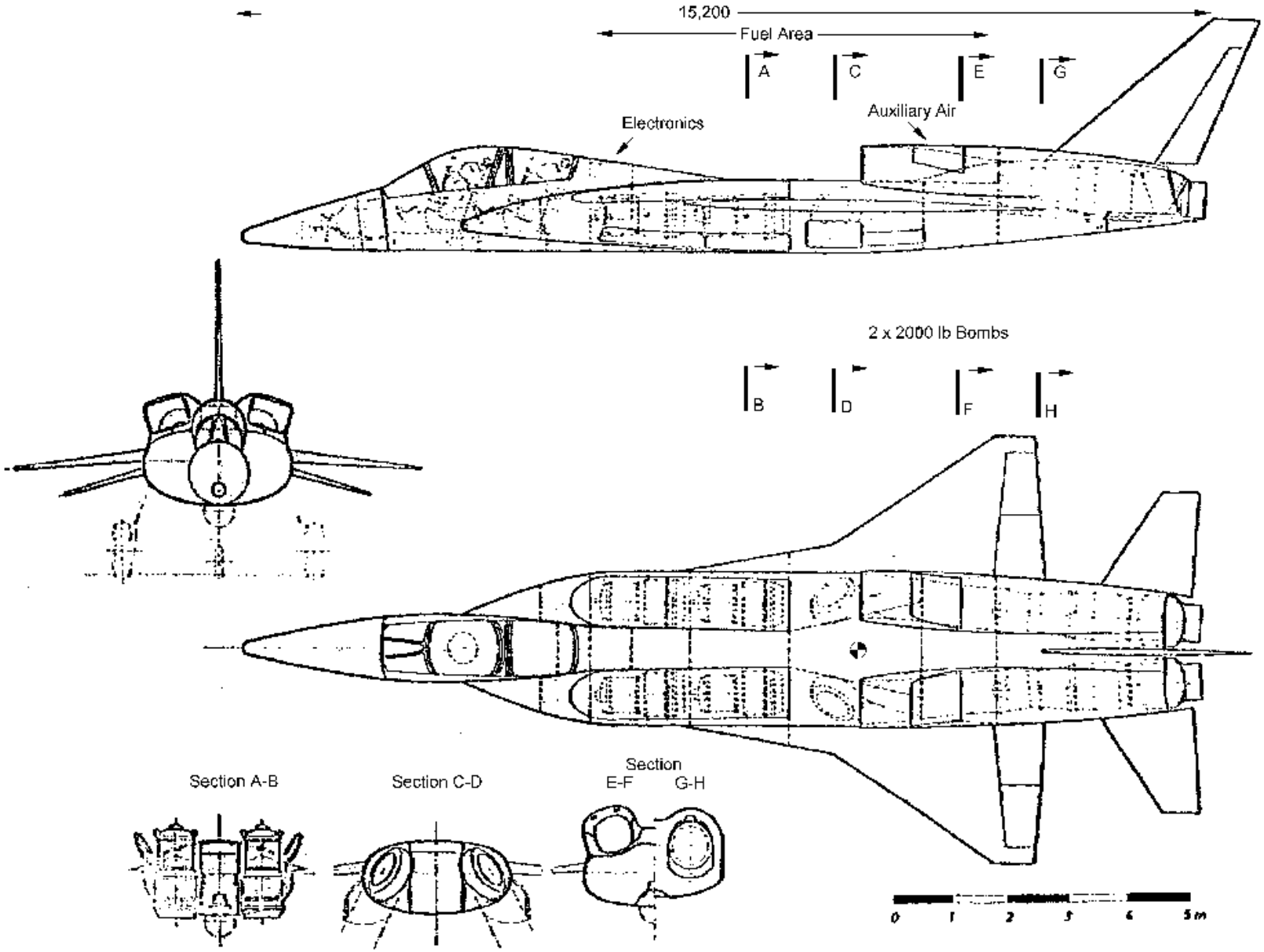

- VJ 101D represented major design shift away from VJ 101C demonstrator aircraft due to a NATO shift in strategy in mid-1961
- Primary VJ 101 combat role redefined to that of a low altitude VTOL strike fighter with supersonic high altitude capability
- Aircraft reconfigured with 2 fuselage mounted lift/cruise 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

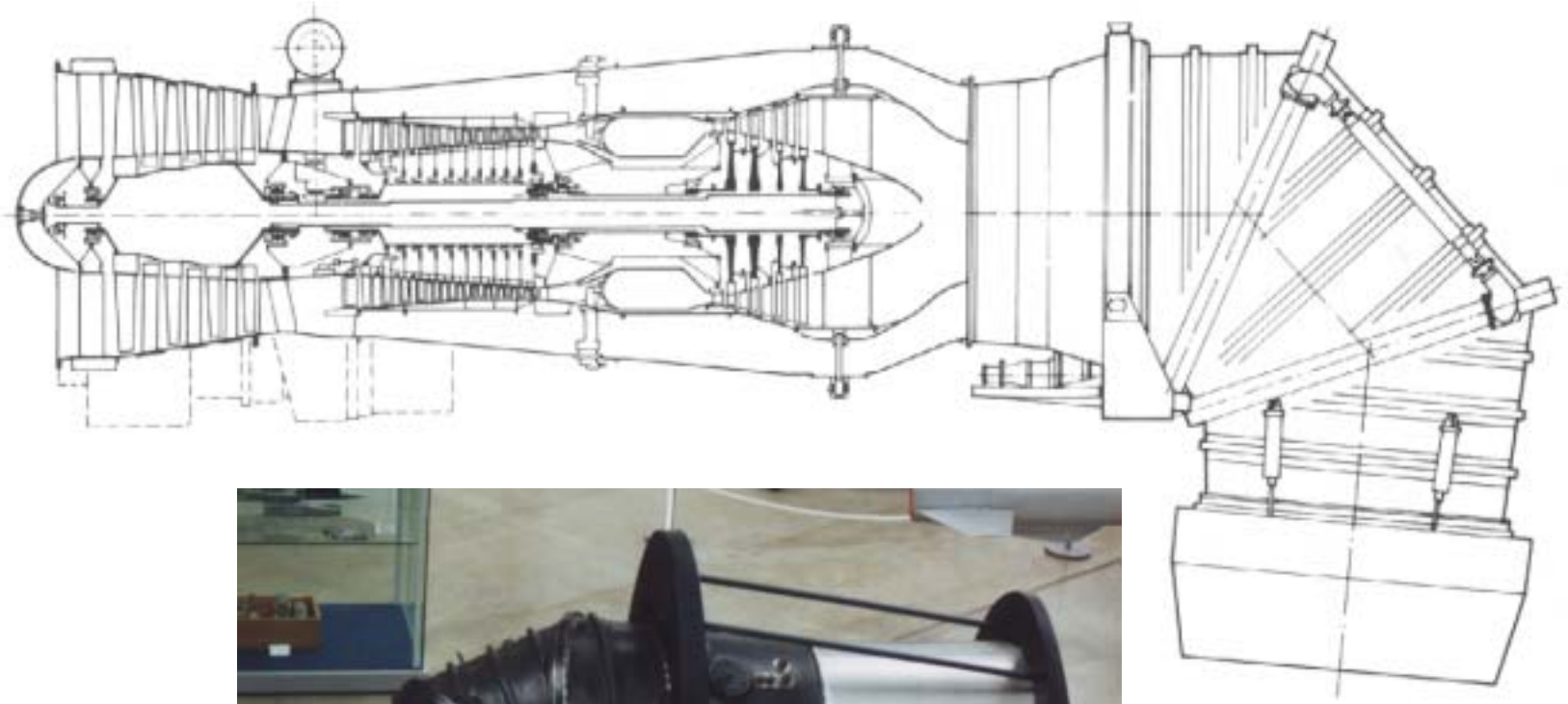


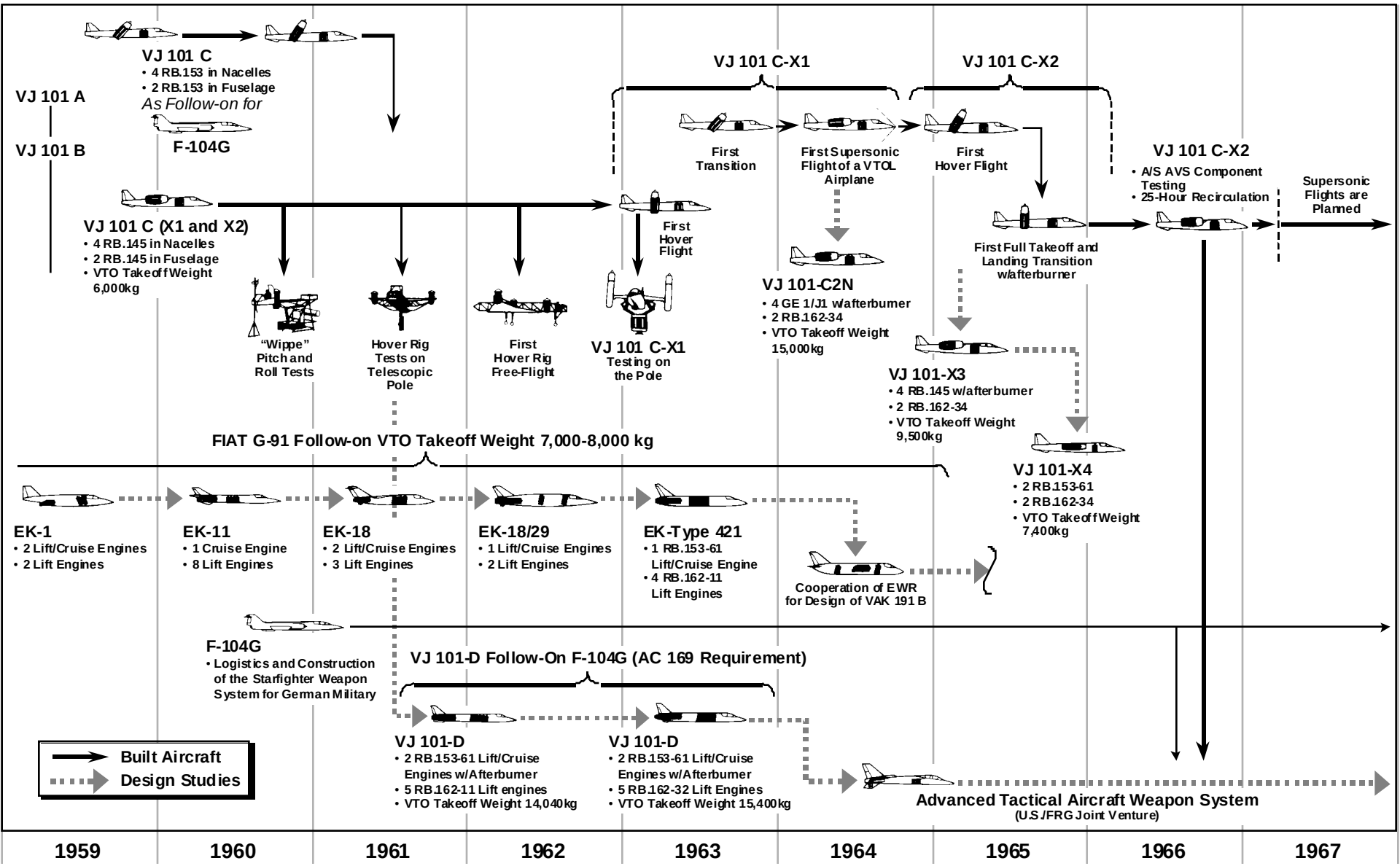

- Deflector nozzles with 15° swivel
- 6,850 lb thrust (30.5 kN)
- 11,750 lb in afterburner (52.3 kN)
- 6 engines were built
- Total running time 1,502 hours

# VJ 101E


15,200
Fuel Area
A
C
E
G
Electronics
Auxiliary Air
2 x 2000 lb Bombs
B
D
F
H
Section A-B
Section C-D
Section
E-F G-H
0 1 2 3 4 5m

# VJ 101E Propulsion System



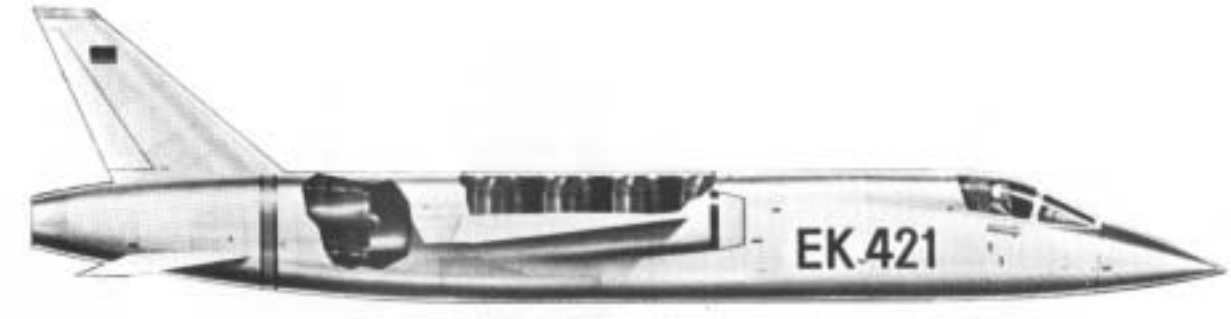

VJ 101 A
VJ 101 B
VJ 101 C
• 4 RB.153 in Nacelles
• 2 RB.153 in Fuselage
As Follow-on for
F-104G
VJ 101 C (X1 and X2)
• 4 RB.145 in Nacelles
• 2 RB.145 in Fuselage
• VTO Takeoff Weight 6,000kg
"Wippe" Pitch and Roll Tests
Hover Rig Tests on Telescopic Pole
First Hover Rig Free-Flight
First Hover Flight
VJ 101 C-X1 Testing on the Pole
VJ 101 C-X1
First Transition
First Supersonic Flight of a VTOL Airplane
VJ 101-C2N
• 4 GE 1/J1 w/afterburner
• 2 RB.162-34
• VTO Takeoff Weight 15,000kg
VJ 101 C-X2
First Hover Flight
First Full Takeoff and Landing Transition w/afterburner
VJ 101-X3
• 4 RB.145 w/afterburner
• 2 RB.162-34
• VTO Takeoff Weight 9,500kg
VJ 101 C-X2
• A/S AVS Component Testing
• 25-Hour Recirculation
Supersonic Flights are Planned
FIAT G-91 Follow-on VTO Takeoff Weight 7,000-8,000 kg
VJ 101-X4
• 2 RB.153-61
• 2 RB.162-34
• VTO Takeoff Weight 7,400kg
EK-1
• 2 Lift/Cruise Engines
• 2 Lift Engines
EK-11
• 1 Cruise Engine
• 8 Lift Engines
EK-18
• 2 Lift/Cruise Engines
• 3 Lift Engines
EK-18/29
• 1 Lift/Cruise Engines
• 2 Lift Engines
EK-Type 421
• 1 RB.153-61 Lift/Cruise Engine
• 4 RB.162-11 Lift Engines
Cooperation of EWR for Design of VAK 191 B
F-104G
• Logistics and Construction of the Starfighter Weapon System for German Military
VJ 101-D Follow-On F-104G (AC 169 Requirement)
VJ 101-D
• 2 RB.153-61 Lift/Cruise Engines w/Afterburner
• 5 RB.162-11 Lift engines
• VTO Takeoff Weight 14,040kg
VJ 101-D
• 2 RB.153-61 Lift/Cruise Engines w/Afterburner
• 5 RB.162-32 Lift Engines
• VTO Takeoff Weight 15,400kg
Advanced Tactical Aircraft Weapon System
(U.S./FRG Joint Venture)
Built Aircraft
Design Studies
1959
1960
1961
1962
1963
1964
1965
1966
1967

# 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

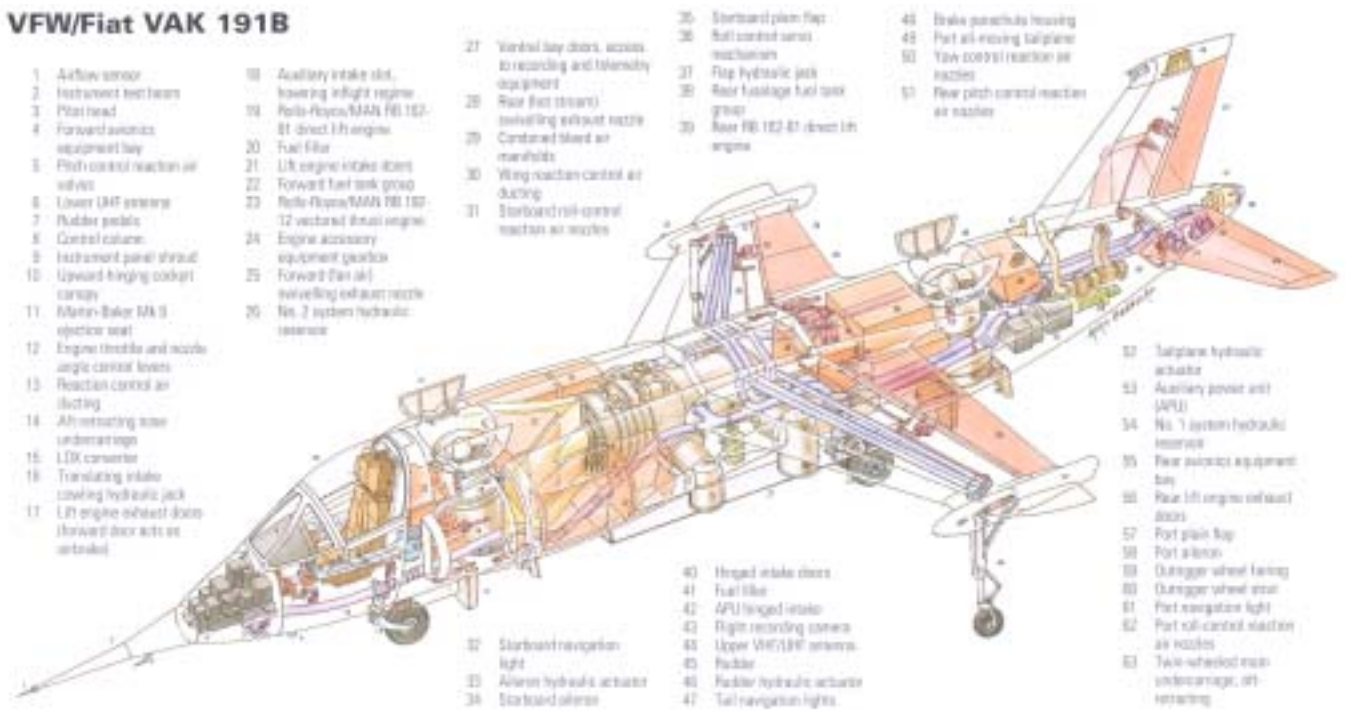



- Program began in 1962 to replace Fiat G.91 ground attack fighter with VTOL aircraft optimized for nuclear strike role
- Development undertaken by multi-national team led by a (northern) German consortium known as Vereinigte Flugtechnische Werke (VFW), which included Focke-Wulf, Heinkel and Weser
  - 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

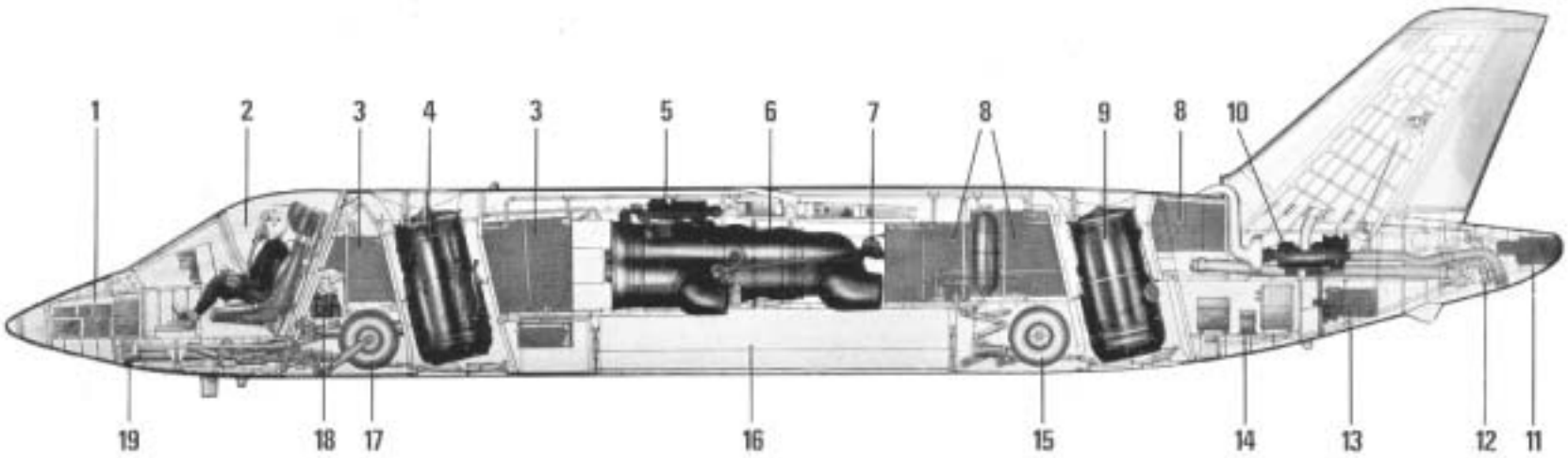
- After change in NATO strategy project refocused as experimental V/STOL technology demonstrator
- 3 VAK 191B aircraft flown during flight test program from 1970-1972, further tested from 1974-75
- Many V/STOL and other advanced aircraft technologies, such as fly-by-wire (FBW) flight control systems,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

# VAK 191B Concept



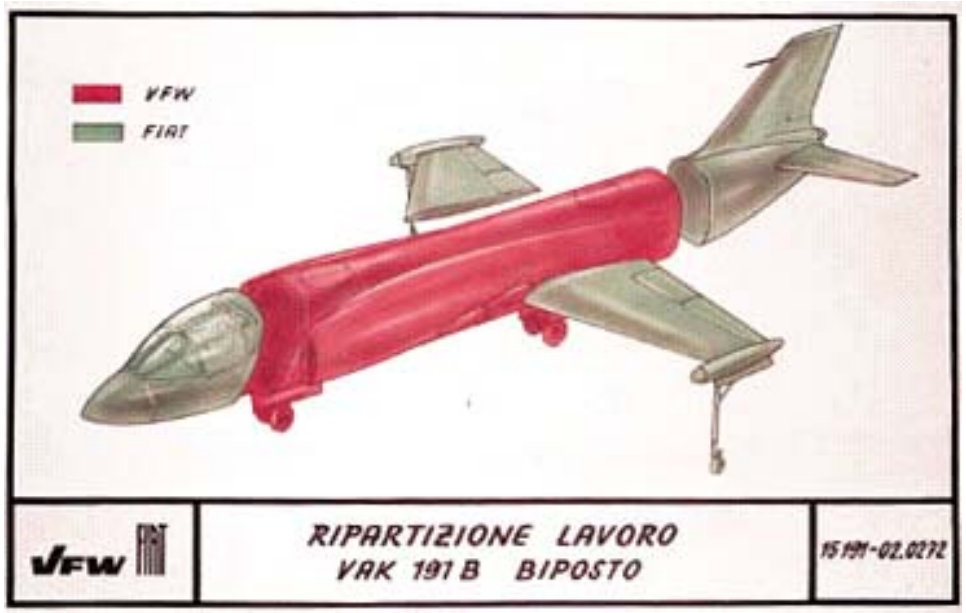

- Rolls-Royce and MTU teamed for propulsion
- German design team reasoned it was inefficient to design a VTOL aircraft with a single large vectored thrust engine
  - unnecessarily heavy/oversized for cruise
  - uneconomical operation
  - high aircraft drag resulting from large inlet area

# NATO VAK 191 Requirement

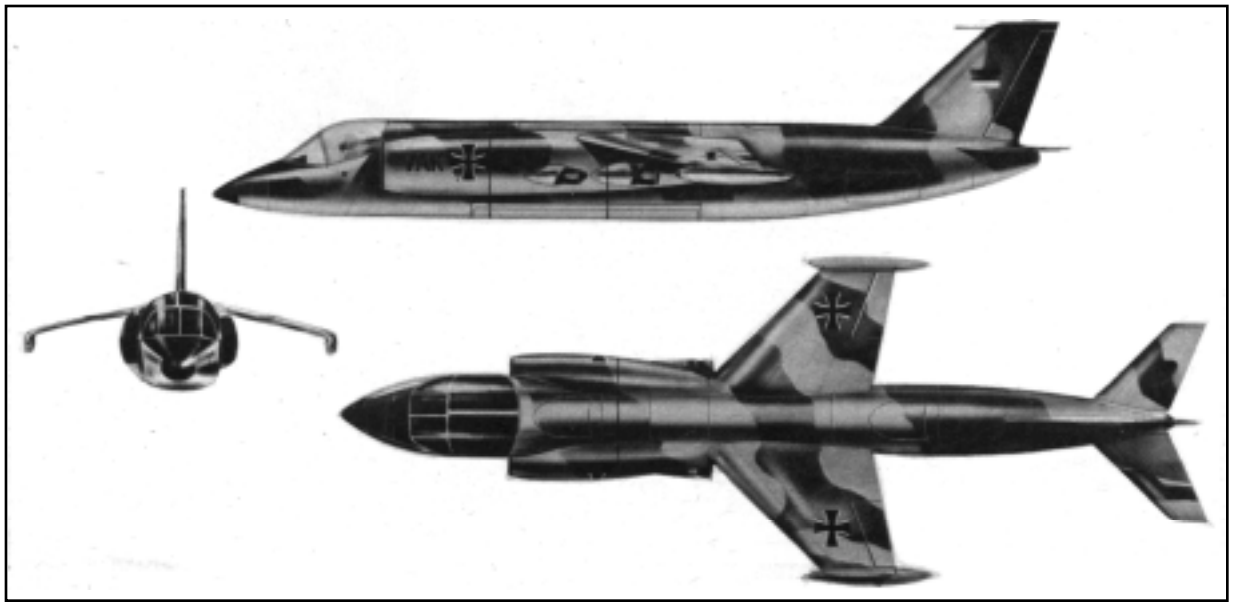



- Fiat G.91 Replacement
  - UK, Italy, Germany
- Formal NATO VAK 191 specifications:
  - Delivery of a single nuclear weapon at Mach 0.92 and low altitude
  - Low-low mission profile with a combat radius of 320 km (180 nm)
  - VTOL operations from dispersed hardened sites
  - Supersonic dash capability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

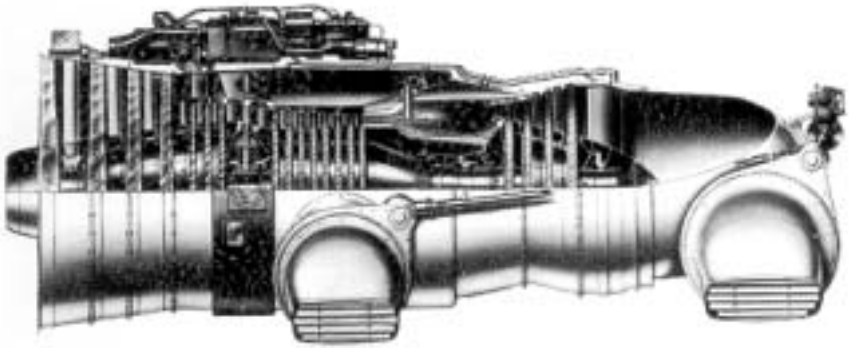
# Fiat Involvement

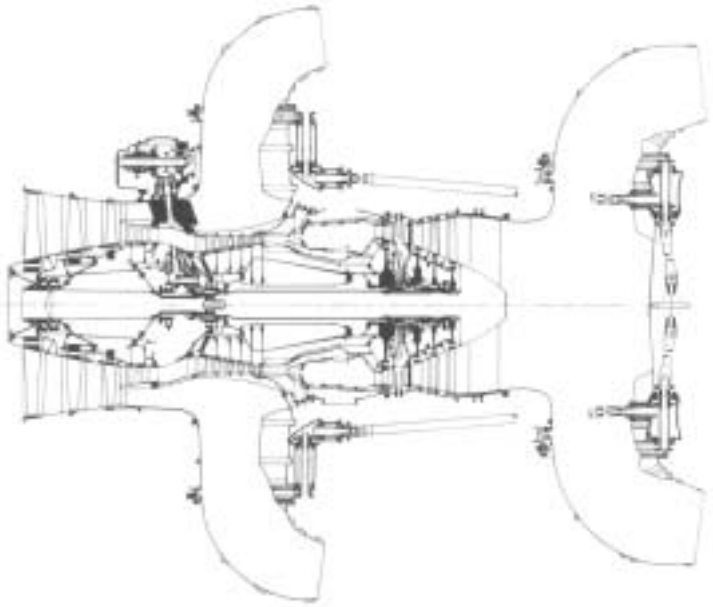


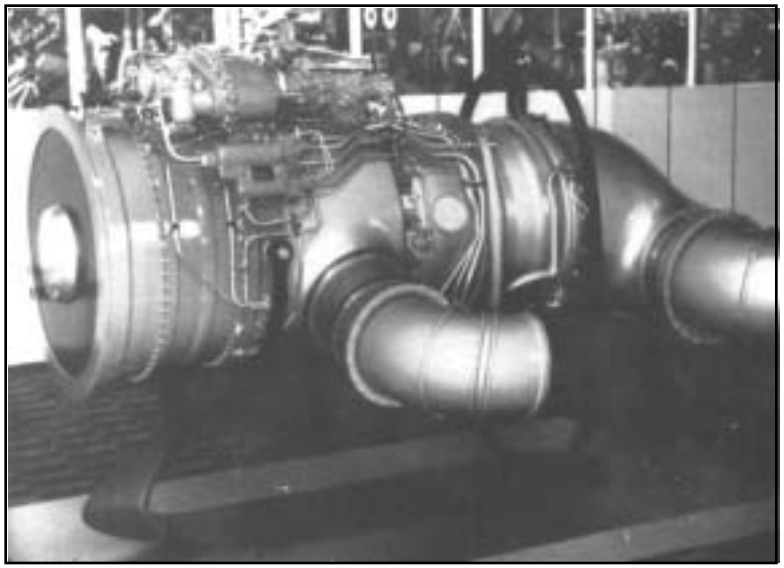

- Originally Italy had a 40% stake in the program
- Fiat major subcontractor
- Two-seat trainer planned but cancelled in 1966
- Italy withdrew in 1967
- Fiat remained a partner



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

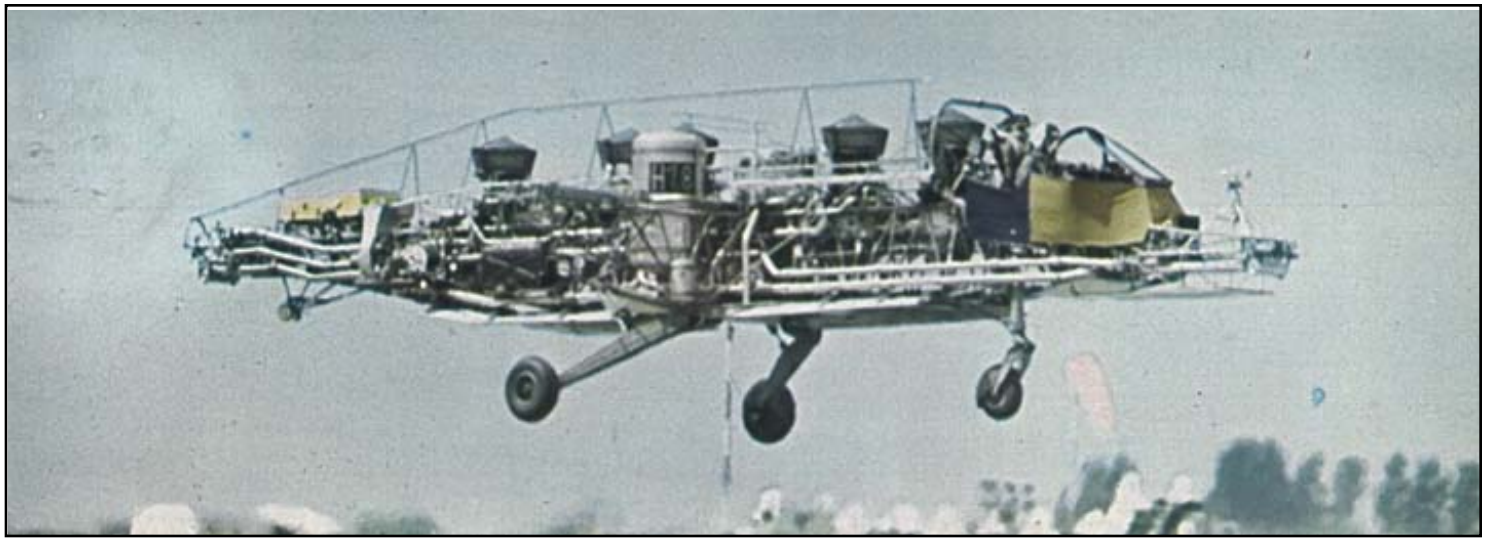






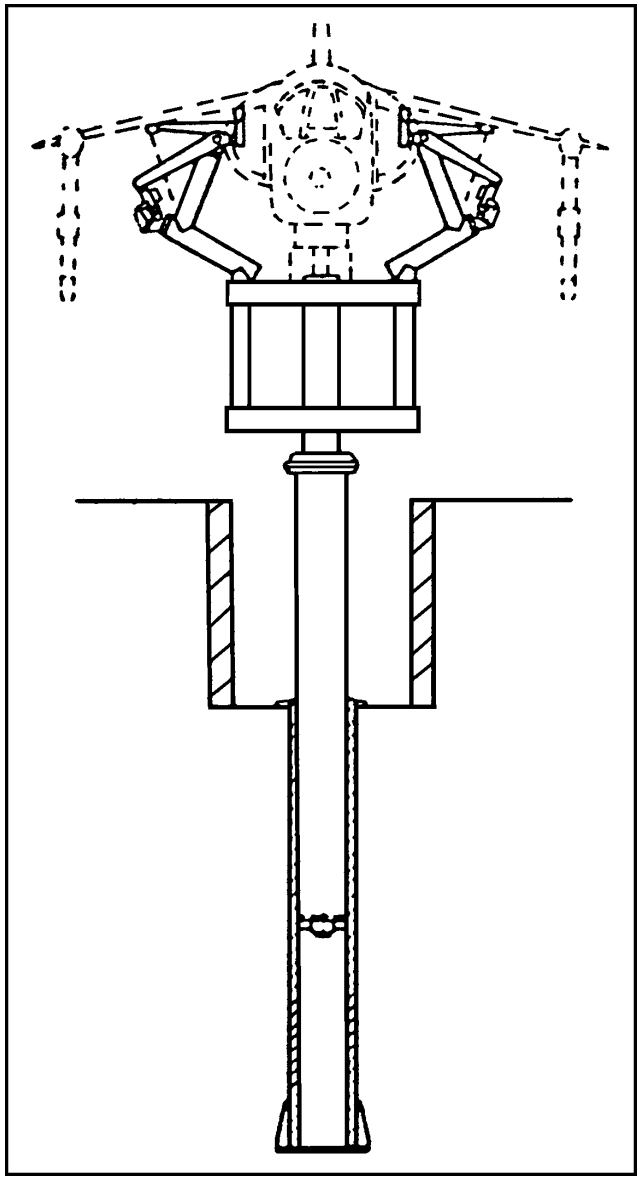
| | | |
|---|---|---|
| **Dimensions:** | | |
| Length overall: | 101.4 in | 2.6 m |
| Fan diameter: | 34.3 in | 0.87 m |
| **Weights:** | | |
| Basic Engine: | 1,742 lbs | 790 kg |
| Installed Engine: | 2,315 lbs | 1050 kg |
| **Maximum Thrust:** | 10,163 lbs | 45 kN |

# 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

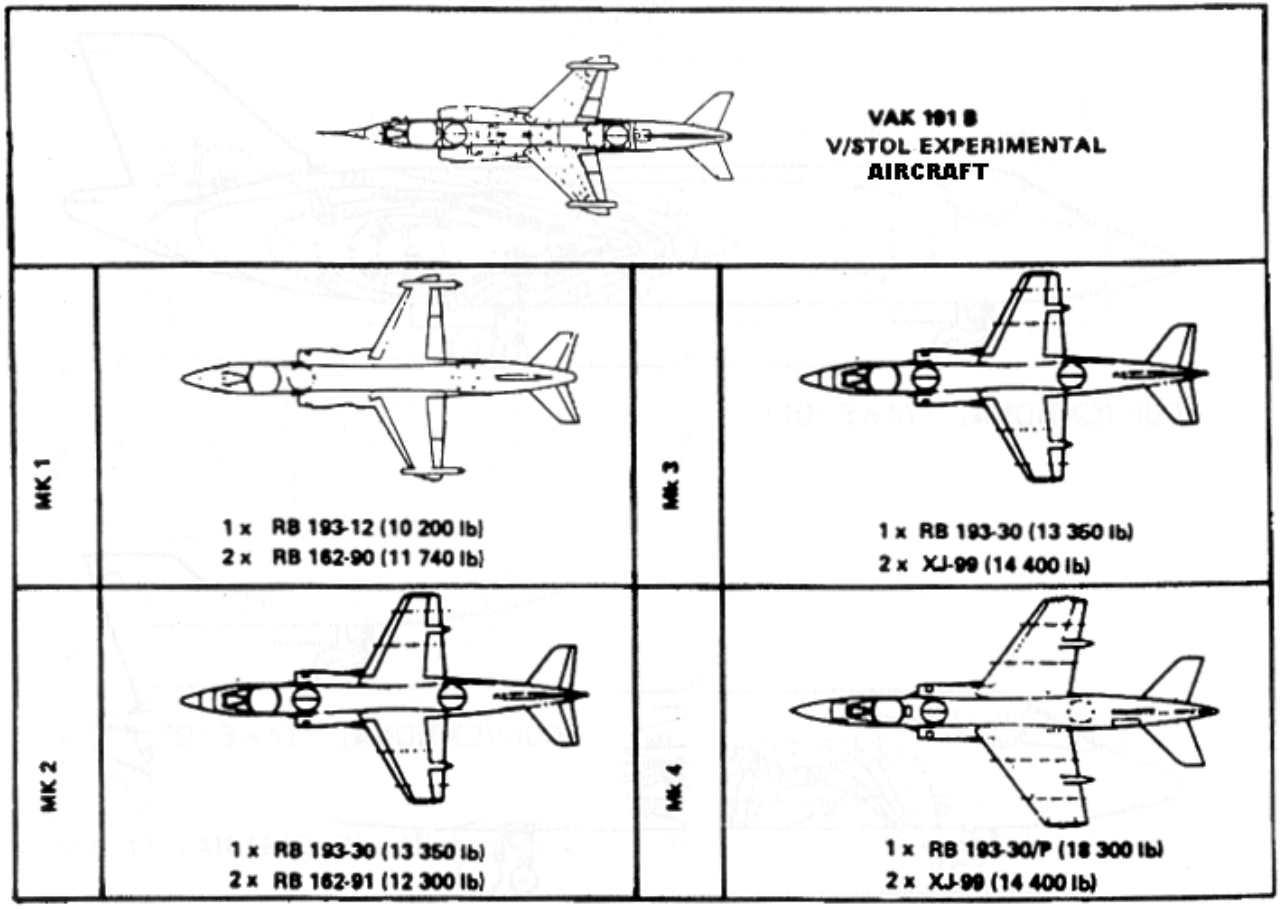
# Conventional Takeoff and Landing

- 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




- 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
  - Uprating of lift/cruise engine thrust by 30%
  - Uprating of lift engine thrust by 5%
  - Addition of 4 underwing ordnance pylons

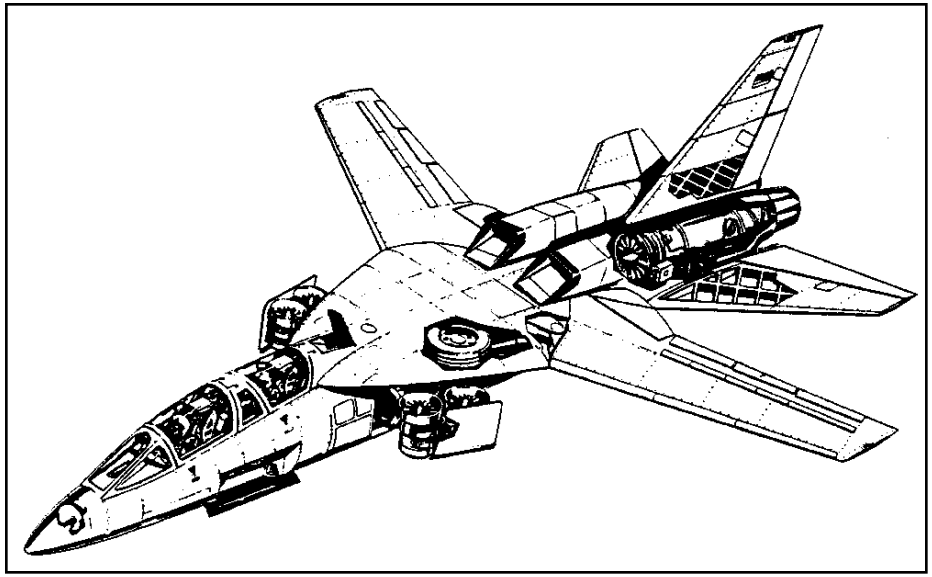
# VAK 191B Observations

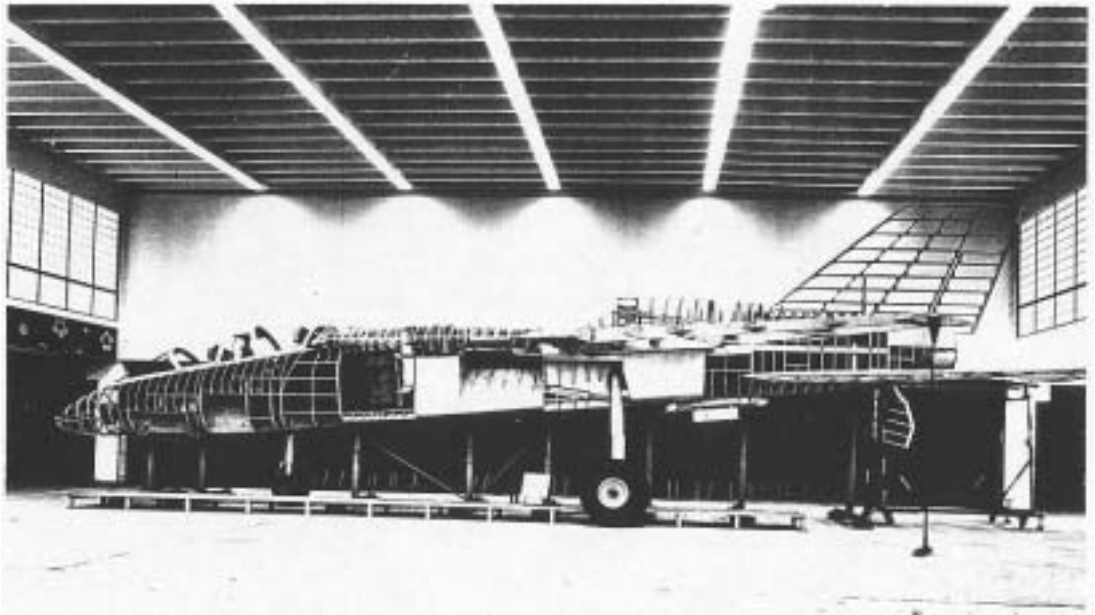
- VAK 191B designed as smallest VTOL aircraft capable of flying a single nuclear strike mission
- Design concept resulted in an aircraft with severely limited flexibility for other missions
- Design was not amenable to growth without carrying high risk of an uncontrollable weight spiral
- Aircraft had 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

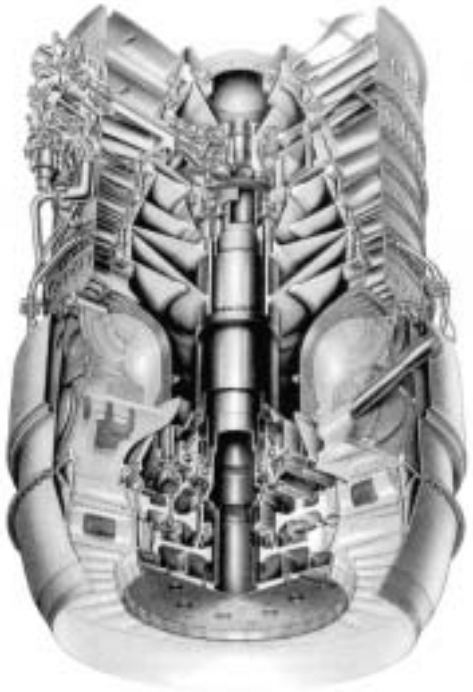

- Advanced V/STOL Tactical Fighter Weapons System (AVS)
- Design study for an F-104G successor with V/STOL capability
- Joint German / US project with EWR / Boeing then EWR / Fairchild Hiller Republic
- Program ran from 1964-68

# AVS

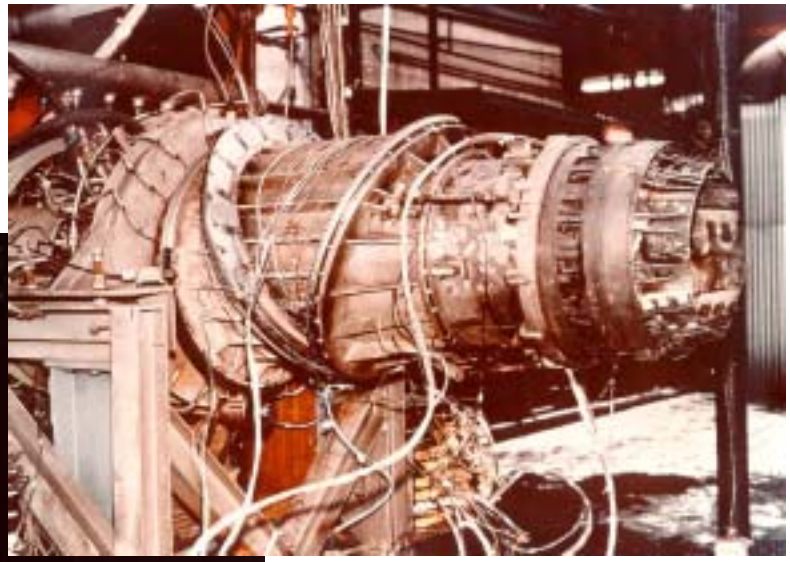




# Aftermath: AVS Propulsion System



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

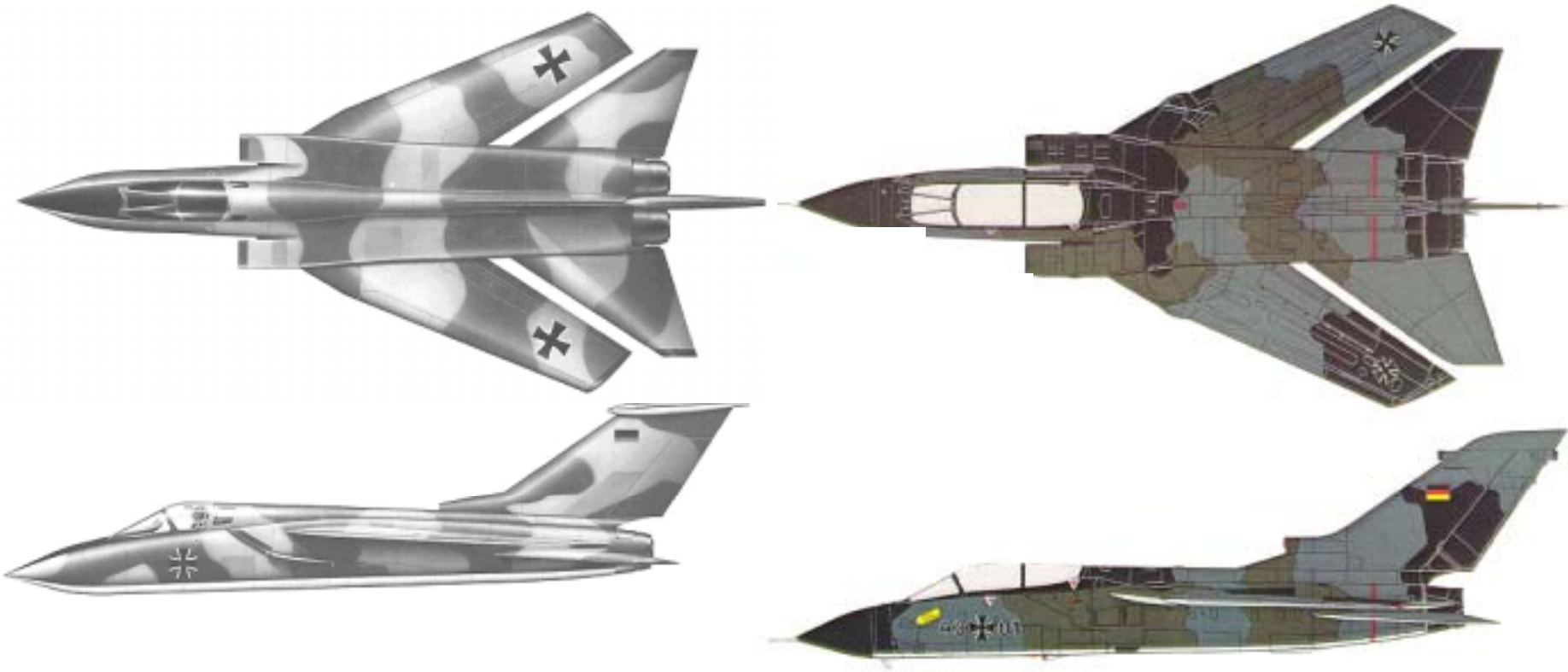


- Lift/Cruise engine with three-bearing swivel nozzle
- Nozzle tests conducted
  - Half-scale actuated
  - Full-scale non-actuated
  - Afterburner operations

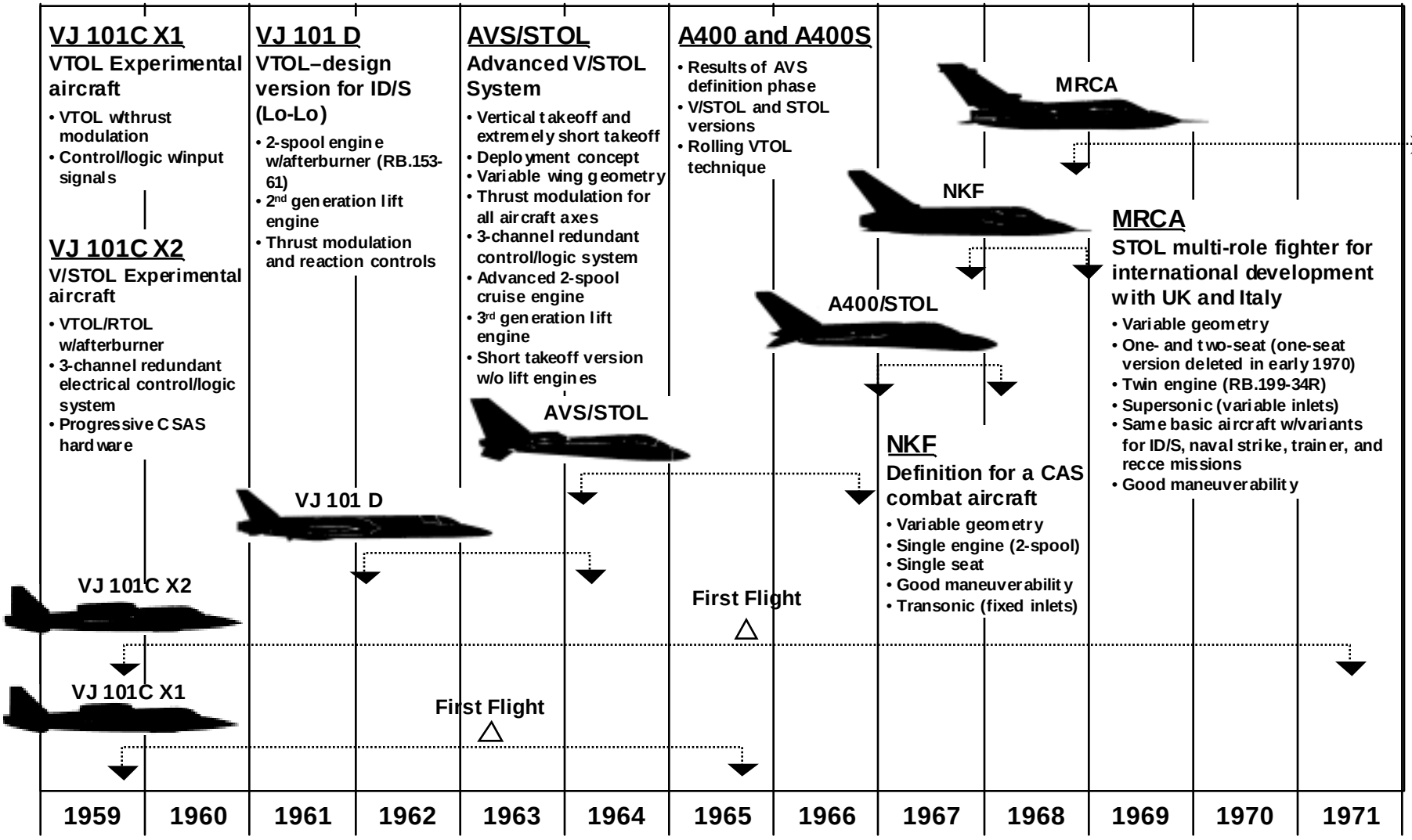
# Aftermath: EWR A 400 Design Study


- 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


VJ 101C X1
VTOL Experimental aircraft
• VTOL w/thrust modulation
• Control/logic w/input signals
VJ 101C X2
V/STOL Experimental aircraft
• VTOL/RTOL w/afterburner
• 3-channel redundant electrical control/logic system
• Progressive CSAS hardware
VJ 101 D
VTOL–design version for ID/S (Lo-Lo)
• 2-spool engine w/afterburner (RB.153-61)
• 2nd generation lift engine
• Thrust modulation and reaction controls
AVS/STOL
Advanced V/STOL System
• Vertical takeoff and extremely short takeoff
• Deployment concept
• Variable wing geometry
• Thrust modulation for all aircraft axes
• 3-channel redundant control/logic system
• Advanced 2-spool cruise engine
• 3rd generation lift engine
• Short takeoff version w/o lift engines
A400 and A400S
• Results of AVS definition phase
• V/STOL and STOL versions
• Rolling VTOL technique
MRCA
NKF
A400/STOL
AVS/STOL
VJ 101 D
VJ 101C X2
VJ 101C X1
First Flight
First Flight
NKF
Definition for a CAS combat aircraft
• Variable geometry
• Single engine (2-spool)
• Single seat
• Good maneuverability
• Transonic (fixed inlets)
MRCA
STOL multi-role fighter for international development with UK and Italy
• Variable geometry
• One- and two-seat (one-seat version deleted in early 1970)
• Twin engine (RB.199-34R)
• Supersonic (variable inlets)
• Same basic aircraft w/variants for ID/S, naval strike, trainer, and recce missions
• Good maneuverability
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971

# 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