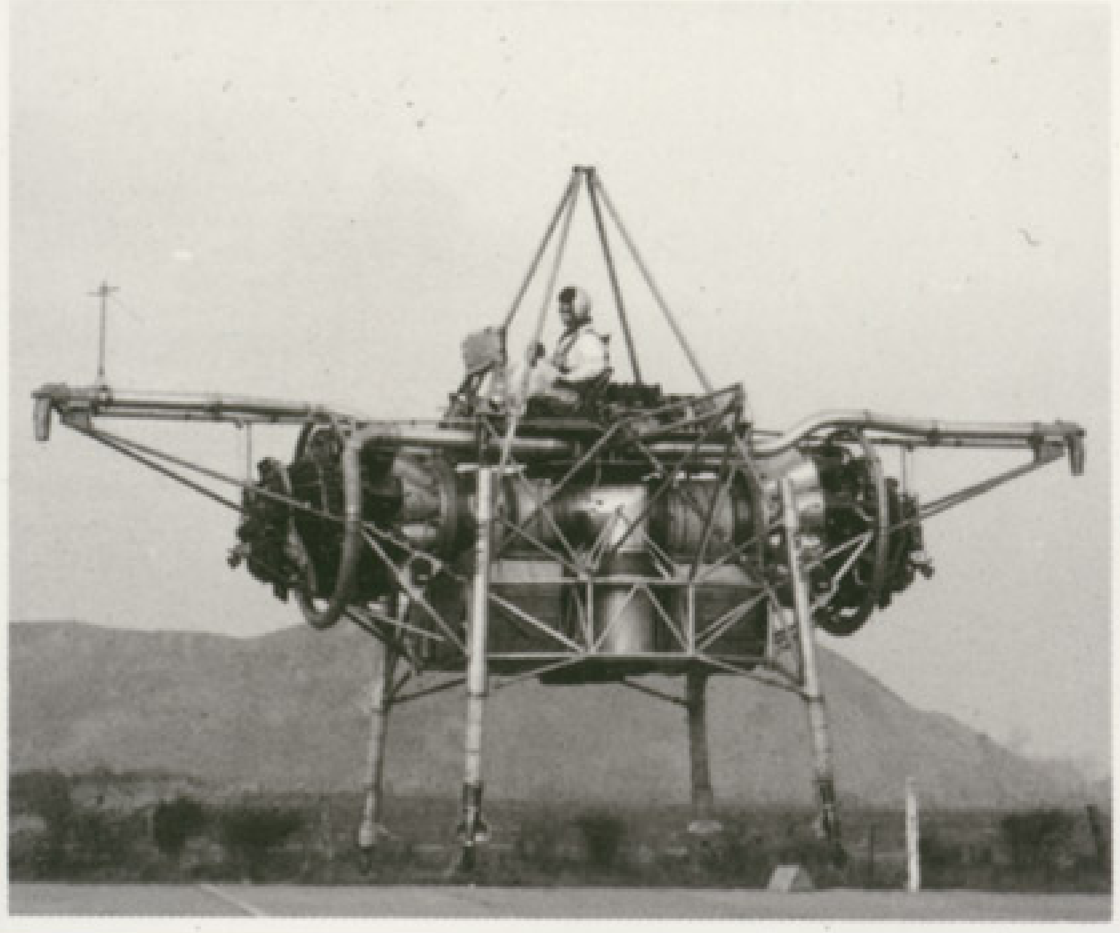

V/STOL

Experience & capability

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TS3563

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Preface

Since the first flight of the 'Flying Bedstead' in 1954, Rolls-Royce has been to the forefront of technology developments for vertical and short take-off and landing (V/STOL) propulsion systems primarily through the Pegasus vectored thrust turbofan which powers all versions of the Harrier aircraft.

The unrivalled experience gained through the Pegasus and many other vectored thrust/lift engine programmes, has enabled Rolls-Royce to make a major contribution to short take-off and vertical landing (STOVL) technology as the pioneering company in this demanding field.

Today as the concept of STOVL operation gains more credibility, the development of new propulsion systems, including those with supersonic capability, are being studied.

Rolls-Royce, through its Technical Collaboration Agreement with Pratt & Whitney and the studies carried out under the UK/US Memorandum of Understanding, in addition to its own programmes including advanced plenum chamber burning, is still at the forefront of V/STOL propulsion technology. This brochure illustrates the Company's experience — and the role it will play in the future.

J D Wragg
Director Military Engines

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1 Introduction

Rolls-Royce — leader in powered lift

In 1941 the Chief Scientist of Rolls-Royce, Dr A A Griffith issued his first paper on jet-lift for vertical take-off and landing (VTOL). In August 1954, the Rolls-Royce 'Flying Bedstead' completed the world's first piloted free-flight by a jet-lift vehicle. Since then Rolls-Royce has been actively engaged in providing jet powerplants for vertical or short take-off and landing (V/STOL) applications.

The Company has successful flight experience with direct-lift engines, vectored-thrust engines, various types of thrust deflection devices and swivelling engine installations. Articulated reheat pipes have been tested, lift-fan projects have been studied in depth and research into plenum chamber burning is continuing.

In addition to the manufacture of special duty lift engines, the Company is also involved in the engineering of complete V/STOL powerplants which include full installation features. Installation work has been completed on such subjects as air intakes, thrust vectoring, hot gas recirculation, ground erosion, and hovering aircraft stability and control by means of engine bleed air or thrust modulation.

This brochure records Rolls-Royce's V/STOL experience over the past three decades which has resulted in a unique wealth of background knowledge within the Company. It contains details of V/STOL engines both past and present, these are followed by a section on the diverse V/STOL technology experience which Rolls-Royce can draw upon. Engine test facilities are covered as are the various V/STOL engine applications namely the rigs and the aircraft. The brochure concludes with a section on the future of V/STOL, this includes several Advanced Short Take-Off Vertical Landing (ASTOVL) propulsion fighter concepts.

Rolls-Royce is continuing to lead the world in powered lift technology by drawing on its considerable experience in the integration of a powerplant into an airframe.

Rolls-Royce V/STOL milestones

1941	Paper to ARC by Dr Griffith (Rolls-Royce Chief Scientist) on jet lift
1952	Dr Griffith proposal for civil VTOL supersonic airliner
1954	First free hover by Flying Bedstead
1955	First run of RB108 first generation direct lift jet
1957	First complete transition by Ryan X-13 Vertijet powered by Avon engine
1959	First run of Pegasus, the world's first vectored thrust engine
1960	First complete transition by Short SC1 powered by 5 RB108 engines
1961	First complete transition by Pegasus powered Hawker P1127
1961	First run of RB145 lift/cruise engine
1961	First run of RB162 second generation direct lift jet
1963	First double transition by MD Balzac (one Orpheus plus eight RB108 engines)
1963	First complete transition by EWR VJ101CX-1 (six unreheated RB145 engines)
1963	First run of RB153 lift/cruise engine
1963	First operations from a ship using vectored thrust
1964	First run of BS100 vectored thrust engine
1965	First reheated transition by EWR VJ101CX-2 aircraft
1966	First transition by Marcel Dassault Mirage III-V (eight RB162 engines)
1966	First flight of Harrier
1967	First transition by Dornier Do 31 VTOL transport (two Pegasus 5 and eight RB162 engines)
1968	First run of XJ99 third generation lift jet
1969	First production Harriers delivered to RAF
1971	First hover of VFW – Fokker VAK 191B (one RB193 and eight RB162 engines)
1971	First USMC squadron of Harrier (AV-8A) aircraft formed
1972	First RAF squadron of Harrier (GR Mk 3) aircraft formed
1976	First Spanish Navy squadron of Harrier (AV-8S) aircraft formed
1979	Sea Harrier entered service in Royal Navy
1981	First flight of McDonnell Douglas/British Aerospace AV-8B
1983	Sea Harrier entered service in Indian Navy
1983	AV-8B entered service
1985	First flight of McDonnell Douglas/British Aerospace GR Mk 5
1986	First flight of AV-8B 2-seater trainer
1987	First GR Mk 5 delivered to RAF

Pioneering advanced technology

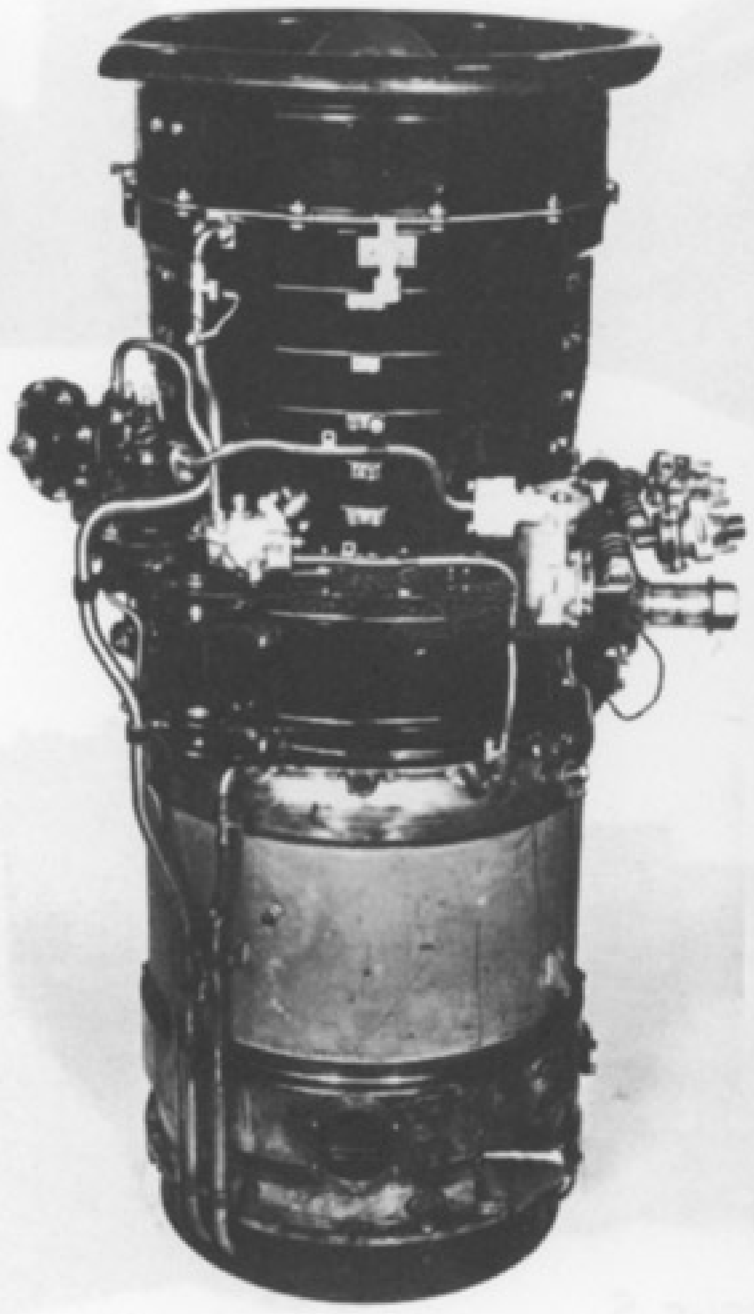
In the search for high thrust-to-weight and high thrust-to-volume ratios, the design of each generation of specialised V/STOL engine pioneered advanced technology features, most of which were subsequently adopted for conventional propulsion engines. A list of some of the features pioneered by the eight different families of Rolls-Royce V/STOL engines over the years is given below.

Air impingement starting	RB108, RB162, XJ99
Contra-rotating engine spools	Pegasus, BS100, RB153, RB193, XJ99
Deletion of LP compressor IGVs	Pegasus, BS100, RB193, XJ99
Development of compressors tolerant to maldistribution of pressure and temperature	All V/STOL engines
Extensive use of composite materials	RB162, RB193
Fully annular combustion systems	All V/STOL engines
High turbine entry temperatures	All V/STOL engines
Highly loaded compressor stages	All V/STOL engines
High speed bearings	All V/STOL engines
Large quantity bleed or offtakes	All V/STOL engines except RB145
Lightweight structures	All V/STOL engines
Low flow total loss oil systems	RB108, RB162, XJ99
Overhung LP compressor rotor assemblies	Pegasus, BS100, XJ99
Plenum chamber burning and articulated reheat systems	BS100, RB153, Pegasus
Rapid and precise thrust response	All V/STOL engines
Short, annular and rapid mixing lift engine exhaust nozzles	RB108, RB162, XJ99
Titanium turbine disc	RB162, XJ99
Welded rotor constructions	All V/STOL engines

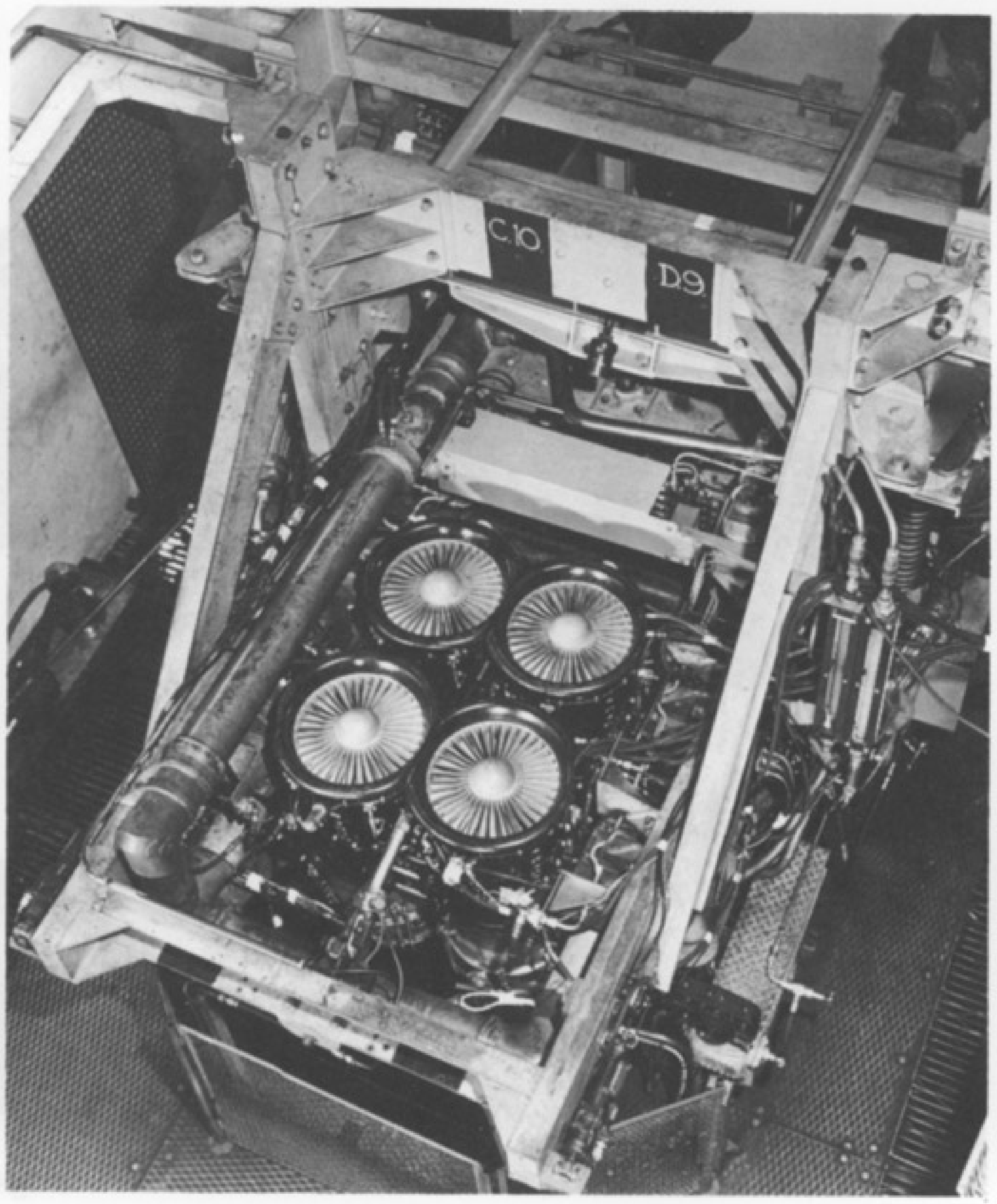
2 V/STOL engines – past and present

RB108 lift engine

Engines on final assembly



RB108



Short SC1 installation on test

Description

The RB108 was the first purpose built direct lift VTOL engine. It was a single shaft design with an eight-stage axial compressor, an annular combustion system with 12 duplex burners, a two-stage unshrouded turbine and a short exhaust unit. The one piece aluminium compressor rotor was assembled from pre-machined discs orbitally welded together. Other design features include spring-loaded bearings to prevent 'Brinelling' damage during cruise when the lift engines are inoperative, a total loss oil system, and a turbine blade air impingement starting system.

The RB108, mounted on tubular trunnions incorporated into its bleed air offtake, has been used in both fixed and swivelling engine installations. The thrust-to-weight ratio of this first generation lift jet was 8.7 to 1 for a thrust rating of 2300 lb.

History

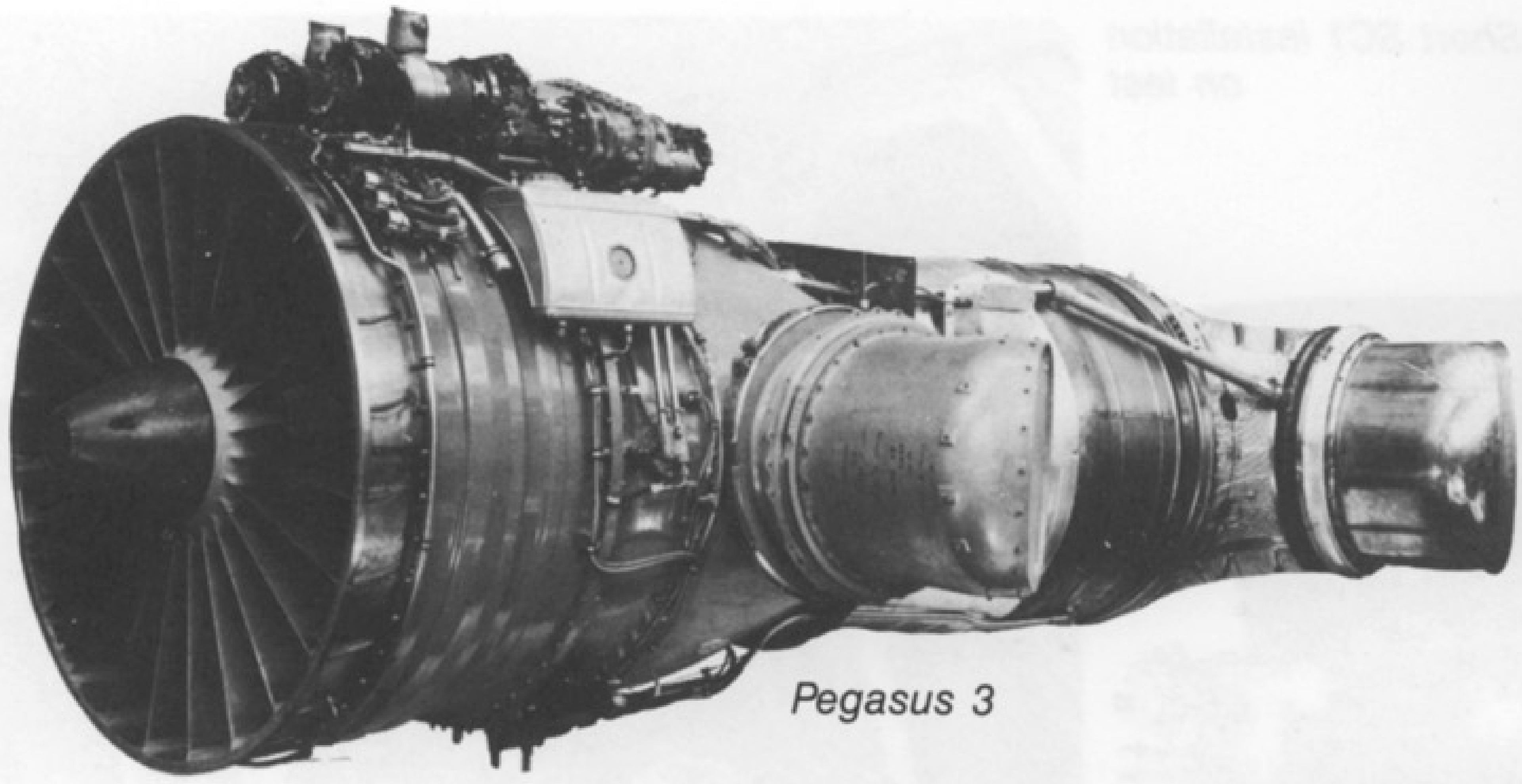
Prior to the RB108, much pioneering work had been completed on the design, development and installation of lightweight expendable engines for winged missiles. The first missile engine, the RB82, was succeeded by the RB93 Soar engine which first ran in 1952 achieving a thrust-to-weight ratio of 6.6 to 1. By the end of 1956, 760 hours running experience had been accumulated by a total of seven RB82 and 47 RB93 engines.

The RB108 first ran in July 1955 and 42 were built and used in eleven different VTOL installations.

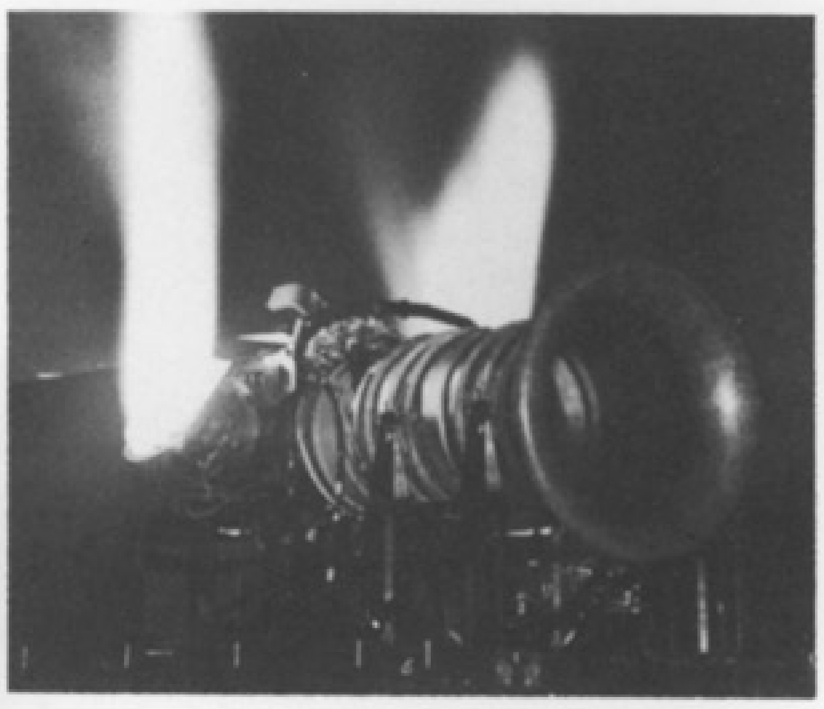
Experience

Total RB108 running time exceeded 8500 hours and included over 120 000 starts or separate engine operating cycles. No RB108 ever suffered a perceptible thrust loss or needed to be shut-down in flight as a result of failure.

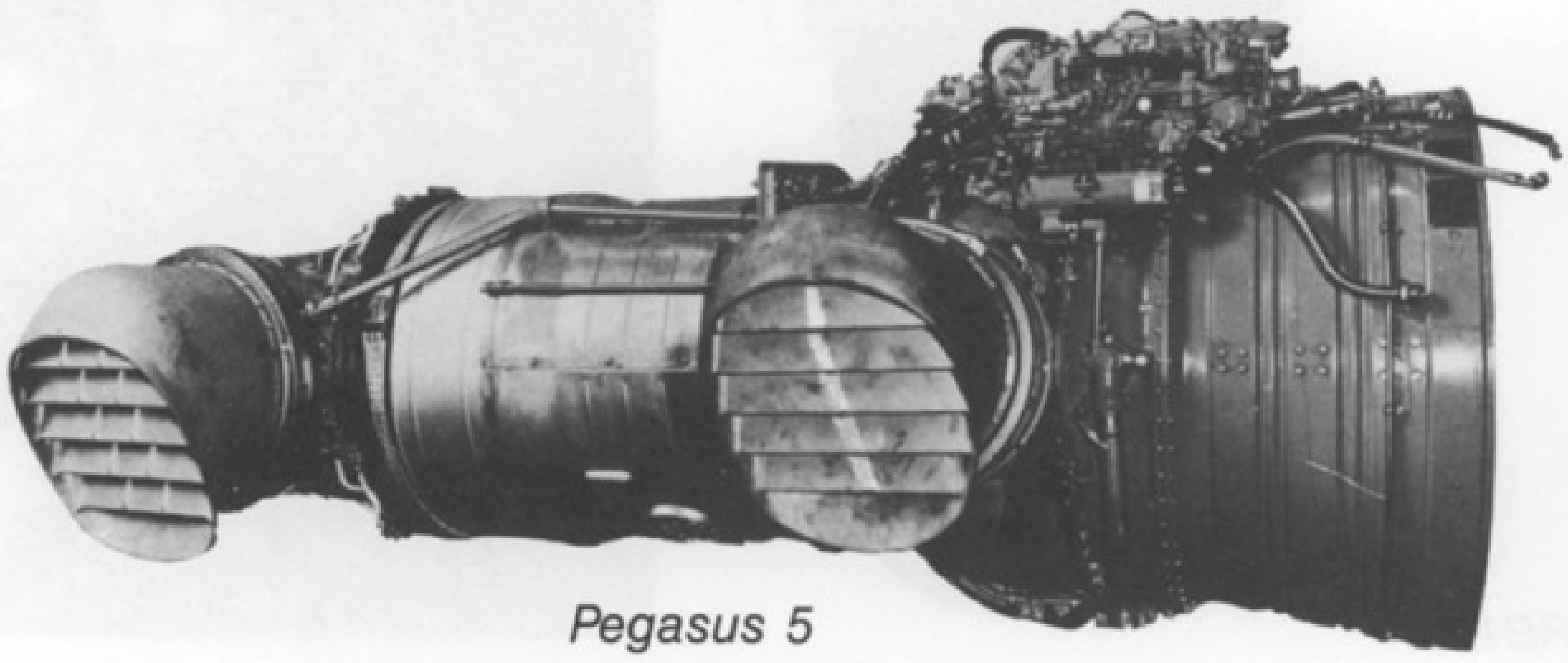
Pegasus vectored thrust engines



Pegasus 3



Pegasus 2
with plenum chamber
burning on test



Pegasus 5

Description

The Pegasus vectored-thrust turbofan has two mechanically independent spools rotating in opposite directions to minimise gyroscopic effects. The outer stream of air from the LP compressor flows into a plenum chamber surrounding the HP compressor and out to the front (cold) pair of rotating nozzles. The inner stream of air passes through the HP compressor, combustion chamber and turbines into a bifurcated exhaust system then to the rear (hot) pair of rotating nozzles. All four nozzles are mechanically linked and can be controlled by a single cockpit lever to give any thrust vector between full propulsive and full vertical thrust. Whatever the nozzle angle, the resultant thrust vector always passes near to the aircraft centre of gravity. Up to 18 lb/sec of HP compressor delivery air for aircraft stabilisation purposes can be bled from an annulus surrounding the combustion chamber.

History

In 1956 the French engineer Michel Wibault conceived the idea of a vectored thrust engine using a Bristol Orion turboprop driving four swivelling volute centrifugal compressors. This idea was refined in 1957 to become the BE53 proposal in which an Orpheus gas generator drove two stages of Olympus LP compressor, with a vectoring nozzle at each side of the casing. The next step was to replace the conventional gas generator jet pipe of the BE53 proposal with two more vectoring nozzles, so producing the Pegasus 1 engine with the now familiar four-nozzle layout.

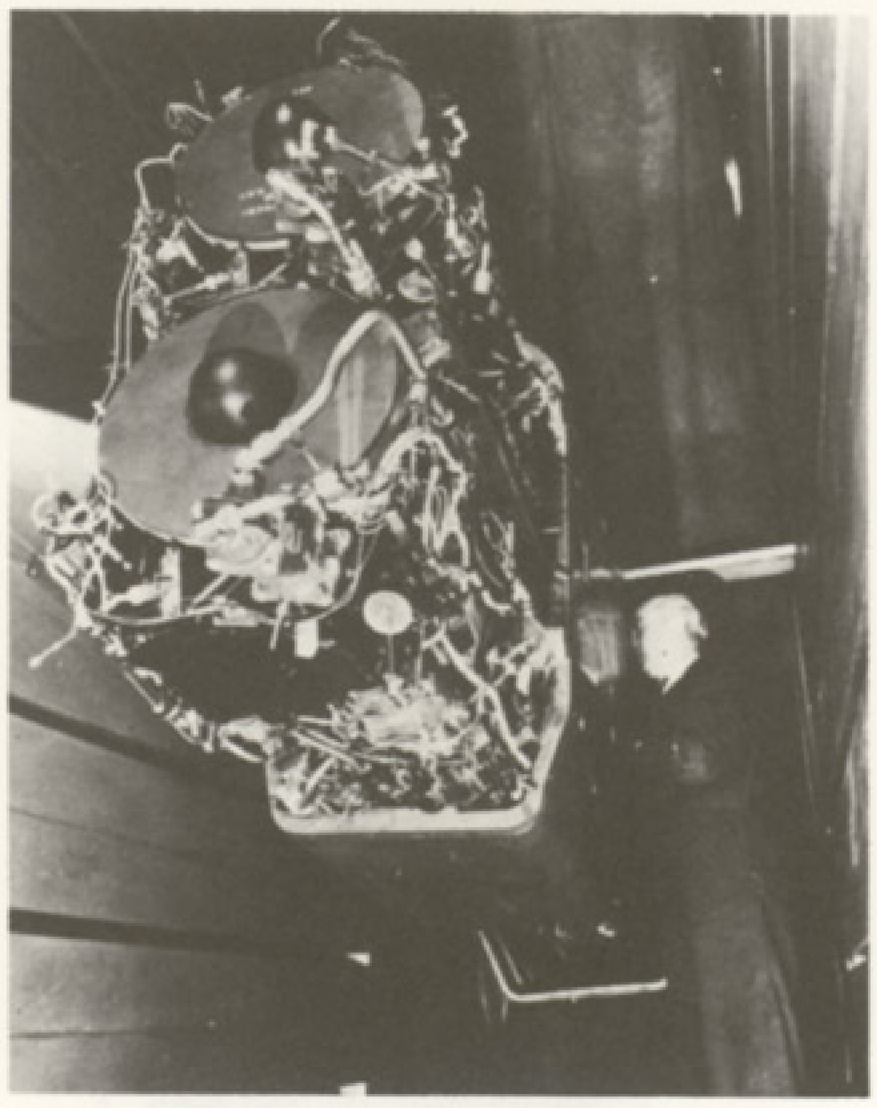
The 9000 lb thrust Pegasus 1 engine first ran in September 1959, followed in 1960 by the 12 000 lb thrust Pegasus 2, which had a two-stage LP compressor, seven-stage HP compressor, cannular combustion system, single-stage HP turbine and a two-stage LP turbine. This engine was installed in the first prototype Hawker P1127 which commenced hovering trials in October 1960. The Pegasus 3 had its thrust increased to 14 000 lb by adding a stage to both the HP compressor and HP turbine, and first ran in April 1961, flying in the P1127 in April 1962.

The later 15 500 lb thrust Pegasus 5 featured a three-stage LP compressor without inlet guide vanes, an annular vapourising combustion chamber and air-cooled first stage HP turbine blades. This engine ran in June 1962 and flew in the Hawker Siddeley Kestrel aircraft in February 1964. Dornier's large hovering rig and the two Dornier Do31 prototypes each used two Pegasus 5 engines.

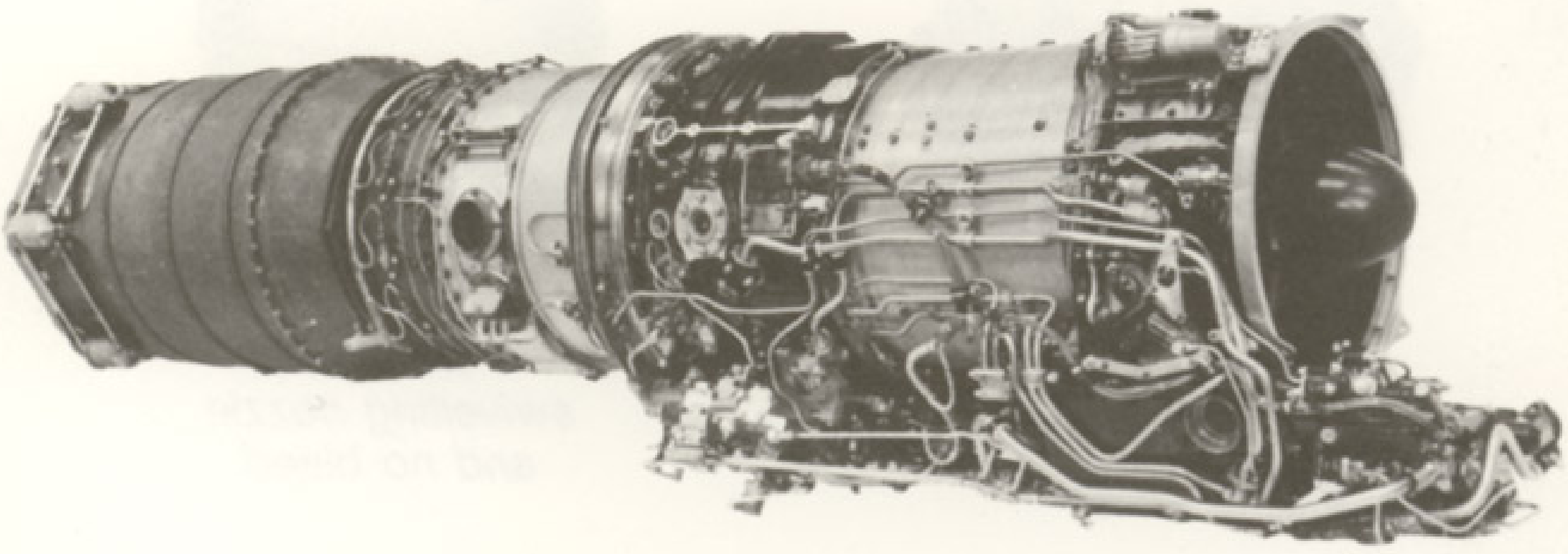
Experience

Engine type	Numbers built	Date of first run	Accumulated running time
Pegasus 1, 2 & 3	20	Sept 1959	3950 hrs
Pegasus 5	27	June 1962	5650 hrs

RB145 lift/cruise engines



Podded engines in wind tunnel



RB145 engine with reheat

Description

The RB145 was developed from the RB108 specifically to power the two EWR VJ101C supersonic VTOL research aircraft. Three distinct types of RB145 were produced; firstly a short exhaust unit, non-reheat, direct-lift engine for fixed fuselage installation (both aircraft); secondly a non-reheat lift/cruise engine for the swivelling wingtip-pod installation (first aircraft); and thirdly a reheated lift/cruise engine for the swivelling wingtip-pod of the second high-speed prototype.

The basic RB108 design was adapted by adding an 'O' stage to the compressor, general strengthening to accept the higher inlet temperatures associated with supersonic flight, and an external gearbox. This gearbox carried the engine and reheat fuel units as well as the hydraulic starter and hydraulic pump units. A recirculating oil system is used.

The RB145 was developed to achieve precise and rapid thrust response in both its dry and reheated forms since the VJ101C stability and control system relied on differential engine throttling during transition. Dry thrust of the RB145 was 2750 lb, rising to 3650 lb with reheat. A fully modulating reheat system was developed to be capable of operation at low engine speeds thereby avoiding problems associated with slow thrust response, and possible step changes in thrust following reheat selection.

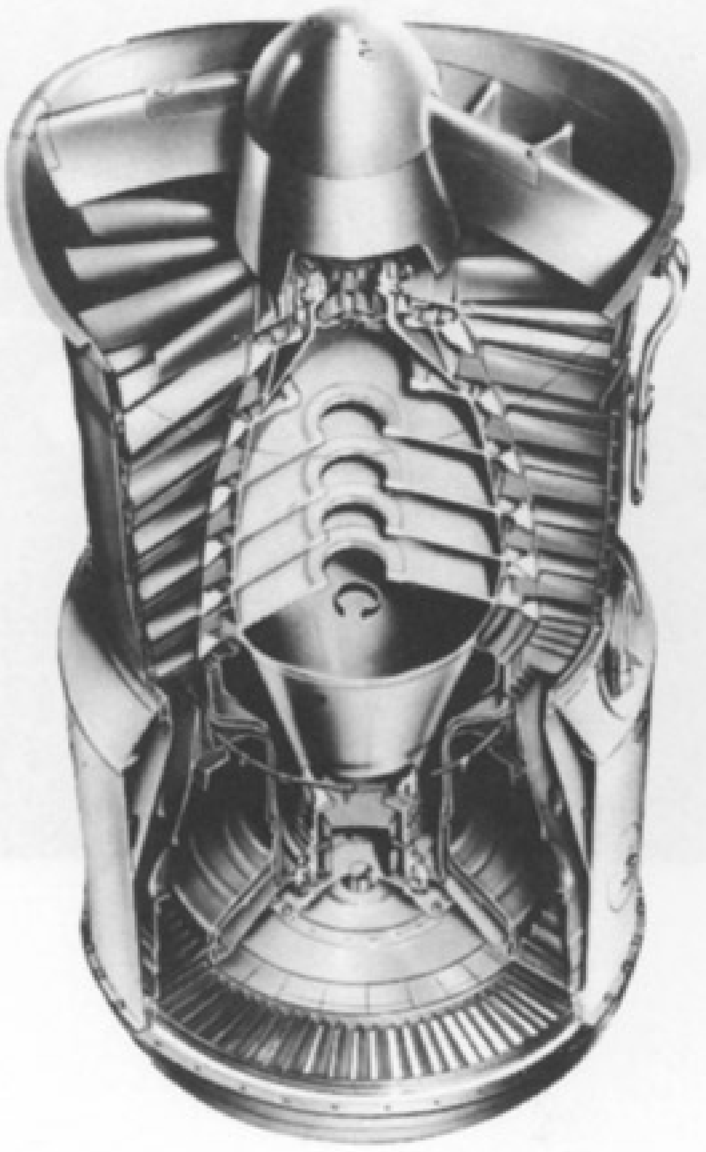
History

The RB145 first ran in April 1961. The first VJ101C aircraft powered by six non-reheat RB145 engines successfully completed its initial free hover in April 1963. The second aircraft, which had the four reheated RB145R wingtip engines, undertook its first free hover in June 1965.

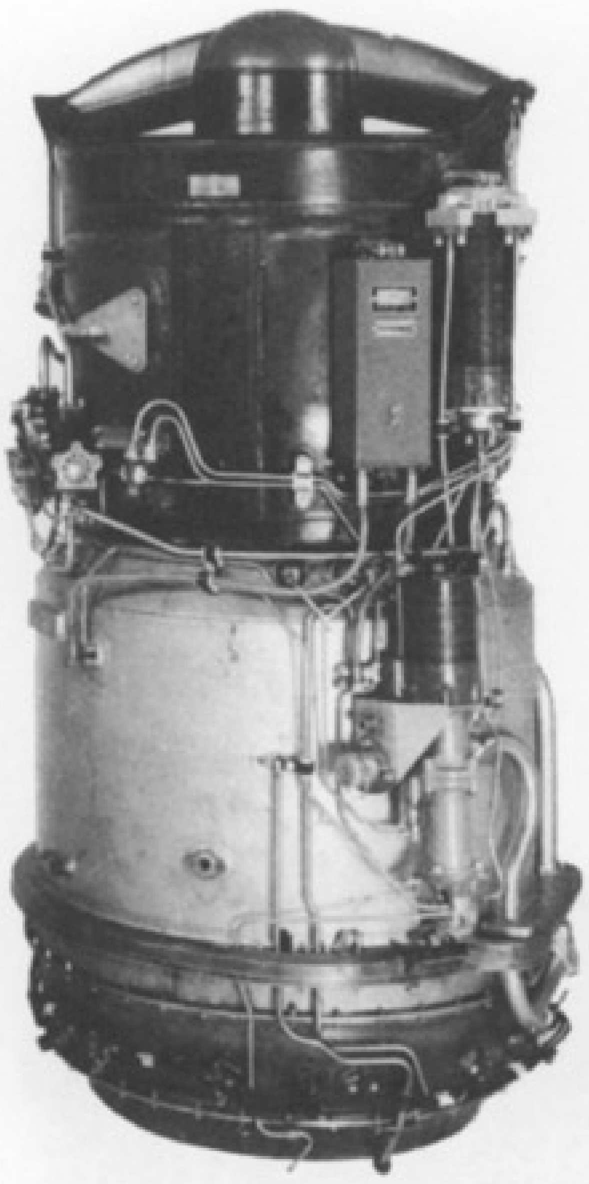
Experience

A total of twenty-two RB145 engines were built and achieved a total running time of 4011 hours which included more than 55 000 starts or separate engine operating cycles

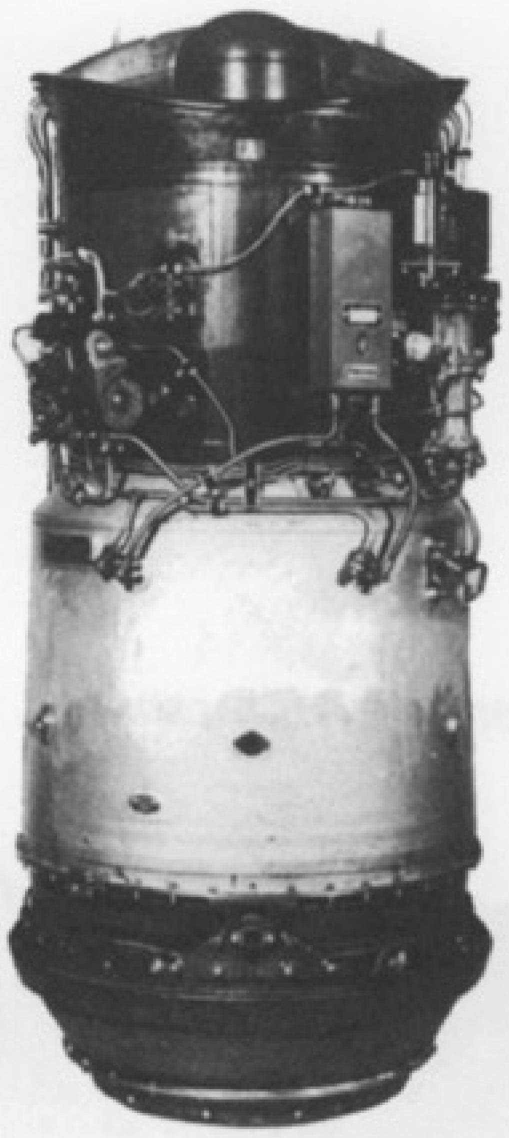
RB162 lift engines



Internal arrangement



-1 with 10% bleed for Mirage III-V



-4 with ± 15° swivelling nozzle and no bleed

Description

With the RB162-1, a second generation of Rolls-Royce lift jets emerged, having a thrust-to-weight ratio of 16 to 1.

The RB162 combined RB108 experience in simplified lightweight constructions and systems (such as a total loss oil system and impingement air starting) with new lightweight materials (such as extensive use of glass fibre in the compressor, and a titanium turbine disc).

The engine design featured a six-stage axial compressor, an annular combustion chamber having eighteen simple fuel nozzles with splash plate atomisation, a single-stage turbine and a short annular exhaust nozzle.

For aircraft control, the RB162-1 provided 9.3% continuous, or up to 11.3% intermittent, compressor bleed. The RB162-4 was a non-bleed version of the -1 and was fitted with a ± 15° swivelling final nozzle to suit the yaw control requirements of the Dornier Do31 during hover.

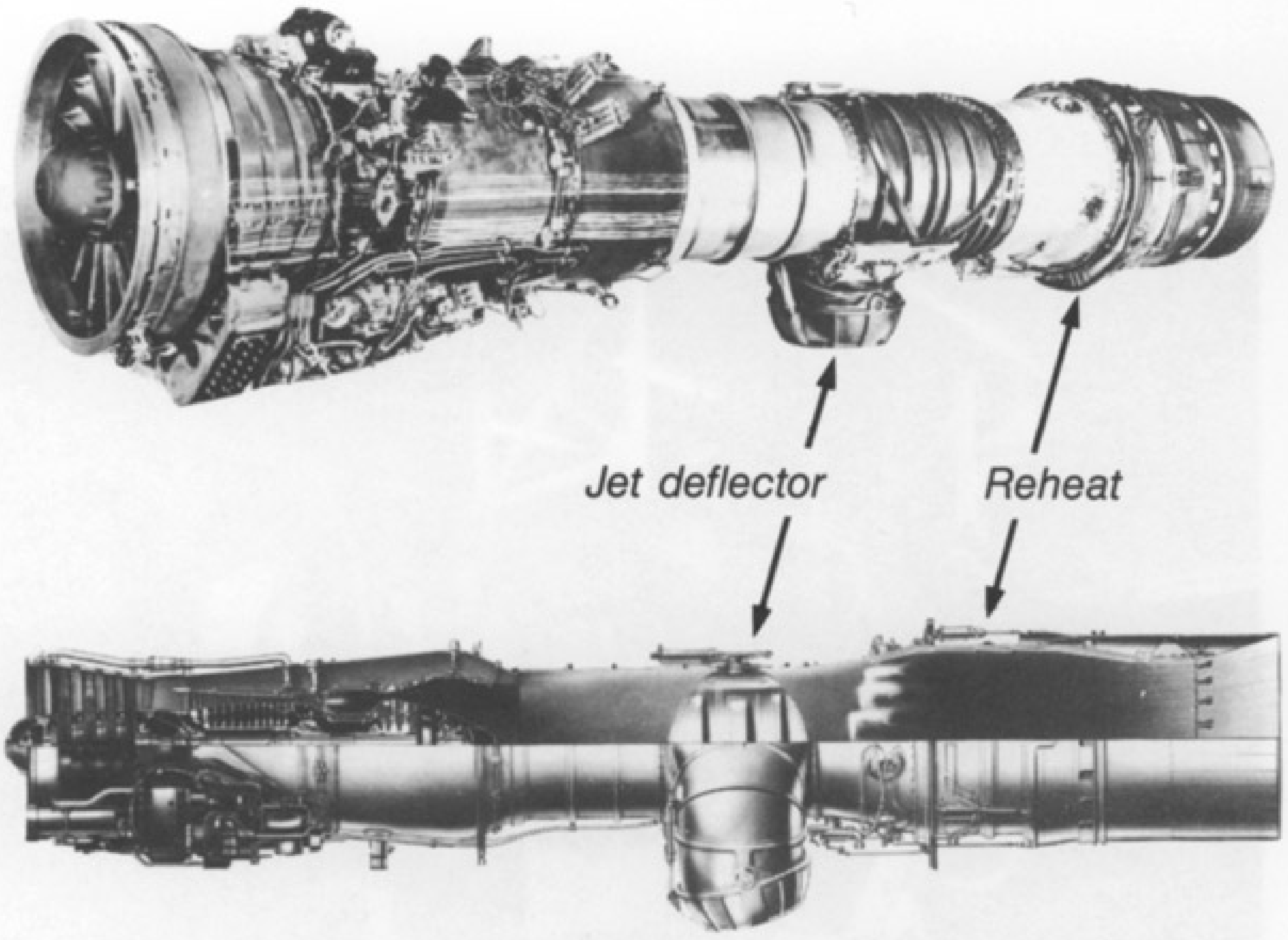
History

Major design work on the RB162 started in September 1959. In November 1961 Rolls-Royce was authorised to proceed with development of the RB162-1 (for the Mirage III-V) and the -4 (for the Dornier Do31) under the terms of the Tripartite Phase I programme financed by the British, French and German Governments.

Experience

Engine type	Numbers built	Date of first run	Engine running experience	
			Hours	Operations
RB162-1	30	Dec 1961	670	13 391
RB162-4	24	April 1964	558	10 207

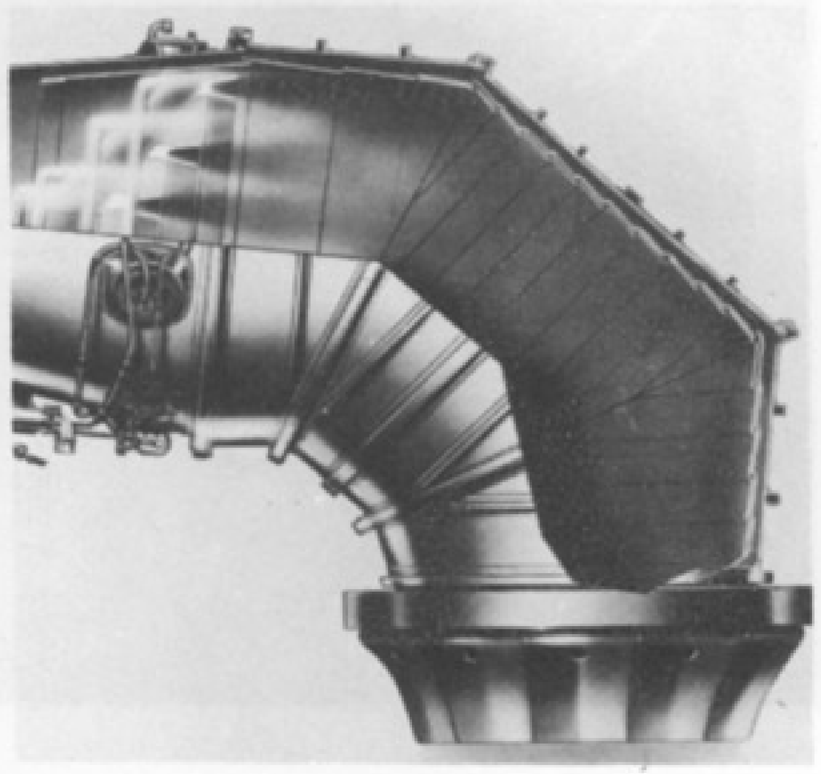
RB153 lift/cruise engine



With jet deflector and straight-through reheat

With deflected reheat — on test

With deflected reheat — internal arrangement



Description

The RB153-61 was essentially a three-quarter linear scale of the military Spey engine. It was designed and developed jointly by Rolls-Royce and MAN (now MTU) specifically for side-by-side installation the EWR VJ101D supersonic VTOL strike fighter. The requirement was for an engine having a good sea level fuel consumption at Mach 0.92 coupled with a capability of Mach 1.15 at sea level and 2.2 at altitude. Between the engine and its variable straight-through reheat system was a switch-in thrust deflector comprising a single-sided clam shell door leading to the ± 15° swivelling final nozzle used for VTOL.

The engine was a two-shaft bypass propulsion engine featuring contra-rotating shafts to minimise gyro-couples during hovering flight. Both the four stage LP and twelve stage HP compressors were driven by two stage turbines. The basic engine thrusts were 6850 lb non-reheat or 11 750 lb with reheat.

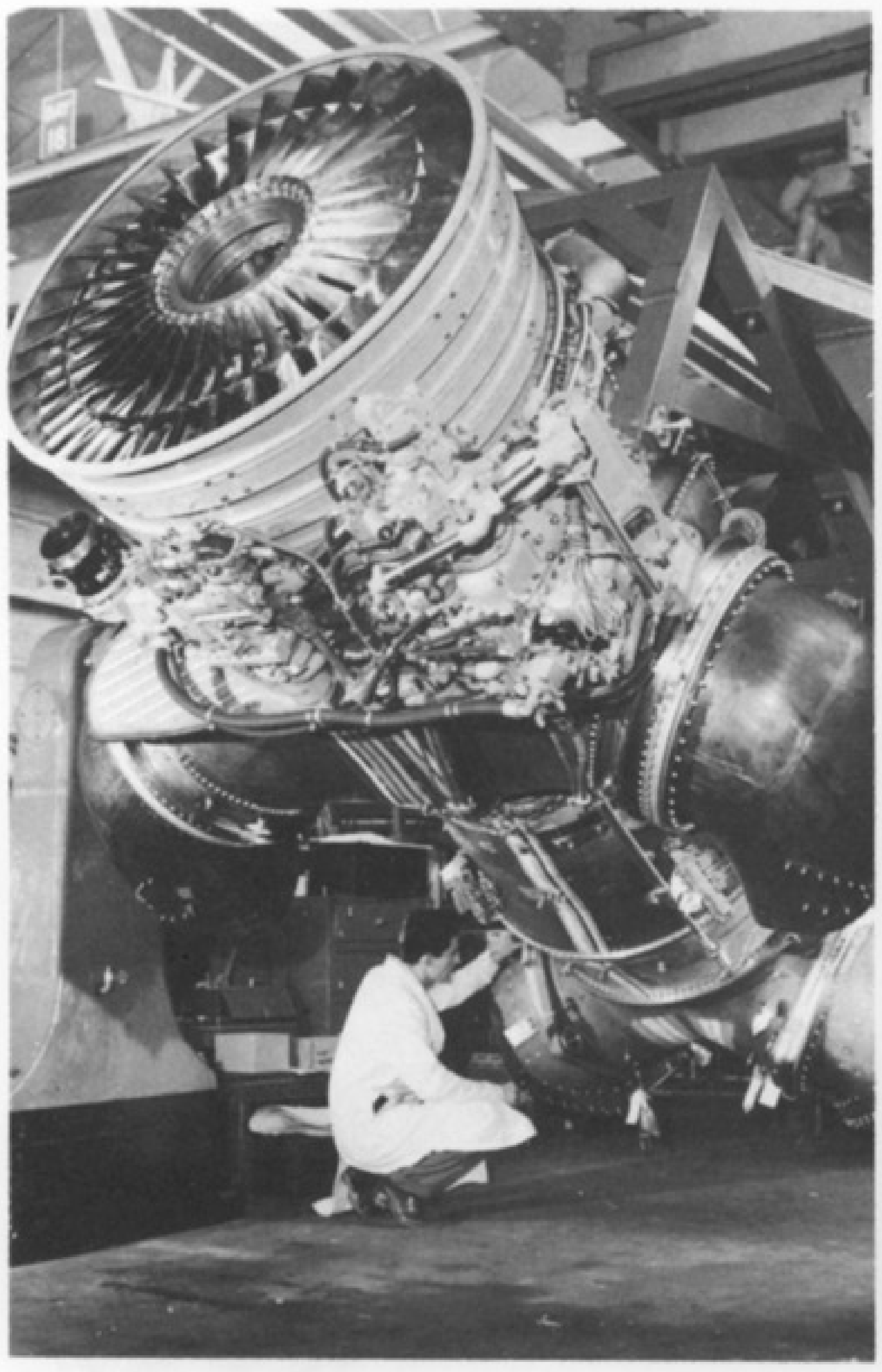
History

The first RB153-61 ran in November 1963. The straight-through reheat system, based on an earlier Rolls-Royce/Allison design for the Medway engine, was first tested as a separate unit in the Derby Altitude Test Facility prior to running behind the RB153-61. Initial testing of the switch-in thrust deflector system was completed using a slave Avon engine. The EWR VJ101D aircraft was cancelled and MTU München then used the RB153-61 for experimental development of an articulated or lobster tail' thrust vectoring reheat system.

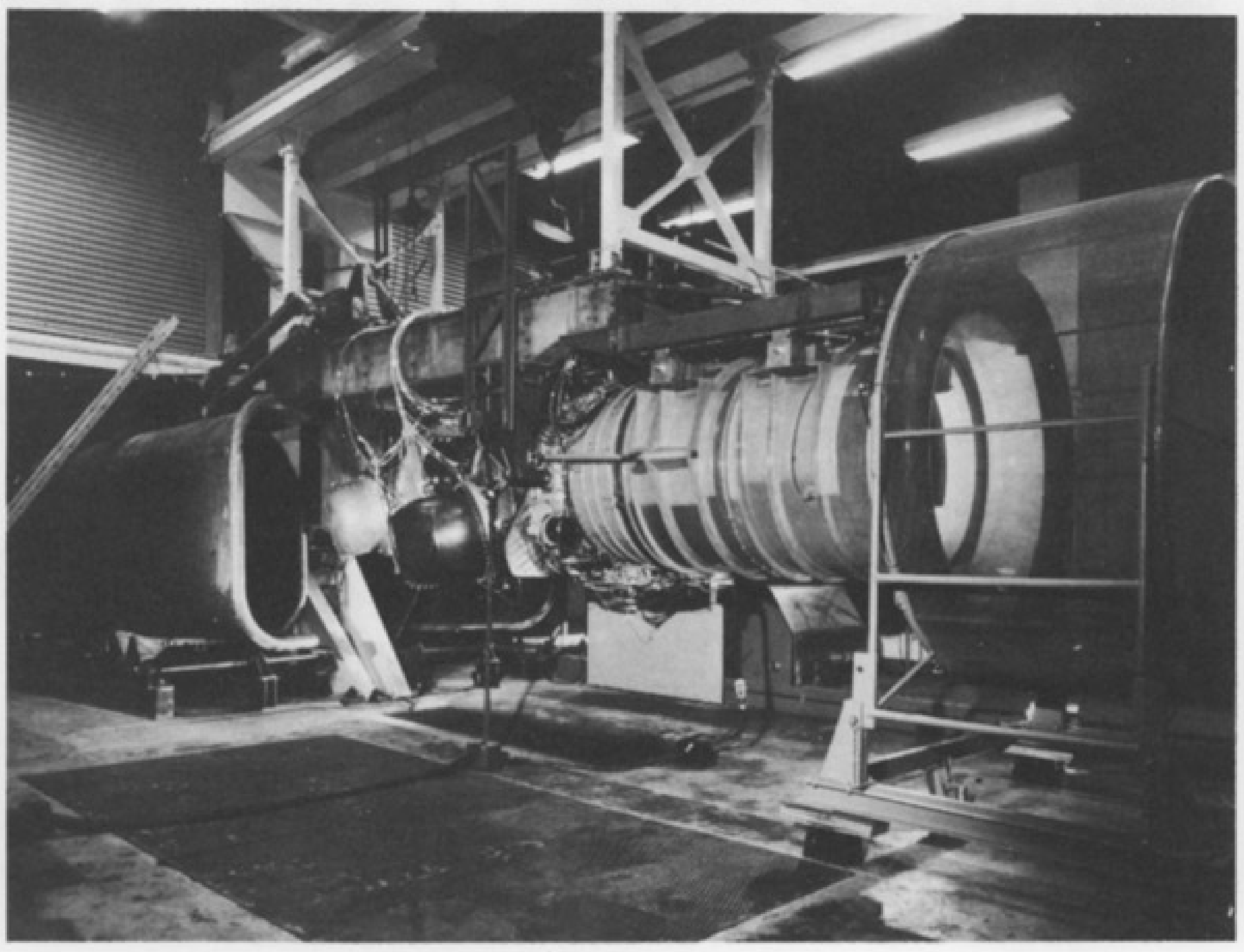
Experience

A total of 6 RB153-61 engines were built. These achieved a total running time of 1502 hours which included 29 hours running with the articulated reheat system.

BS100 vectored thrust engine



Vectoring nozzles with plenum chamber burning



On test bed

Description

This engine was basically a large supersonic Pegasus with a further stage added to the fan and the introduction of plenum chamber burning (PCB) to the forward nozzles. PCB is the name given to the system developed by Rolls-Royce whereby the thrust produced by the fan is augmented by burning fuel in the plenum chamber prior to discharge through the front vectoring nozzles. By this means a significant increase in thrust is made available for V/STOL and for supersonic flight.

History

The BS100 engine was conceived for the Hawker Siddeley P1154 aircraft which was similar in concept to the Harrier but was larger and had Mach 2 capability. This aircraft was eventually cancelled but not before the BS100 had shown its ability to run at a rated thrust of over 30 000 lb. Much of the initial development work on the BS100 PCB system was carried out on a specially adapted Pegasus 2 engine.

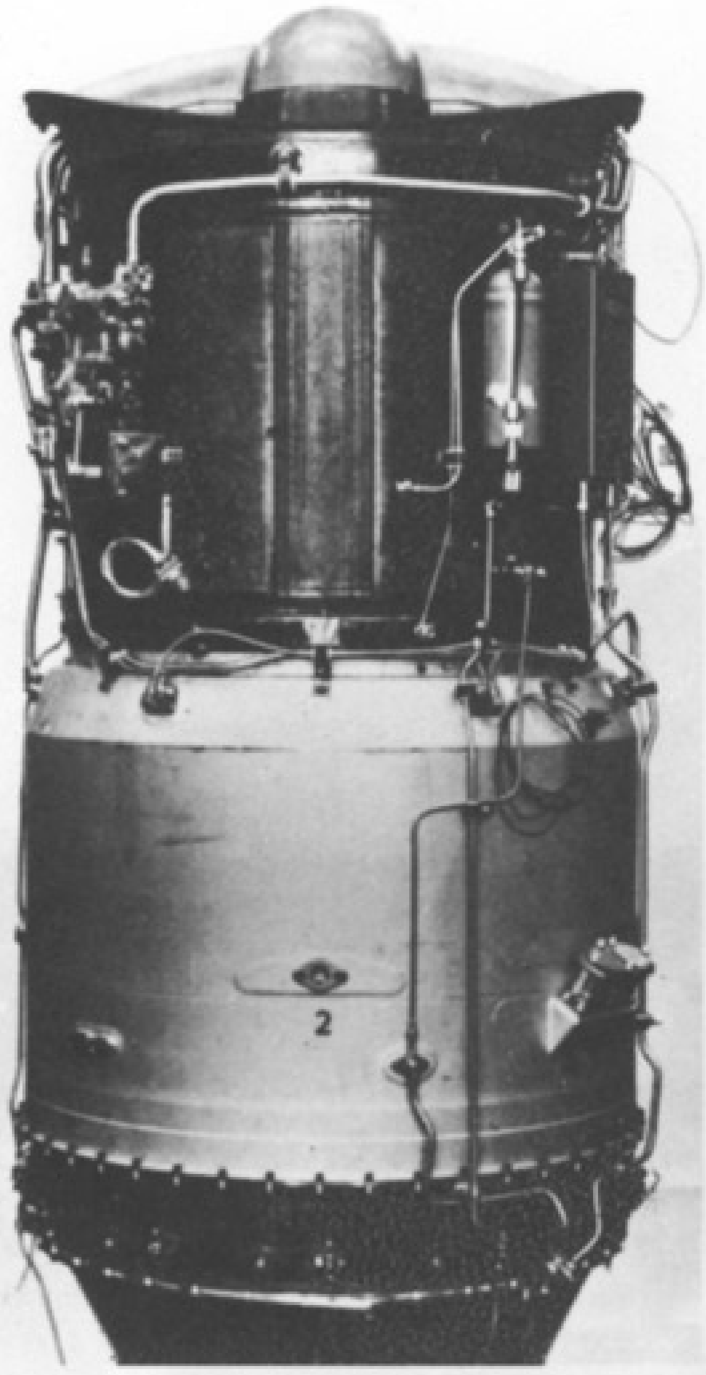
The BS100 first ran in October 1964. The first test with PCB was undertaken in March 1965.

Experience

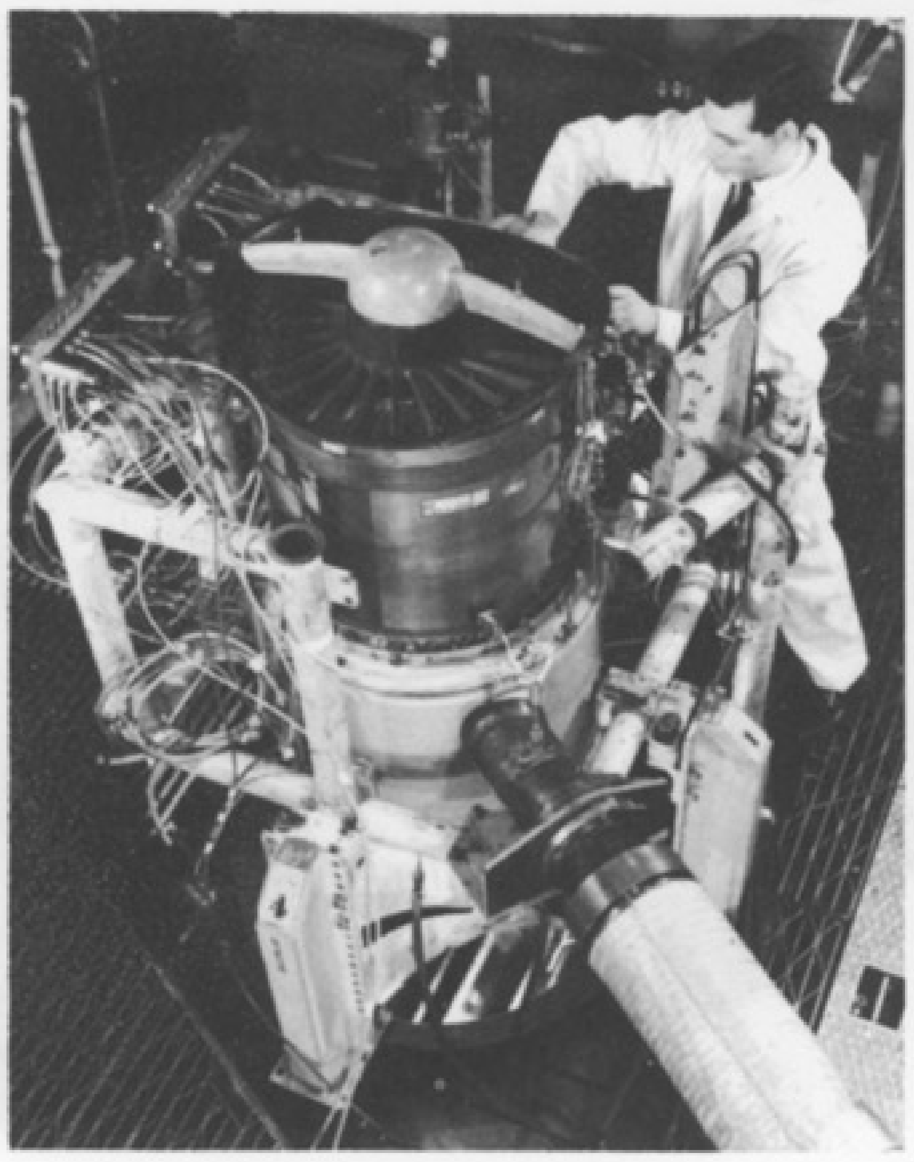
Engine type	Number built	Accumulated running time
BS100	5	350 hrs

Type of PCB experience	Accumulated running time
Rig testing BS100 engine Pegasus engine	Over 300 hrs About 10 hrs Over 400 hrs

RB162 lift engines & civil booster



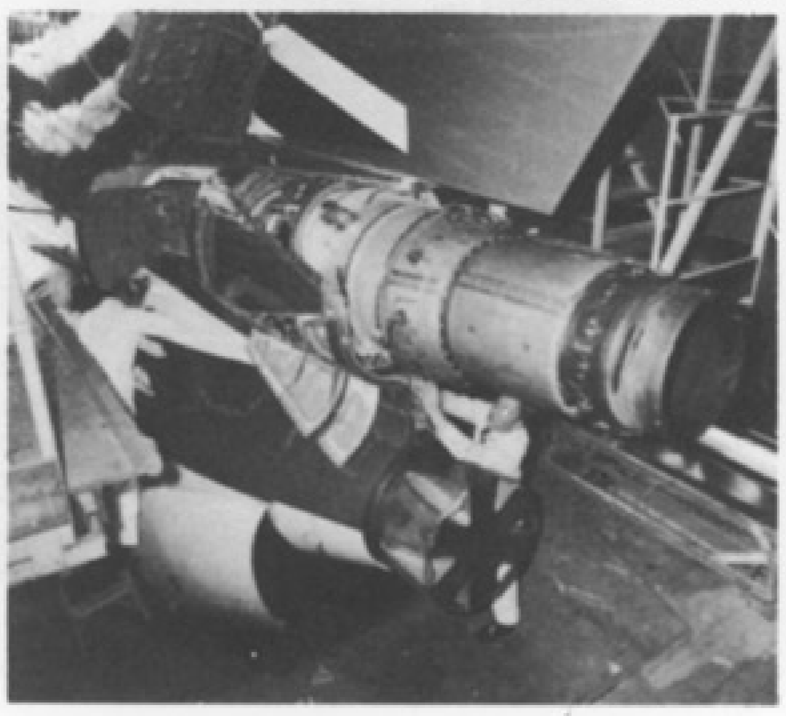
-31 8% bleed engine on test



-81 8% bleed engine on test

-86 booster in Trident 3B

-86 booster installation



RB162-31

In March 1964, Rolls-Royce commenced the RB162 Tripartite Phase II programme. The main objective was a considerable thrust growth which was achieved by a 1.125 linear scale of the basic RB162-1 design to produce the -31 8% bleed lift engine. The opportunity was also taken to incorporate a number of design improvements such as revisions to the oil pump, fuel system and combustion chamber primary zone.

RB162-81

To obtain even greater thrust, the -31 design was further refined to accept higher flame temperature and rotational speed within the same internal dimensions. The major new feature of the resulting -81 design was the adoption of air-cooled turbine blades. The -81 completed a 25 hour lift engine type approval test at its brochure thrust of 6000 lb, and eighteen flight engines were delivered for the three VFW-Fokker VAK191B prototypes.

RB162-86

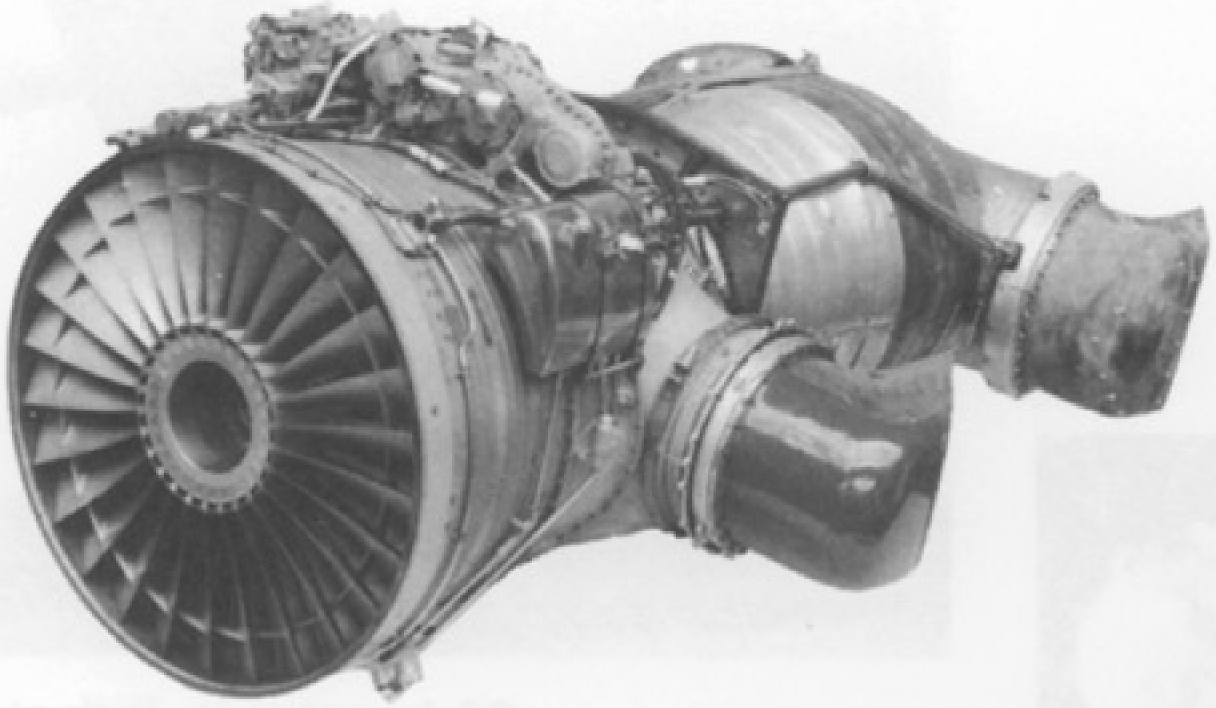
The -86 is basically the -81 lift jet redesigned to meet civil booster engine operating requirements. New design features included a steel anti-iced front bearing housing, a revised oil system for horizontal running and a longer jet pipe. The -86 achieved its full brochure thrust of 5400 lb on its first run and received its Full Transport Category Type Certificate from the ARB in January 1971. All guarantees were met by the engine which was still in commercial service at the end of 1985.

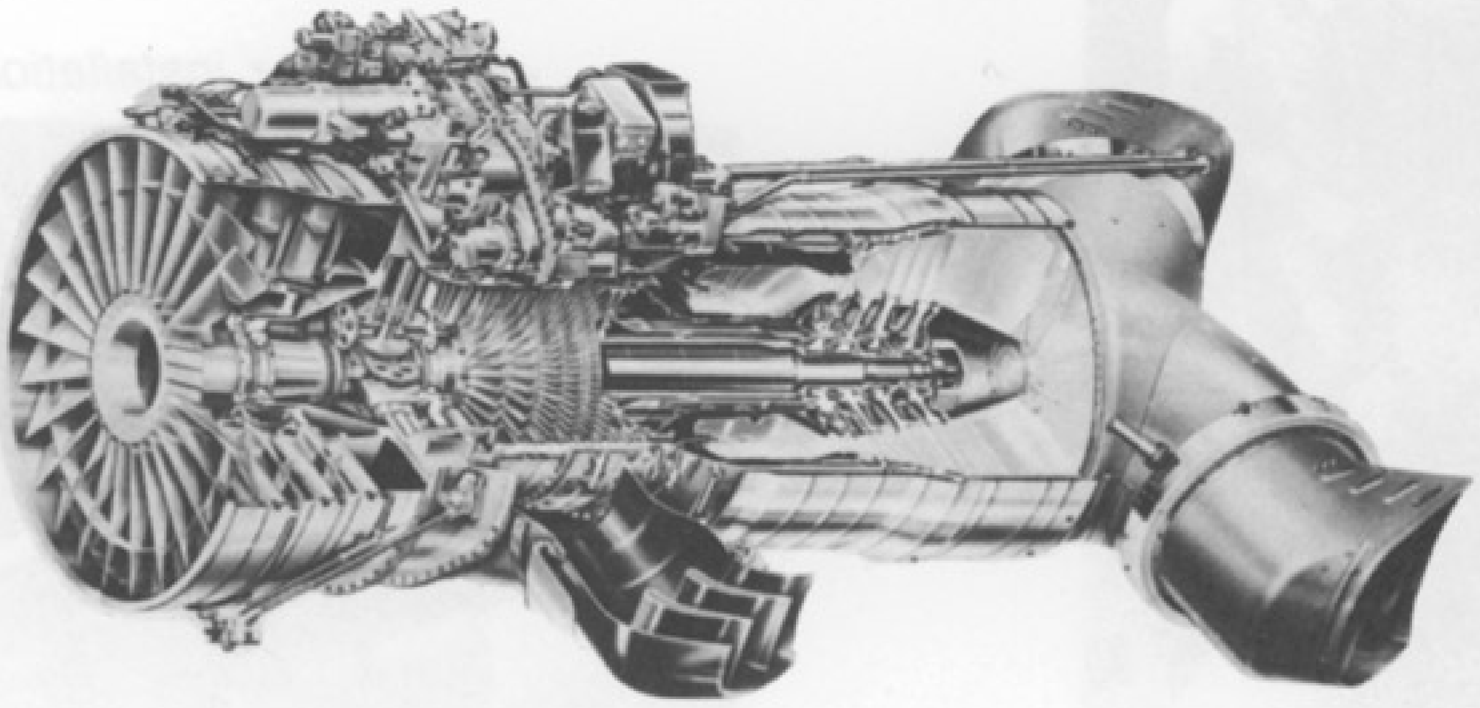
Experience

Engine type	Numbers built	Date of first run	Running experience to date	
			Hours	Cycles
RB162-31	8	Feb 1965	454	7248
RB162-81	19	Aug 1966	619	8987
RB162-86	47	May 1969	—	over 100 000

Pegasus vectored thrust engines

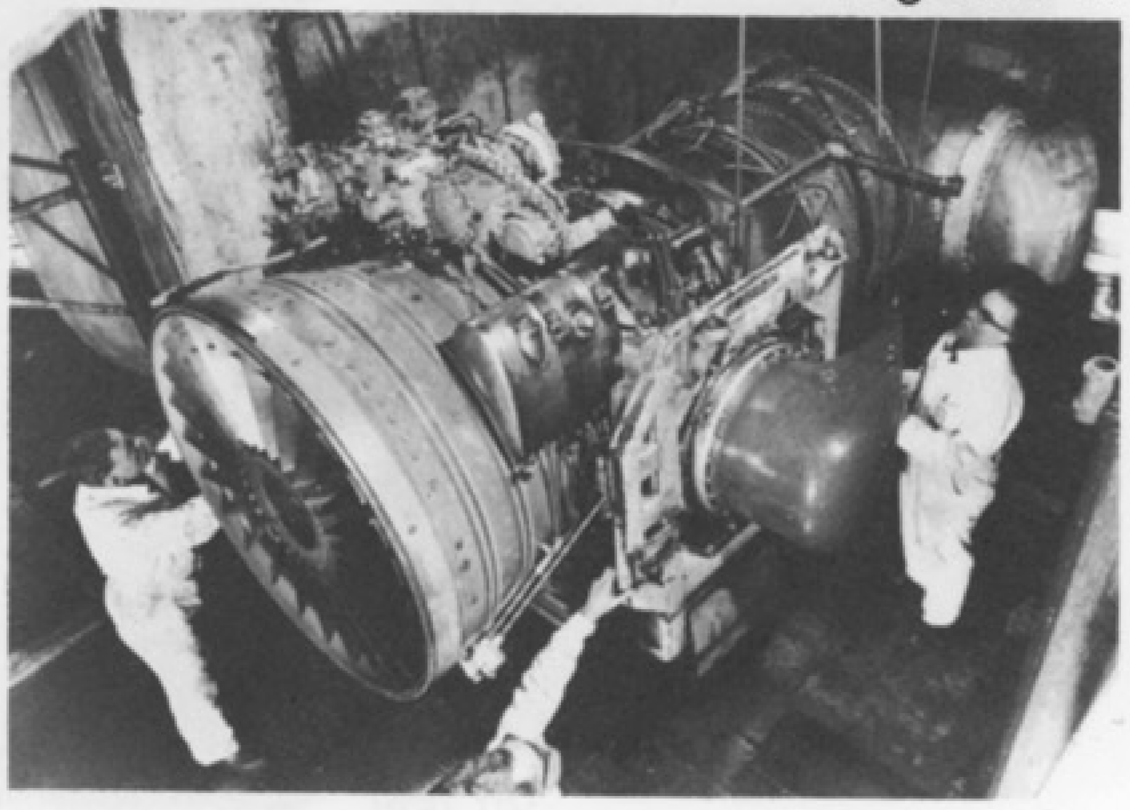
Pegasus 6





Pegasus internal arrangement

Pegasus 10



Pegasus 6

Relative to the Pegasus 5, the 19,000 lb thrust Pegasus 6 incorporated an all-titanium fan, a revised combustion system with water injection for hot day thrust restoration, air-cooling of the second stage of the HP turbine, a revised fuel system and two-vane nozzles. The Pegasus 6 first ran in March 1965 and flew in the first development Harrier aircraft in August 1966. The engine received full Type Approval in March 1968 and entered service with the RAF in 1969 as the Pegasus Mk101.

Pegasus 10

This was an interim standard production engine which was basically similar to the Pegasus 6 but uprated to 20,500lb thrust by increased TET and use of water injection to give thrust boost. The Pegasus 10 ran for the first time in February 1969 and received Type Approval as the Pegasus Mk102 in March 1970. In the AV-8A Harriers of the US Marine Corps it was known as F402-RR-402. The first squadron of Pegasus 10 powered USMC Harriers was formed on 16th April 1971.

Pegasus 11

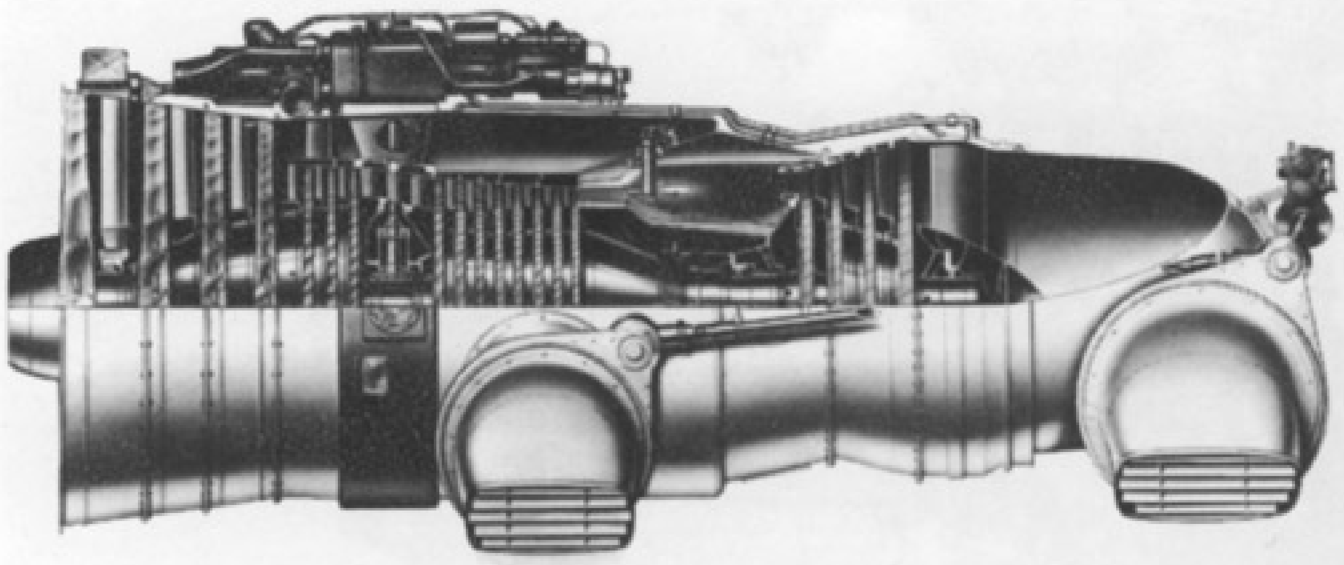
The 21,500lb thrust Pegasus 11 is a development of the Pegasus 10 with the thrust uprating achieved mainly by increasing the air mass flow of the fan. The engine also incorporates fuel system revisions, an improved water injection system and improved turbine cooling. The Pegasus 11 ran for the first time in August 1969 and received Type Approval in July 1971.

A version incorporating aluminium fan and intermediate casings and extensive anti-corrosive coatings was developed for the Sea Harrier and is now in service with the Royal Navy and the Indian Navy.

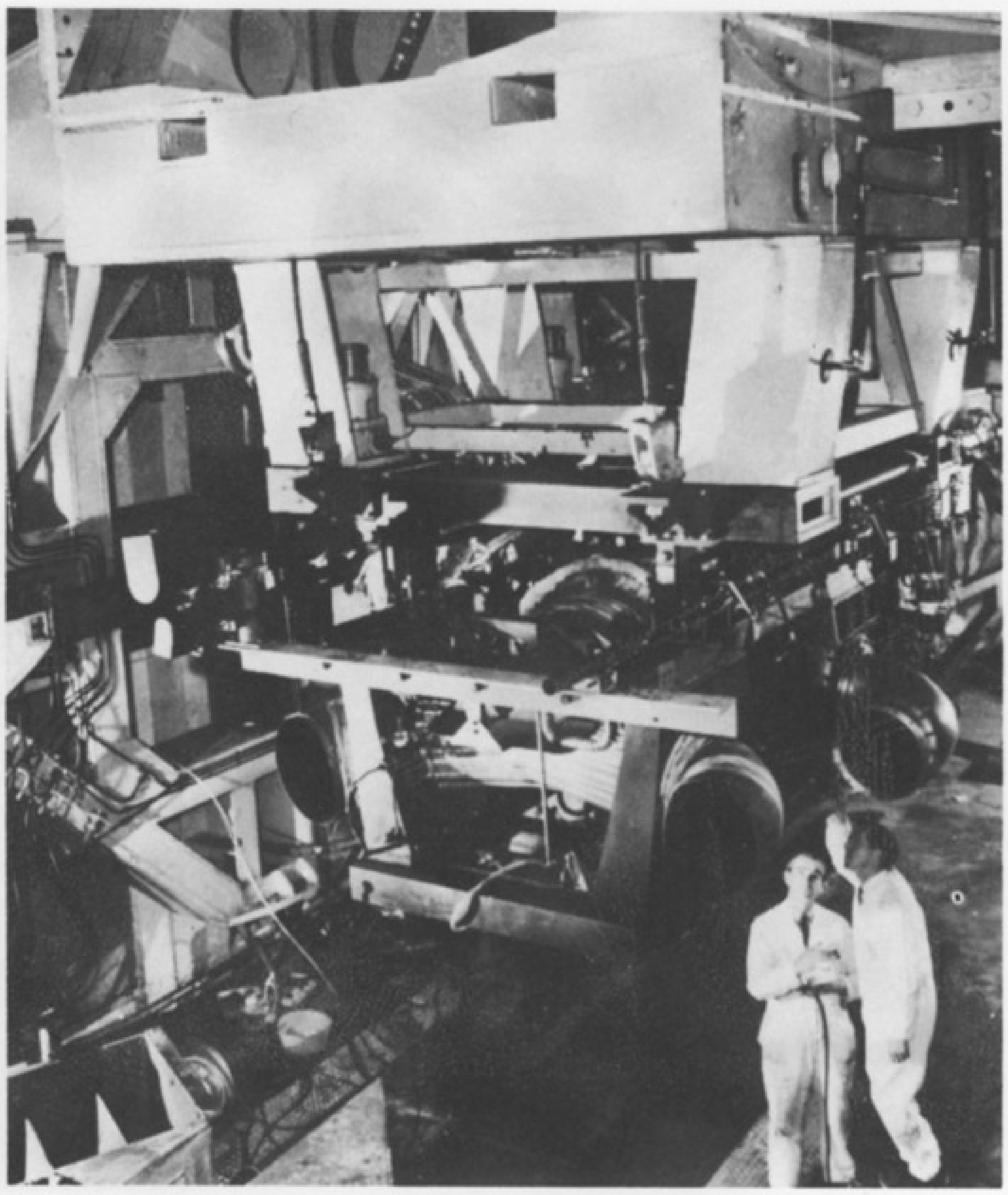
Experience

Engine type	Date of first run	Running experience
Pegasus 6	March 1965	23 000 hrs
Pegasus 10	Feb 1969	27 000 hrs
Pegasus 11	Aug 1969	Over 600 000 hrs

RB193 vectored thrust engine



Internal arrangement



On test bed

Description

The RB193-12 was developed jointly by Rolls-Royce and MTU München as the lift/cruise engine for the VFW-Fokker VAK191B aircraft. It was a four-nozzle, two-shaft vectored thrust turbofan with a nominal thrust rating of 10 163 lb.

The bypass and turbine exhaust streams discharged separately, each through a pair of swivelling nozzles which were derived from the well-proved Pegasus design, and synchronised to vector thrust between vertical and propulsive settings. An overall pressure ratio of 16.5 to 1 was achieved in 11 stages of compressor without inlet guide vanes or any form of variable geometry. Four stages of LP and three stages of IP compressor were driven by the three-stage LP uncooled turbine. The HP rotor, comprising an eight-stage compressor driven by a single-stage air-cooled turbine was supported on two bearings. Minimisation of gyroscopic couples was achieved by contra-rotation of the two shafts.

Other design features included a fully annular combustion chamber, provision for bleeding off up to 22% of the HP compressor mass flow for aircraft stability control, and manufacture of the front nozzle casing in glass-reinforced composite material.

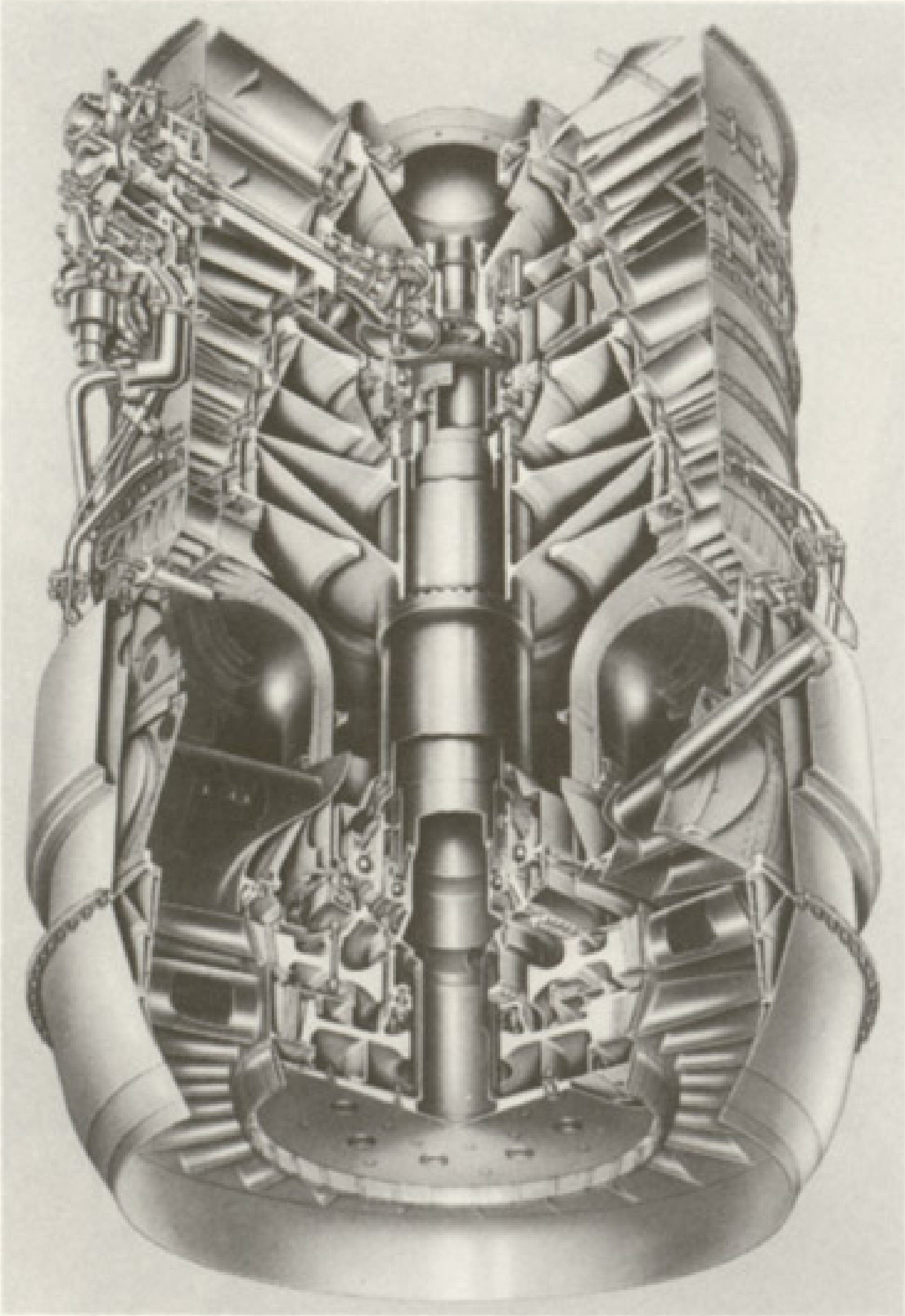
History

The RB193-12 first ran in December 1967. Its first 25 hour flight clearance test was completed in December 1969 and the first of nine flight engines ordered for the VAK191B programme was supplied in September 1970. Three VAK191B prototype aircraft were built.

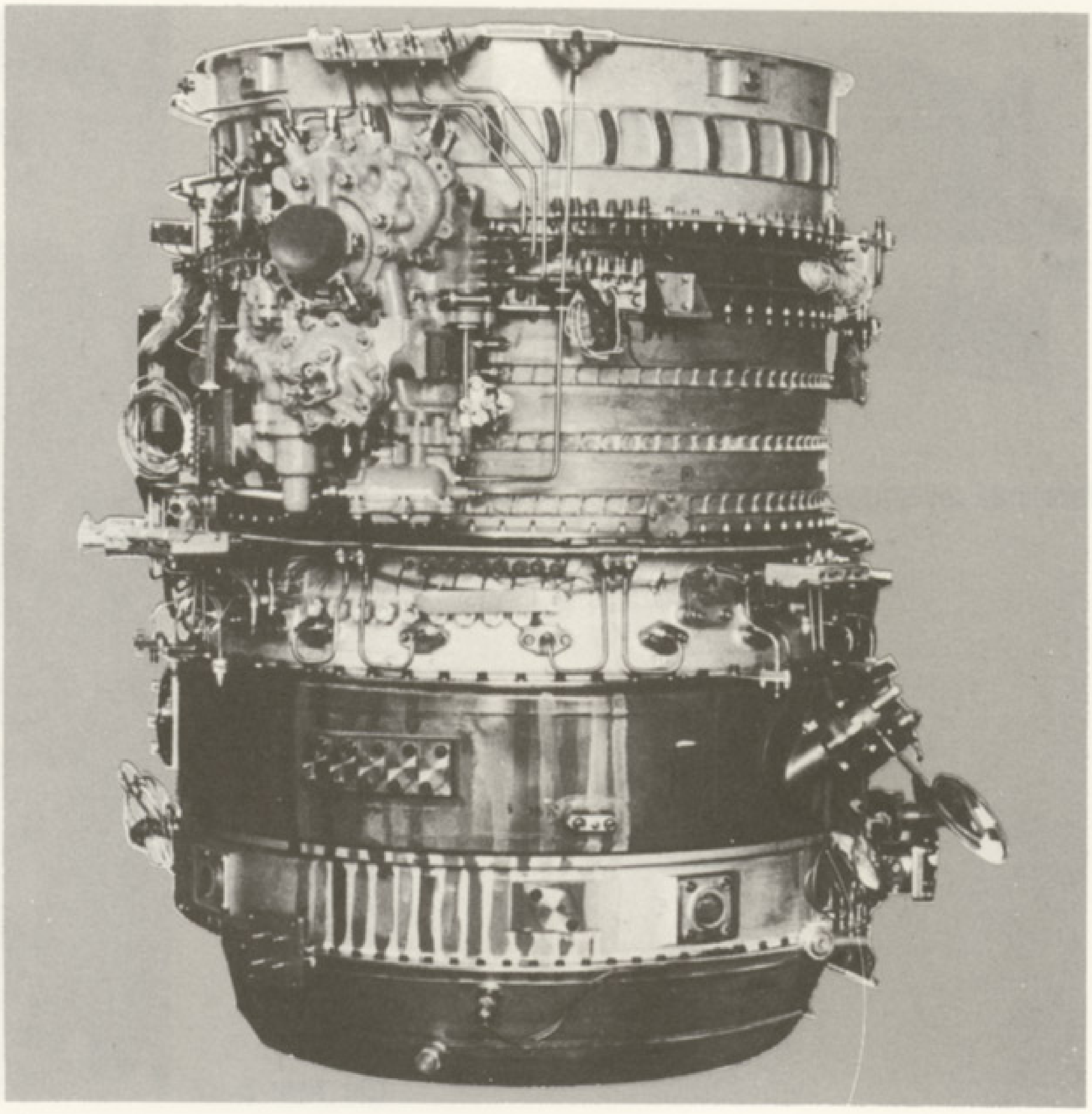
Experience

Engine type	Numbers built	Date of first run	Accumulated running time
RB193-12	13	Dec 1967	853 hrs

XJ99 lift engine



Internal arrangement



Description

The XJ99 was a third generation turbojet lift engine in the 9000 lb thrust class. The two-shaft design made use of high aerodynamic loadings and close-coupled components to minimise engine volume, and achieved a thrust-to-weight ratio of almost 20:1 by making extensive use of titanium in the manufacture of the major components.

The two shaft systems, which were contra-rotating to cancel out gyro couples, consisted of a two-stage LP and a four-stage HP compressor, driven by close-coupled single-stage turbines with no intermediate nozzle guide vanes. The combustion chamber was a short, small annular type. Lubrication was by a low-flow total loss oil system.

History

In 1965 the American and British Governments signed a Memorandum of Understanding for the design and development of an advanced lift engine for military use. The engine was to be known as the RA-XJ99, and grew out of work on an advanced lift engine designated RB189. This was a project based on the engine experience built up by Rolls-Royce on the RB108 and RB162 lift engines.

Design and development was conducted jointly by Rolls-Royce and Detroit Diesel Allison Division of General Motors Corporation.

The XJ99 was originally selected for a collaborative aircraft project between America and West Germany which was abandoned at an early stage. The engine development programme was then rearranged to demonstrate the viability of the engine cycle and its component technology.

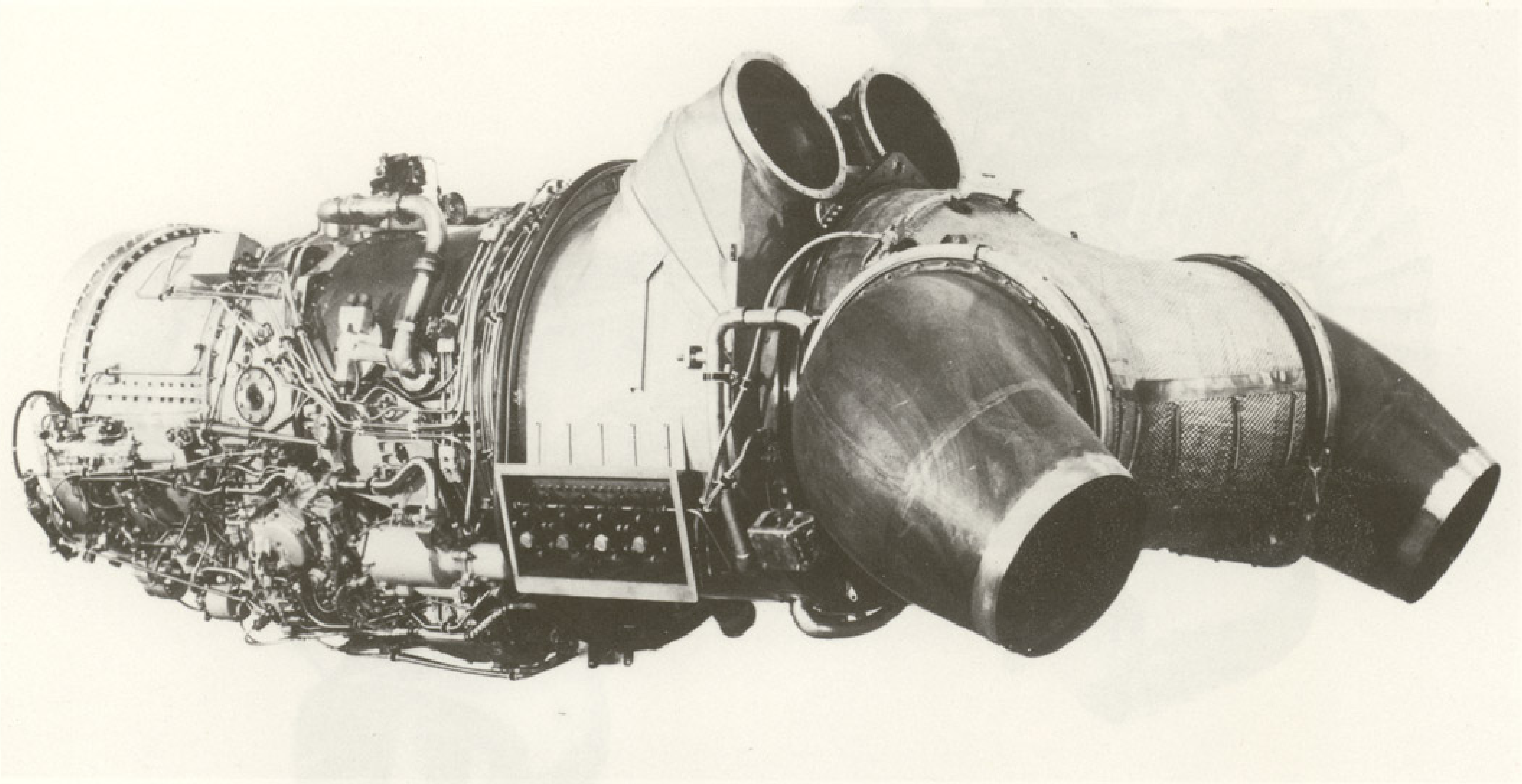
The objectives of the programme were successfully achieved and the engine demonstrated a specific thrust at a temperature and speed significantly less than the design values.

Three engines were built, the first one running in Derby in July 1968 and initiating the development programme which ran until May 1971. Two of the engines were tested by Rolls-Royce and one by Allison.

Experience

A total of 32 hours vertical test operation was accumulated.

Spey 801 split-flow engine



Description

The Spey 801 split-flow (801 SF) was a modified version of the Spey Mk 511 which powers the Gulfstream II and III aircraft.

The modifications carried out by Rolls-Royce of Canada to the Mk 511 to produce a Mk 801 SF included a new bypass duct to collect the fan air and direct it to two 13 inch diameter offtakes on top of the engine, and installation of a vectoring nozzle in place of the normal tail-pipe.

History

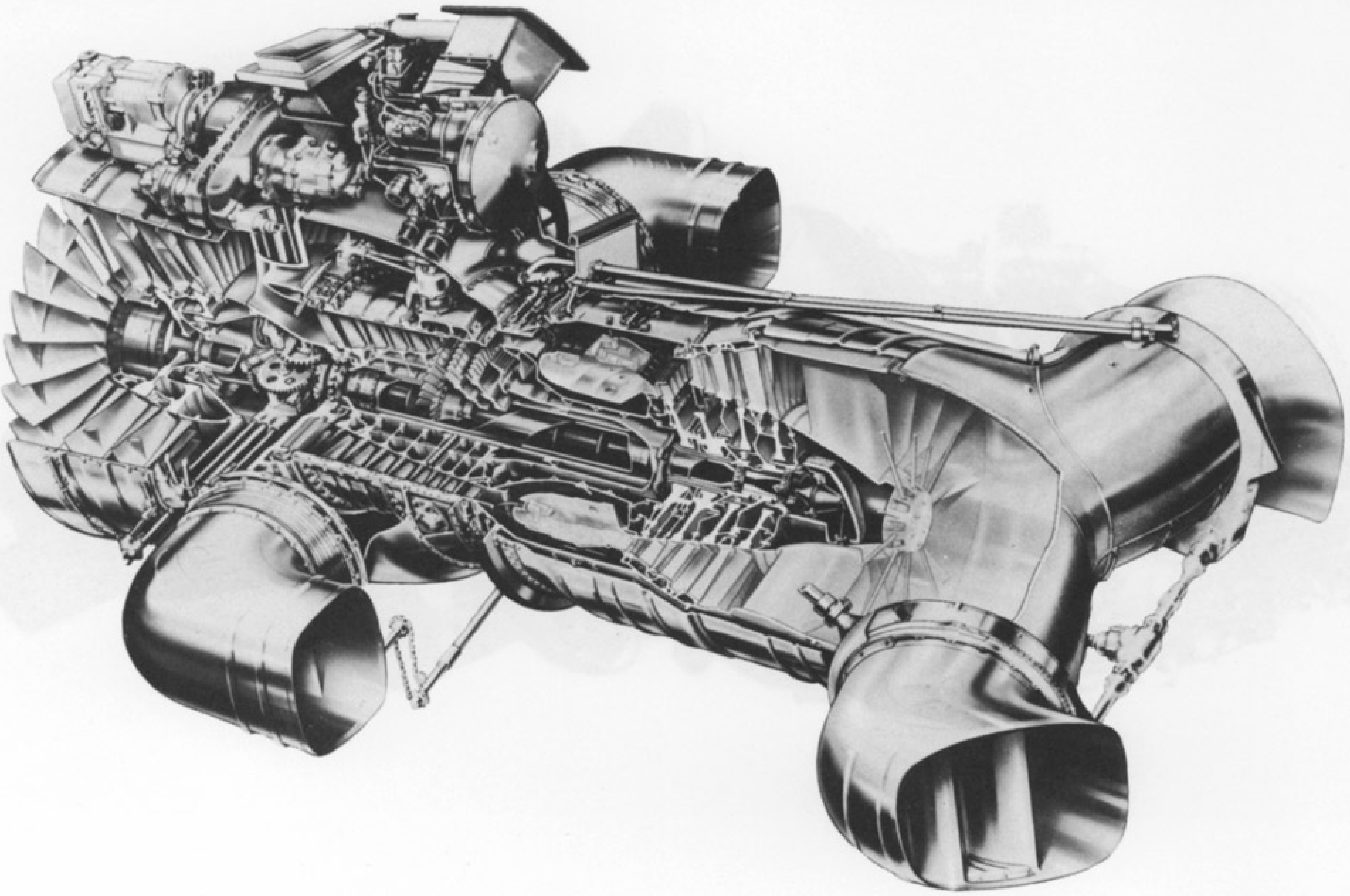
Only two Spey 801 SF engines were produced for the NASA/DITC (Department of Industry, Trade & Commerce) Buffalo augmentor wing aircraft. First flight was on 1 May 1972.

Further details covering this application are in Section 6 of this brochure.

Experience

After their first run in April 1971 the 2 engines were used in a 12 month flight test programme which achieved over 1000 hours experience.

Pegasus 11-21



Description

The Pegasus 11-21 is based on the Pegasus 11 but designed for enhanced reliability, durability and maintainability. The engine also offers improved performance.

The 11-21 features advanced developments which combine to give a high engine overhaul life and few unplanned engine removals:

A digital engine control system gives improved control over the Pegasus 11 allied with lower cost of ownership.

A new wide-chord first stage fan gives resonance free operation.

A new swan neck intermediate casing produces minimum airflow distortion and improved HP spool performance.

The zero scarf front nozzles have a high turning efficiency resulting in enhanced thrust. Their light construction in a nickel-based alloy gives long life and low maintenance.

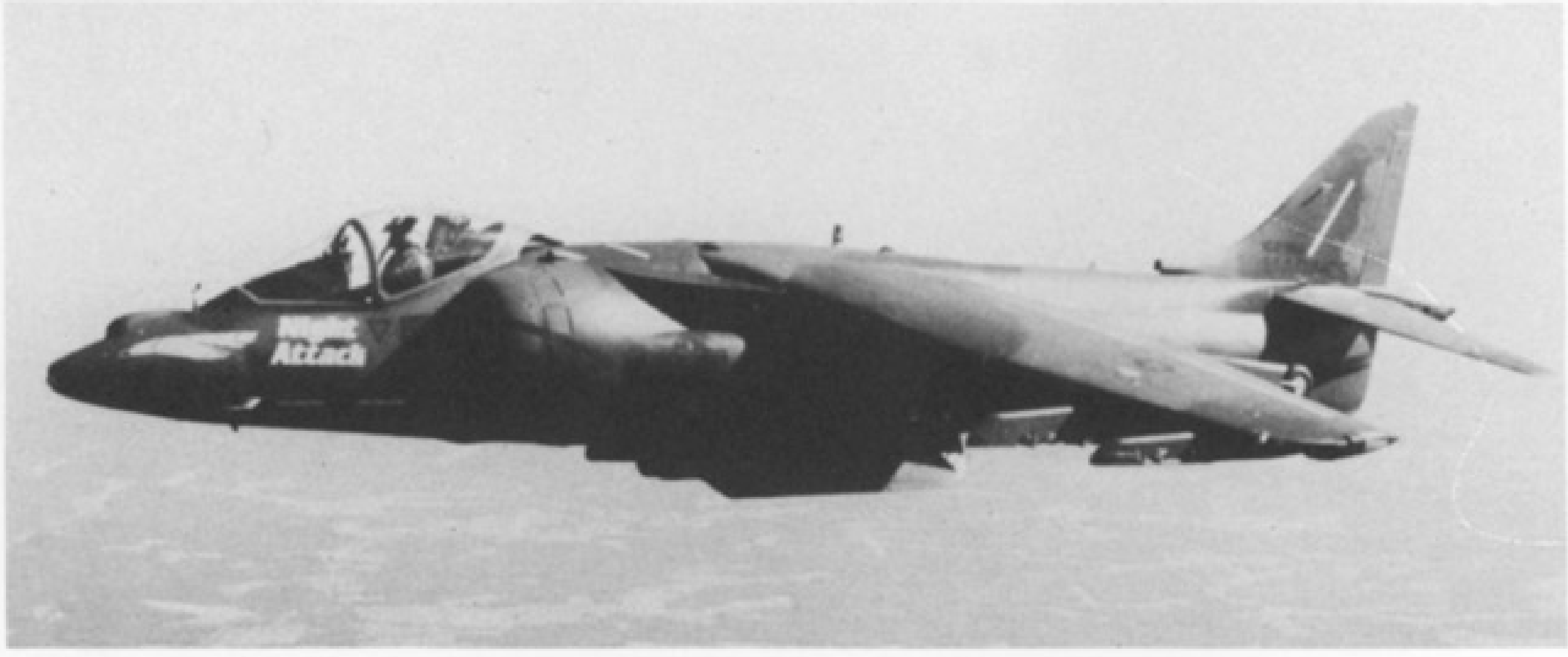
Experience

The 11-21 first ran on 24 September 1980 and entered service in November 1983 with the USMC. It is now also in service with the Royal Air Force and the Spanish Navy in their Harrier II aircraft.

The 11-21 engine series has also been adopted by the Royal Navy for use in Sea Harriers (FRS Mk 1).

Uprated Pegasus

XG-15 on test



Description

The uprated Pegasus is designated the 11-61 (F402-RR-408 by the US) and it will be flight tested in 1989 with production deliveries commencing in 1990.

This engine is a derivative of the 11-21 which will lead to improved combat effectiveness of the Harrier II and will provide scope for both airframe growth and role development.

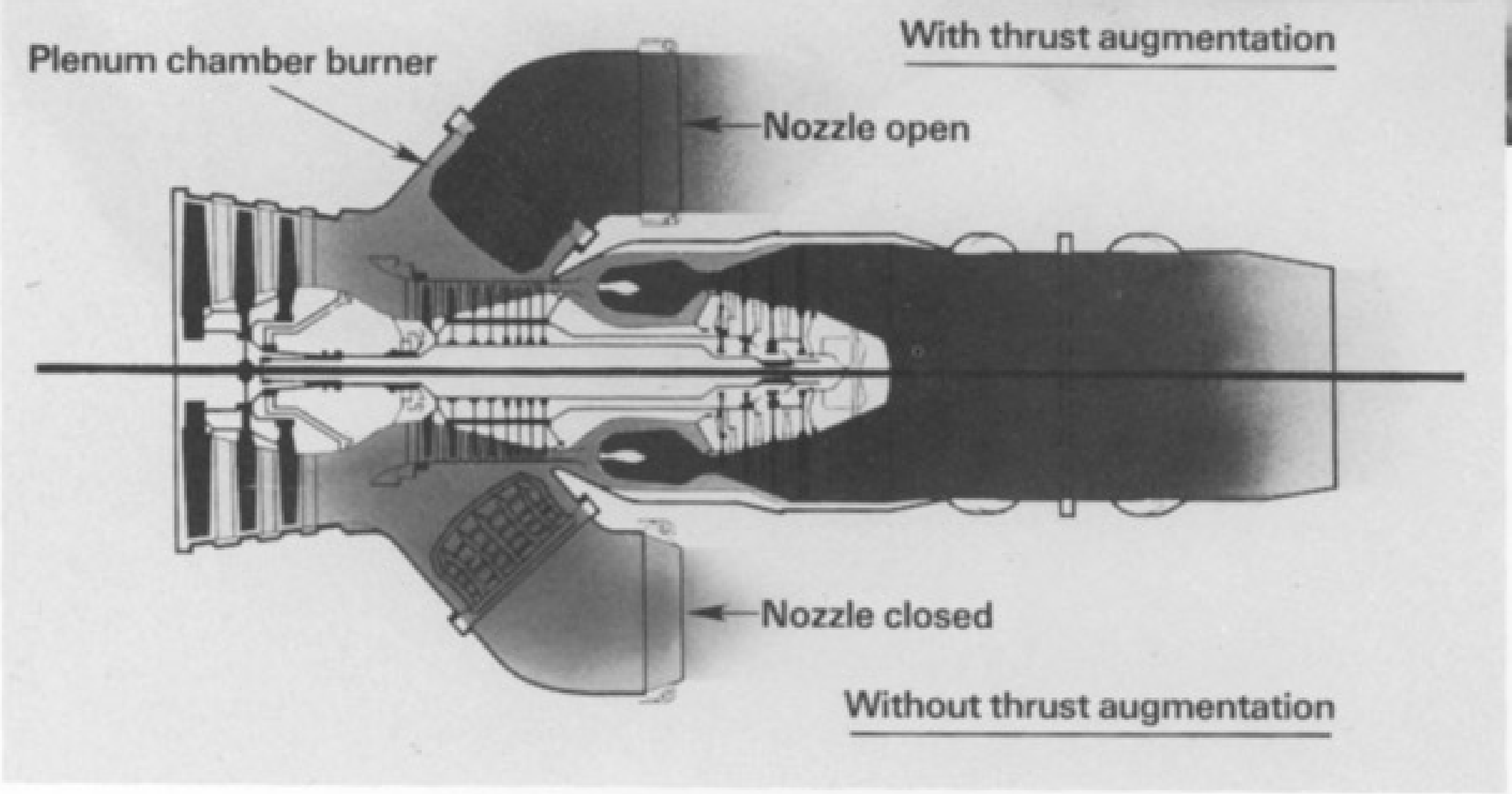
The 11-61 features an LP compressor with increased pressure ratio, turbines with increased temperature capability, a new geometry combustion chamber and is of modular construction.

Experience

New technology features of the 11-61 are based on experience gained from the XG-15 demonstrator programme. This programme, funded by the UK government and by Rolls-Royce, has included extensive component and module rig testing. A full demonstrator engine first ran on 22 October 1986 achieving all its preset performance objectives.

3 V/STOL engine technology

Plenum chamber burning



Description

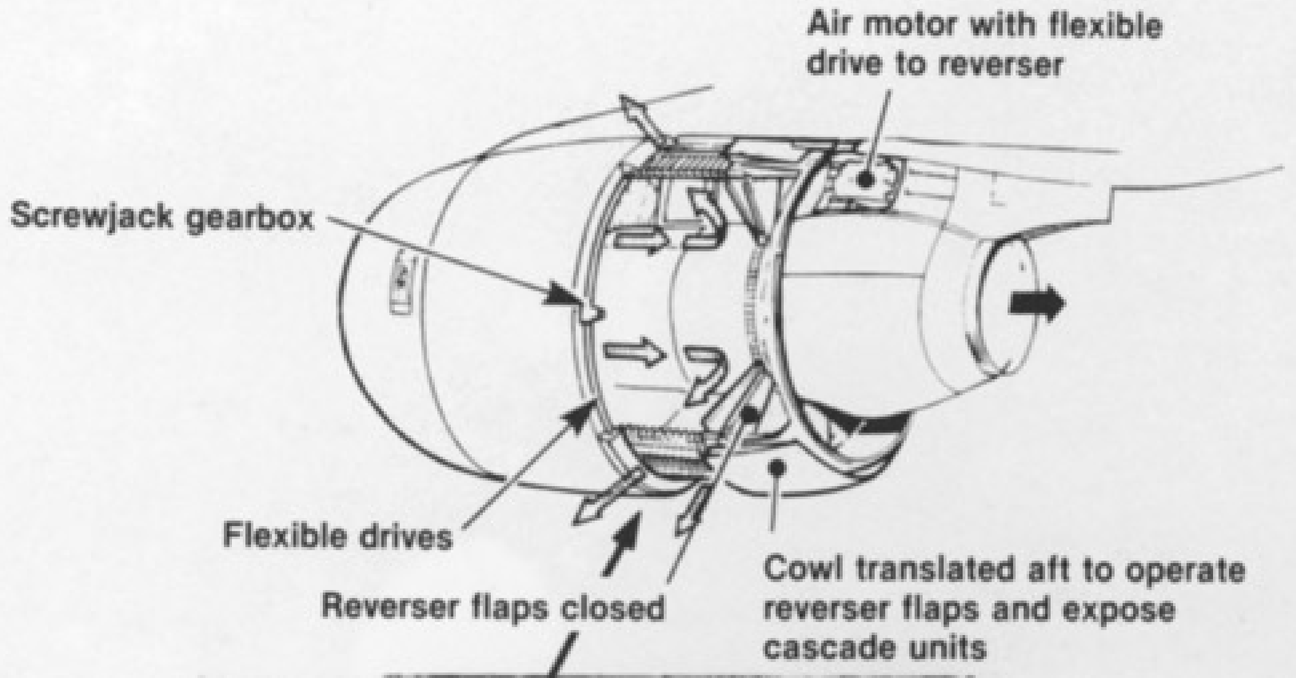
Plenum chamber burning (PCB) is one method of obtaining thrust augmentation necessary for supersonic flight and vertical take-off/landing. Fuel is burnt in the plenum chamber which supplies bypass air to the front nozzles on a separate flow vectored thrust turbofan engine like the Pegasus.

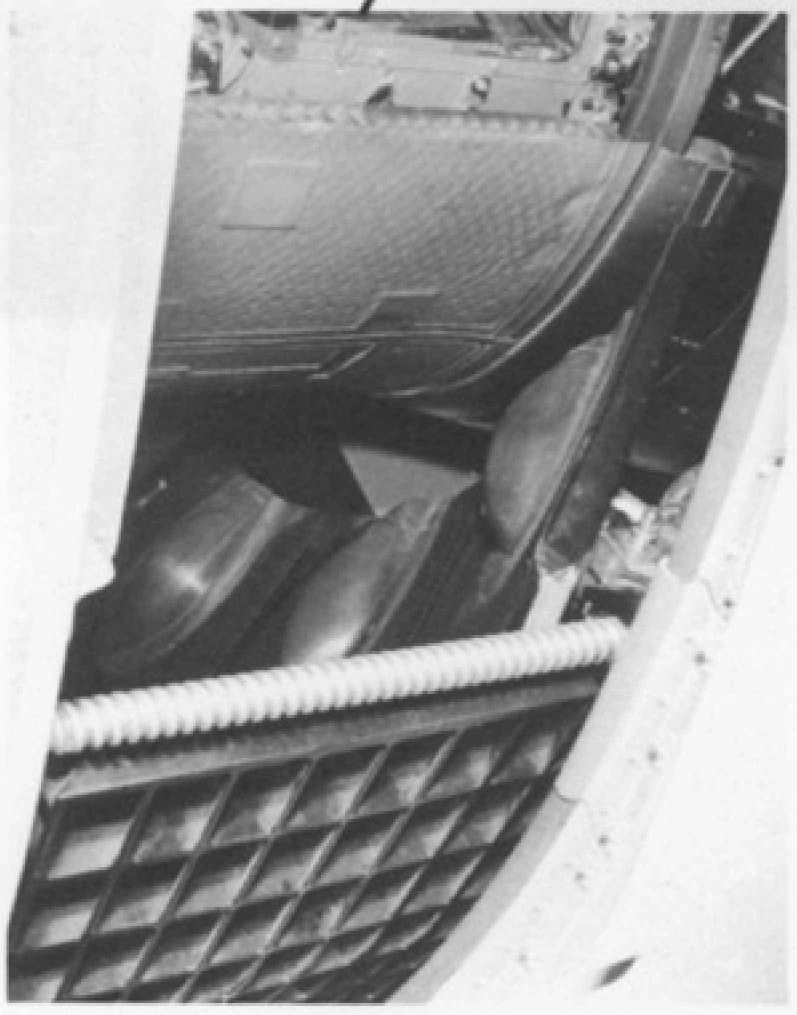
Experience

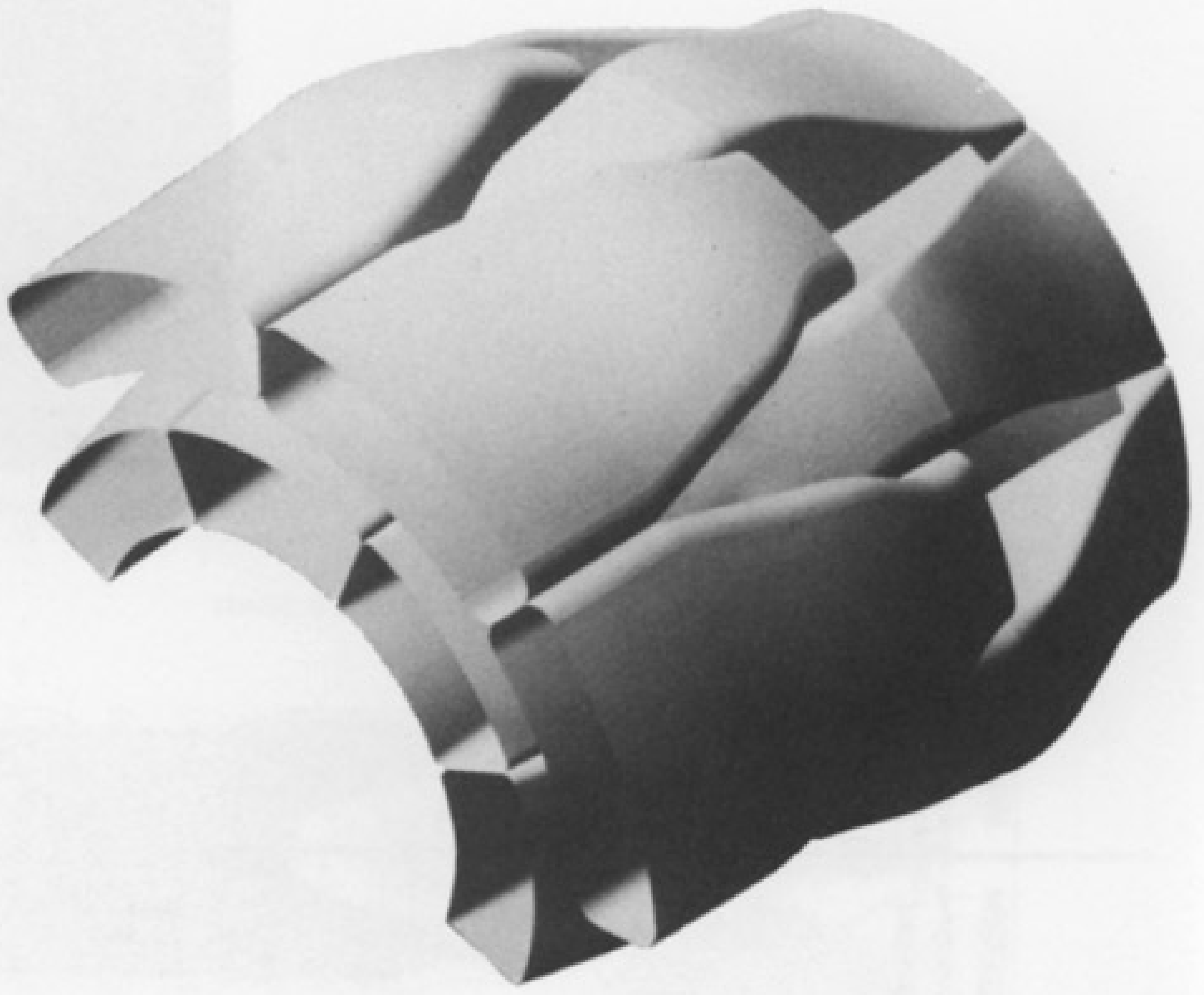
Early PCB testing was carried out on both BS100 and Pegasus 2 engines. More recent tests have been carried out on a Pegasus 2A engine at an open air facility at the Ministry of Defence Proof and Experimental Establishment at Shoeburyness in Essex, England. The tests included basic performance calibrations of the combustion system along with studies of the effect of intake distortion and water ingestion. Further tests were carried out on installation effects, ground erosion and noise trials. This work showed up the limitations of the low nozzle pressure ratio and the fixed nozzle area. Consequently it was decided to continue the PCB studies on a Pegasus 11 engine. Bench testing of this configuration started in 1985.

The most recent testing involved a Pegasus 11 equipped with variable area nozzles installed in a Harrier airframe. This commenced on 29 October 1987. Hot gas reingestion data is being gathered to supplement the nozzle temperature profiles already obtained; this data will be used in the design of future ASTOVL configurations.

Valves







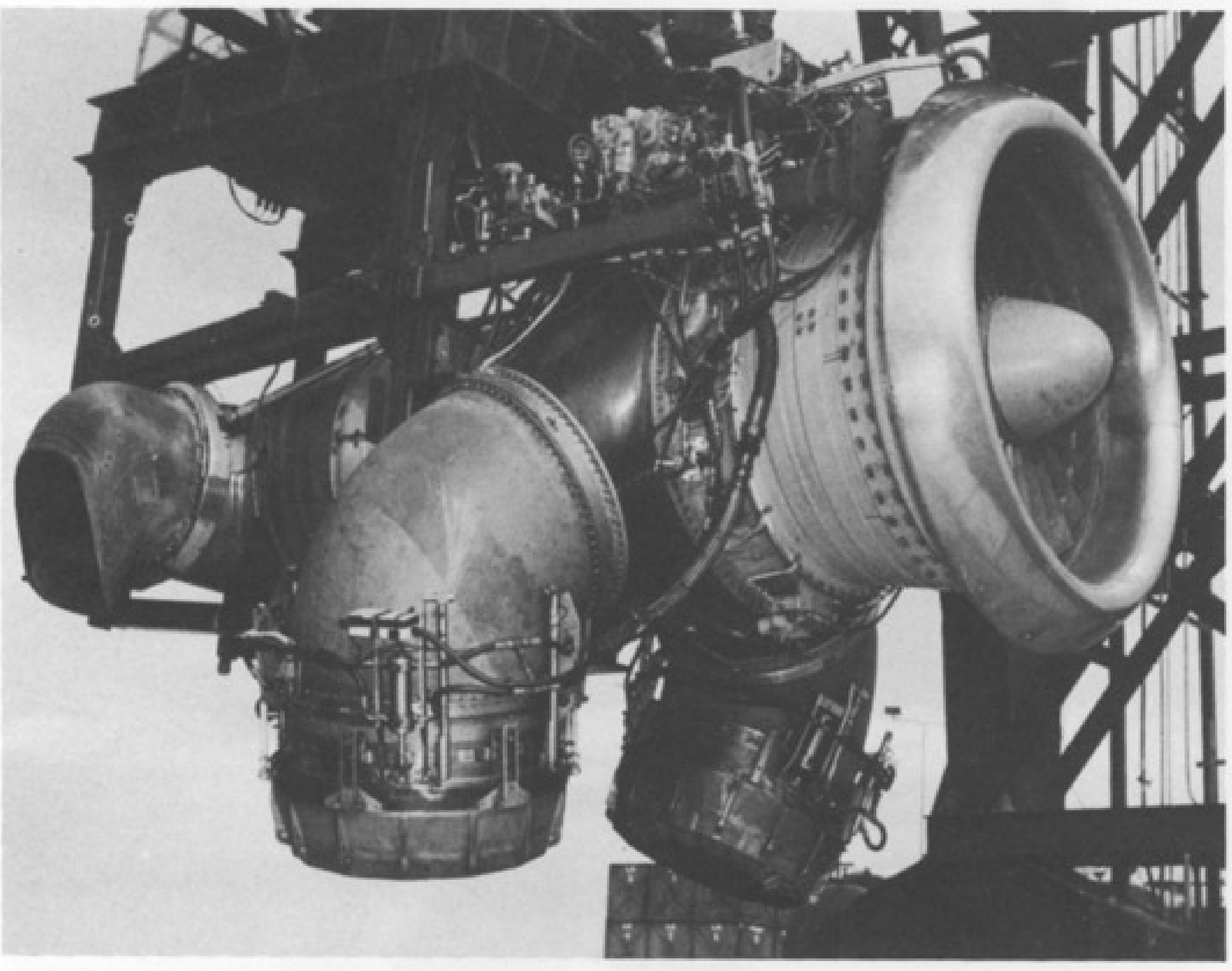
Changeover valves

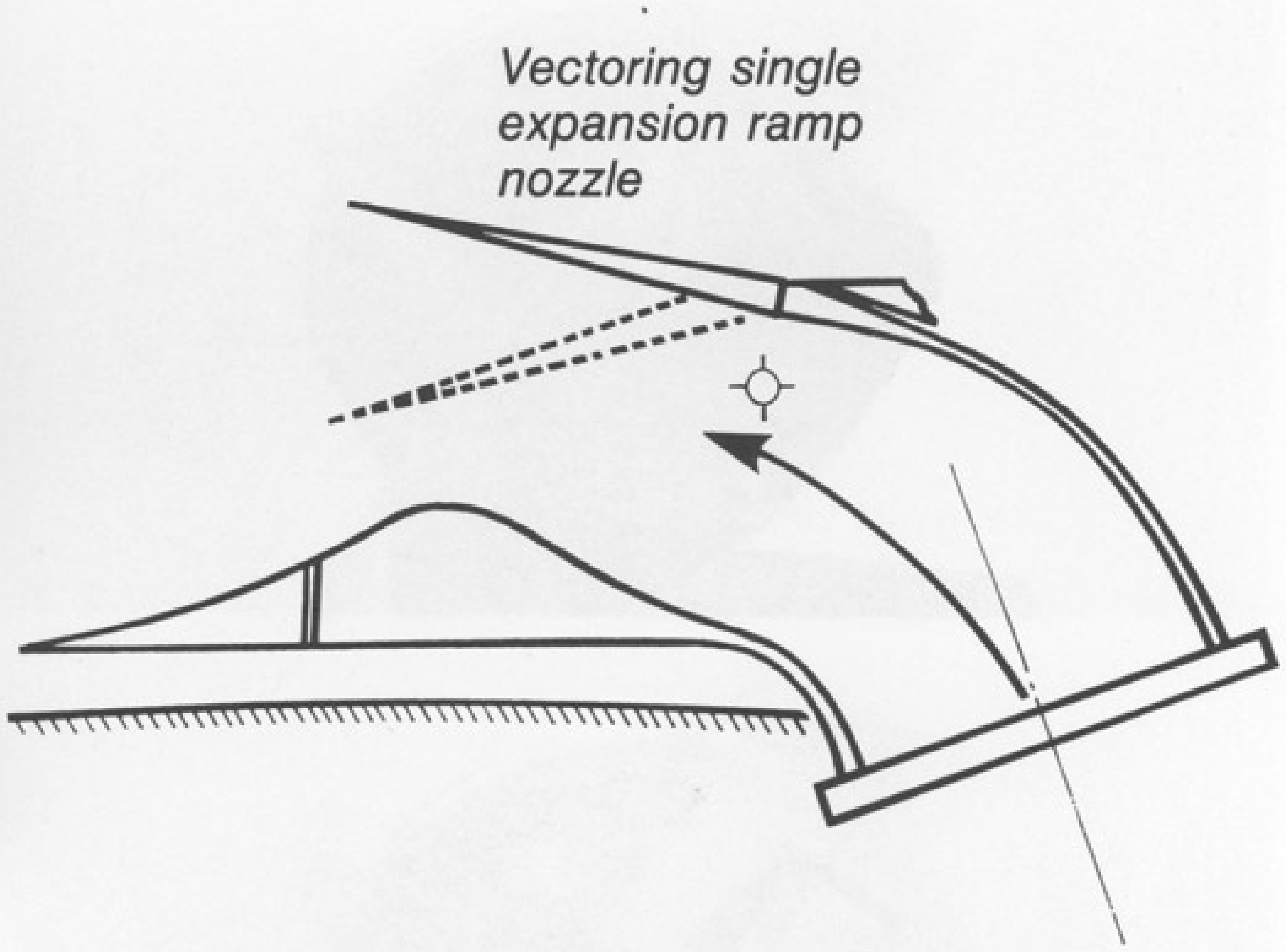
Changeover valves are a requirement of several of the V/STOL engine concepts including the Tandem fan (detailed in Section 7 of this brochure) which are being considered for future ASTOVL applications. Rolls-Royce have carried out design studies on changeover valves to suit a wide range of options but particularly for high fan pressure ratios.

Future ASTOVL concepts create the requirement to divert bypass air to remote lift systems; one method of obtaining this is to use a system based on the civil engine bypass thrust reverser system with which Rolls-Royce has considerable experience in the form of the RB211.

Another such arrangement consists of two elements; the front fixed and the rear moving. Two sets of passageways in each part of the valve match at a common interface. The passageways in the front part feed either to the rear fan or to the front nozzle plenum. Thus, by rotating the rear part one pitch the flow can be switched so that the front fan either delivers to the plenum (parallel mode) or to the rear fan (series mode) while the auxiliary intake at the same time feeds to the rear fan and plenum respectively.

Exhaust systems





Nozzles

Rolls-Royce is conducting development work on nozzles for supersonic combat, medium speed and transport aircraft. This work includes a variety of nozzle rig tests which help to provide a database of information on axisymmetric nozzles, ramp nozzles and convergent-divergent nozzles.

Clearly in the design of an advanced STOVL aircraft the nozzle design and configuration are critical. The landing phase is the critical STOL phase for aircraft force and moment balance and the nozzle design needs to take account of this.

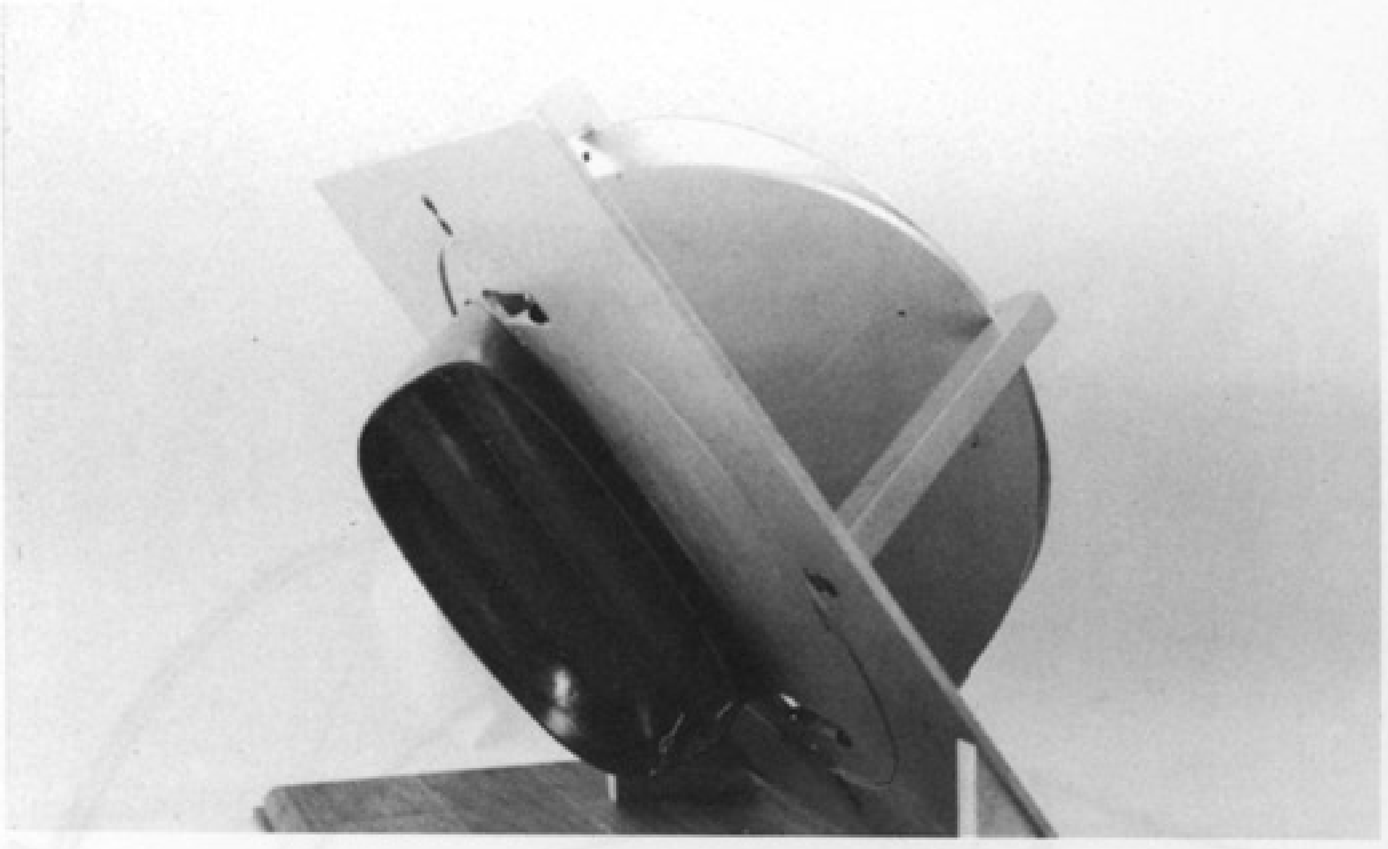
Several types of variable area nozzle are under consideration including:

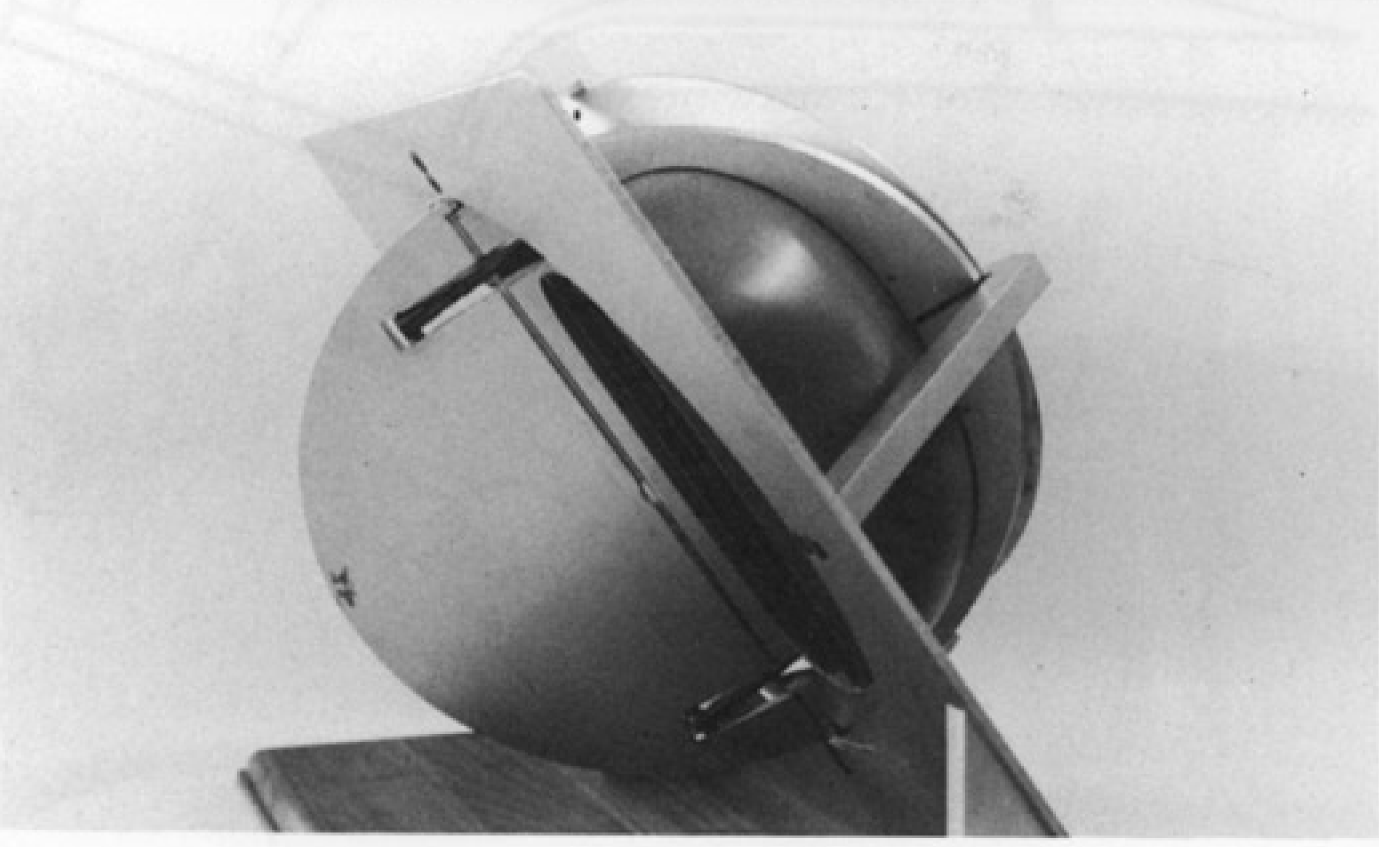
— Simple axisymmetric side nozzle
— Vectoring single expansion ramp nozzle (VSERN)

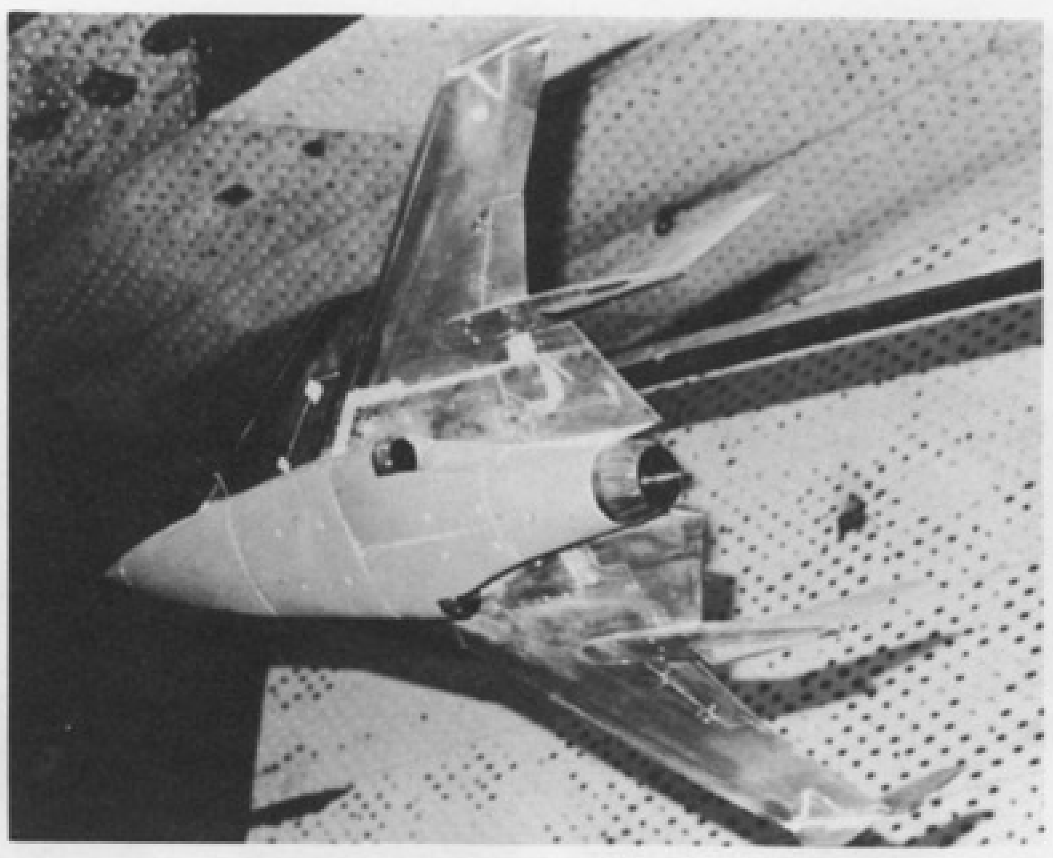
The VSERN is non-axisymmetric and provides some degree of convergent-divergent thrust.

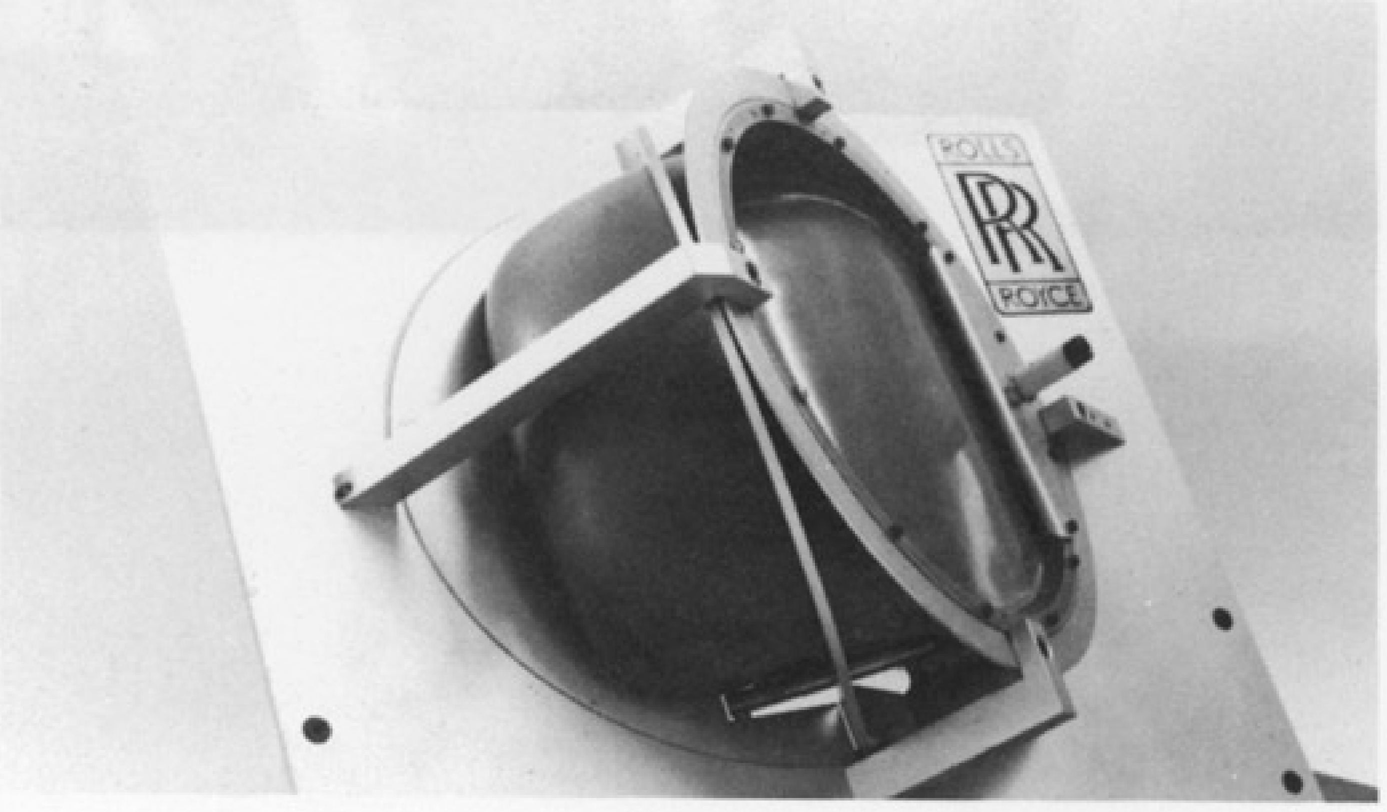
— Vectoring convergent-divergent nozzle either in 2-D form or axisymmetric.

Exhaust systems









STOL exhaust nozzle test

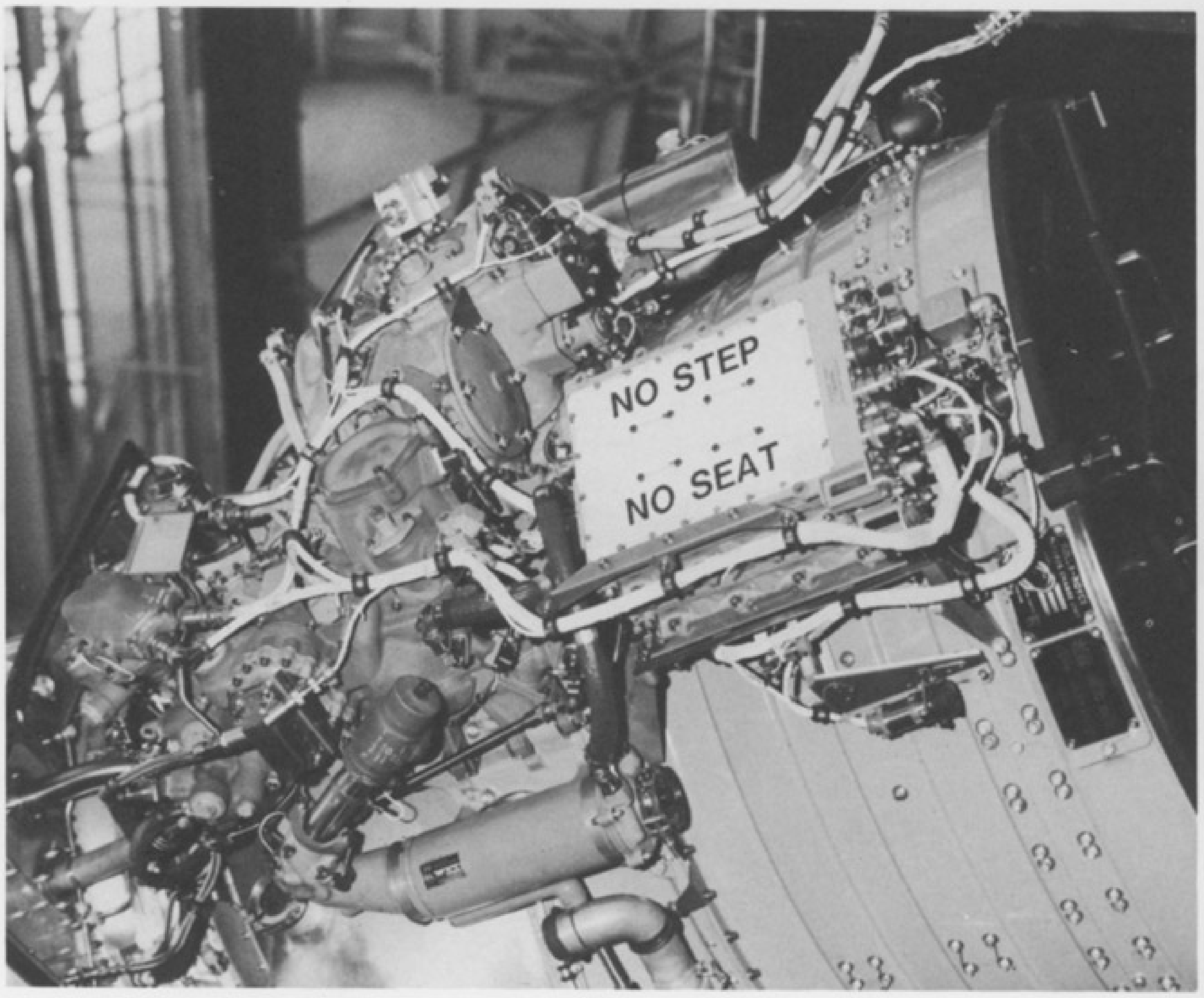
Many studies have been carried out on both STOL and V/STOL nozzle systems under various R&D contracts and under Rolls-Royce funding. Typical of these studies was a STOL exhaust nozzle (STOLEN) study where various configurations were tested. They were tested on the modified Rockwell HIMAT (highly manoeuvrable aircraft technology) model in the 16 foot transonic wind tunnel at the Arnold Engineering Development Center, Tullahoma, Tennessee.

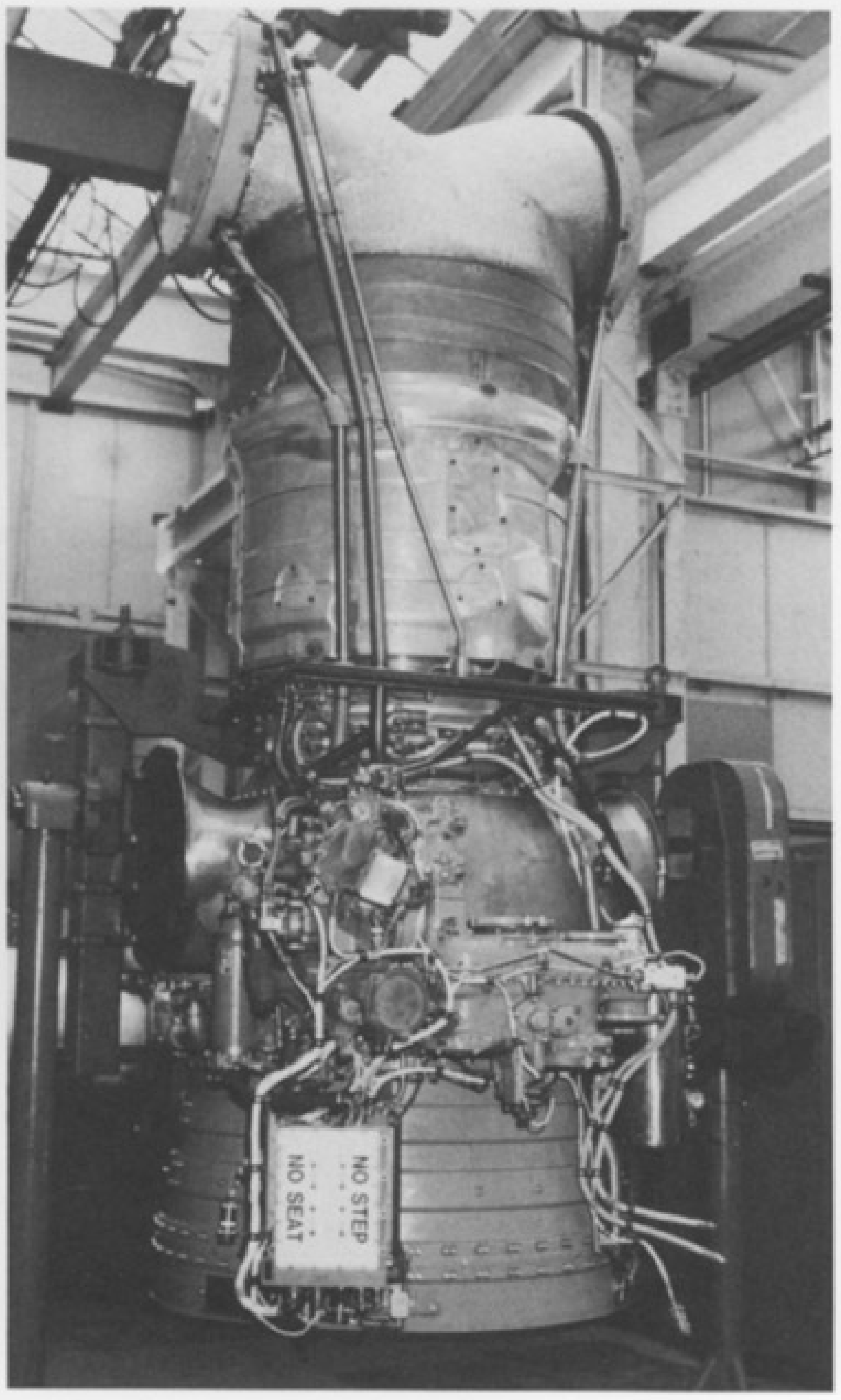
Phase 1 of the STOLEN concepts programme developed and evaluated a number of vectoring nozzle concepts and their integration into advanced tactical aircraft configurations to achieve short-field performance.

The second phase commenced with the internal performance evaluation of sub-scale models of the vectoring nozzle concepts of NASA Langley Research Center, Virginia.

The photographs above show a model of a retractable vectoring nozzle which was designed by Rolls-Royce as part of other studies into future V/STOL requirements.

Controls





First Pegasus with DECS

Pegasus Digital Engine Control System (DECS)

The latest production version of the Pegasus, the 11-21, is fitted with a digital engine control system.

DECS is a closed loop system designed to produce more accurate engine control. Maintenance is reduced by the elimination of in-service adjustors, their fuction has been programmed into the control unit which both improves controlability and reduces weight. The DECS has a comprehensive built-in test facility which makes fault diagnosis quick and easy. The system also reduces pilot workload.

The DECS features combine to produce an overall reduction in the cost of ownership. It has hydromechanical components and duplicated digital engine control units. A back-up manual fuel control system is provided to give added confidence in a single-engine installation.

Controls

VAAC Harrier

VAAC

Vectored thrust aircraft advanced flight control (VAAC) is a digital fly-by-wire flight control system.

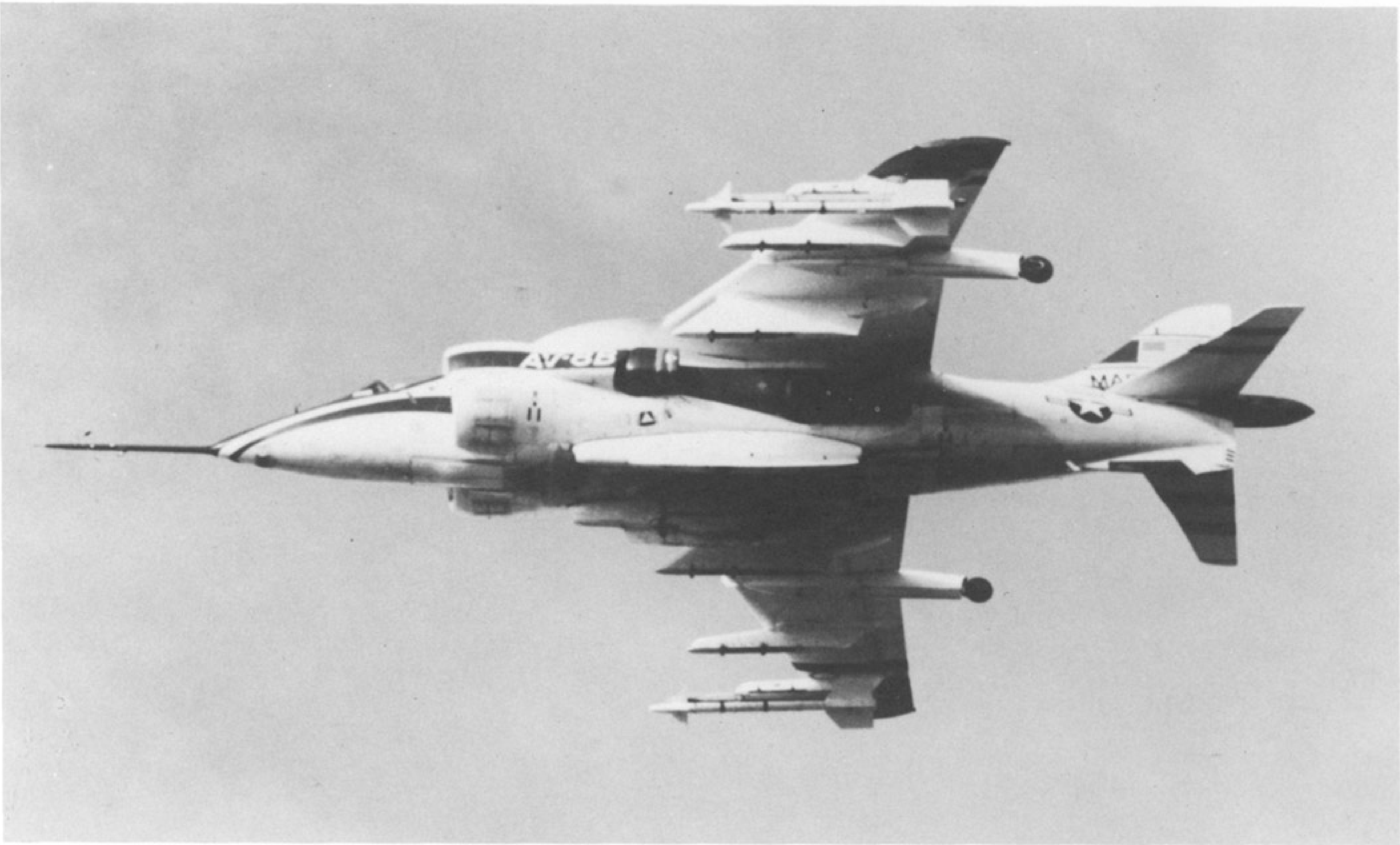
An ambitious evaluation programme is continuing at the Royal Aircraft Establishment Bedford in the UK to test control concepts for British Aerospace's advanced vectored-thrust designs including an all-digital supersonic Harrier.

The VAAC Harrier first flew in September 1986 and it has achieved over 50 flights.

Using the VAAC system, aircraft control movements are sensed by transducers, the signals are then processed by a single digital computer. Full authority control of the throttle and nozzles is exercised via servos driving the existing mechanical inputs.

The VAAC system is capable of control system monitoring. New flight modes can easily be programmed into the computer. It will enable the simulation of new concepts such as a Harrier with PCB, the remote augmented lift system and the Hybrid tandem fan.

Controls



Vertical systems research aircraft

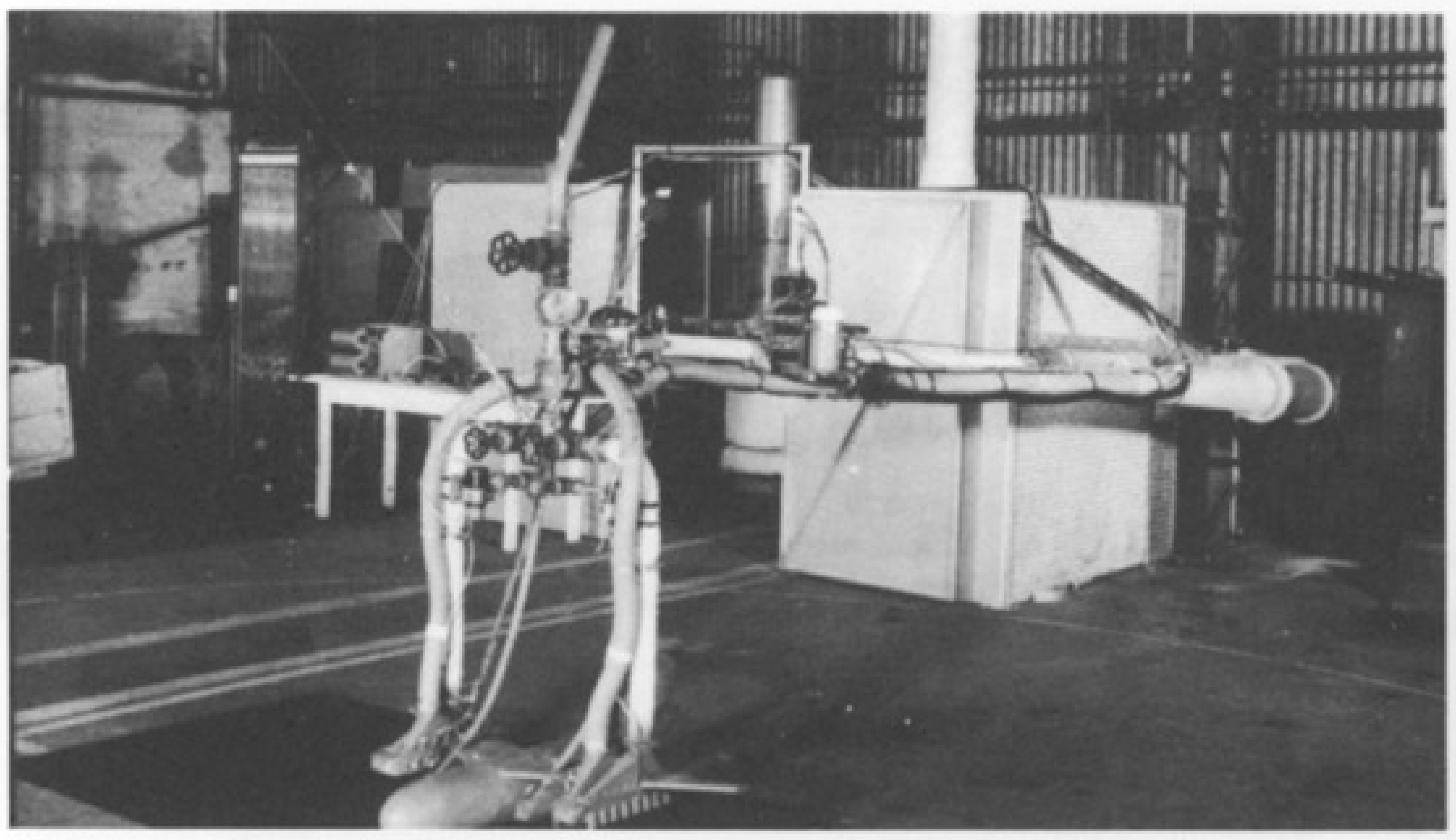
This is a flight research programme conceived and controlled by NASA Ames with participation by Rolls-Royce. Its purpose is to understand the features of Naval V/STOL aircraft which are important in the take-off and landing flight phases. Of particular interest is the reduction of reaction control bleed requirements and a study on their effects on the engine.

The vertical systems research aircraft is the remaining YAV-8B with modifications incorporated by NASA for the research programme. The aircraft was delivered to NASA on 7 April 1984 and first flew on 26 August 1985.

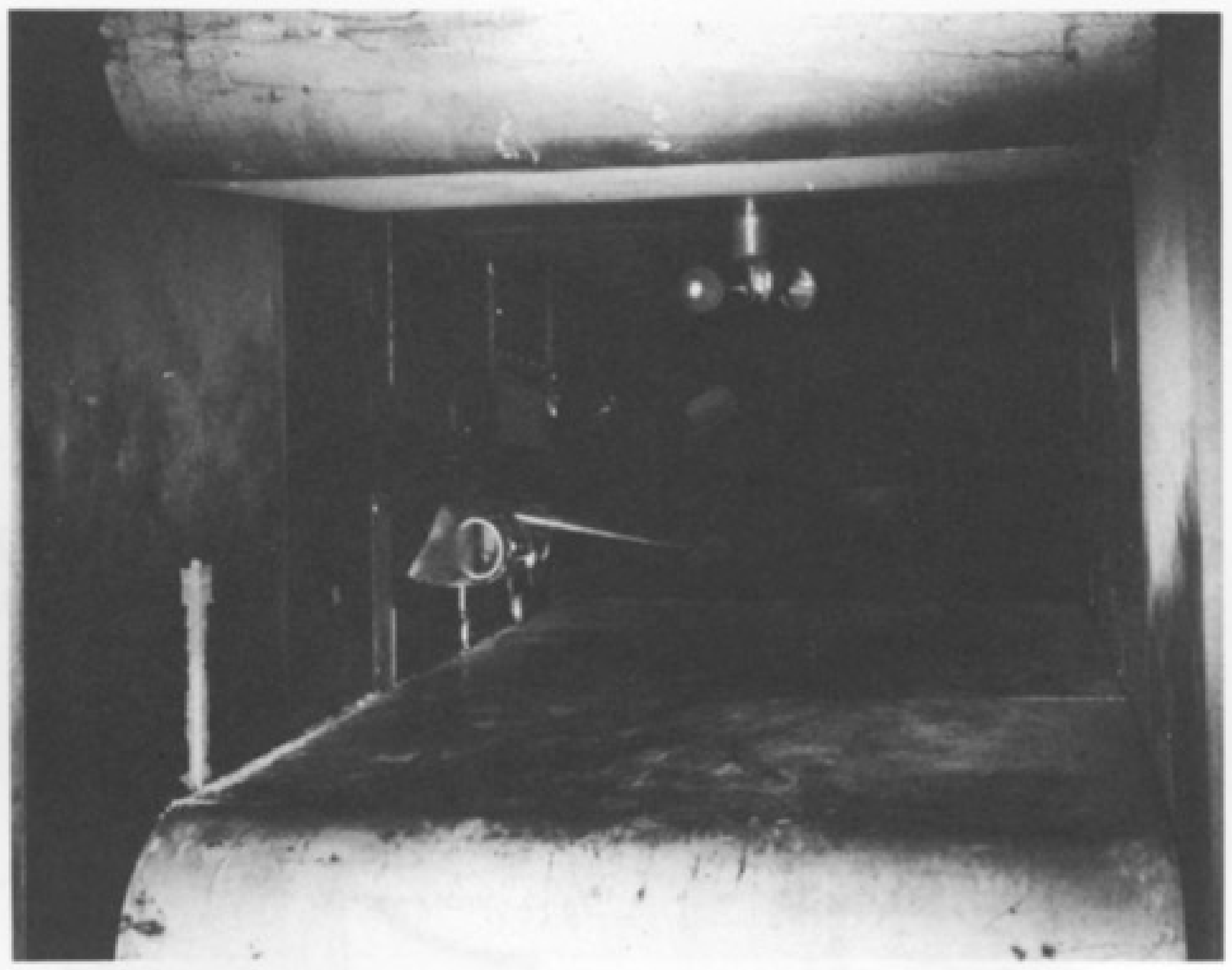
The programme is quantifying the interaction between the operational requirements (e g landing in a confined area, at sea, in bad weather) and the configuration of the aircraft. This will not only benefit potential naval versions of the AV-8B (and the Sea Harrier) but it will also provide a background of experience for a future advanced supersonic aircraft.

5 V/STOL engine applications – rigs

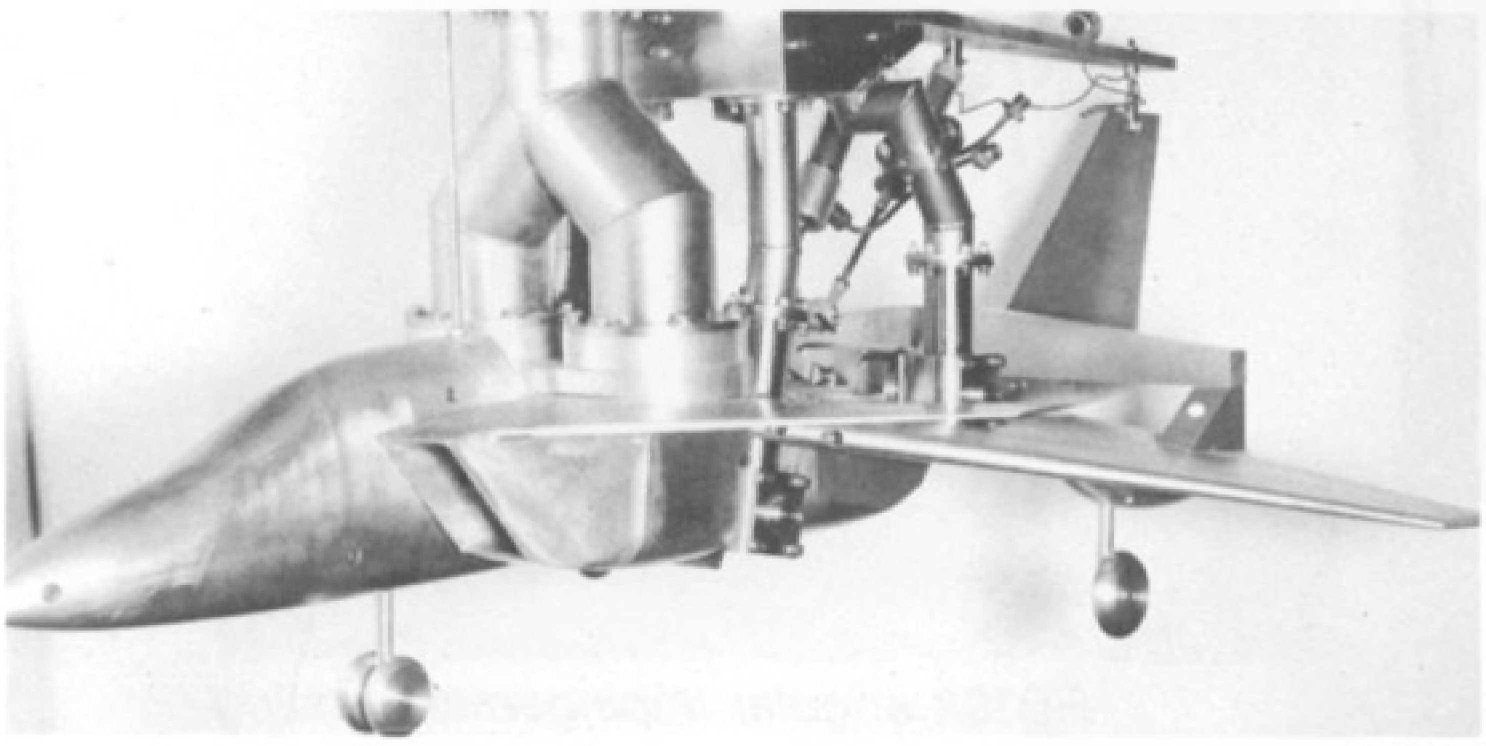
Hot gas recirculation rigs



VTOL transport model under test at Hucknall



Harrier model under test at Bristol



Location

Hucknall, Nottinghamshire (recirculation rig)
Bristol, Avon (reingestion tunnel)

Description

The Hucknall rig is used for the investigation of ground proximity flow effects on aircraft by means of model tests. The rig can be supplied with air of temperatures up to 250°C and steam can be mixed with the air for flow visualisation. During V/STOL testing, up to eight lift engines and two propulsion engines could be represented at the required pressure ratios in models of up to 1/10 scale for fighter aircraft or 1/20 scale for large transport aircraft. Intake suction and crosswind conditions can be represented with the aircraft at varying heights above the ground.

The Bristol reingestion facility is an open circuit tunnel which can accommodate aircraft models up to about half-scale with representative intake and nozzle flows. High speed temperature and pressure scanning of the test intake is normally used in addition to flow visualisation techniques.

Experience

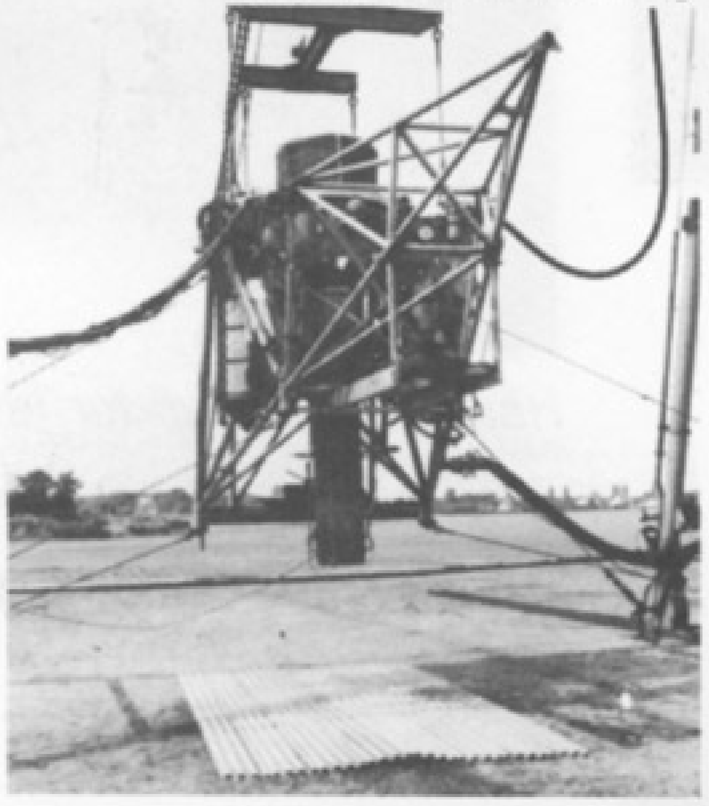
In addition to basic research into near- and far-field hot gas recirculation, Rolls-Royce has carried out general test programmes aimed at establishing, for both V/STOL strike/fighters and V/STOL transports, the relationship between hot gas recirculation characteristics and choice of airframe and powerplant configuration. Specific test programmes in support of the Mirage III-V, Dornier Do31 and Harrier aircraft were conducted. Model to full-scale correlation was successfully achieved.

Further model testing carried out is to define hot gas reingestion scaling laws by reproducing the full-scale work at Shoeburyness on PCB.

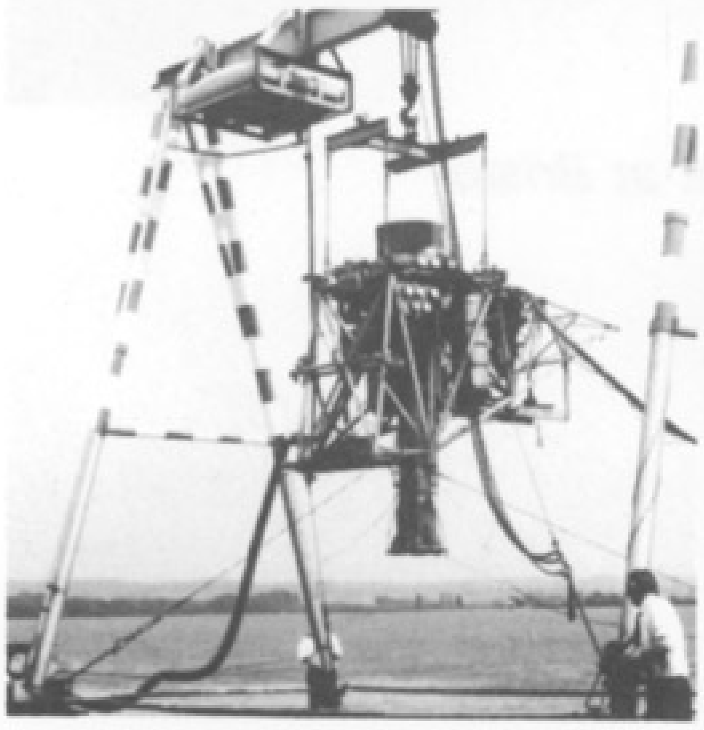
Ground erosion test rigs

Reheated Avon erosion rig

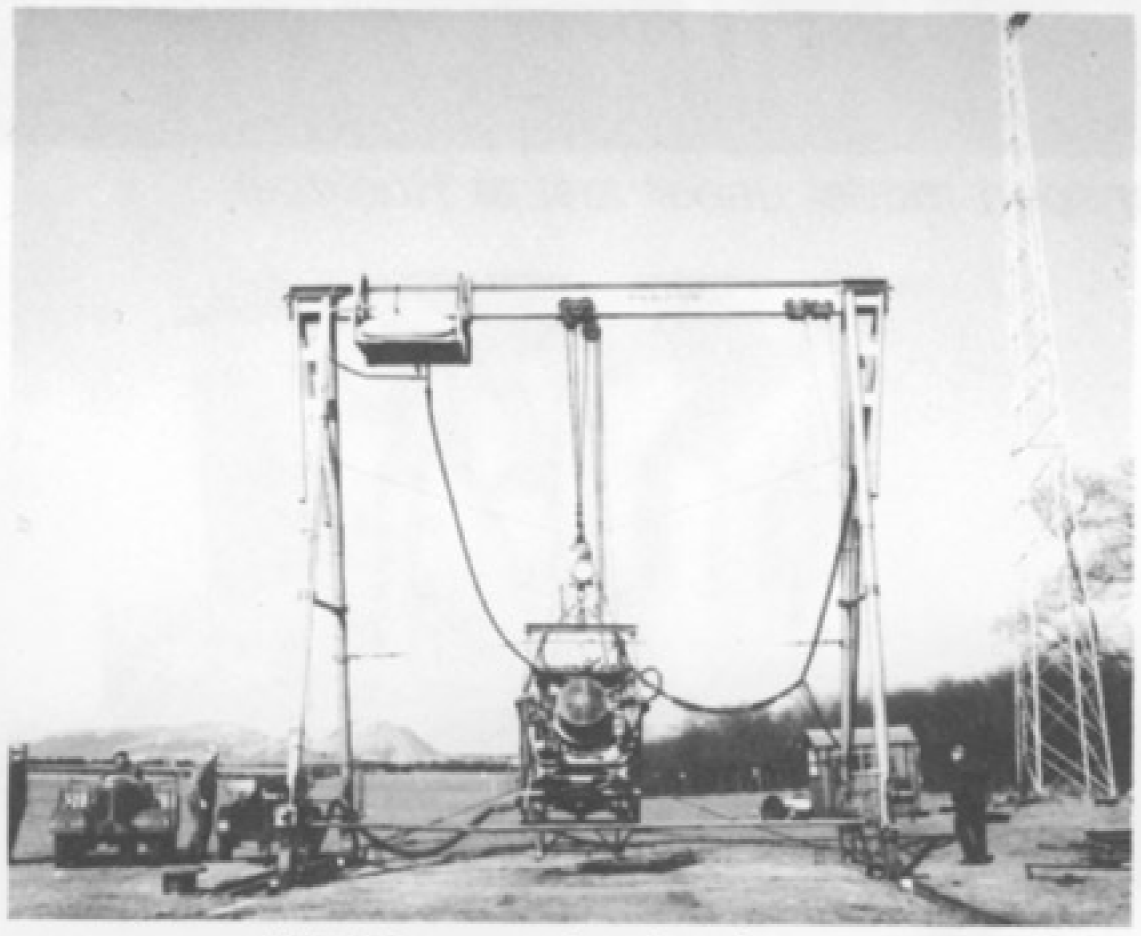
RB108 exhaust visualisation testing



RB108 testing over aluminium planking



RB108 at full thrust over grassland



RB108 angular impingement testing

Location

Hucknall, Nottinghamshire

Description

Any system deriving lift from air or gas emitted vertically downwards will tend to disturb unprepared surfaces. To investigate the magnitude of this problem and ways of alleviating it a rig was designed which consisted basically of an engine suspended vertically in a gantry. The height of the engine above the test surface, its angle to the vertical and the engine thrust setting were all variable. In addition, the whole gantry was made sufficiently mobile to enable it to be moved from one test surface to another.

Early work was carried out using an RB108 engine and testing, which commenced by finding the optimum concrete mix for building permanent VTOL bases, soon turned to an investigation of various materials, such as lightweight aluminium planking or hardboard, for rapid VTOL site preparation. However, the main bulk of RB108 testing was conducted over completely unprepared grass pastureland.

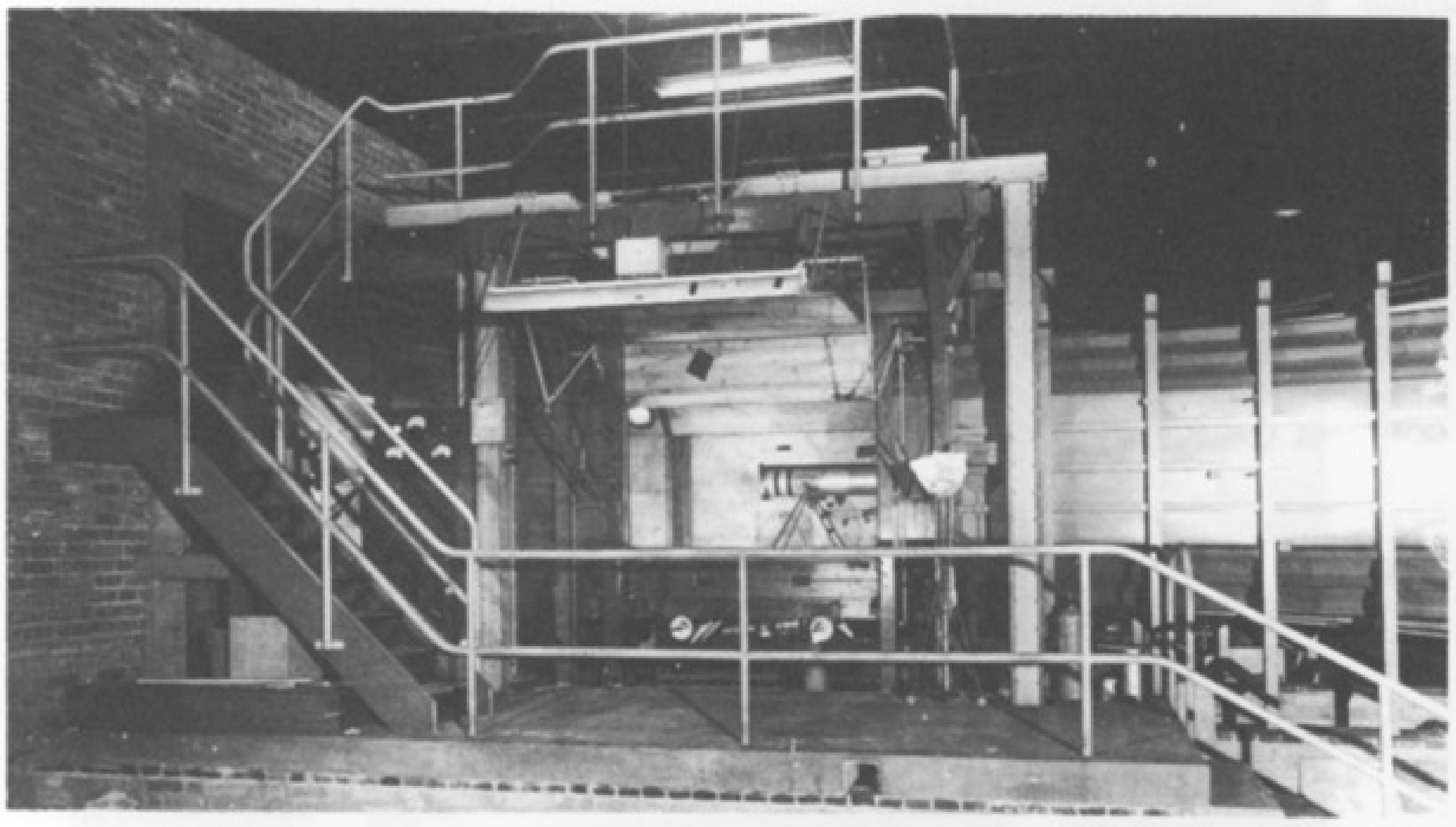
In order to represent more accurately advanced lift engines with their increased exhaust pressure ratios and considerably higher exhaust gas temperatures, the rig was eventually modified to use a vertically-mounted reheated Avon engine. This gave independent control of exhaust pressure and temperature.

As well as ground erosion testing, both the RB108 and Avon rigs were used to investigate debris scatter, hot gas recirculation, ground impingement pressures, temperatures and noise levels. These rigs were also used to develop a range of multi-exit, low thrust loss, rapid mixing nozzles.

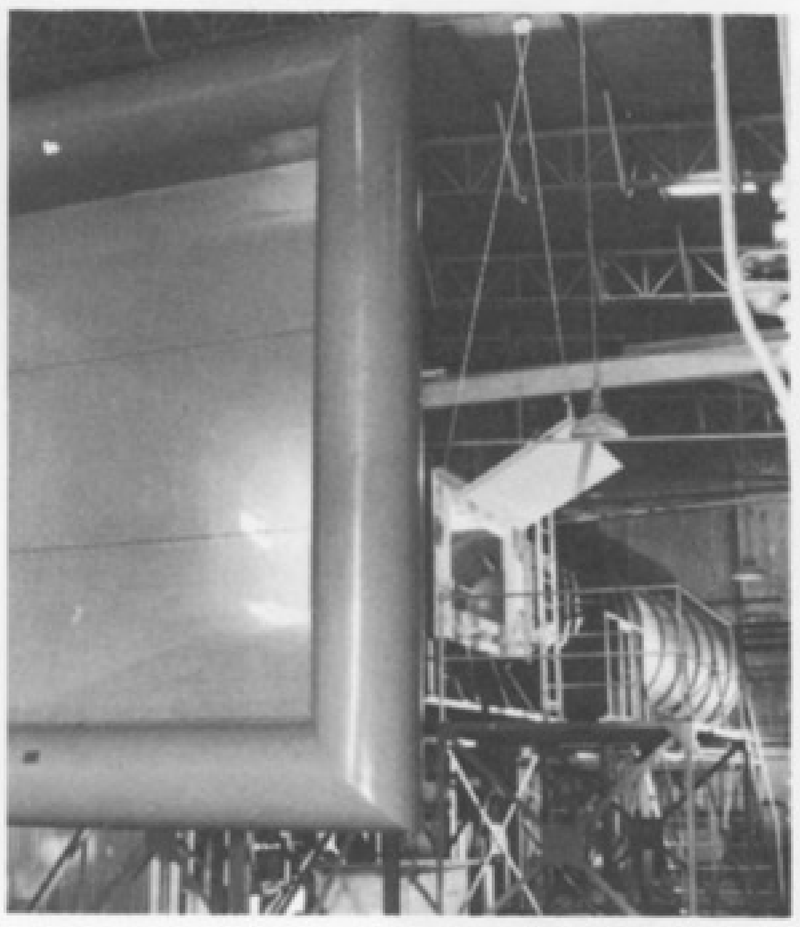
Experience

Test engine	Summary of completed testing		Total engine running time	Total number of engine operations
RB108	Concrete	November 1960	65 hrs	1100
	Grassland	December 1960		
	Aluminium planking	June 1963		
	Debris scatter	October 1964		
	Twelve-outlet nozzle	November 1965		
Re-heated Avon	Grassland	August 1966	7 hrs	144
	Nine-outlet nozzle	November 1966		
	Ground pressure survey	March 1967		
	Near-field noise testing	July 1967		

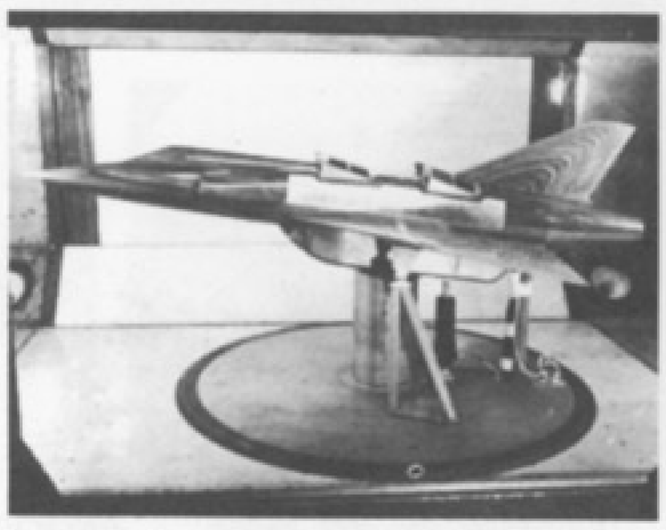
Low-speed wind tunnels



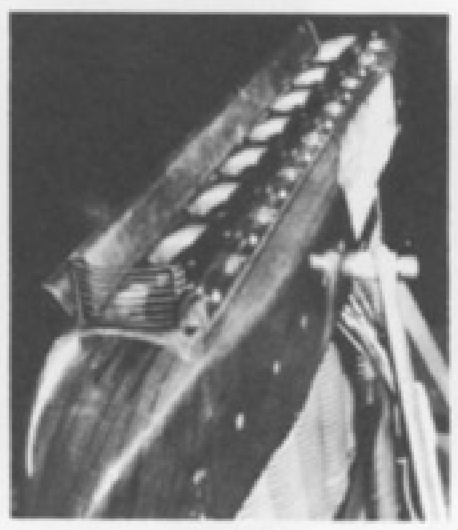
Hucknall tunnel



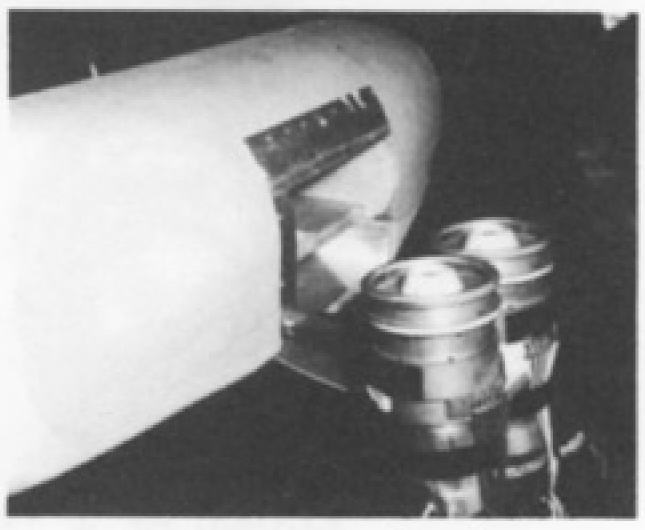
Bristol tunnel



Mirage III-V model



Model of transport aircraft lift pod



Swing-out lift engine model

Locations

Hucknall, Nottinghamshire
Bristol, Avon

Description

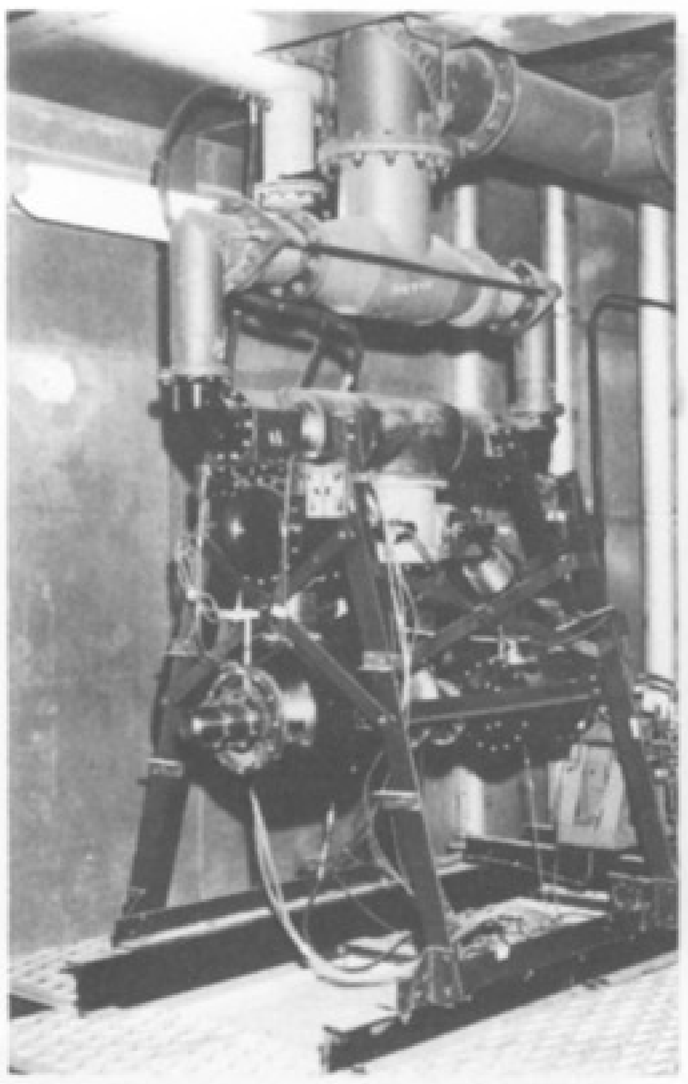
The wind tunnel at Hucknall has a working section of 7ft x 5ft cross section with a four-bladed fan driven by a 75hp electric motor giving speeds up to 120 ft/sec. Intake flow is drawn through the intake measuring sections by a fan mounted beneath the tunnel floor. Sufficient power is available to test an eight lift-engined aircraft model at 1/8 scale.

The Bristol wind tunnel has a closed working section of 15 sq ft cross-section and is capable of speeds up to 175 ft/sec. Auxiliary suction equipment allows engine models of about 1/5 scale to be tested up to choking conditions in the intake. Thrust minus drag measuring equipment is available for sting-mounted models as required.

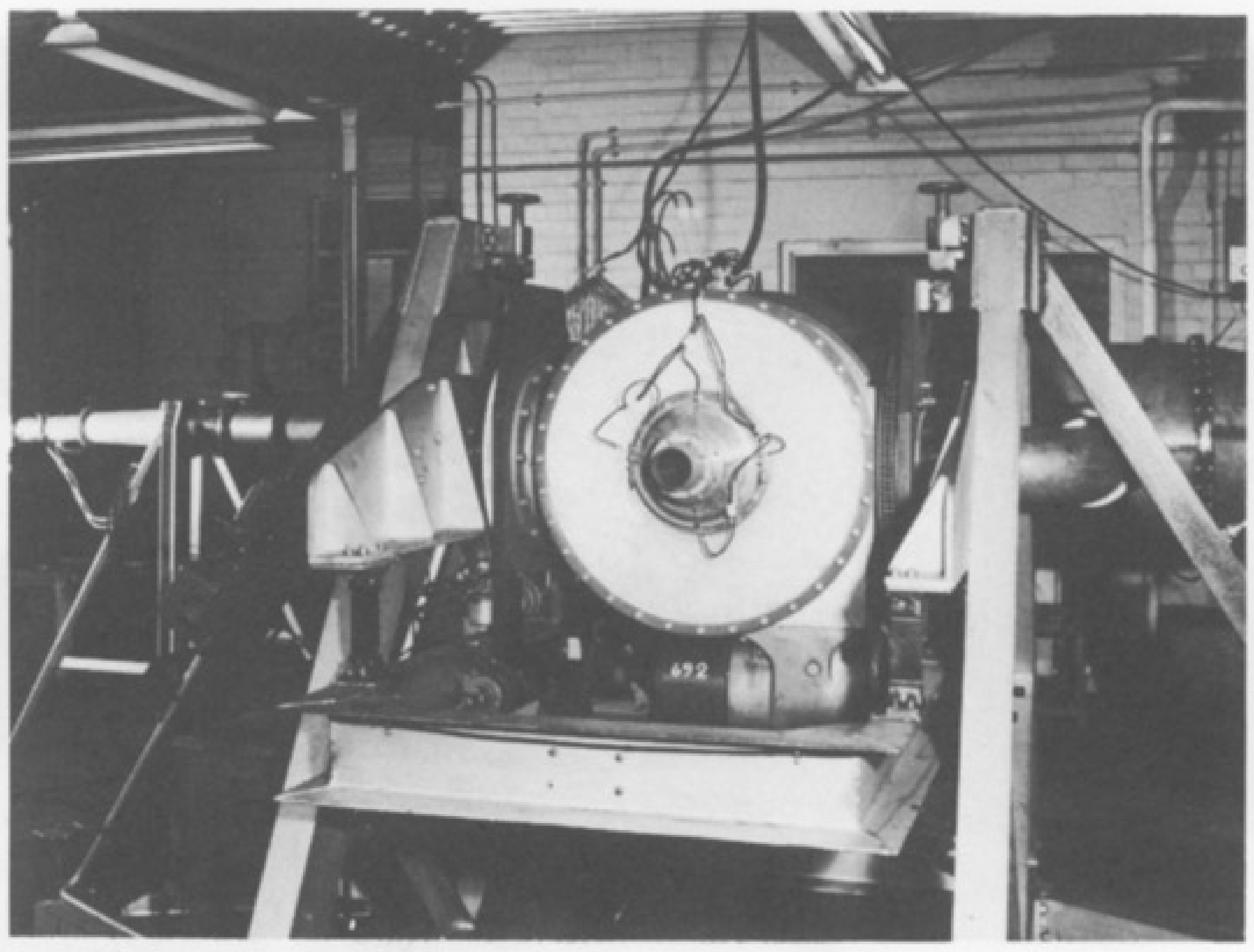
Experience

In addition to basic research plus extensive testing of experimental and generalised V/STOL intake configurations, Rolls-Royce undertook the development testing of the specific V/STOL air intake arrangements eventually flown in the SC1, Balzac, VJ101C, Mirage III-V and Harrier aircraft.

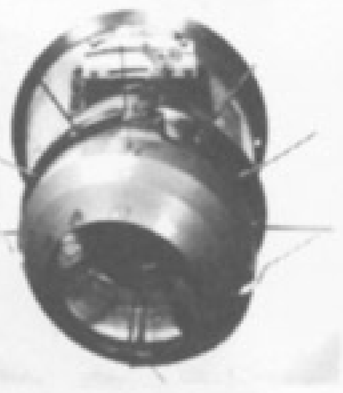
Thrust measuring rigs



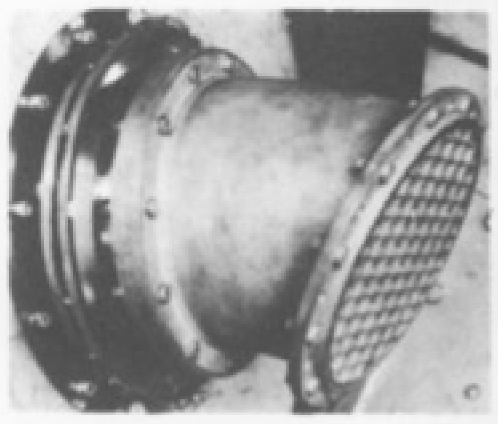
Bristol facility



Hucknall facility

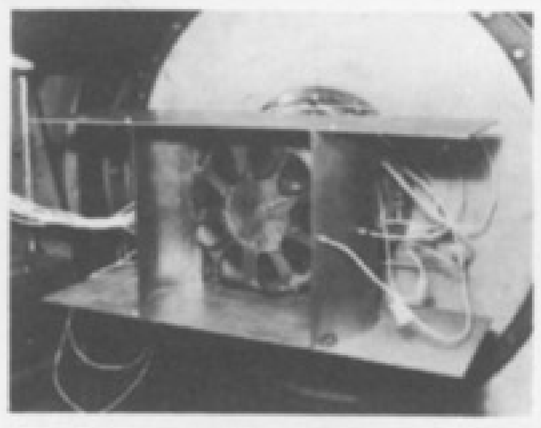


Model of ± 15° swivelling nozzle



Model or rotating cascade thrust deflector

Thrust augmentation model



Model of lift bay

Model PCB nozzles

Locations

Hucknall, Nottinghamshire
Bristol, Avon

Description

Thrust deflectors with nozzles up to an exit area of 18 sq in. were tested on the Hucknall rig. The mass flow available was 14 lb/sec at a pressure ratio of 2 to 1 at the nozzle and the supply temperature was 180°C. The Bristol test rig used for evaluating model nozzle performance uses an air bearing support system.

These Rolls-Royce test rigs have the capability of measuring the magnitude and direction of the thrust vector from any exhaust nozzle, thrust vectoring device or thrust augmenting system.

Experience

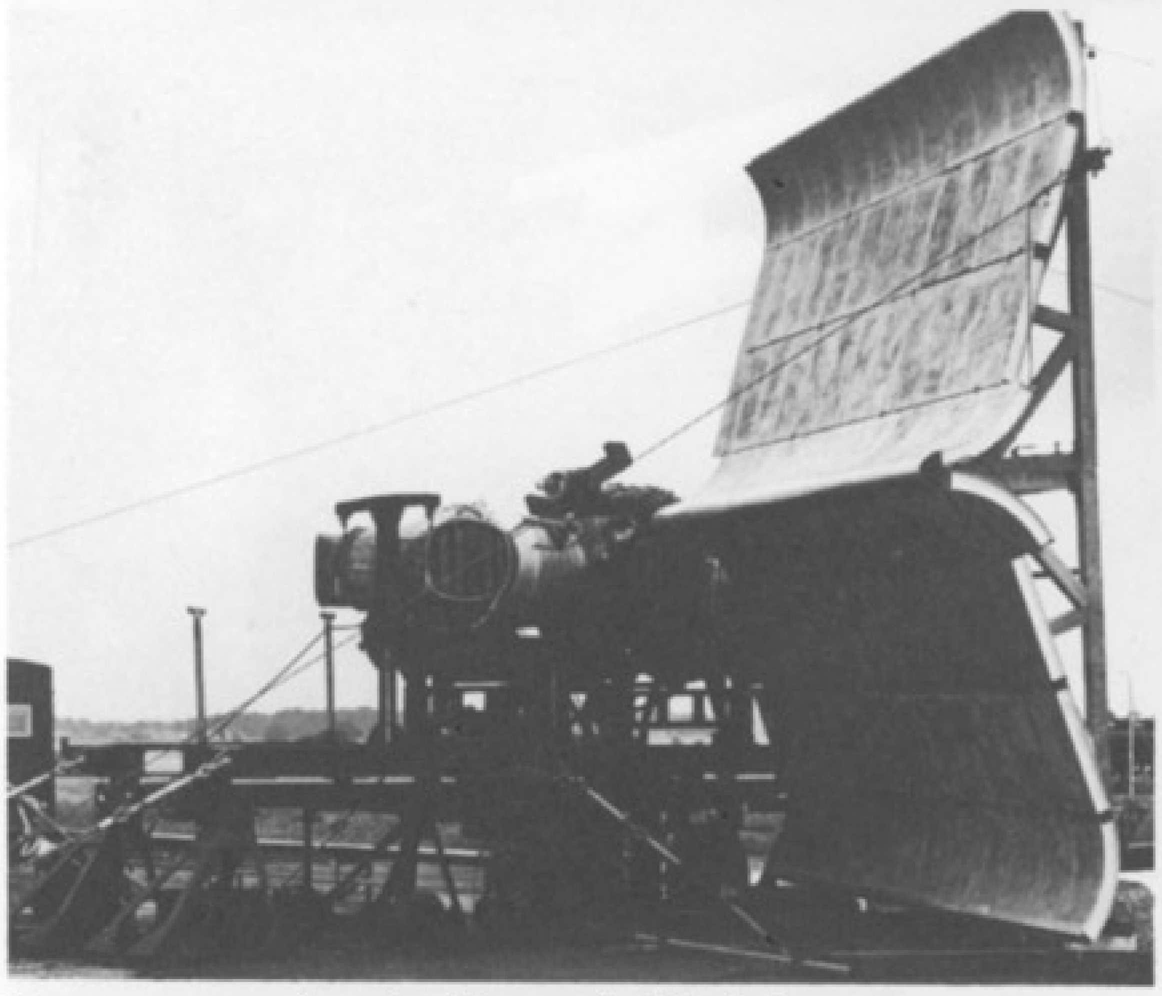
In addition to thrust deflection research and experimental developments, these model testing facilities were also used to develop several different types of thrust deflectors which subsequently were successfully tested and flown behind full-scale engines. Some of these full-scale thrust deflection systems are listed below. Other V/STOL investigations completed in these facilities include extremely short annular exhaust units for lift engines, rapid mixing nozzles to reduce exhaust energies and the characteristics of jet spreading in ground effect.

Rolls-Royce-designed and tested thrust deflection systems

Lift engine jet deflectors	Lift/cruise jet deflectors	Thrust reversal systems
RB108 (Balzac deflecting door)	RB153-61	Avon
RB162 (Do31 swivelling nozzle)	Pegasus	Conway
RB162 (VAK191B deflecting door)	RB193-12	Spey
	BS100	RB211

Noise testing facilities

Anechoic chamber at Ansty



Pegasus noise testing at Bristol

Open air test stand

Locations

Bristol, Ansty, Hucknall and Derby

Description

Up to the early 1970s, apart from sonic fatigue of aircraft structure, engine noise attenuation had not been seriously studied in relation to military V/STOL and much more attention must be given to this subject in future projects. Rolls-Royce has extensive noise testing facilities, many of which have been employed on work directed towards the successful development of engines quiet enough for civil V/STOL. In general, noise testing facilities can be divided into those aimed at component noise investigation and those capable of evaluating the noise of complete engines. An example of each type of noise testing facility which has provided noise information on V/STOL engines is described below, though more advanced facilities are now in existence:

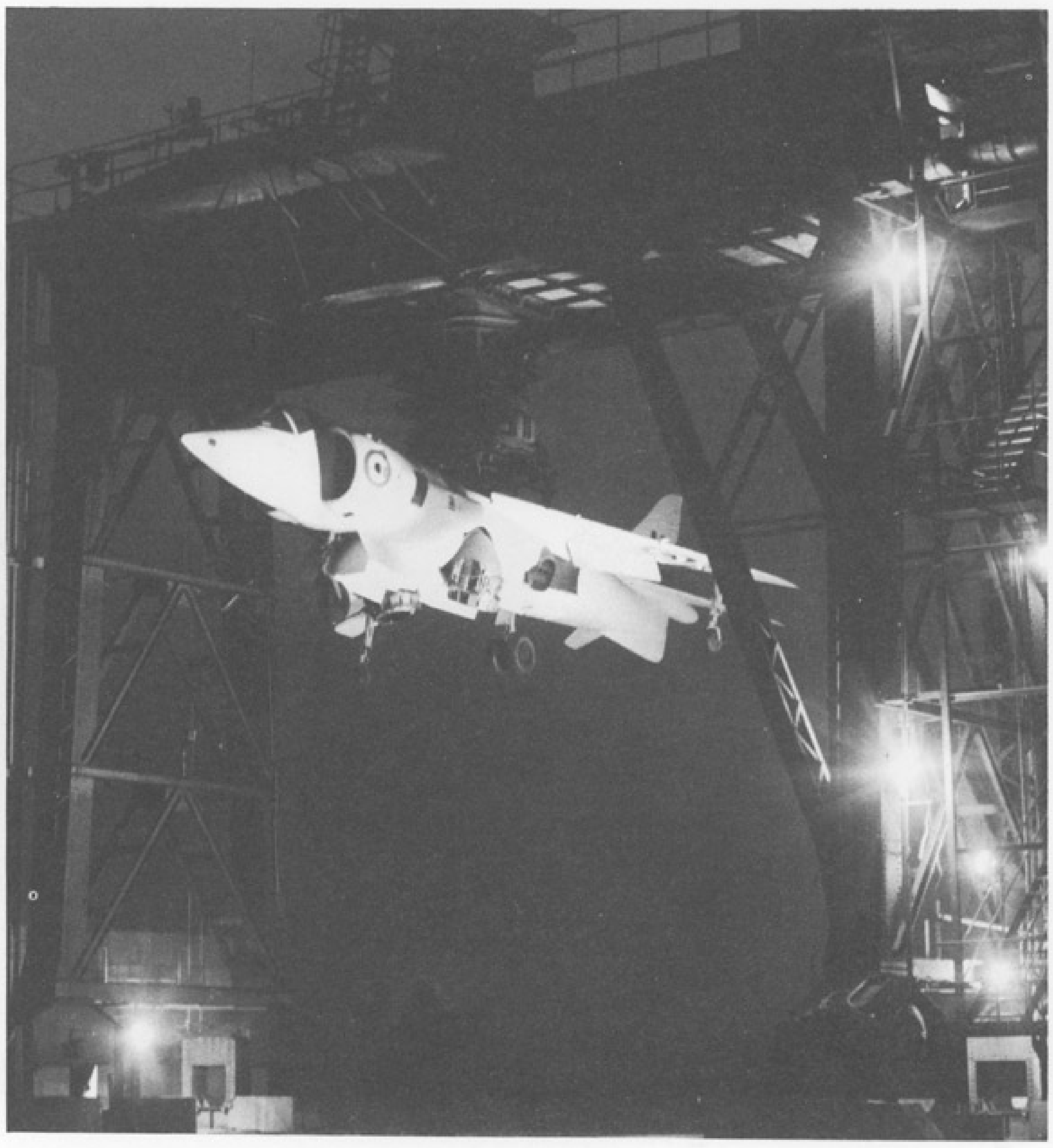
Ansty test facility

This facility was especially designed for the noise evaluation of fans and compressors. The anechoic chamber has a working area of over 100 ft by 100 ft and has fully automatic microphone traversing. Its power availability is 7000 hp and it is possible to reverse the fan mounting so that both forward and rearward radiated noise can be measured. The anechoic lining consists of independent absorbent pads mounted 2 feet from all wall surfaces so that inlet and efflux air is moved efficiently without disturbance within the chamber. Testing of components for the RB202 direct lift fan project was carried out in this facility in 1970.

Hucknall noise test stand

This open air facility is situated on a flat site, allowing noise measurements to be made over an almost complete 180° arc around the engine up to distances of 200 feet over an acoustically reflective surface, and a mobile jet muffler is provided to prevent jet noise interfering with forward arc measurements. Noise testing of the RB162-86 commenced on this test stand in 1970.

Shoeburyness test facility



Location

Ministry of Defence Proof and Experimental Establishment, Shoeburyness, Essex, England.

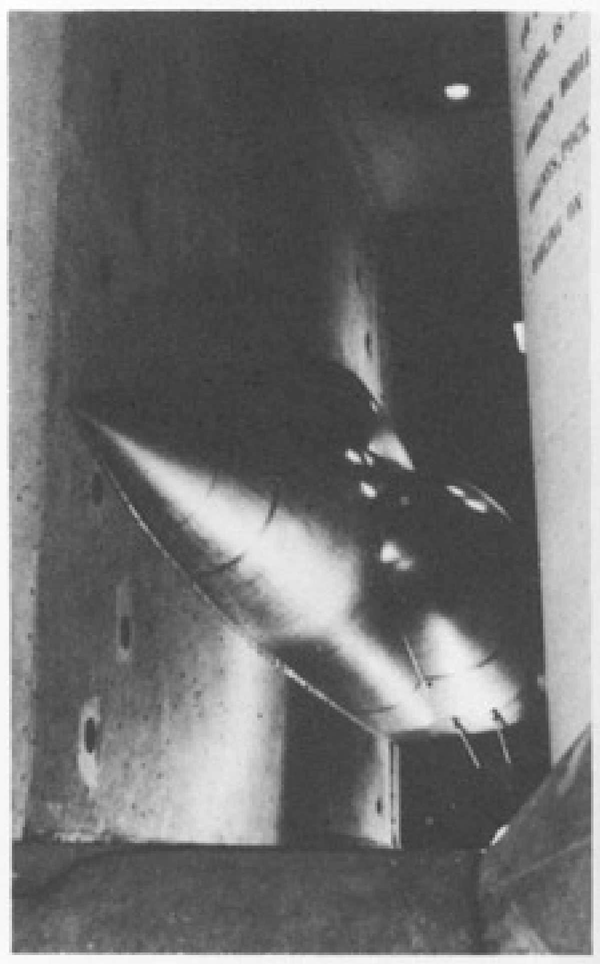
Description

This facility was designed for running installed V/STOL powerplants at supersonic thrust levels. It consists of a 140 ton Goliath crane (originally used to lift gun turrets) modified to allow an adapted Harrier airframe, with an engine, to be suspended beneath it.

A specially designed mechanism allows the airframe to pitch, roll and yaw. The airframe can be positioned at various heights up to a maximum of 30 feet above the ground with vertical landings being simulated at descent rates of up to 10 feet/sec.

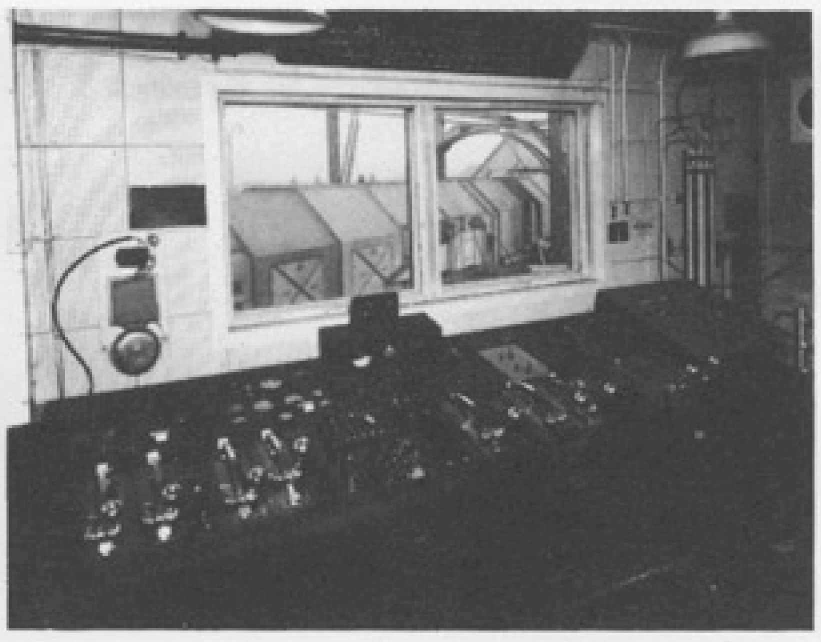
A Pegasus 2 engine was tested using the facility between 1982 and 1984. The most recent testing is with a Pegasus 11 installed in a Harrier airframe.

Full-scale V/STOL wind tunnel

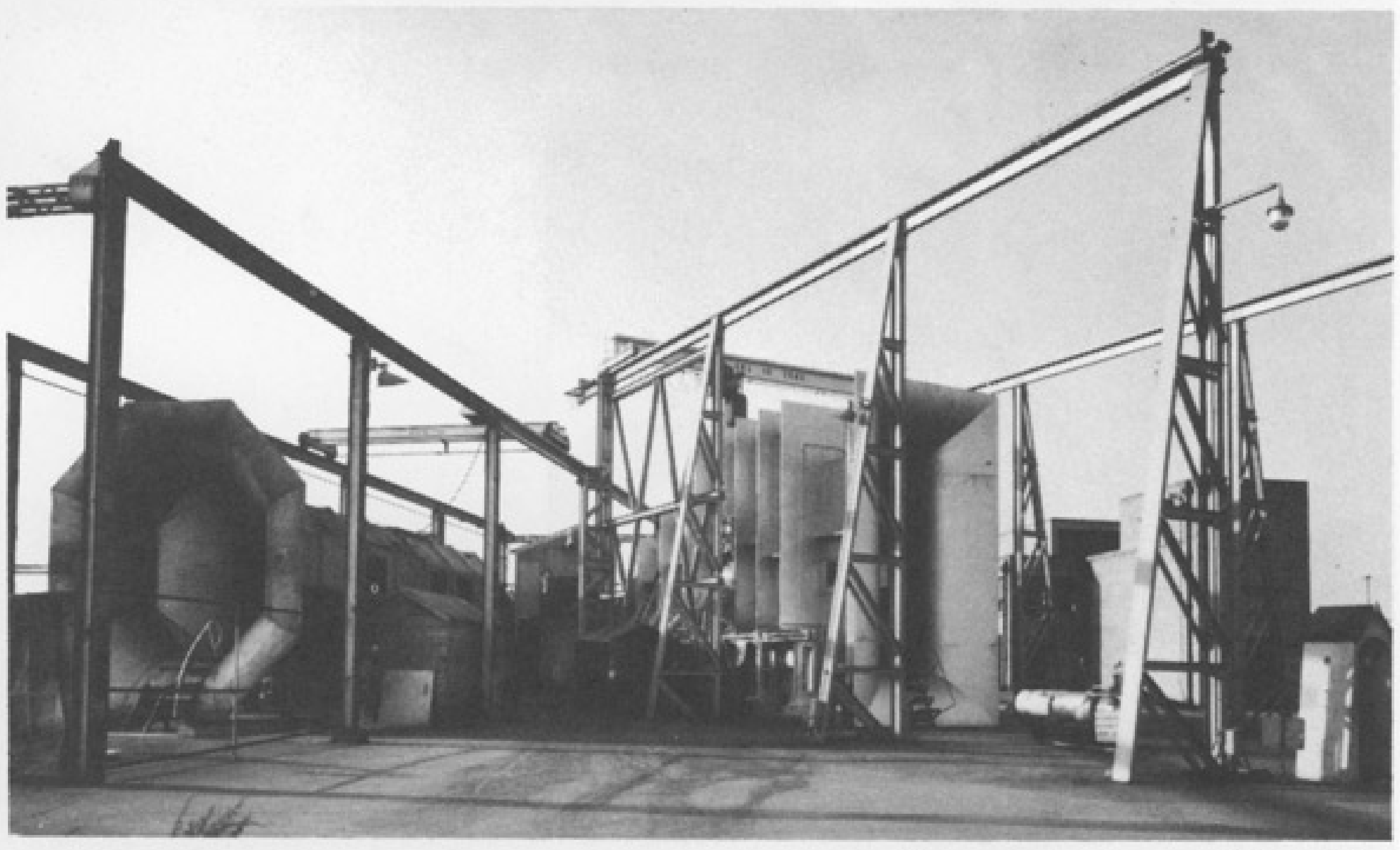


Balzac half fuselage

VJ101C pod



Control panel



General view of facility

Location

Hucknall, Nottinghamshire

Description

This facility enabled a group of V/STOL engines to be run and 'flown' through their complete take-off and landing transition profiles. This was done by supplying appropriate inlet and exit conditions to a full-scale representation of the aircraft fuselage or wing-pod mounted in the tunnel working section. Any incompatibility or systems problem associated with the engine installation thereby revealed itself at an early stage in the development programme.

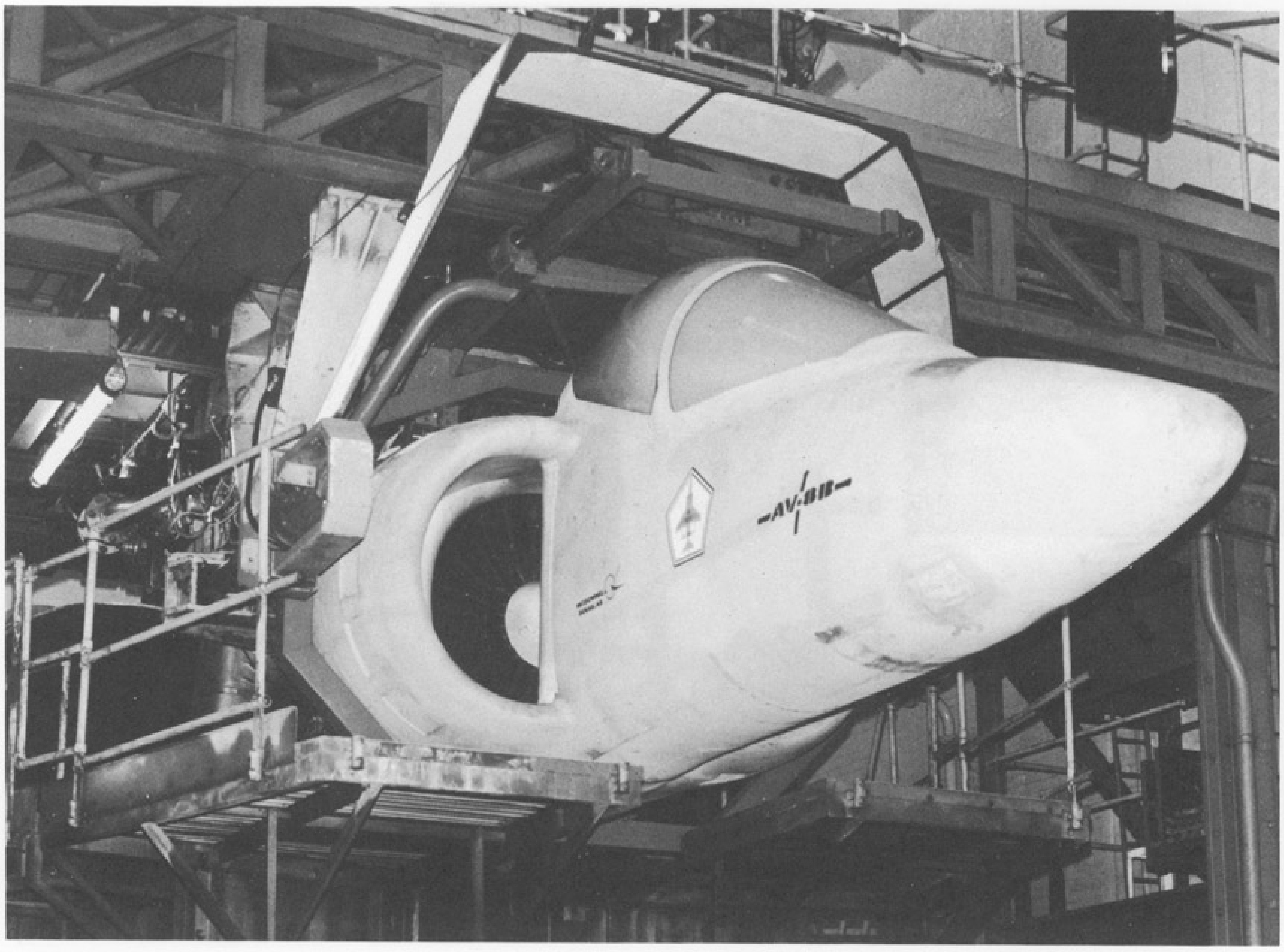
Basically the tunnel was of the ejector type powered by two Avon engines. Two working sections were built, forming a 'Y' configuration with the single ejector exhaust tube. This tube could be connected separately to either ejector working section, so enabling preparation of the succeeding installation to proceed in parallel with the current test programme. Each working section was approximately 30 feet long with its cross-sectional configuration tailored to each test installation.

A model test programme was used to define the working section configuration needed to represent accurately the required free-stream conditions around each test installation in the relatively restricted V/STOL tunnel environment

Experience

Aircraft installation	Test commencement date	Engine type	Total lift engine running time	Number of lift engine operations
Marcel Dassault Balzac	March 1962	RB108	26.3 hrs	244
EWR VJ101C (non-reheat)	August 1962	RB145	40.7 hrs	154
Marcel Dassault Mirage III-V-01	February 1963	RB162-1	11.8 hrs	306
EWR VJ101C (reheat engines)	August 1963	RB145R	26.0 hrs	85
Dornier Do31	November 1964	RB162-4	15.3 hrs	430
VAK 191B	February 1970	RB162-81	5.0 hrs	28

Pegasus test beds



Description

At Rolls-Royce in Bristol four test beds are available to test both production engines and development engines in a variety of configurations.

The two production test beds are used with the nozzles aft but the two development beds can cater for nozzles in vertical or intermediate positions.

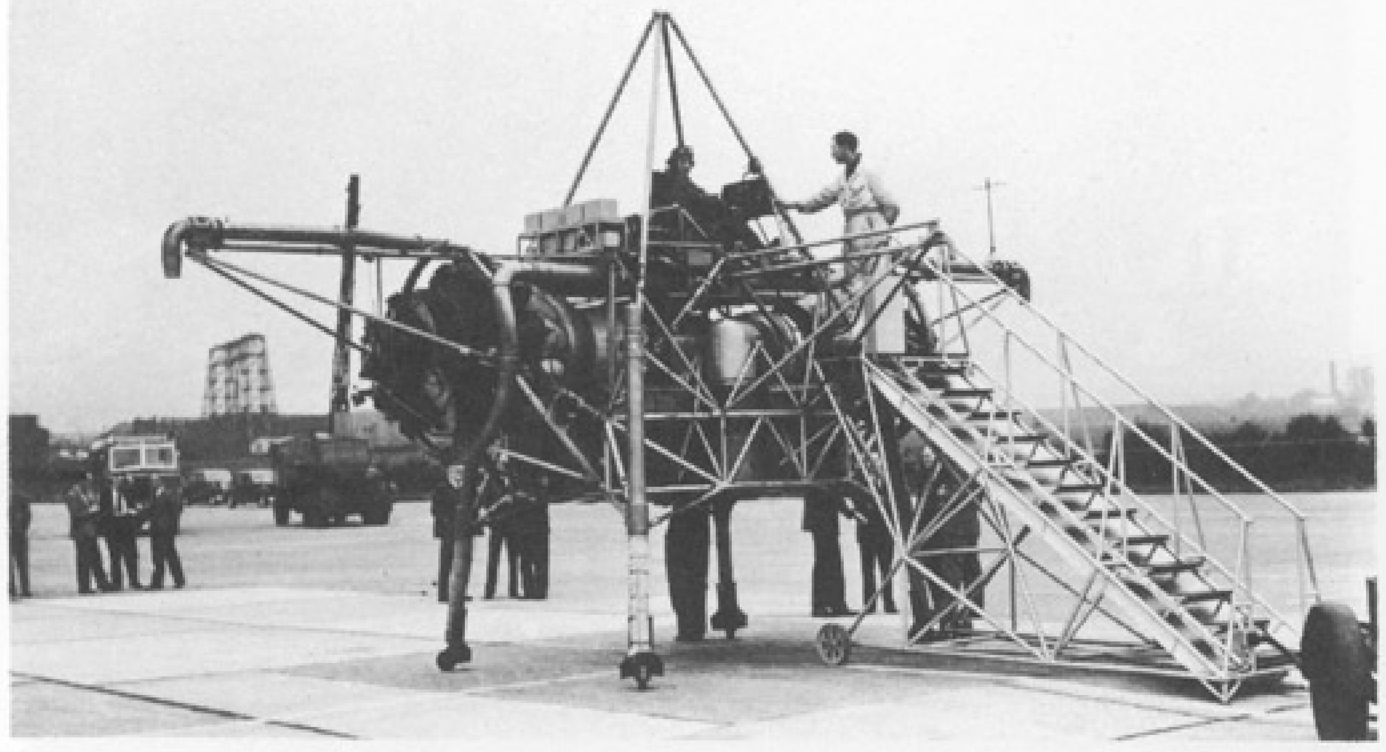
Aircraft intakes can be used on the development beds so that true flight conditions can be simulated.

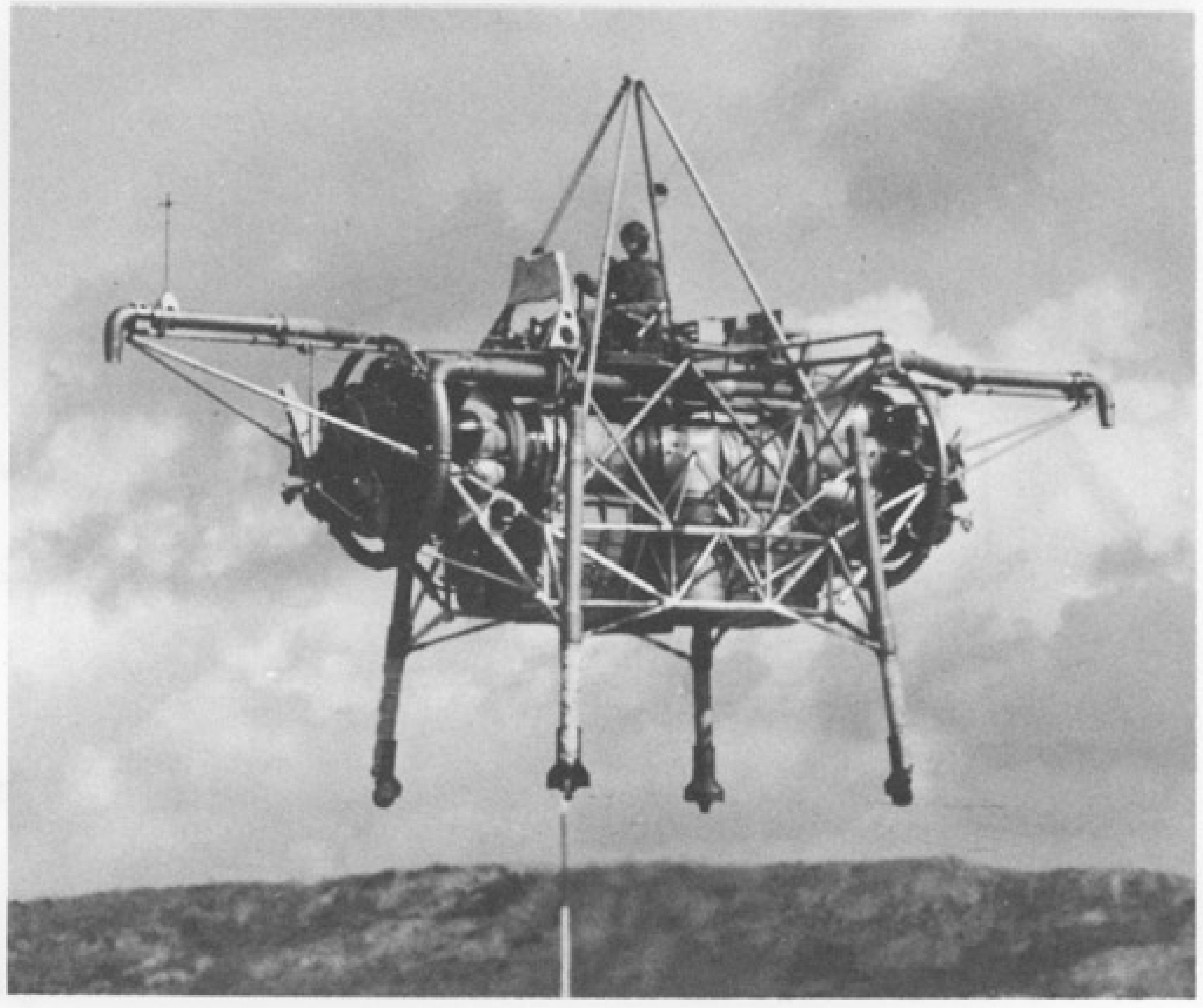
Thrust measurement is obtained on the test beds through mounting a floating cradle on load cells; both fore-aft and vertical thrust can be accurately determined.

All four of the Pegasus test beds can be used for intake distortion tests so that surge margins can be determined.

5 V/STOL engine applications – rigs

Flying Bedstead





Description

Two of these test rigs were designed and built at Hucknall to demonstrate the principle of jet lift and to investigate suitable control and stabilisation systems.

Each rig consisted of two Nene turbojets mounted horizontally in a framework, positioned back-to-back to avoid gyroscopic effects, with their jets deflected 90° downwards. One Nene engine exhausted through a single central nozzle located directly below the rig centre of gravity while the other fed two 'half-size' exhaust nozzles positioned either side of this central nozzle to minimise overturning moments in event of engine failure.

Control about all three axes was provided by four downward-pointing air-jet reaction nozzles or 'puff-pipes' mounted on outriggers and fed by a constant 9% of compressor bleed air supplied from each engine. The pitch nozzles could each swivel by up to ± 30° to provide yaw control.

History

Although some early literature refers to this rig as both the 'Jet Control Research Unit' and the 'Thrust Measurement Rig', its appearance soon led to the unofficial name of 'Flying Bedstead' being universally adapted.

Roll-out of the first Flying Bedstead (XJ314) took place at Hucknall on 3 July 1953 to be quickly followed by the first tethered hover beneath the specially constructed test gantry. On 3 August 1954 the historic first free hover was made. On 15 December the rig completed its final test at Hucknall (actually the sixteenth free hover) prior to being overhauled for despatch to RAE Farnborough.

In June 1956, this rig was taken to RAE Bedford where it continued VTOL stability and control testing until severely damaged in a non-fatal accident on 16 September 1957. XJ314 was eventually rebuilt, using some parts from the second rig, for display in the Science Museum at South Kensington in London.

The second rig (XJ426) was rolled-out on 19 August 1955 and completed its first tethered and free hovers on 17 October 1955 and 12 November 1956 respectively. A fatal accident occurred in the Hucknall test gantry on 28 November 1957, following loss of height control, probably caused in part by the relatively slow thrust response of the Nene engines.

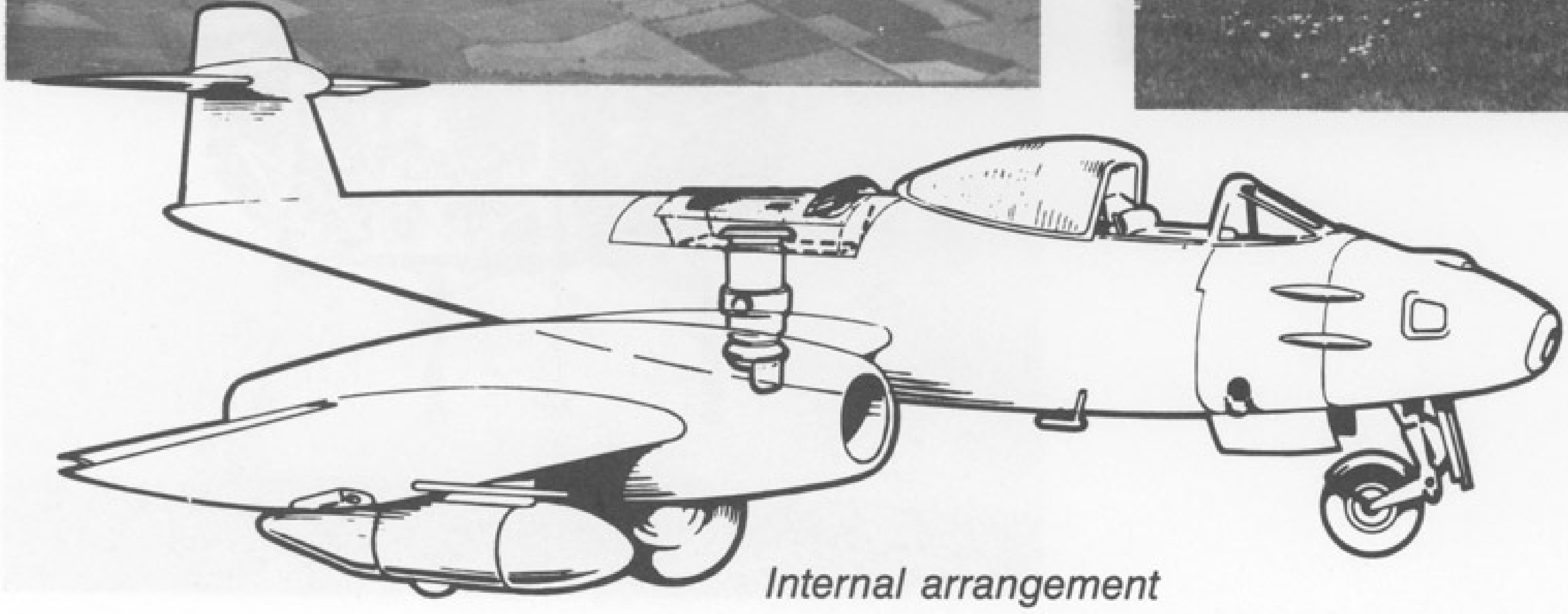
Experience

The two Flying Bedsteads completed approximately 380 tethered and 120 free flights.

Meteor flying test bed for RB108

Intake development for Short SC1

Recirculation testing



Internal arrangement

Description

A standard Gloster Meteor FR9 aircraft was converted to include an RB108 lift engine in a special bay located in the fuselage centre section. Provision was made to swivel the complete engine ± 30° about the vertical position. With the aircraft taxiing, the final nozzle of the RB108 was about 30 in. above the ground level.

History

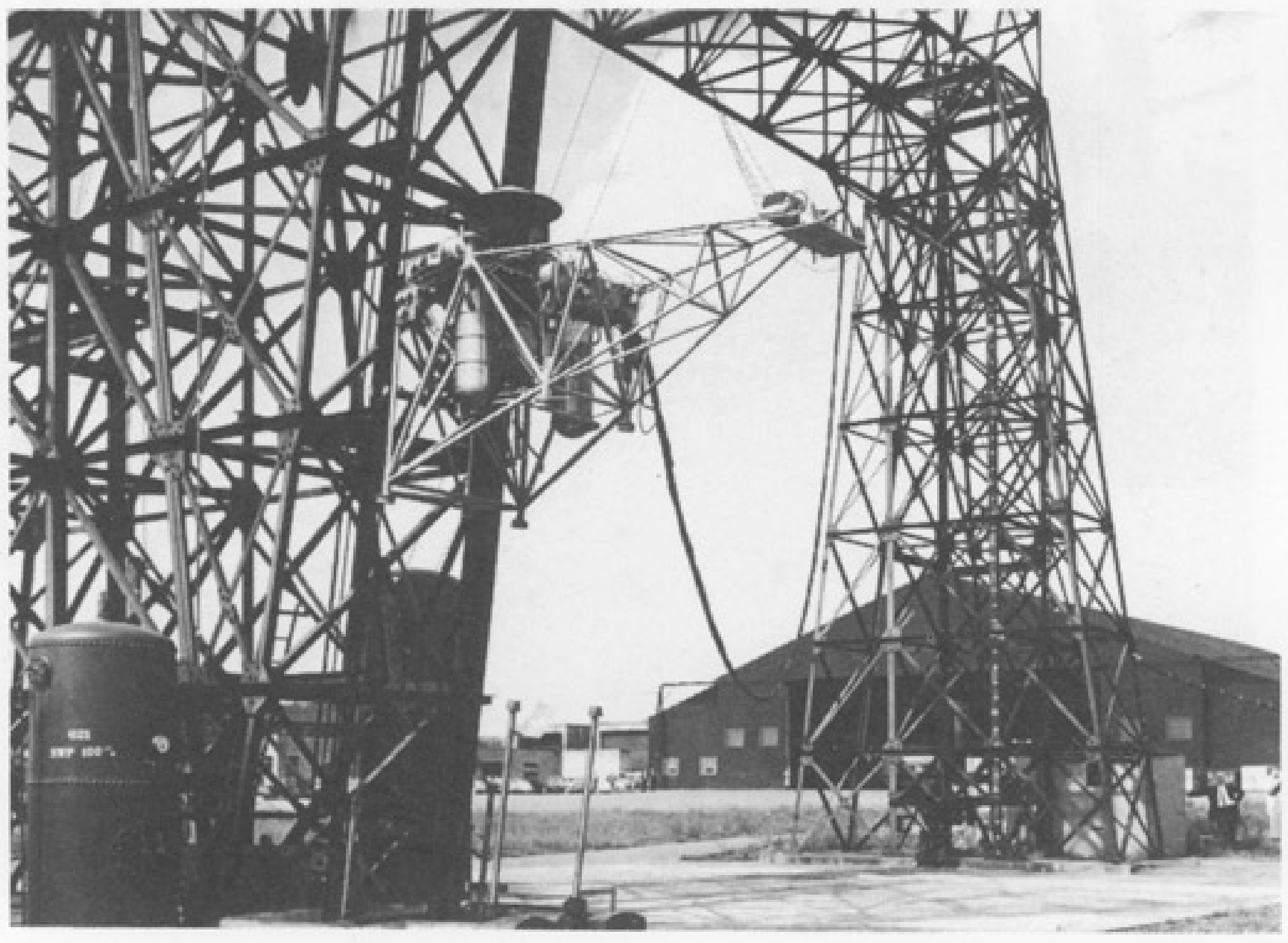
This Meteor aircraft was used as a flying test bed to develop the RB108 installation principles for the Short SC1 aircraft. The initial checkout flight following modification was carried out at Tangmere on 18 May 1956. The actual test flying programme commenced on 2 August with a short series of tests to develop the propulsion engine air intake for the Short SC1. Development testing of the SC1 lift engine installation commenced in July 1957 and an intake and exhaust arrangement was evolved which allowed the swivelling RB108 engine to operate satisfactorily under the rigorous conditions inherent with its vertical installation.

Following this flight programme, the aircraft was used as a non-flying test rig to assess the alleviation produced on both hot gas recirculation and ground erosion by the rolling vertical take-off technique. This involved taxiing at various speeds over different surfaces for various RB108 thrust settings and vector angles. This work was carried out at Hucknall between 10 May 1960 and 26 June 1964.

Experience

Test duty	Number of tests	Number of lift engine operations	Total lift engine running time
Installation flight testing	540	892	135 hrs 45 mins
Ground effect testing	24	58	2 hrs 15 mins

RB108 height control rig



Description

This rig consisted of one RB108 engine mounted vertically in a tubular structure which slid on two near-vertical rails attached to the 'Flying Bedstead' gantry at Hucknall. The tubular structure containing the engine, fuel tanks and radio altimeter weighed 1817 lb with full fuel. Total travel of the rig along the rails was 38 ft and the rig could be set to descend rapidly to any predetermined height above the ground between 30 ft and 5 ft. The maximum hovering duration was 10 minutes.

The rig was intended to explore automatic height control as means of minimising fuel consumption during vertical landing with an ultimate objective of developing techniques which will eventually allow V/STOL aircraft to operate in zero visibility conditions

History

The first engine run was made on 22 April 1958 followed by the first test on 15 May. Testing continued over the next two years until completion of the programme in July 1960.

Experience

Total engine running time	Total number of engine operations
24 hrs 45 mins	214

EWR 'Wippe' rig

Pitch axis testing

Roll axis testing

Description

The 'Wippe' or 'see-saw' rig was essentially a horizontal beam supported at one end but free to move up and down at the other. An RB108 engine was mounted in such a position that the engine thrust imparted an upward force to the free end of the rig. It was designed for investigation of aircraft control by engine thrust modulation, a primary feature of the EWR VJ101C development programme.

Before a test began the rig was locked in a horizontal position to a pole. For 'take-off' the pilot released the locking device and the rig was balanced by engine thrust. For pitch control tests, the pilot's seat was mounted on the free end of the rig just in front of the engine which in this case represented a fuselage lift engine. For roll control tests, the pilot's seat was positioned on a side extension. Most of the tests were carried out with the rig in the pitch control configuration.

History

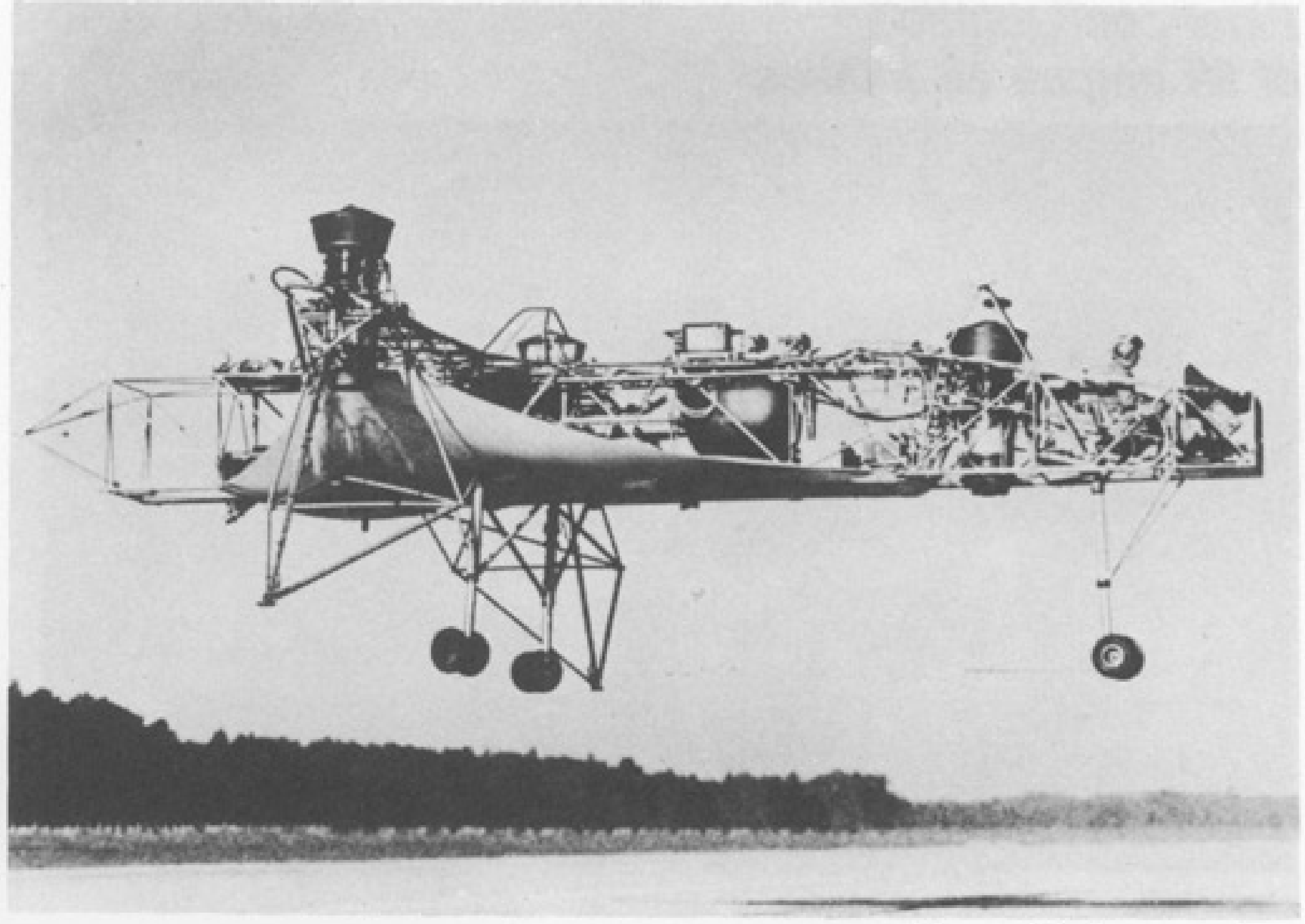
Entwicklungsring Süd (EWR) was formed in 1959 by the combination of design teams from Bölkow, Heinkel, and Messerschmitt to develop a Mach 2 V/STOL interceptor

The Wippe rig arrived at Rolls-Royce Hucknall from Germany on 28 January 1960 and testing took place between 16 May and 10 November.
The rig then returned to Germany on 28 January 1961 and a further series of tests were carried out between 30 July 1962 and 8 May 1963.

Experience

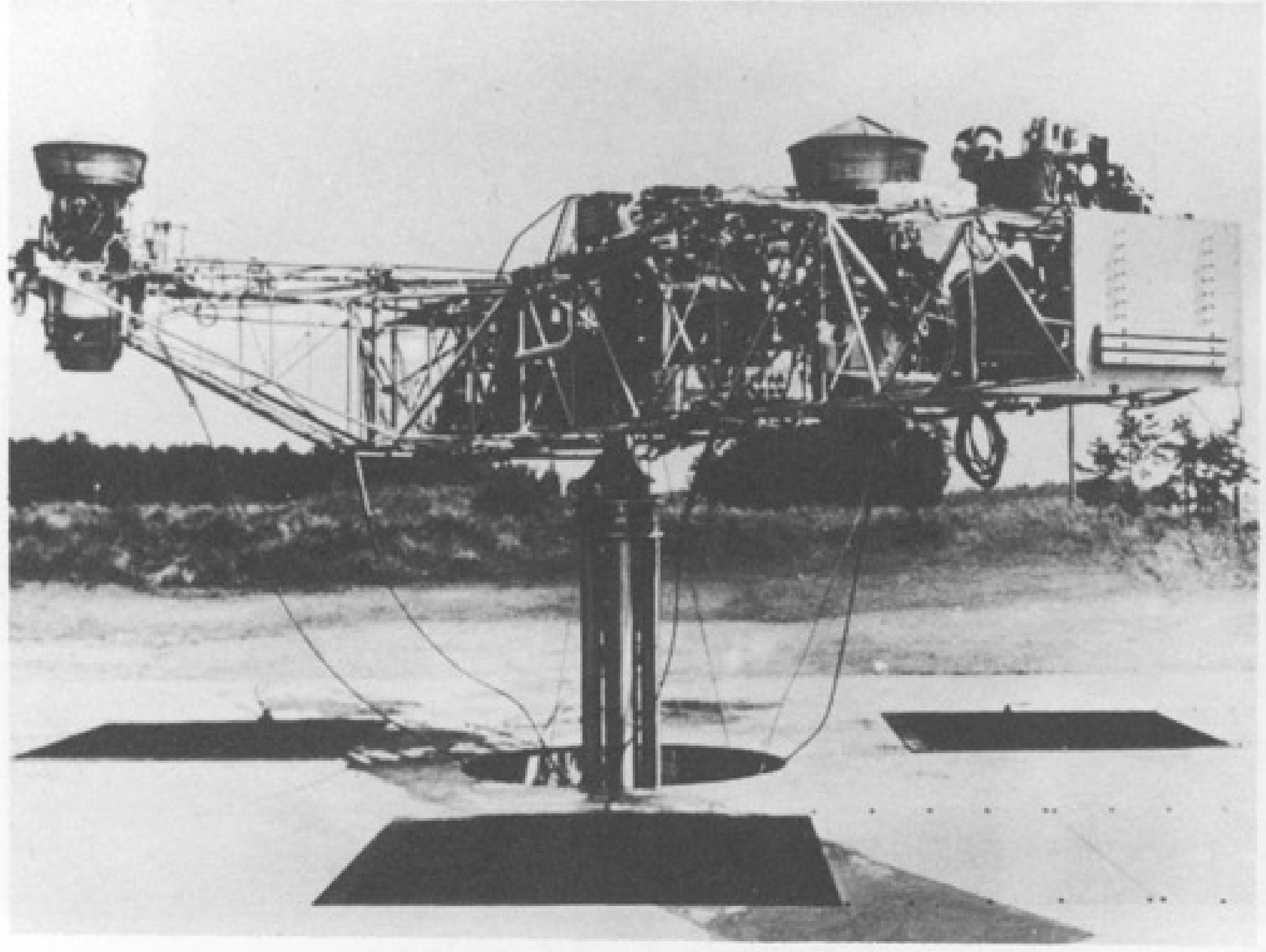
Test location	Number of tests	Total engine running time
Rolls-Royce Hucknall	146	27 hrs 50 mins
EWR Manching	61	13 hrs 30 mins

EWR hovering rig



Free-flight testing

Pedestal testing



Description

Following the success of the 'Wippe' rig, EWR built a hovering rig as the next step in proving the principle of VTOL aircraft control by thrust modulation. This rig consisted of a tubular structure with three RB108 lift engines mounted in the form of a triangle to represent the geometry of the VJ101C aircraft. A Cardan joint was installed at the rig's centre of gravity to allow testing with the rig attached to a pedestal. Both roll and pitch control were accomplished by differential engine throttling while yaw control was by differential swivelling of the 'wingtip' engines.

By matching the moments of inertia of the rig to its geometry, control characteristics were obtained which were subsequently proved similar to those of the VJ101C itself. Therefore, in addition to its value as a research tool, this rig showed itself well-suited for pilot familiarisation. Three hovering tests were carried out in a safety gantry which quickly confirmed that ground testing was much easier using the pedestal facility.

History

Initial ground running commenced on 20 March 1961. The rig was first tested on the pedestal on 6 June and in the safety gantry on 9 August.

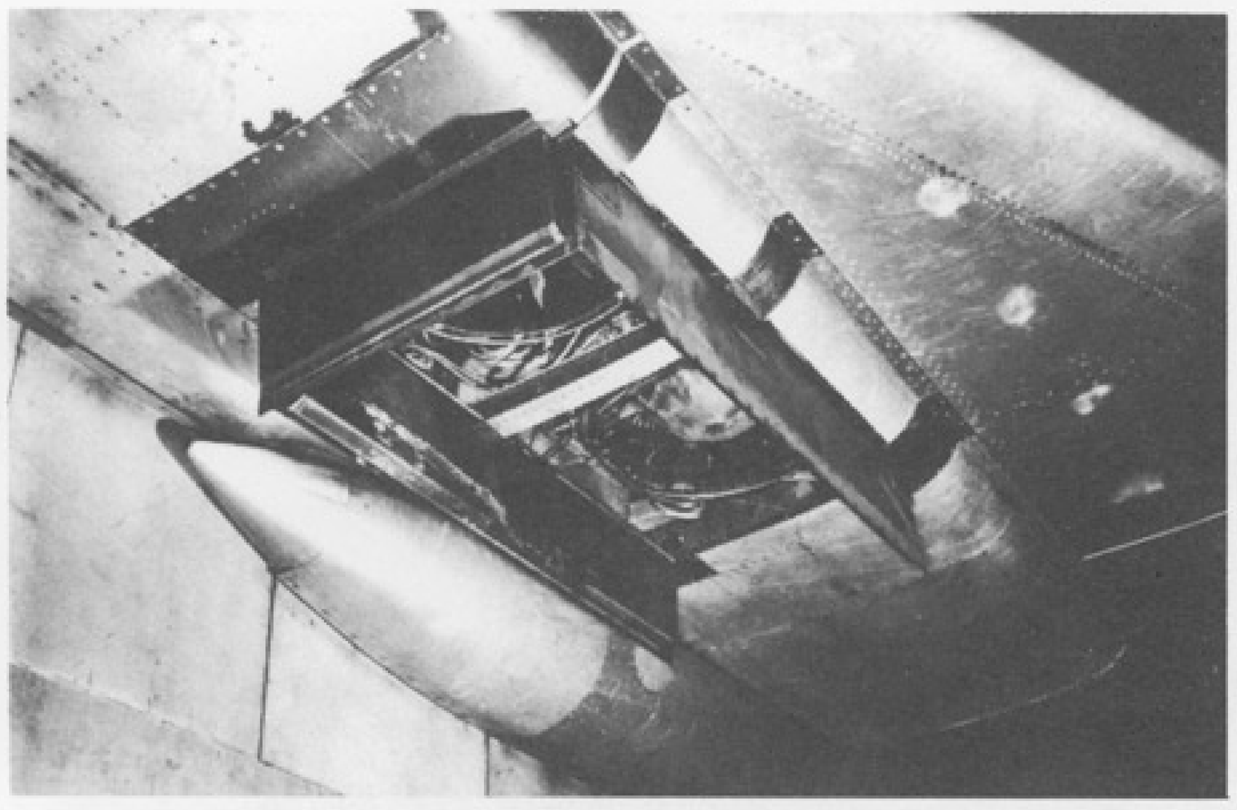
The first free hovering flight was undertaken on 21 March 1962 and testing continued until September 1964. This rig was flown under extremely varied weather conditions by four EWR pilots, and eight other German and foreign pilots.

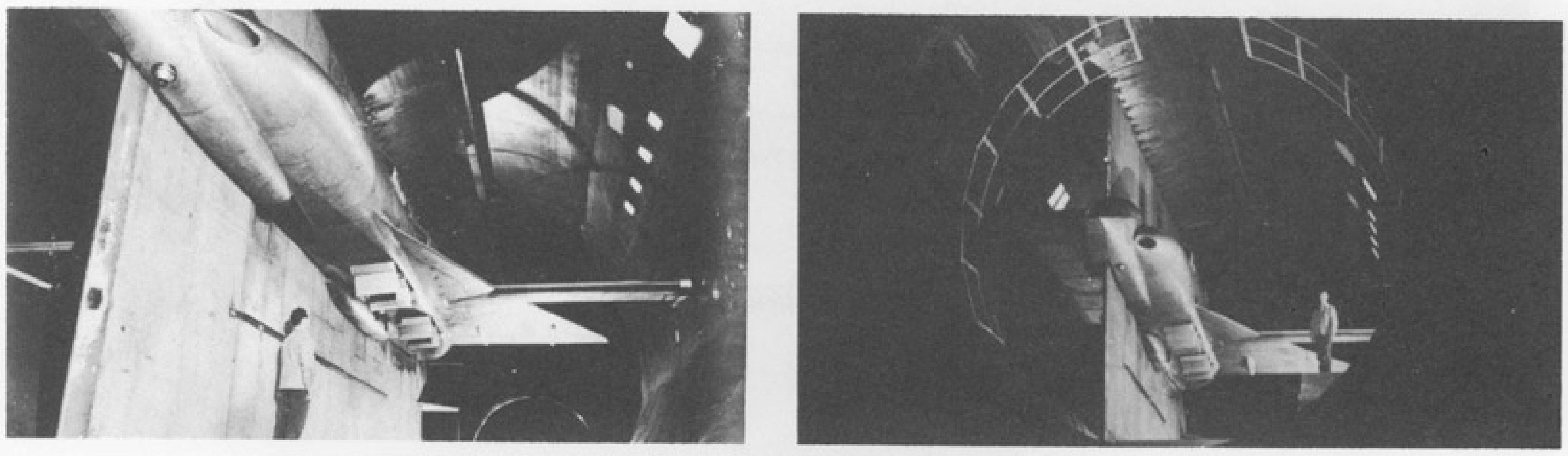
Experience

Test duty	Number of tests	Total engine running time	Total engine flying time
Ground running tests	99	224 hrs	35 hrs
Tethered tests			
– on pedestal	217		
– in gantry	3		
Free flights	126		

Mirage III-V wind tunnel testing


Final configuration of lift engine air intakes


Final configuration of lift engine exhaust system


Four RB162-1 engines installed in full-scale half fuselage

Description

The S1 wind tunnel is the largest of the four tunnels which comprise the ONERA test facility at Modane, situated at an altitude of 3600 ft in the French Alps. It is a closed circuit tunnel working at atmospheric pressure, with the capability of exchanging 40% of the airflow every circuit. There are three interchangeable working sections, each 26 ft diameter and 46 ft long, mounted on movable 'chariots' to facilitate rapid test preparation and de-rigging.

A full-scale representation of the port half of the Marcel Dassault Mirage III-V fuselage and port wing was mounted in this facility. Four RB162-1 lift engines were installed in pairs in two bays each equipped with representative intake and exhaust configuration. The aircraft hovering control bleed system and LP fuel system were also represented.

History

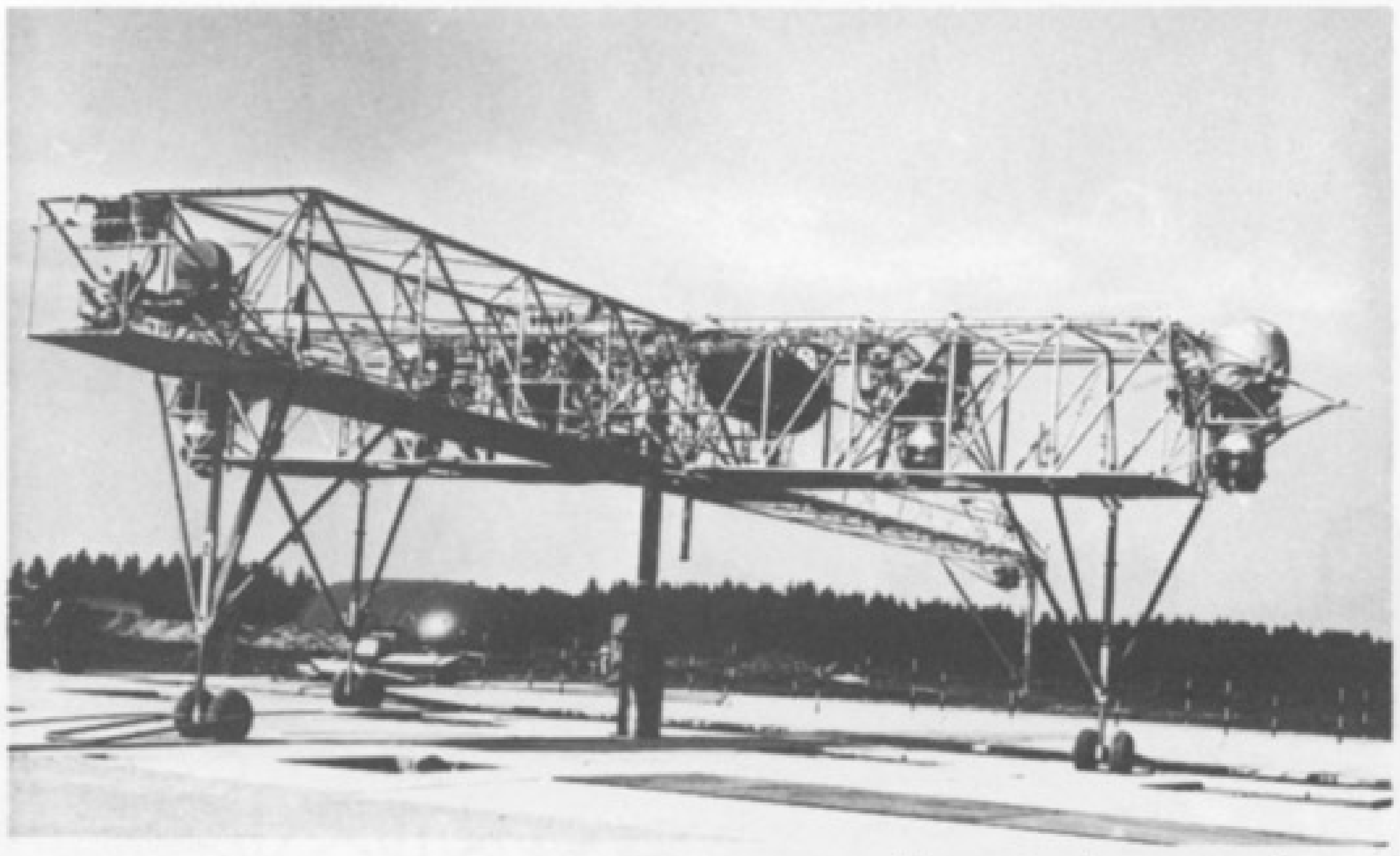
Marcel Dassault did not employ hover rigs prior to first flight of the Mirage III-V. In August 1963, testing commenced in the Modane tunnel to verify the transition characteristics of the first aircraft with particular emphasis on the lift engine air intake and exhaust arrangements. In this aircraft configuration, each RB162-1 lift engine had a single louvred air intake scoop and two exhaust deflecting doors.

The second prototype aircraft test programme started in July 1964 with the development of an improved design lift engine bleed valve. In January 1965 both engine bays were fitted with the improved intake and exhaust systems which had been proposed for the second aircraft. The new intake configuration replaced each scoop by simple intake doors. The new exhaust configuration comprised a scuttle plus exhaust doors. The final test series, which commenced in March 1966, proved all the various lift engine installation improvements as a complete system. These were then successfully test flown in the second aircraft.

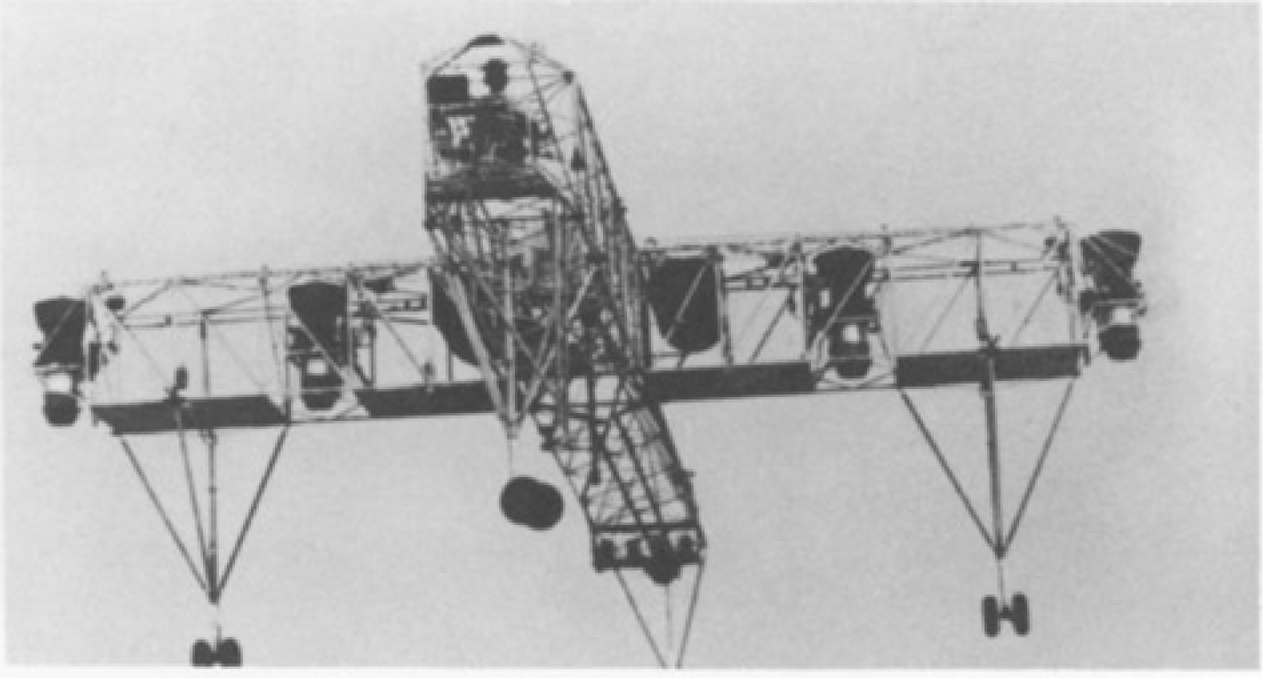
Experience

Aircraft configuration	Total engine running time	Total number of engine operations
Mirage III-V-01	42 hrs	897
Mirage III-V-02	81 hrs	3794

Dornier small hovering rig



Mounted on pedestal



Free-flight testing

Description

This rig was the first constructed to evaluate stability and control systems for the Dornier Do31. It had four widely-spaced vertical RB108 engines mounted in a tubular framework. In plan view this framework was cruciform, thereby representing the fuselage and wing of the final aircraft. Each inboard RB108 represented a Pegasus, while each outboard RB108 simulated one of the wingtip lift pods of the Do31. The RB108 final nozzles were approximately 10 feet above ground level. Roll control was provided by differential throttling of the outboard RB108s which could also be differentially swivelled to achieve yaw control. For pitch control, air was bled from the compressors of the two inboard RB108s and ducted to tail-mounted up-and-down 'puff-pipes'. Initial testing was conducted using a hydraulic ram type of pedestal mounted in the centre of a large exhaust pit covered by a steel grid supported on cascade vanes.

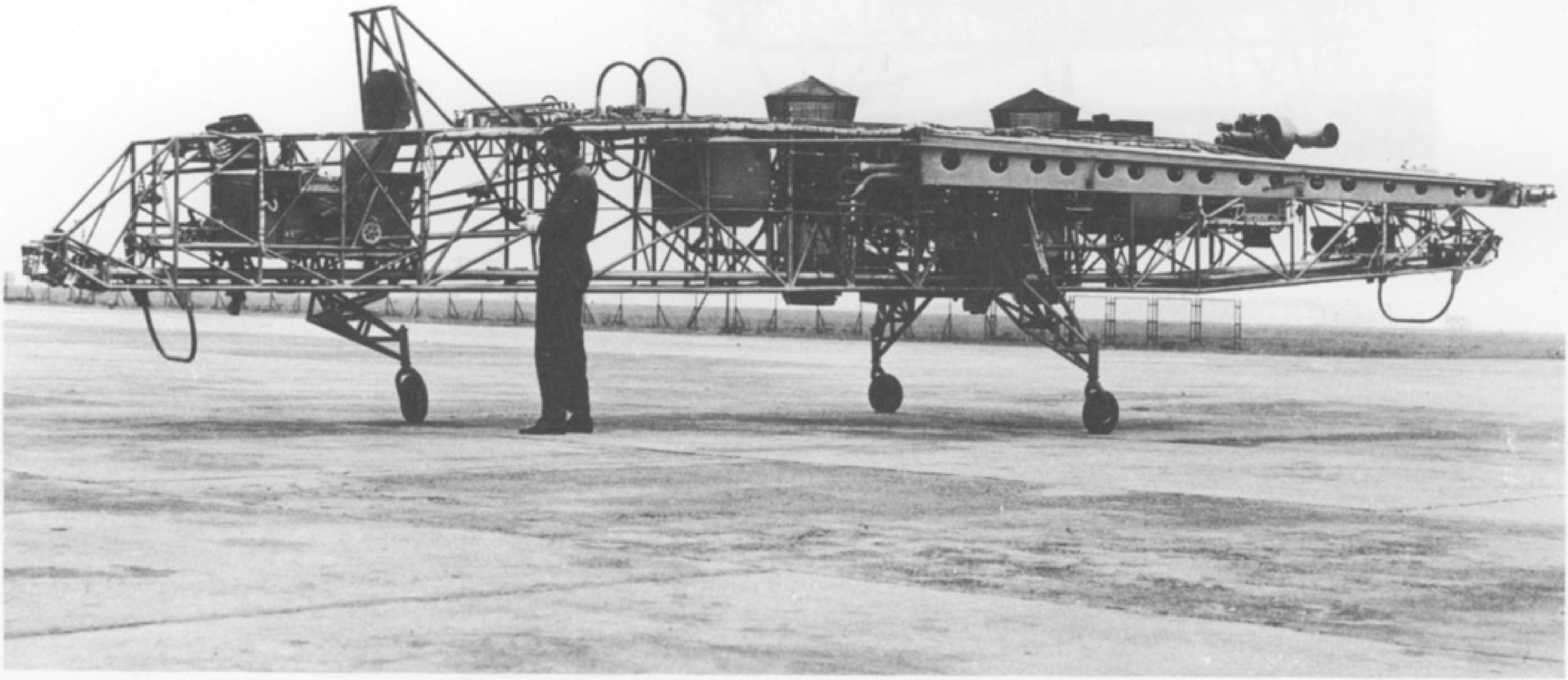
History

All testing of this rig was conducted at Oberpfaffenhofen Airfield near Munich. Initial ground running of all four engines began on 23 August 1963, and the first pedestal test with all axes free followed on 10 September. The first free hovering flight was made on 21 April 1964; testing ended in June 1965.

Experience

Test duty	Number of tests	Total engine running time	Total number of engine operations
Ground running tests	105	255 hrs	2242
Pedestal tests	285		
Free hovering flights	243		

Fiat hovering rig



Description

The layout of the projected Fiat G95/4 V/STOL light strike fighter was simulated by this rig. The two vertical RB108 engines were mounted in tandem along the framework fuselage on either side of the rig centre of gravity. Hovering control in all three axes was by 'puff-pipes' fed by air bled from both engine compressors.

For tethered testing, the rig was attached by means of a swivelling joint to a sliding pedestal located in an exhaust gas pit. The rig could hover up and down this sliding pedestal (with or without counter-weight assistance) whilst maintaining freedom in all three axes. The exhaust gas pit comprised the usual arrangement of a gridded surface with underlying cascades to deflect the gases to an exit chute.

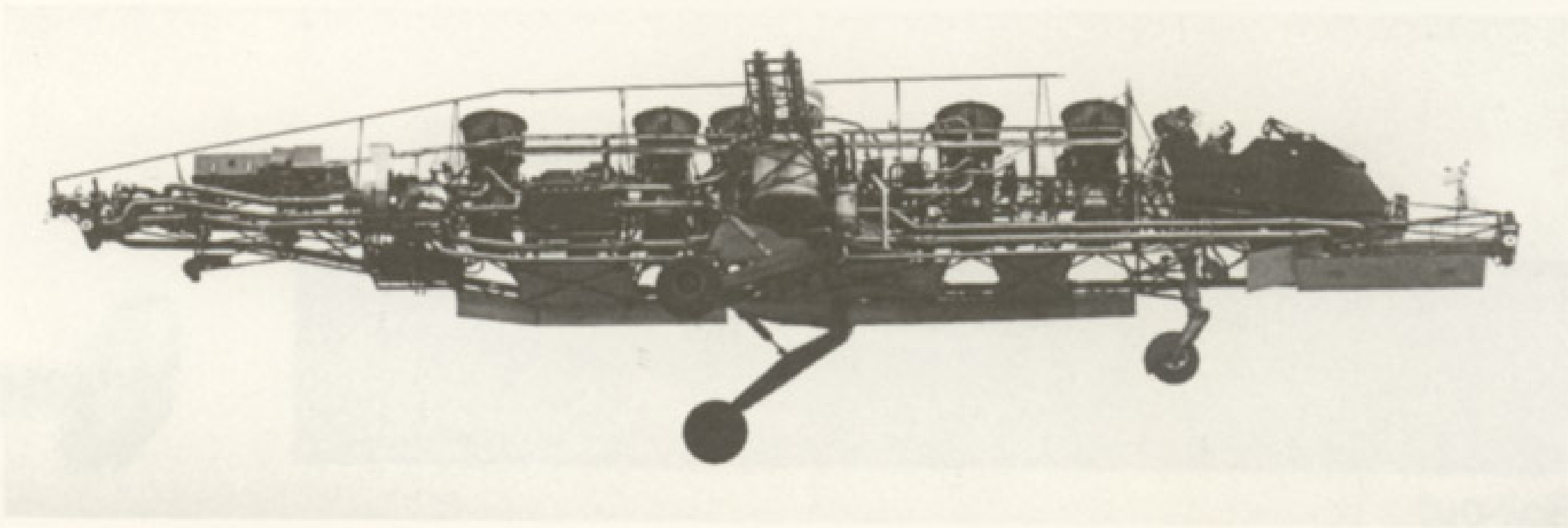
History

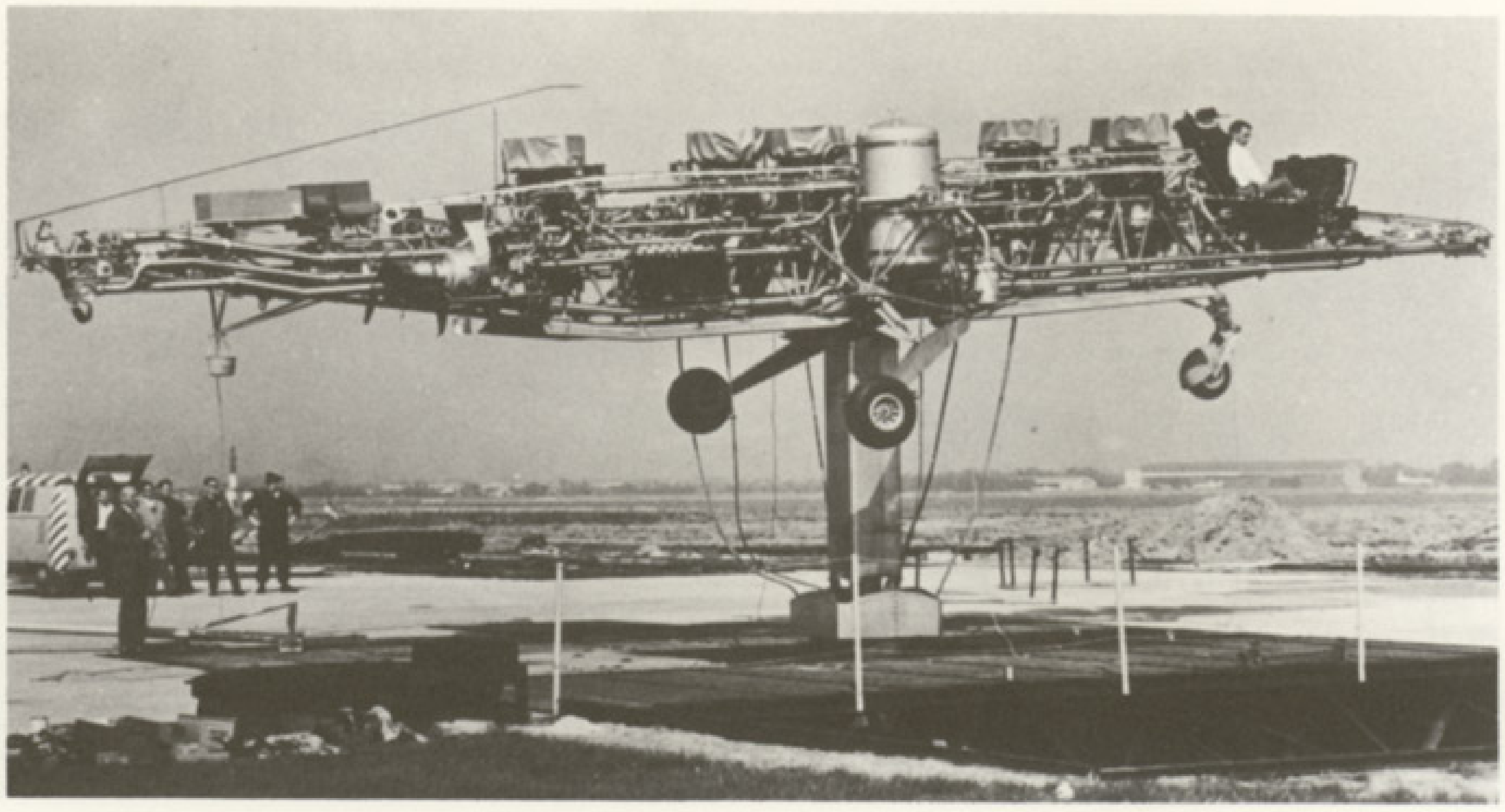
Ground running of both engines commenced on 26 April 1965. First 'flight' of the rig on the pedestal with all axes free was completed in January 1966. Owing to the abandonment of the G95/4 aircraft, the hover rig programme was closed in March 1966 without free flight being attempted.

Experience

Total engine running time	Number total of engine operations
20 hrs	164

VFW hovering rig


Free-flight testing


Mounted on pedestal

Description

Constructed to simulate the characteristics of the VFW-Fokker VAK191B strike aircraft, this rig was powered by five RB108 engines which were mounted vertically in line along the framework fuselage. The three central RB108s were spaced to simulate the RB193-12 of the VAK191B, while the two outer RB108s each represented one of the two RB162-81 lift engines of the final aircraft. Control of the rig about all three axes was achieved by a duplicated 'puff-pipe' system. Air bled from the three central engines fed one system, and the outer engines supplied air to the second system.

A pedestal was built at Bremen airfield to permit tethered testing of the rig. This facility was the usual type of hydraulic ram positioned in the centre of a gridded exhaust pit equipped with cascades. The rig maximum lift-off weight was 8912 lb and its endurance was 10½ mins. Its normal operating forward speed and altitude were 50 kt and 650 ft respectively.

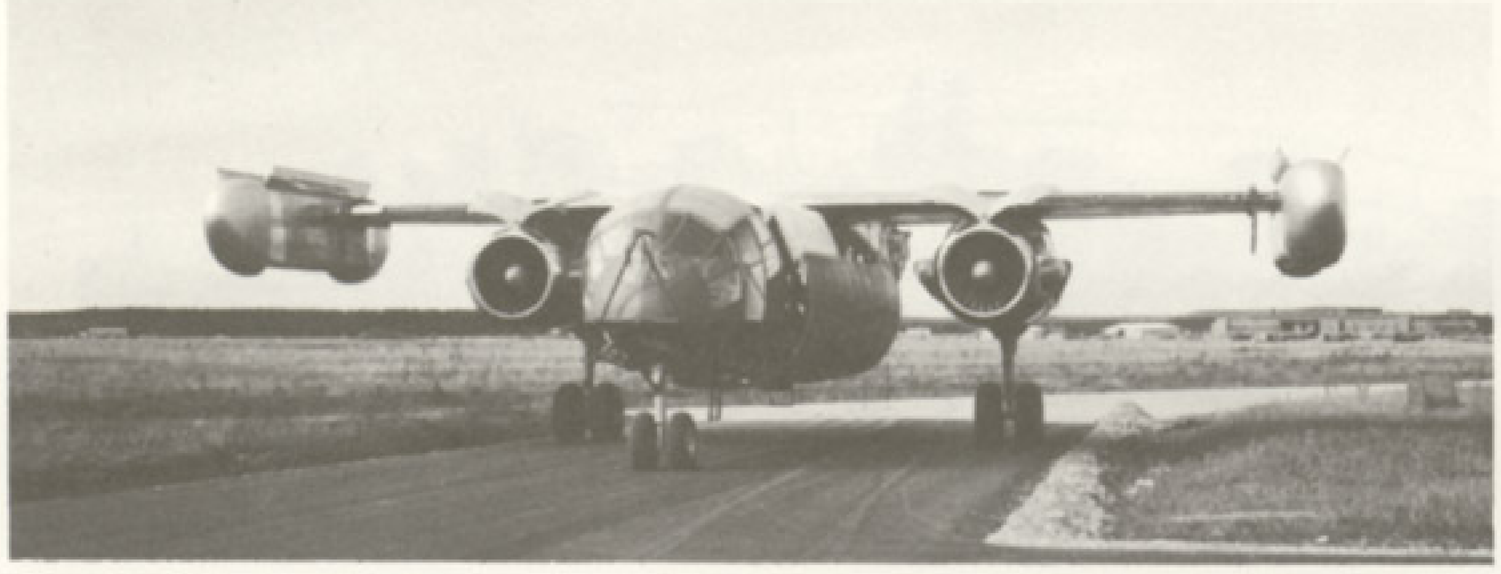
History

The initial ground run using all five engines was undertaken on 1 July 1965. The first test programme on the pedestal facility comprised extensive development testing of the VAK191B stabilisation system. First pedestal test with all axes free was completed on 21 January 1966, and the first free hover was made on 5 August. The rig was demonstrated at the Hanover Air Show in April 1968. Its last test was completed on 13 November 1969 at which date the rig total free flight time exceeded 15 hours and it had been flown by twelve different pilots.

Experience

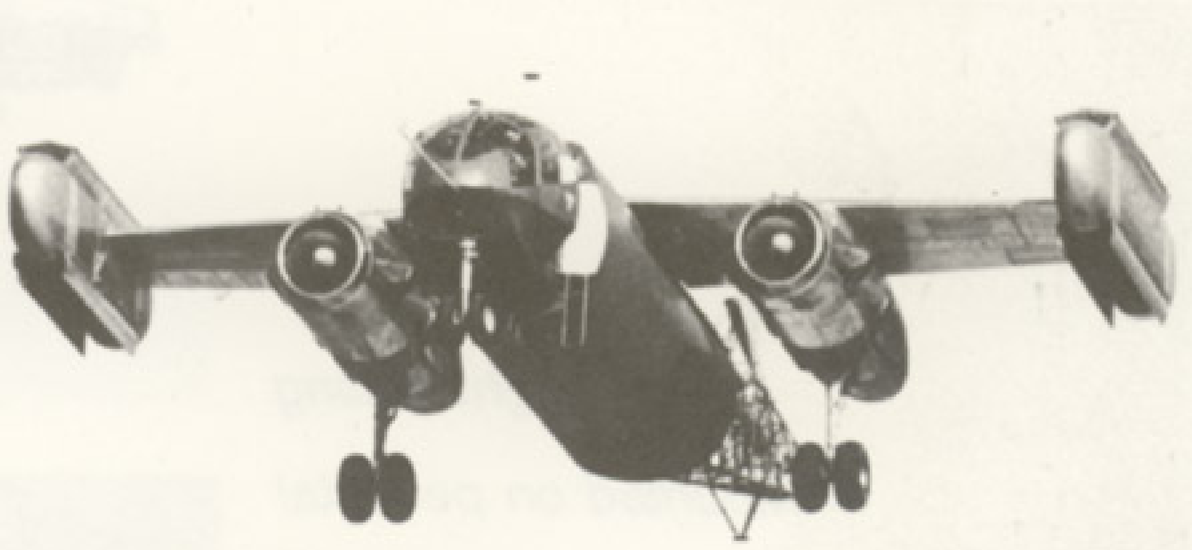
Test duty	Number of tests	Total engine running time	Total number of engine operations
Ground running tests	304	262 hrs	1938
Pedestal tests (wheels off ground)	183		
Free hovering flights	141		

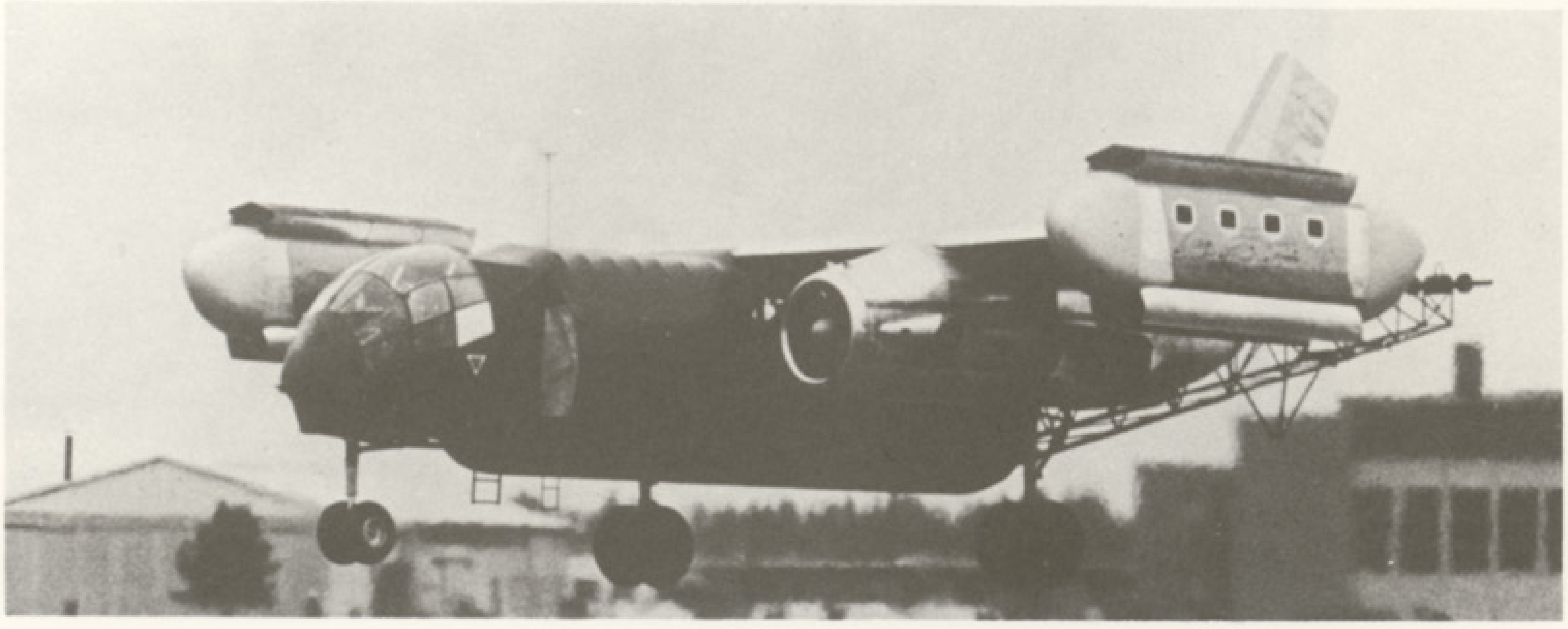
Dornier large hovering rig



Roll-out

Free-flight testing





First hover

Description

This rig was constructed around the full-scale Do31 wing and powerplant nacelles. Two Pegasus 5 vectored thrust engines were used and the two wingtip lift pods were the same as those used on the actual Do31 aircraft, except that each pod contained three rather than four RB162-4 engines. The rig used exactly the same hovering control system, undercarriage and fuel system as the Do31. The aircraft fuselage was represented by a steel tube framework, fabric-covered except for the two-man enclosed cockpit, which had the same layout as that of the Do31.

The prime purpose of this rig was to prove the Do31 hovering stability and control system. In addition, however, valuable development testing of the aircraft powerplant installation was also completed during an extensive ground running programme which included hot gas recirculation and ground erosion testing.

History

Testing was undertaken at Oberpfaffenhofen airfield. The first pedestal test with axes free was completed on 20 July 1966 followed by the first free hover on 24 January 1967. All the testing necessary to prove the Do31 hovering control and stabilisation systems was completed by 12 May 1967. From 26 September to 22 October 1969 this rig was used for Do31 pilot training purposes.

Experience

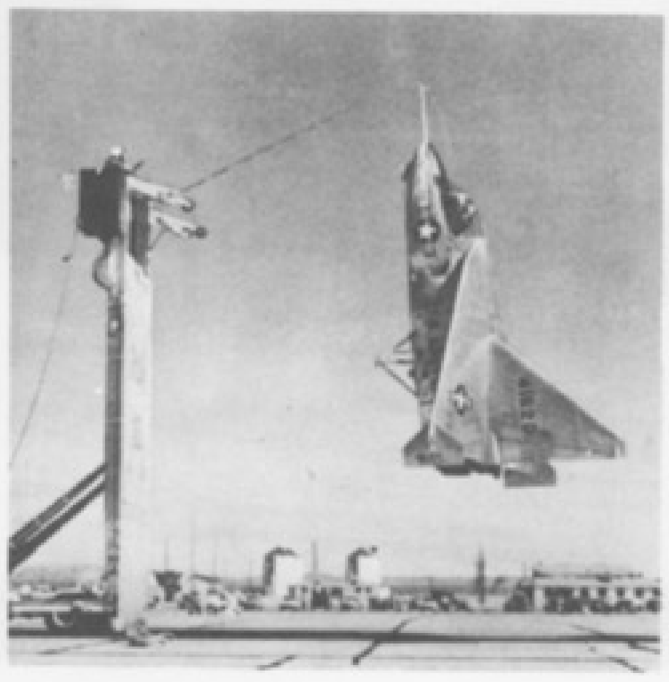
Test duty	Number of tests	Total Pegasus running time	Total lift engine experience	
			Time	Operations
Ground running tests	112			
Pedestal tests	203	50 hrs	65 hrs	1262
Free hovering flights	31			

6 V/STOL engine applications – aircraft

Ryan X-13 Vertijet

Preparation for take-off

Demonstration in Washington



Hover

Description

The Ryan X-13 Vertijet was a small, single-seat, tail-sitting VTOL research aircraft powered by a single Avon turbojet of 10 000lb thrust. The aircraft had a high-set delta wing with small wingtip fins and a large vertical tail fin and rudder. No undercarriage was fitted and the aircraft used a mobile ground servicing trailer with a platform which was raised hydraulically to the vertical position to suspend the aircraft from a hook under its forward fuselage for VTOL operation. This hook engaged on a nylon rope stretched across the front of the vertical servicing platform. During hover the aircraft was controlled by exhaust jet deflection and thrust variations, with roll control supplied by airjets in the wingtips. The pilot's seat pivoted so he could sit in a nearer-upright position with the aircraft in the VTOL attitude.

History

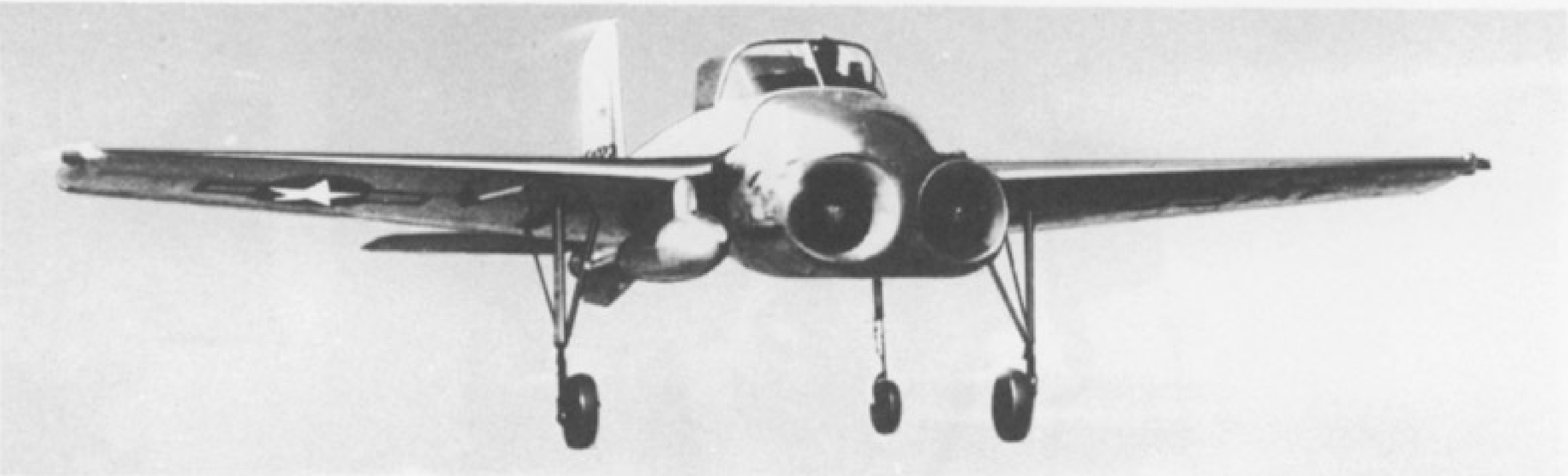
Ryan began research into the possibilities of a VTOL jet aircraft in 1947 by mounting an Allison J33 engine on a horizontal test stand, to investigate methods of varying jet thrust for directional control. Next, the J33 was mounted in a vertical rig (1950-52) and finally was equipped with a cockpit, controls and a delta wing for piloted tethered tests which were Navy funded. As a result of this programme, Ryan received an Air Force contract for the X-13 in 1953 and two Rolls-Royce Avon powered prototypes were built.

The first aircraft, 41619, flew on 10th December 1955 equipped with a temporary undercarriage to permit conventional take-offs and landings. After fitting the tail-sitting landing skid, the first vertical hovering flight was made on 28th May 1956, followed by simulated hook-ons to a nylon rope stretched between two upright steel towers.

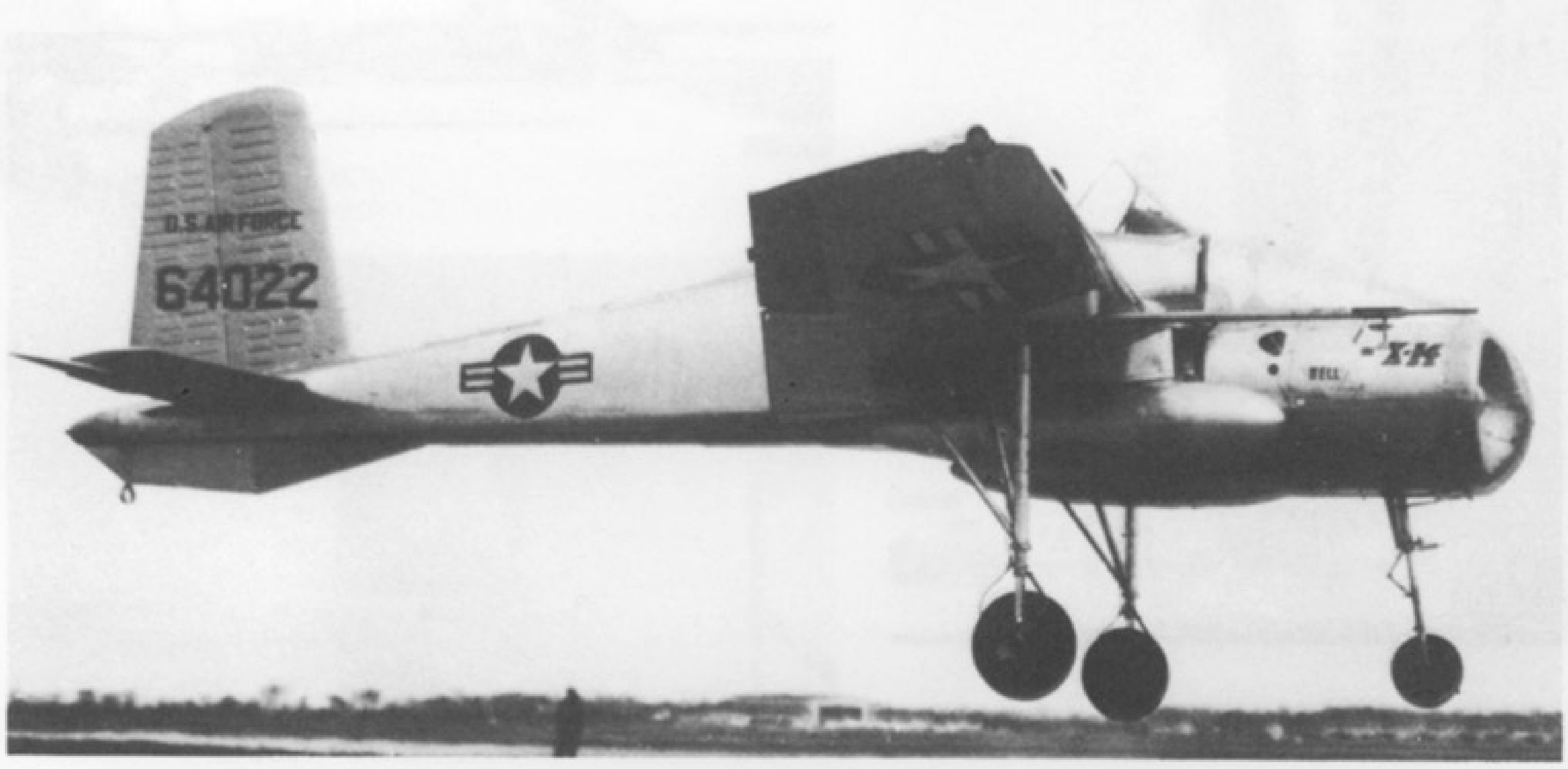
The second prototype, 41620, fitted with a temporary fixed undercarriage, made the first transition from horizontal flight to vertical flight and back to horizontal flight on 28 November 1956. The first complete flight sequence of vertical take-off, transition to horizontal cruise flight and return to vertical landing was accomplished by 41620 on 11 April 1957. In the summer of 1957 this aircraft was demonstrated to the public at the Golden Anniversary of Airpower Air Show at Andrews AFB and at the Pentagon.

The two aircraft completed testing at Edwards AFB in 1958 by which time over 125 VTOL flights had been made. The first aircraft was handed over to the Smithsonian Institute and is now displayed at its birthplace, San Diego, whilst the second aircraft can be seen at the USAF Museum at Dayton, Ohio.

Bell X-14



Free-flight



Hover

Description

The Bell X-14 was an open cockpit mid-wing V/STOL research aircraft, with a wing span of 34 ft and a length of 25 ft. It was originally powered by two Viper turbojet engines mounted horizontally side-by-side in the fuselage nose. Cascade vane type thrust diverters mounted behind the engines directed the jet efflux towards the ground during vertical take-off and landing. At a safe height the jet efflux was directed rearwards to produce a component of forward thrust, this being progressively increased until conventional flight was achieved. The landing transition procedure was the reverse of the take-off technique. Aircraft control during transition was provided by 'puff-pipes' located at the wingtips and tail and supplied with air bled from the engine compressors.

History

The USAF awarded Bell the contract to develop the X-14 in July 1955 and the aircraft was delivered to the flight test department in October 1956. It made its first free hovering flight on 19 February 1957 at Bell's Wheatfield, New York, facility. The first complete V/STOL transition flight was made on 24 May 1958 at Niagara Falls Municipal Airport.

In October 1959 the X-14 was handed over to NASA Ames Research Centre, Moffett Field, California to begin its extensive V/STOL research programme. NASA equipped the aircraft with a variable stability system and in 1960 replaced the Viper engines with GE J-85s.

Short SC1

Early hover trials
over perforated platform

Operation from
small clearing

Description

The Short SC1 was an experimental delta wing VTOL aircraft powered by five RB108 engines. Four of these were mounted vertically on crosswise pairs inside a central engine compartment to provide lift. The thrust from each pair could be swivelled through a total angle of 35° (25° rearward, 12° forward) about the vertical to assist take-off and landing transitions. The fifth engine was installed horizontally at the tail for propulsion. All five engines supplied compressor bleed air to a common duct which fed air nozzles positioned at the wingtips, nose and tail for stability and control in hovering flight.

History

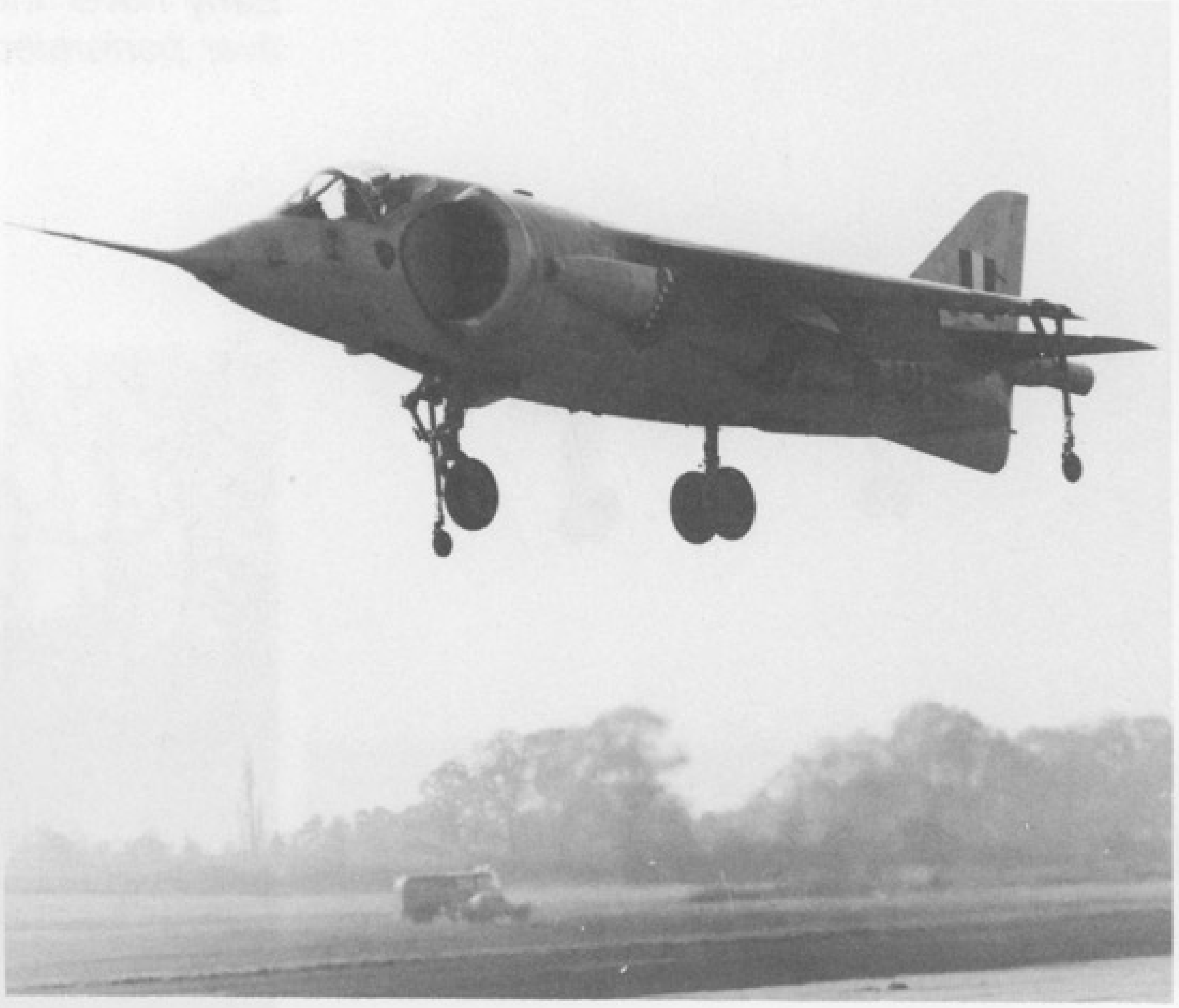
Following a 1954 Ministry of Supply contract, construction of the two SC1 aircraft (XG900 and XG905) began early in 1955. XG900, with a single RB108 installed in the propulsion position, made its first engine run on 7 December 1956 and started taxiing tests at Belfast on 17 December.

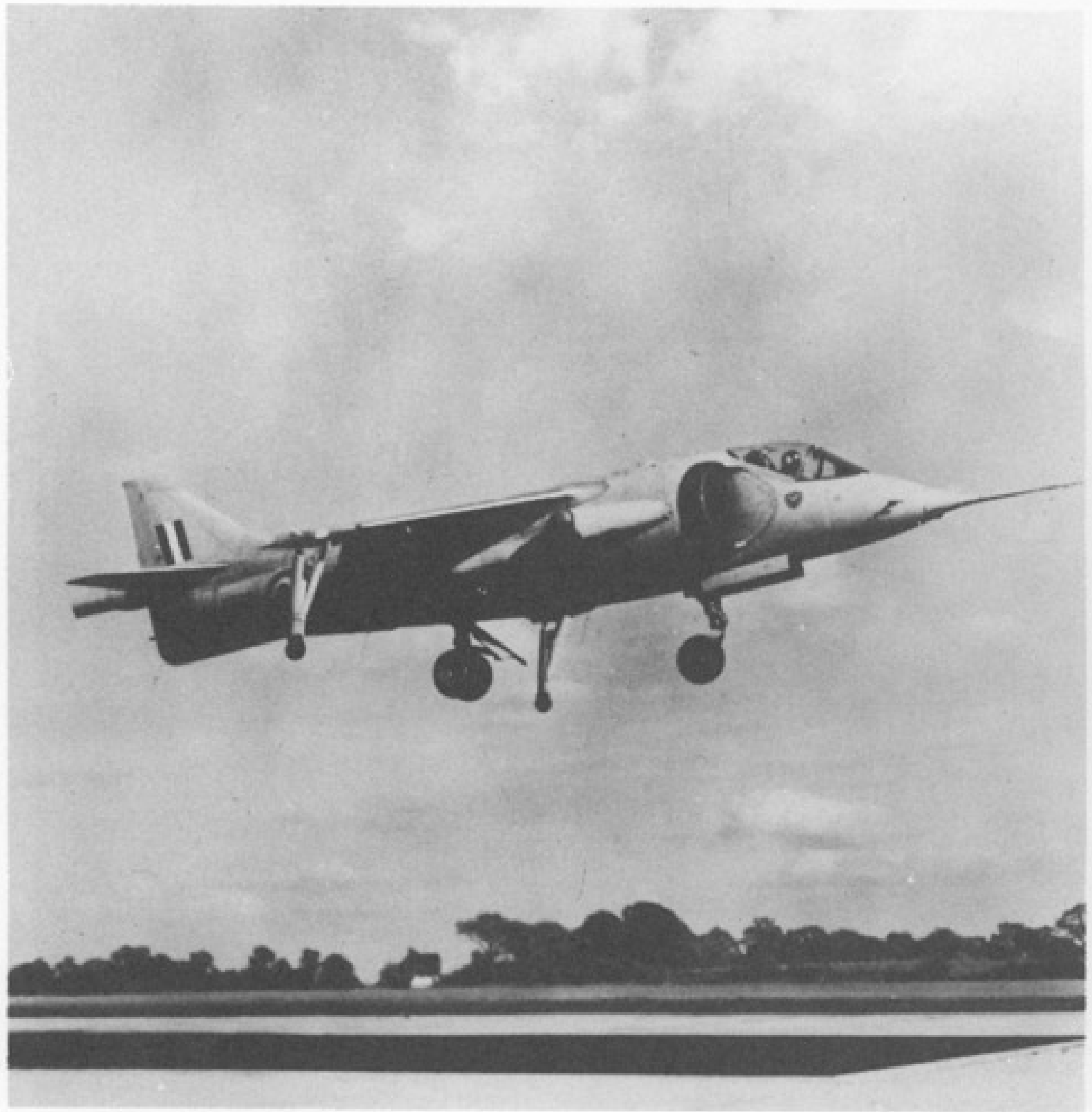
This aircraft was shipped to Southampton and taken by road to the Aircraft and Armament Experimental Establishment at Boscombe Down, arriving on 11 March 1957. Its first flight as a conventional aircraft was then made at Boscombe Down on 2 April 1957. Concurrently, XG905 had been completed at Belfast and this aircraft, with four lift engines installed was positioned in the gantry at Belfast to begin tethered flights on 20 May 1958. Its first free hover was made on 25 October.

In the winter of 1959-60 work began at RAE Bedford to complete the full transition. This task fell to XG905 and the fifth (propulsion) engine was installed while XG900 went into layup. On 27 April 1960, the first complete double transition was made, with XG900 subsequently making its first double transition at Bedford on 23 January 1961. A fatal accident involving XG905 occurred at Belfast in October 1963 due to a gyro system fault during VTOL blind landing testing. XG905 was subsequently rebuilt to restart VTOL flight trials with a hovering flight in the Belfast gantry on 17 June 1966. It then joined XG900 at RAE Bedford in May 1967. Until 27 September 1968, when its test programmes finished, XG900 was used for pilot familiarisation, take-off transitions with imposed side-slip, conventional take-off and flight relighting checks.

This aircraft is now in the Science Museum at South Kensington, London. XG905 continued to do similar work with the addition of V/STOL commercial transport profiles plus further V/STOL stabilisation and control testing, and is now preserved in Northern Ireland.

Hawker P1127





Description

The P1127 was a single seat, shoulder-wing aircraft powered by a single Pegasus engine. The bicycle main undercarriage was supplemented by outriggers mounted at the tips of a single-piece mainplane having very marked anhedral.

The bifurcated air intake was fitted with an inflatable lip to ensure efficient operation during both hovering and high speed flight. This intake fed the Pegasus engine which was mounted in such a position that the resultant thrust of its four nozzles (two on each side of the fuselage) passed very near to the aircraft centre of gravity, independent of their angular position. Control in the hover or partial jet-borne flight was achieved by ducting engine compressor delivery air to 'puff-pipes' located at the wingtips, nose and tail of the aircraft.

History

The privately-funded design study of the P1127 using the original three-nozzle BE53 concept was made in 1957 but was almost immediately revised to incorporate the now familiar four-nozzle system of the Pegasus.

Only seventeen months after first cutting metal, the first prototype, XP831, made the first successful tethered hover on 21 October 1960, by which time a UK Government contract had been awarded for two prototype and four development aircraft. The first untethered hover was achieved on 19 November 1960 and conventional flight trials commenced on 13 March 1961 at RAE Bedford. The first transitions to and from hovering flight were completed on 12 September.

The last of the four development aircraft, XP984, was considerably modified during construction to become the prototype of the Kestrel series of aircraft for the Tripartite Evaluation Squadron.

XP831 is now displayed at the Royal Air Force Museum in London.

Marcel Dassault Balzac

Conventional flight

Vertical take-off

Description

The Balzac was a V/STOL jet lift research aircraft which served as a predecessor to the Mirage III-V. Avions Marcel Dassault converted an early delta wing Mirage III-C prototype airframe to accept one Orpheus propulsion engine plus eight RB108 lift engines. Four near-vertical RB108s were mounted on each side of the central Orpheus air intake duct. Each row of four RB108s was split into two groups of two by the main undercarriage wheel bays, and each pair was fed from a single scoop-type intake fitted with blow-in louvres based on the design principles successfully used for the SC1. Hovering control about all three axes was achieved by wingtip, nose and tail-mounted 'puff-pipes' fed by air supplied from all eight RB108 lift engines.

History

The contract for the Balzac was obtained in February 1961. Initial lift engine ground tests were carried out on 31 July 1962 followed by the first tethered hover on 12 October. Free hovering flights were carried out in late October and early November until the aircraft was grounded for airframe modifications.

The programme resumed on 2 March 1963 with conventional flights and the lift engines were started in the air for the first time on 14 March. On 18 March the first take-off transition was made, followed by the first landing transition on 28 March and the first double transition on the next day. The programme continued with a flight conducted on 18 July with one RB108 deliberately shut-down to demonstrate engine-out safety.

Following the fitting of thrust deflector doors in place of the previous scuttle and door arrangement, further flights were successfully carried out. On 10 January 1964 the aircraft crashed following a divergent oscillation in roll from a stationary hover at 200 feet. It was rebuilt and recommenced its programme with initial lift engine ground runs on 28 January 1965, quickly progressing to a double transition by 22 February. A second crash, caused by a fuel supply fault, curtailed the Balzac programme on 8 September, but by that time the first Mirage III-V had flown.

Hawker Siddeley Kestrel

Tripartite Squadron Kestrels

Development Kestrel

Description

Kestrel was the name given to the nine developed P1127 aircraft jointly ordered for operational V/STOL evaluation by the British, West German and United States governments. Design developments included the use of the 15 500 lb thrust Pegasus 5 engine, a fully-swept wing with reduced span and thickness/chord ratio, a taller fin, a longer front fuselage and a nose camera installation. The inflatable intake lips used on the P1127 were deleted in favour of a simpler fixed design. The Kestrel was the first ever jet V/STOL aircraft to be granted a service release, including night flying.

History

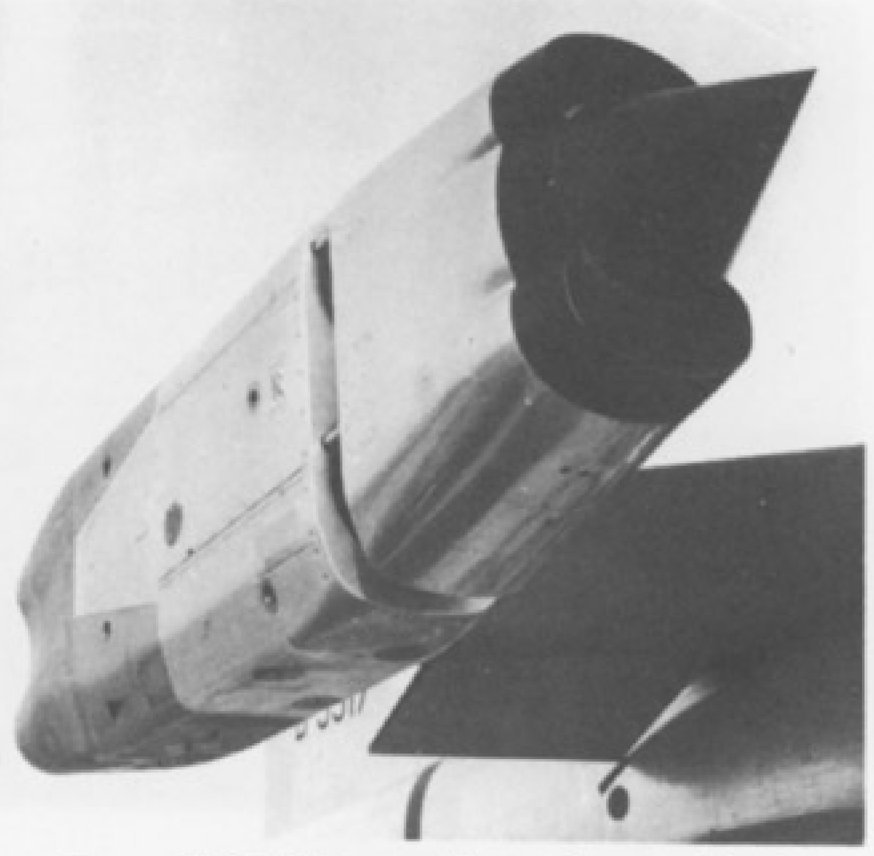
Early in 1962 the order for the nine Kestrel aircraft was announced and the first aircraft, XS688, flew on 7 March 1964. All the aircraft were delivered to the Tripartite Evaluation Squadron which was based at West Raynham, Norfolk, between April and November 1965.

Following this highly successful seven-month evaluation programme, six Kestrels were shipped to the USA early in 1966 where the aircraft became known as the XV-6A and equipped the Tri-Service Team for further evaluation. This trials period with the US Army, Navy and Air Force came to an end on 31 July 1966, after which four of the aircraft were sent to Edwards AFB and the other two to the NASA test facility, Langley, Virginia. The two Kestrels remaining in the UK had meanwhile become associated with the flight development programme of the P1127 (RAF) aircraft which was later named the Harrier.

The Smithsonian Institute, Washington, has a Kestrel XV-6A.

EWR VJ101C

Conventional flight



Two RB145 engines in swivelling wingtip pod

First aircraft (unreheated engines)

Second aircraft (reheated engines)

Description

The EWR VJ101C was a single-seat VTOL experimental high-wing aircraft which was built and tested to provide data for a definitive Mach 2 VTOL interceptor. The aircraft was powered by six RB145 engines and its chief design feature was the use of wingtip engine pods which swivelled through a total angle of 94°. Each wingtip pod contained two RB145 engines. The remaining two engines were mounted in a fixed vertical attitude in tandem in the fuselage centre section. In their vertical thrust position, the two wingtip pods combined with the fuselage lift engines to form a triangular VTOL lifting system which enabled hovering roll and pitch control to be achieved by differential thrust modulation. Yaw control of the hover was accomplished by differential pod swivelling.

Two VJ101C aircraft, X-1 and X-2, were constructed and flown. None of the six RB145 engines in X-1 was fitted with reheat, but X-2 had two RB145R reheated lift/cruise engines installed in each wingtip pod. The pod featured a translating Mach 2 twin-engine air intake plus a sophisticated swivel joint through which all the engine services passed to the wing. The design, development and manufacture of the complete wingtip pods for both X-1 and X-2 was undertaken at Rolls-Royce, Hucknall.

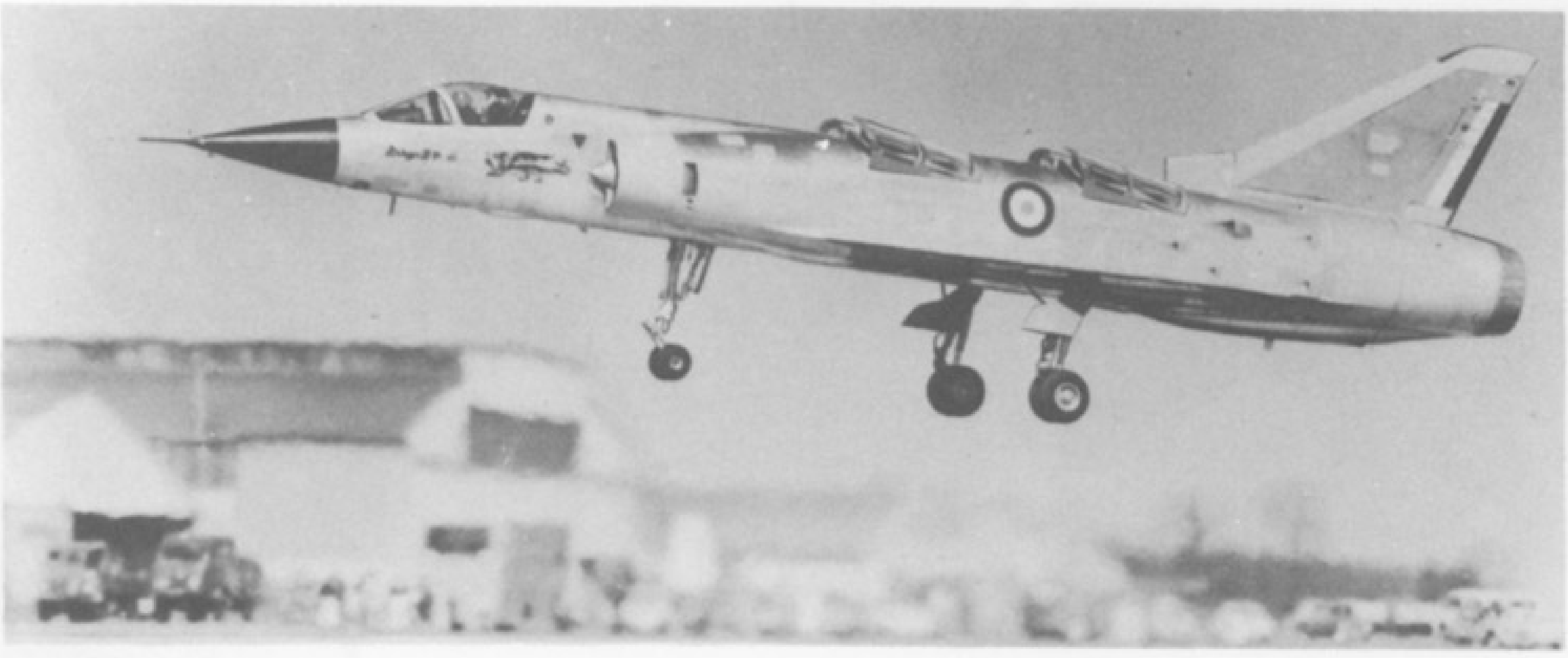
History

Initial ground testing of X-1 took place in January 1963 with the first free hover following on 10 April. Take-off, landing and then double VTOL transitions were successfully completed in September and October. In April and May 1964 the aircraft was demonstrated at the Hanover Airshow. In August, a brief programme of high speed flying was carried out in which the unreheated X-1 aircraft exceeded Mach 1 several times. Following a conventional take-off on 14 September 1964, X-1 was totally destroyed in an accident which was traced to the installation of an incorrect auto-stabiliser unit. The pilot ejected safely.

X-2 commenced ground running in October 1964 and made its initial free hover on 12 June 1965. This aircraft completed its first double VTOL transition using reheat on 22 October 1965 and remained in use for a variety of VTOL flight test programmes until early 1971.

X-2 is preserved at the Deutsches Museum in Münich.

Marcel Dassault Mirage III-V



Description

The layout of this Mach 2 single-seat VTOL strike aircraft was generally similar to that of the conventional and contemporary Mirage III-E. However, the III-V could be distinguished by its lengthened fuselage and its compound-sweep delta wing produced by increasing the wing chord near the leading edge root. Two III-V aircraft prototypes were built. Each had eight RB162-1 lift engines mounted in a near-vertical attitude, four on either side of the propulsion engine air intake duct. As on the Balzac, four separate lift engine bays were used.

Propulsive thrust for the first aircraft was originally provided by a Snecma TF104 but this was subsequently replaced by a reheated Snecma TF106 of 16 775 lb thrust. The second prototype used a reheated P & W TF30 of 18 520 lb thrust and incorporated several other design modifications. These included improved lift engine intake and exhaust configurations, improved lift engine bleed valves, a lengthened fuselage and deletion of the APU. Control during hover on both aircraft was achieved by a wingtip, nose and tail mounted 'puff-pipe' system fed by air bled from the compressors of all lift engines.

History

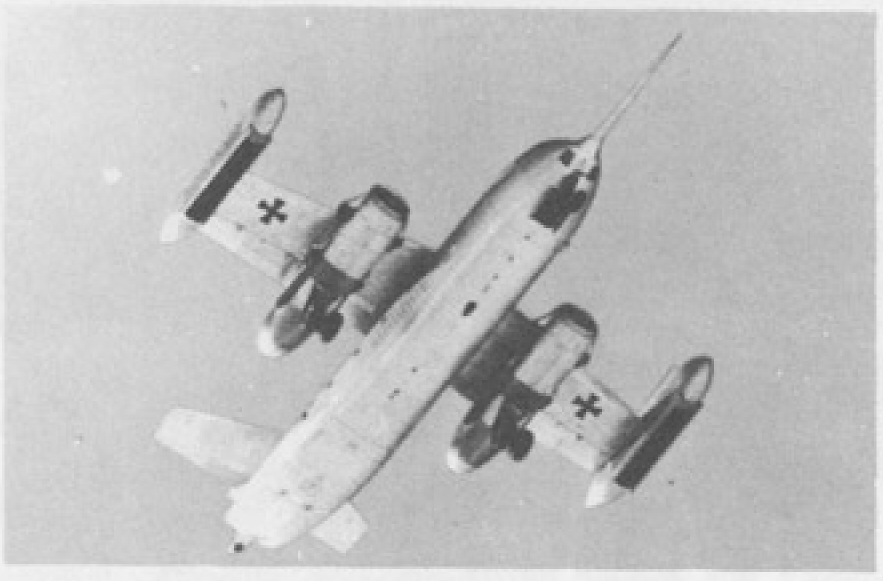
Following the usual build-up of ground checks and tethered hovering trials, the first aircraft (V-01) made its first free hover on 12 February 1965, and the first conventional flight followed on 24 July. During this period the lift engine thrust deflecting doors were removed to reduce drag and weight, eventually to be replaced in the latter part of 1965 by 'bomb-bay' doors. Flight testing recommenced in February 1966 with in-flight starting checks of the lift engines. The first VTOL transitions were made in late March 1966.

The second aircraft (V-02) made its initial free hover on 22 June 1966. Its first conventional flight took place on 1 July and it exceeded Mach 2 on 12 September. VTOL transitions were made in early November. On 28 November, during its sixth transition, V-02 crashed and was totally destroyed. The CEV pilot, who was making his first Mirage III-V flight, ejected safely.

V-01 is held by the Musée de l'Air at Le Bourget.

Dornier Do31

Conventional flight



Hover

Vertical take-off

Description

The Dornier Do31 was an experimental V/STOL transport aircraft powered by two Pegasus 5 vectored thrust engines plus eight RB162-4 direct lift engines. The two Pegasus engines were installed in underwing nacelles which also contained the main undercarriage assemblies. Four RB162-4s were installed in line in each of two wingtip pods. Each RB162 was fitted with a ±15° swivelling final nozzle. Differential swivelling of the port and starboard sets of lift engine nozzles provided aircraft yaw control at the hover. Hovering pitch control was achieved by a duplicated up-or-down rear fuselage located 'puff-pipe' supplied by air bled from both Pegasus engines, while differential thrust modulation of port against starboard lift engines provided hovering roll control.

History

Two Do31 prototypes were constructed under a German Defence Ministry contract. The first of these made its initial flight in February 1967 to prove the airframe conventional flying characteristics. The second aircraft made its first conventional flight in July 1967 to be followed in November by the first free hover, and in December by the first vertical take-off and vertical landing transitions. The final phase of testing included an intensive series of take-off and landing trials conducted in conjuction with NASA. The programme ended in May 1970 and the aircraft were then cocooned.

The programme accumulated important new data on stability and control and also on the optimisation of transition techniques for large V/STOL aircraft. In addition, valuable information was gained on the control and maintenance of multiple engines, all weather V/STOL operation, hot gas recirculation, ground erosion, noise and overload STOL performance. Most of the later testing undertaken by the Do31 was orientated towards obtaining data applicable to the eventual design of VTOL city centre airliners.

The first aircraft is preserved by Dornier at Oberpfaffenhofen, and the second is exhibited in the Deutsches Museum.

VFW - Fokker VAK191B

Description

The VAK191B was designed as a subsonic, VTOL, tactical reconnaissance strike fighter, with one RB193-12 four-nozzle vectored thrust turbofan and two RB162-81 lift jets. The RB162 engines were installed in a near-vertical attitude fore-and-aft of the centrally mounted RB193 engine. For this application, the RB193 was optimised for cruise performance, whilst the two lift engines provided the additional thrust required for VTOL. The attitude of the RB162s was such that they provided some forward thrust component, and flaps blanked the engine exhaust bay when the engines were not in use. Consequently, the aircraft had some horizontal flight capability in the event of failure of the RB193. The highly-loaded anhedral wing was mounted high on the fuselage enabling the RB193 engine to be removed vertically downwards. 'Puff-pipes', located at the wingtips and fuselage extremities, were fed by air bled from all three engines and the ducting system was duplicated to ensure that the loss of any one engine would not result in loss of control.

History

In 1963, the Governments of Germany and Italy jointly instigated a competition to design a VTOL successor to the Fiat G91. The Focke-Wulf Fw1262 was selected and a new company, VFW, was formed to act as prime contractor for the construction and testing of six prototype aircraft, which were renamed VAK191B. The definition phase was started in mid-1964 and go-ahead for the contract was given at the end of 1965.

Due to a reappraisal of Italo-German defence policies and certain economic problems, the programme was successively reduced and the Italian Government finally withdrew in 1968 although Italian participation remained on a sub-contract basis, notably by Fiat. The programme was eventually limited to three single-seat prototype aircraft manufactured by VFW-Fokker, a company formed by merger in May 1969. The three aircraft were completed at Bremen where, after pedestal testing, the first free hover was made on 10th September 1971.

The flight test programme was continued at Manching and the first double transition from jet to wing-borne flight and back was successfully carried out on 26th October 1972. A further double transition, carried out on 6th December, also included undercarriage retraction and wing-borne flight up to a speed of 270 kt. The contract from the German Government ended on 31st December 1972, after which the aircraft were retained as flight systems test beds in the Panavia Tornado programme.

The first aircraft, D-9563, is displayed in the Deutsches Museum.

Augmentor wing C-8A Buffalo

DHC Buffalo

Description

This aircraft was a much-modified de Havilland of Canada C-8A Buffalo. The wing span was reduced, an augmentor flap system was installed including augmentor chokes and drooped ailerons with boundary layer control. Two Rolls-Royce Spey Mk 801SF turbofans were installed which had been modified to produce vectored thrust from vectoring nozzle assemblies.

The modifications were carried out by de Havilland of Canada, Rolls-Royce of Canada and The Boeing Company.

History

The aircraft came about because the US and Canadian governments entered into an international agreement whereby NASA and the Department of Industry, Trade and Commerce (DITC) would modify a C-8A Buffalo to flight test the jet STOL concept.

The modified C-8A was rolled out from the Boeing factory at Seattle on 5 February 1972 and made its first flight on 1 May 1972. It then carried out an extensive 12 month flying programme.

British Aerospace Harrier

USMC AV-8A

Sea Harrier

Vertical take-off

Operation from helicopter platform

Description

Although of similar appearance, the Harrier bears little internal resemblance to the Kestrel. Only about 5% of the basic structure is common to both, while the engineering systems have been completely revised and operational equipment added.

Installation of the more powerful Pegasus 6 (Mk101) engine of 19 000 lb thrust necessitated enlarged air intakes which have auxiliary suction doors disposed around the cowl.

The GR Mk3 and AV-8A versions of the Harrier are powered by the Pegasus 11 engine which develops up to 21 500 lb thrust. The Sea Harrier, a derivative of the GR Mk3, was designed as a fighter, reconnaisance and strike aircraft for defensive/offensive operations from ships. Ninety per cent of the airframe, powerplant and mechanical systems are common with the GR Mk3, but it is fitted with 90% new avionics including a radar. This led to changes in the front fuselage including the raising of the cockpit.

History

The Harrier first flew in August 1966 and production commenced in 1967. Numerous V/STOL operational trials were carried out.

The Harrier entered service with the Royal Air Force in April 1969, the US Marine Corps in 1971 and the Spanish Navy in 1976.

The first flight of the Sea Harrier was in 1978 prior to entry into service with the Royal Navy in 1979 and the Indian Navy in 1982.

The Harrier was ably proved in active service during the Falklands conflict of 1982.

The aircraft has amassed over half-a-million hours in service.

McDonnell Douglas/BAe Harrier II

USMC Harrier AV-8B

Harrier GR Mk5

Description

Developed jointly by McDonnell Douglas and British Aerospace, this aircraft is a direct derivative of the earlier Harrier. It features an enlarged wing with a supercritical aerofoil, with large slotted flaps and ailerons for greater lift capability. The main wing structure and the control surfaces are manufactured in carbon fibre composite.

Lift improvement devices for VTOL have been fitted under the fuselage and leading edge extensions give improved turn performance. The cockpit has been raised to improve the pilots visibility and the rear fuselage lengthened to house new avionics. Carbon fibre has been used extensively and accounts for 26% of the basic airframe weight.

Power is provided by a Pegasus 11-21 which incorporates zero-scarf front nozzles and internal features to reduce operating temperature and increase life and reliability. The air intakes have been modified to improve airflow into the engine.

The aircraft is designated AV-8B for the USMC and GR Mk5 for the RAF.

History

Early in 1976 McDonnell Douglas began work on a series of aerodynamic improvements to the current AV-8A Harrier airframe. Full-size wind tunnel tests indicated sufficient improvement to warrant the modification of two AV-8As into YAV-8B aircraft, although these would go only part way to the proposed final AV-8B design. The first of these flew in November 1978 and the second early in 1979.

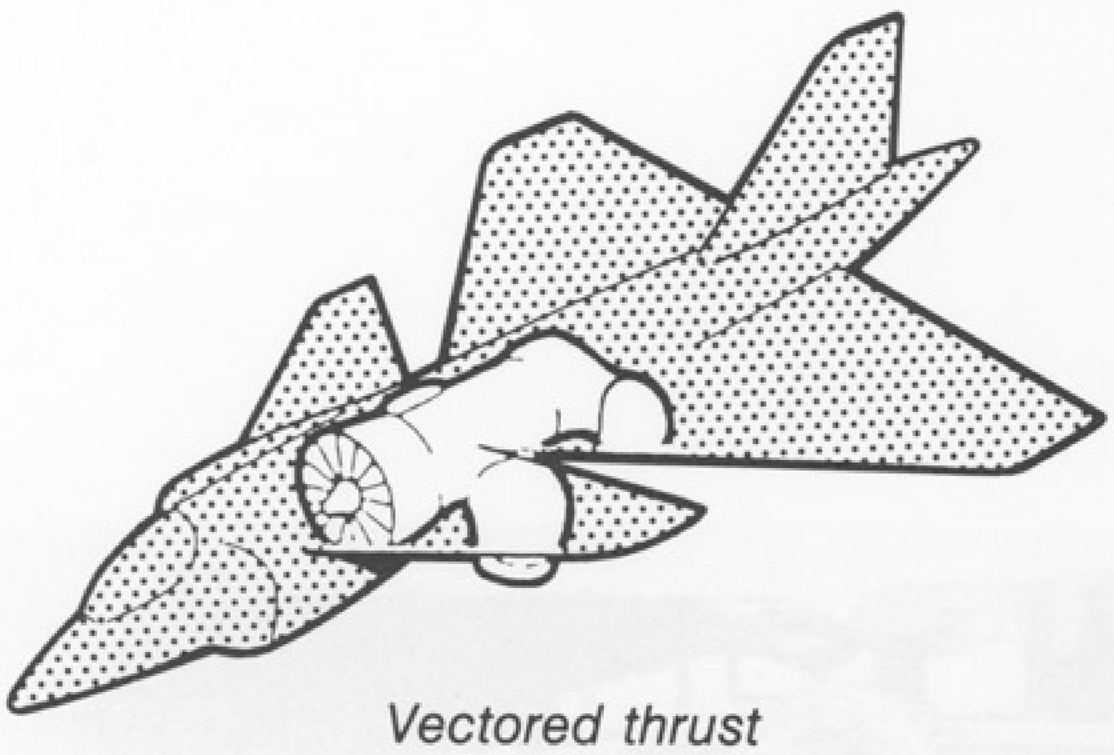
In mid-1978 the US Navy contracted for full-scale development of the AV-8B to proceed with the construction of four aircraft. British Aerospace had worked with McDonnell Douglas from the start of the programme and in 1981 became the major sub-contractor for the AV-8B and prime contractor for the Harrier GR Mk5.

Testing of the AV-8B began in November 1981 and the first of a pre-production batch of twelve aircraft flew in August 1983. A limited production run of 21 aircraft then preceded full scale production of the AV-8B for the US Marine Corps and the Spanish Navy, and the GR Mk5 for the RAF.

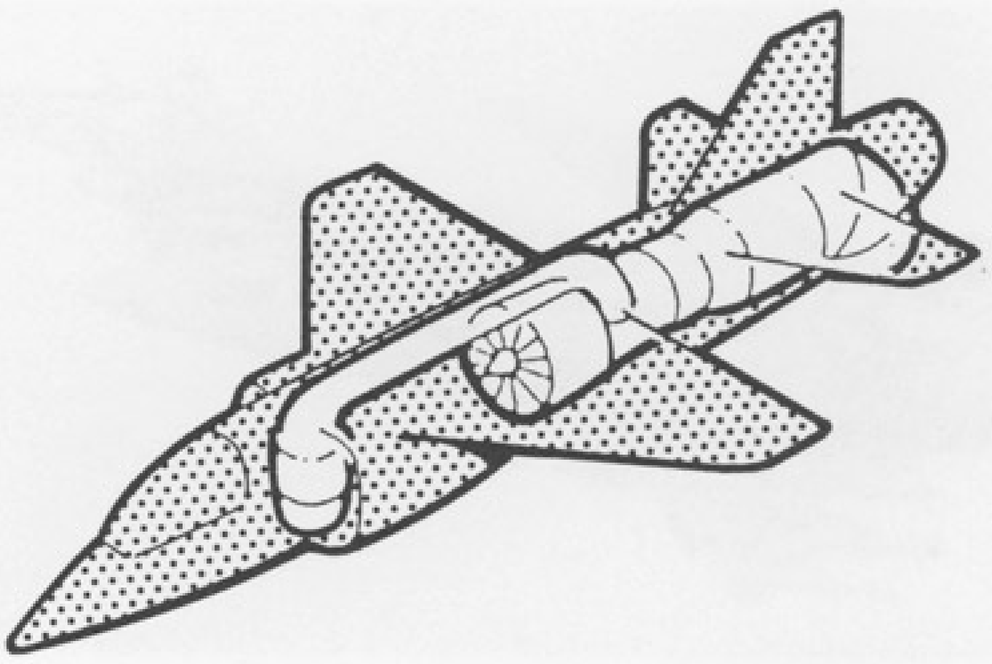
The Harrier II has to date accumulated over 50 000 hours in service in its approved role as a close air support and battlefield attack aircraft. Future developments could lead to a multi-mission Harrier II with radar, a night attack variant and a two-seat tactical aircraft.

7 The future

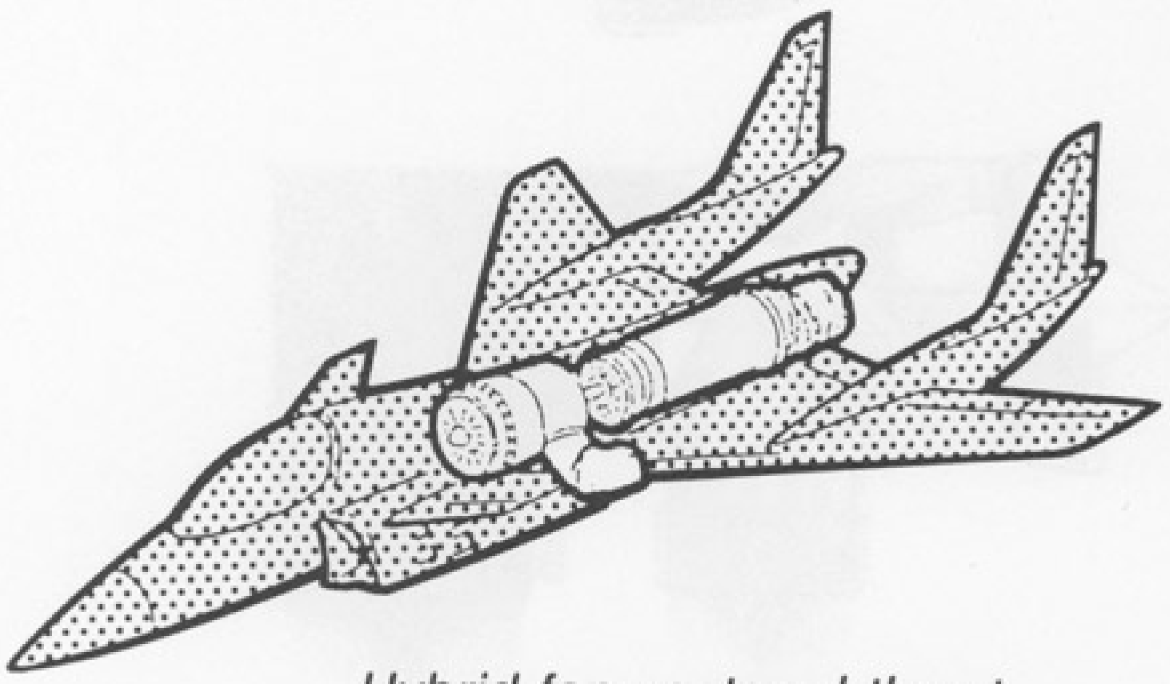
The future



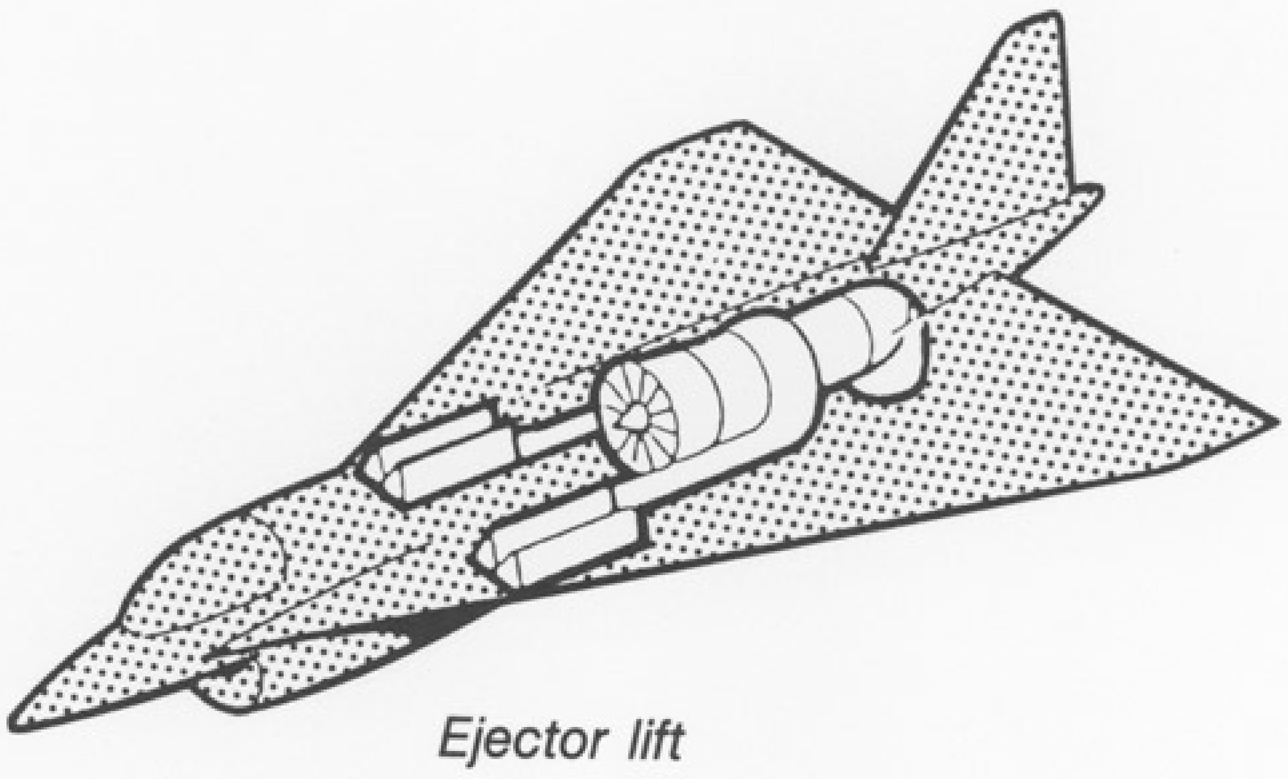
Vectored thrust



Remote augmented lift



Hybrid fan vectored thrust



Ejector lift

Joint studies

Rolls-Royce has undertaken a wide variety of advanced VSTOL studies, specific aspects of which are being further studied following the signature in January 1986 of a US/UK Memorandum of Understanding. Under the terms of this agreement the aim is to evaluate a number of alternative engine concepts/configurations for perceived supersonic advanced short take-off vertical landing (ASTOVL) combat aircraft of the 21st Century.

This work is being undertaken by Rolls-Royce in the UK and US engine manufacturers under separate contracts issued by the respective Governments.

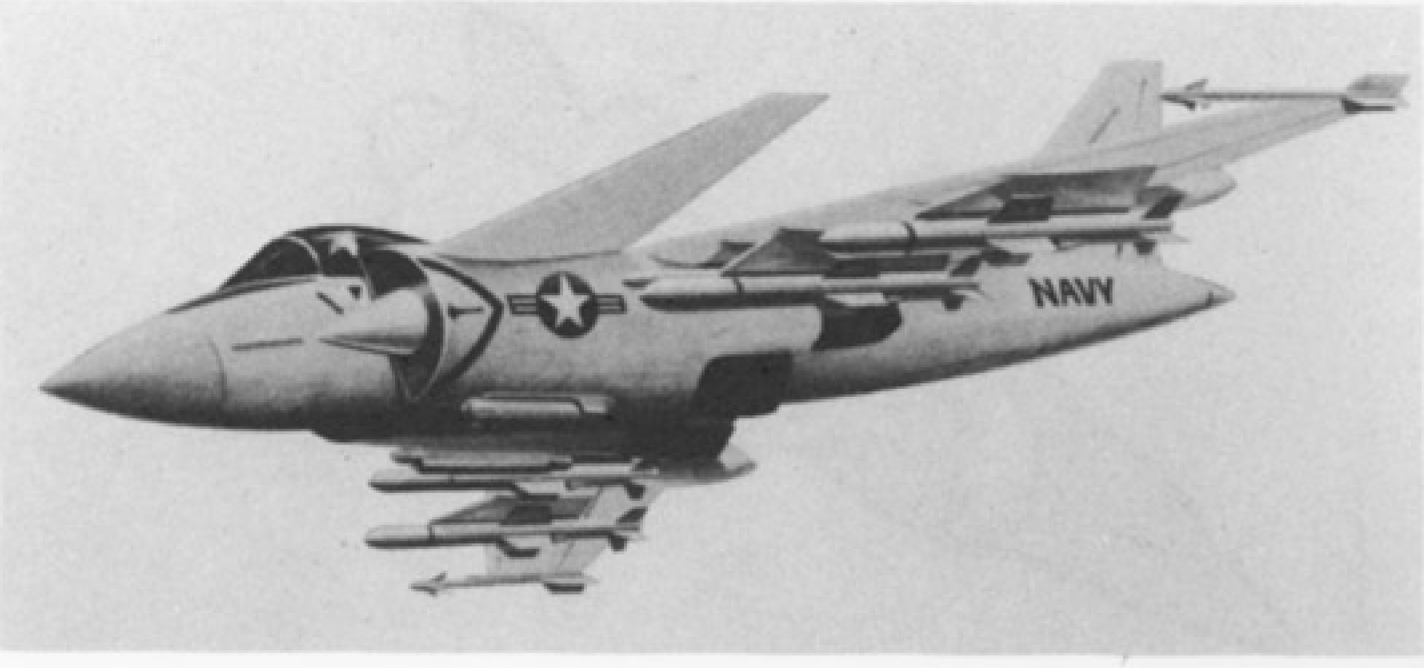
The main concepts under evaluation are:

a) Vectored thrust (with PCB)
b) Tandem/Hybrid Fan
c) Remote Augmented Lift System
d) Injector Lift

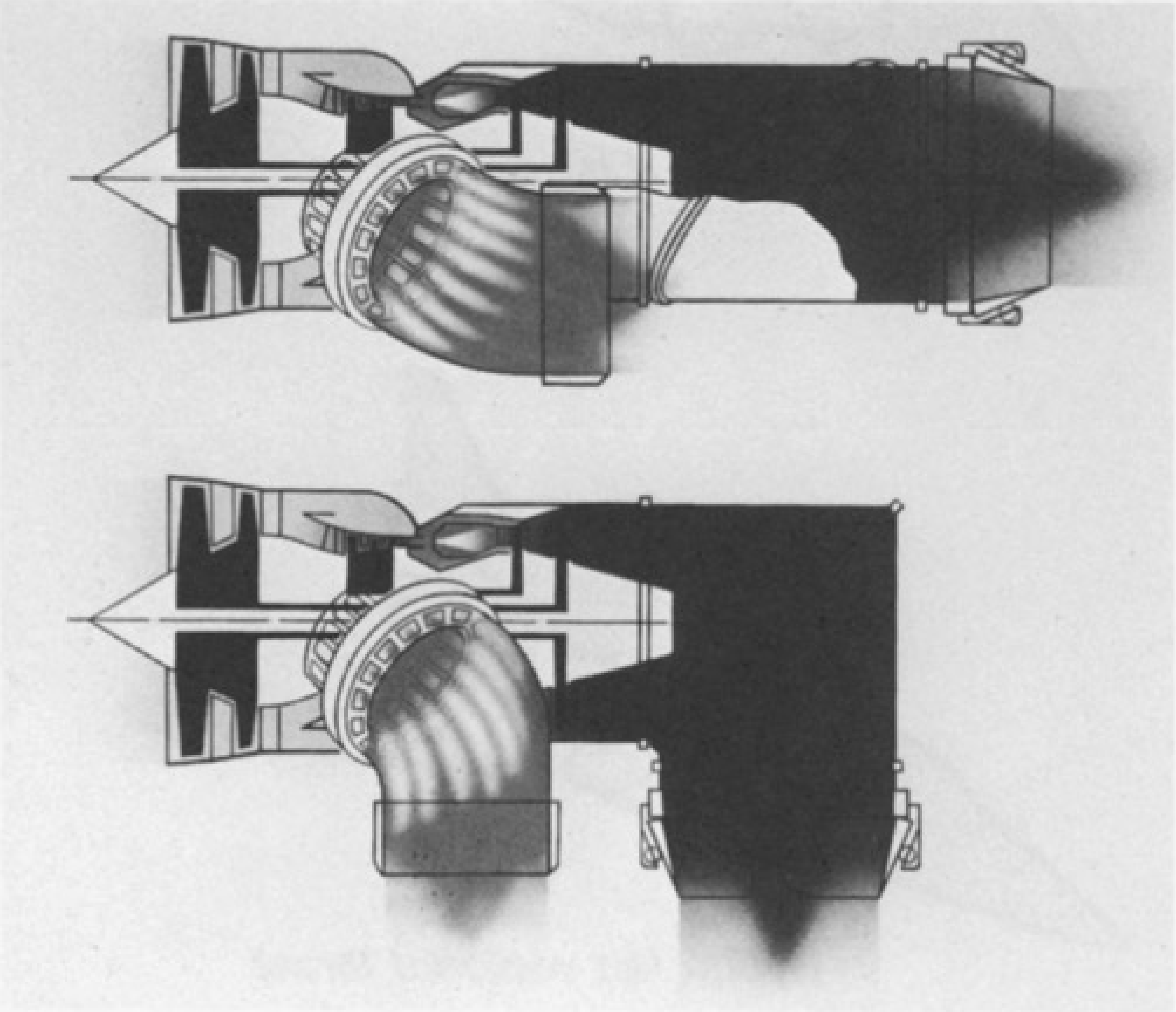
With the exception of PCB these concepts involve variable cycle engine technology and rely heavily on special valve arrangements. (Rolls-Royce valve technology is addressed in Section 3.)

In addition to the Governmental MoU, Rolls-Royce and Pratt and Whitney have signed special agreements in September 1986 and January 1988. These agreements relate to the study of alternative core engines for the 4 main ASTOVL engine concepts. The studies have in view the pursuit of a demonstrator programme, full scale development and production.

Supersonic V/STOL



MD 279-3



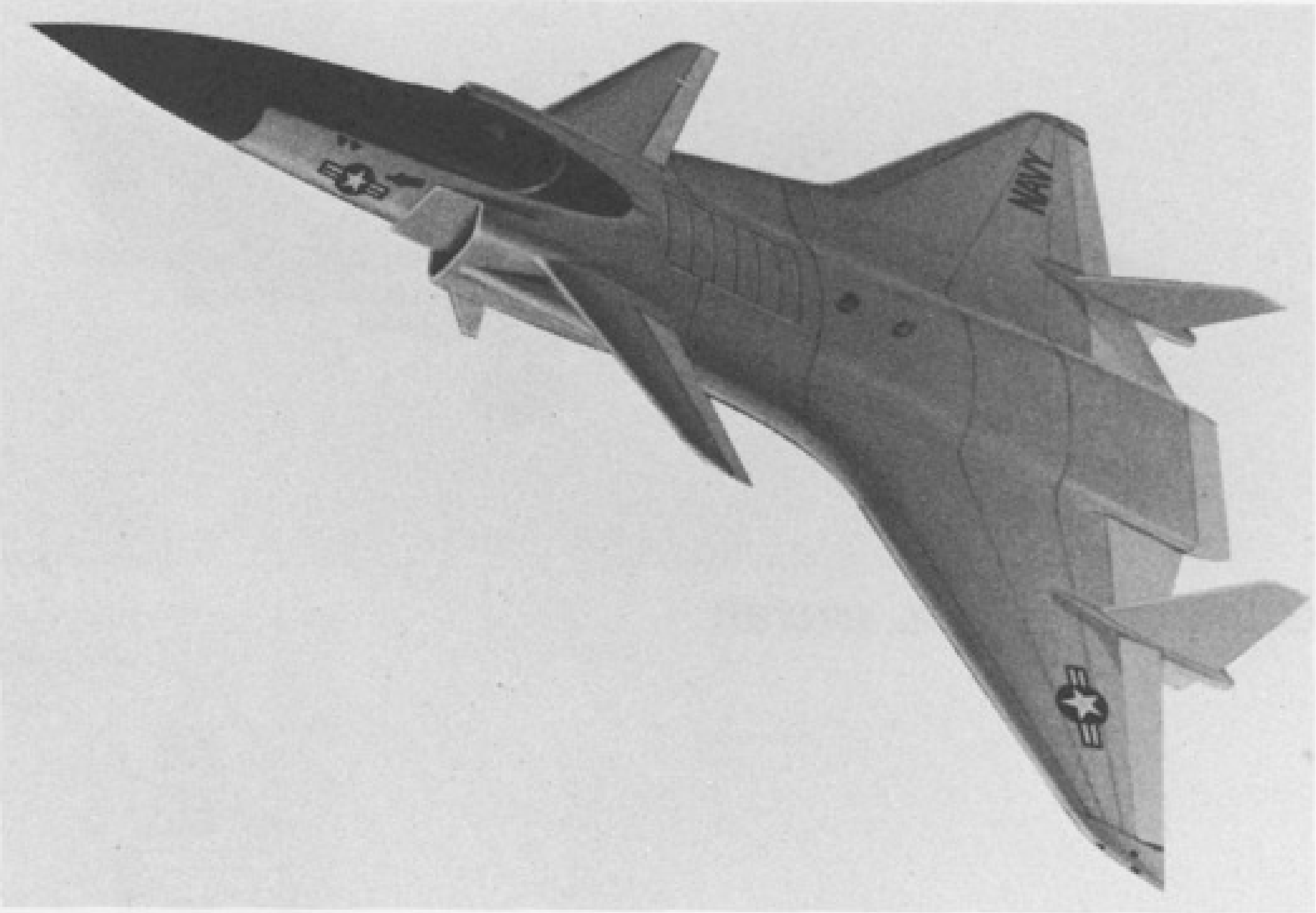
Vectored thrust with PCB

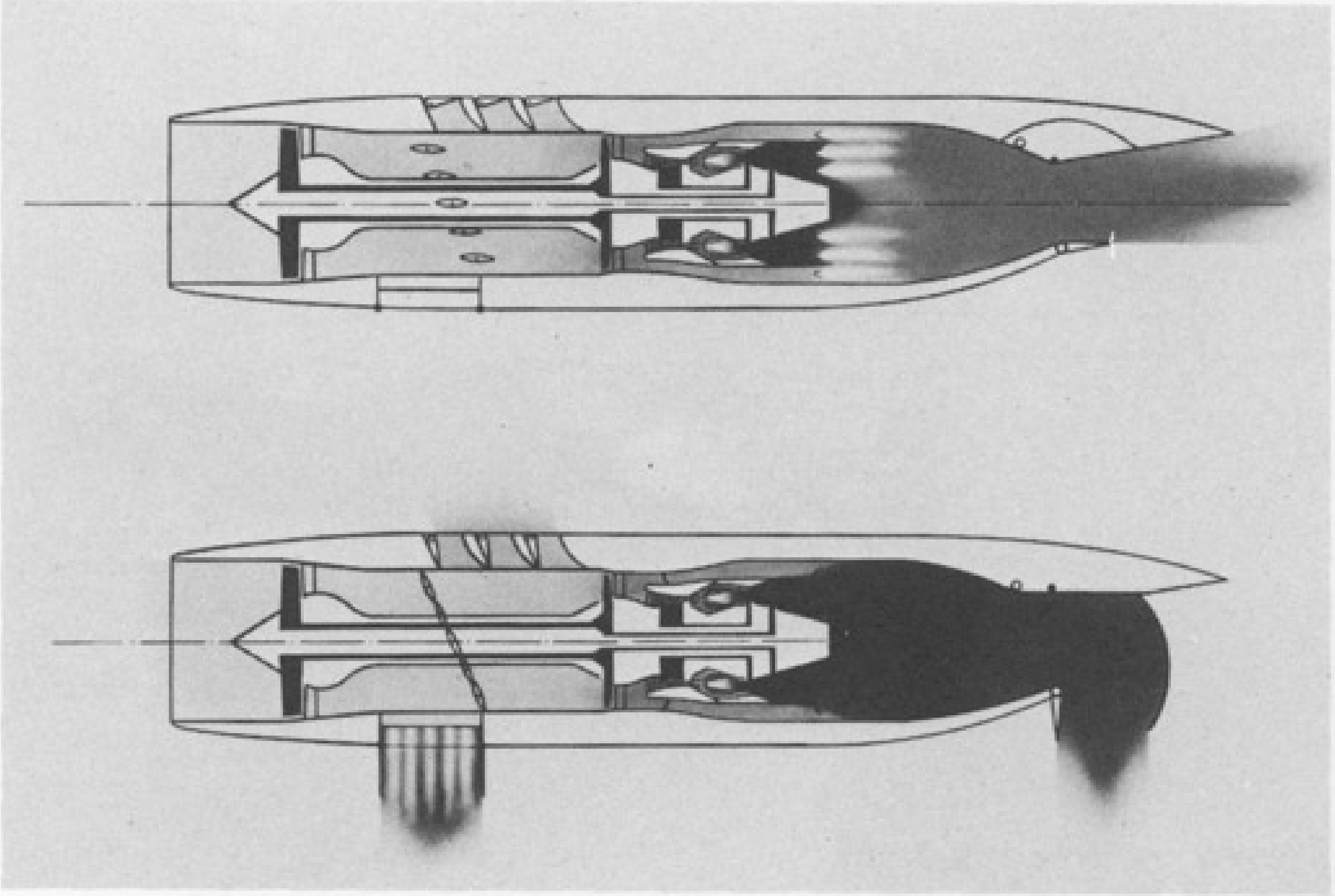
A separate flow powerplant with vectoring nozzles like the Pegasus can achieve a fifty per cent increase in engine thrust by burning fuel in the front nozzles which normally run cold. The aft vectoring system (which may be a single or a pair of nozzles) would remain unaugmented.

PCB can produce nozzle exit temperatures in the region of 1800 K but lesser temperatures might have to be used for vertical operation near the ground to avoid erosion and other problems.

Supersonic V/STOL

Vought TF120 (Tandem fan)





Lockheed hybrid fan concept

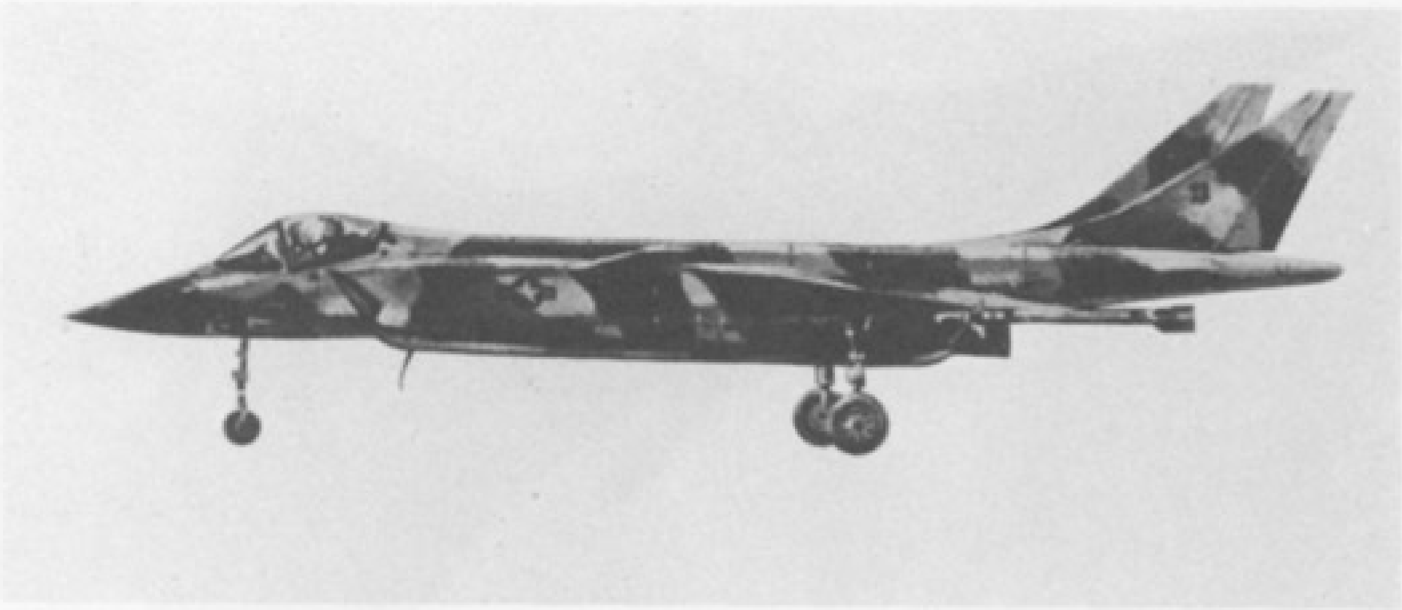
Tandem fan

The tandem fan is a variable-cycle turbofan with an elongated low-pressure compressor shaft so that the fan is in two sections.

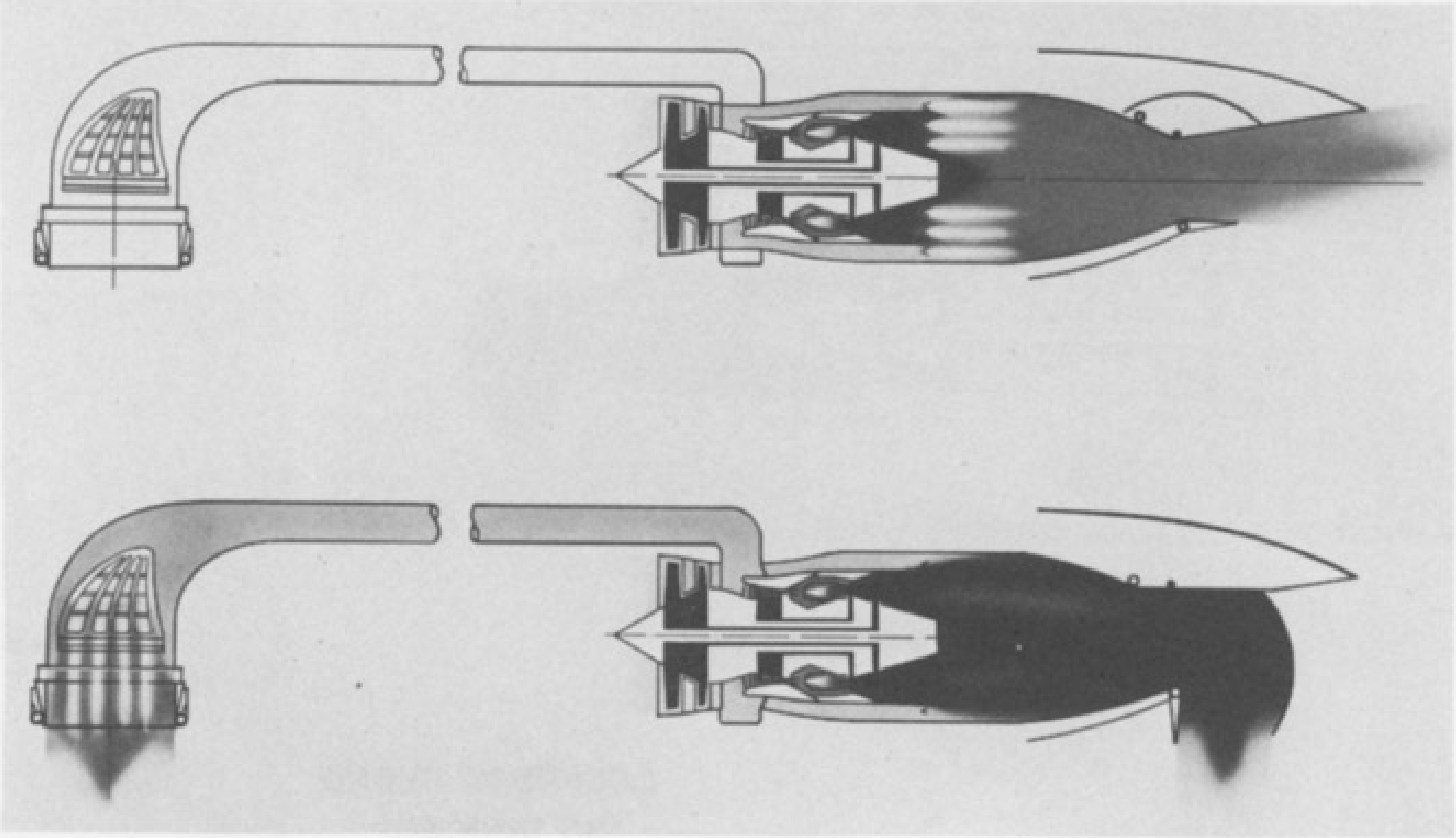
A valve inside the elongated section directs air in one of two directions depending on the flight mode. For take-off and landing the valve directs the front-fan flow into the front nozzle. Intakes on top of the fuselage are opened simultaneously to feed the rest of the engine which has a vectoring rear nozzle. In forward flight the top intakes are closed and the front-fan flow is fed straight to the main engine.

Rolls-Royce has derived a modified version of the tandem fan termed the "Hybrid fan vectored-thrust engine". It has Pegasus-style vectoring front nozzles which can be augmented with PCB. It has the advantage of eliminating problems associated with the transition to or from wingborne flight, the thrust now simply being vectored.

Supersonic V/STOL



Grumman V/STOL aircraft



Remote augmented lift system

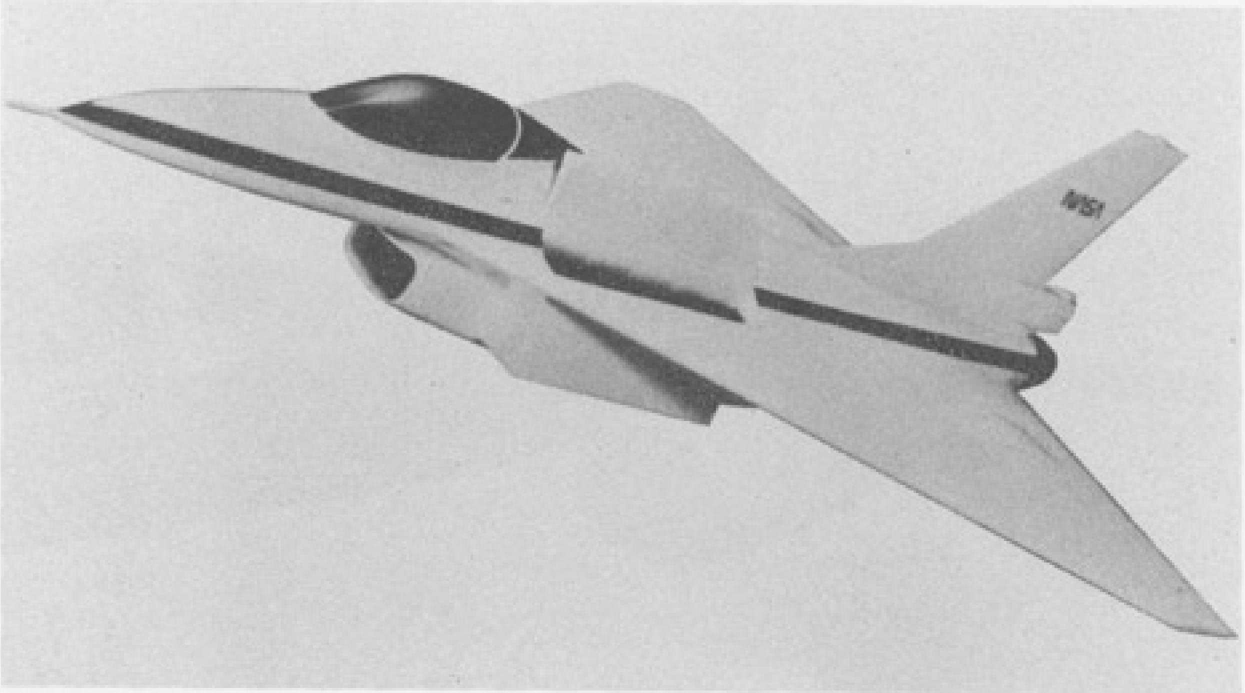
The RALS concept involves the engine being mounted near the rear of the airframe away from the airframe centre of gravity.

Compressed air is piped from aft of the fan into remote nozzles with burners at the front of the airframe. This arrangement provides lift thrust and balancing deflected core thrust from the aft vectoring nozzle.

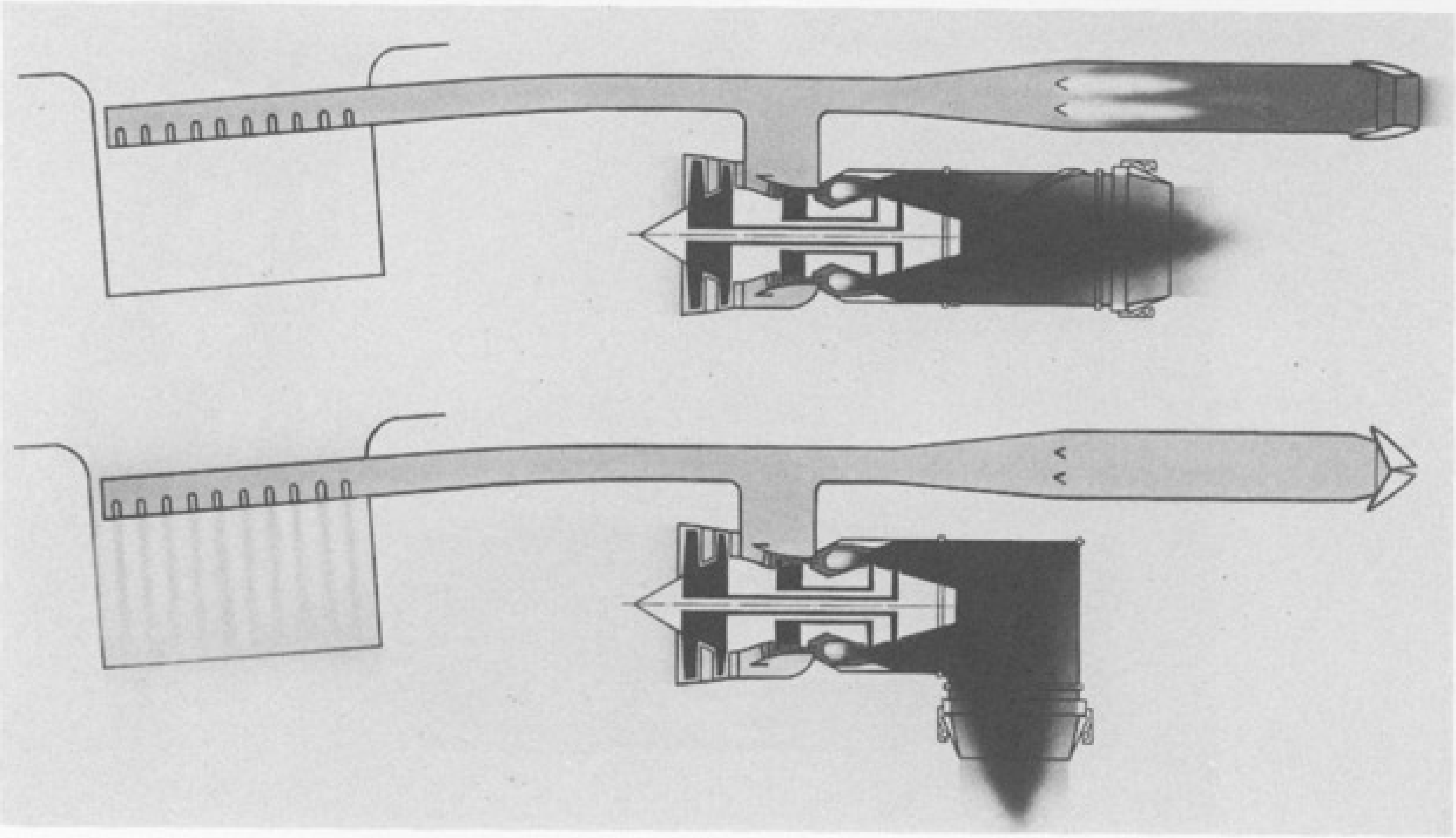
Ducts allow air to move through the fuselage in two opposing directions; a long intake channel feeds the engine, with two smaller channels on either side returning cold air to the front nozzles.

For supersonic wingborne flight the bypass air is ducted to a separate 'afterburning' nozzle or is mixed with the core flow and then burnt.

Supersonic V/STOL



General Dynamics E7



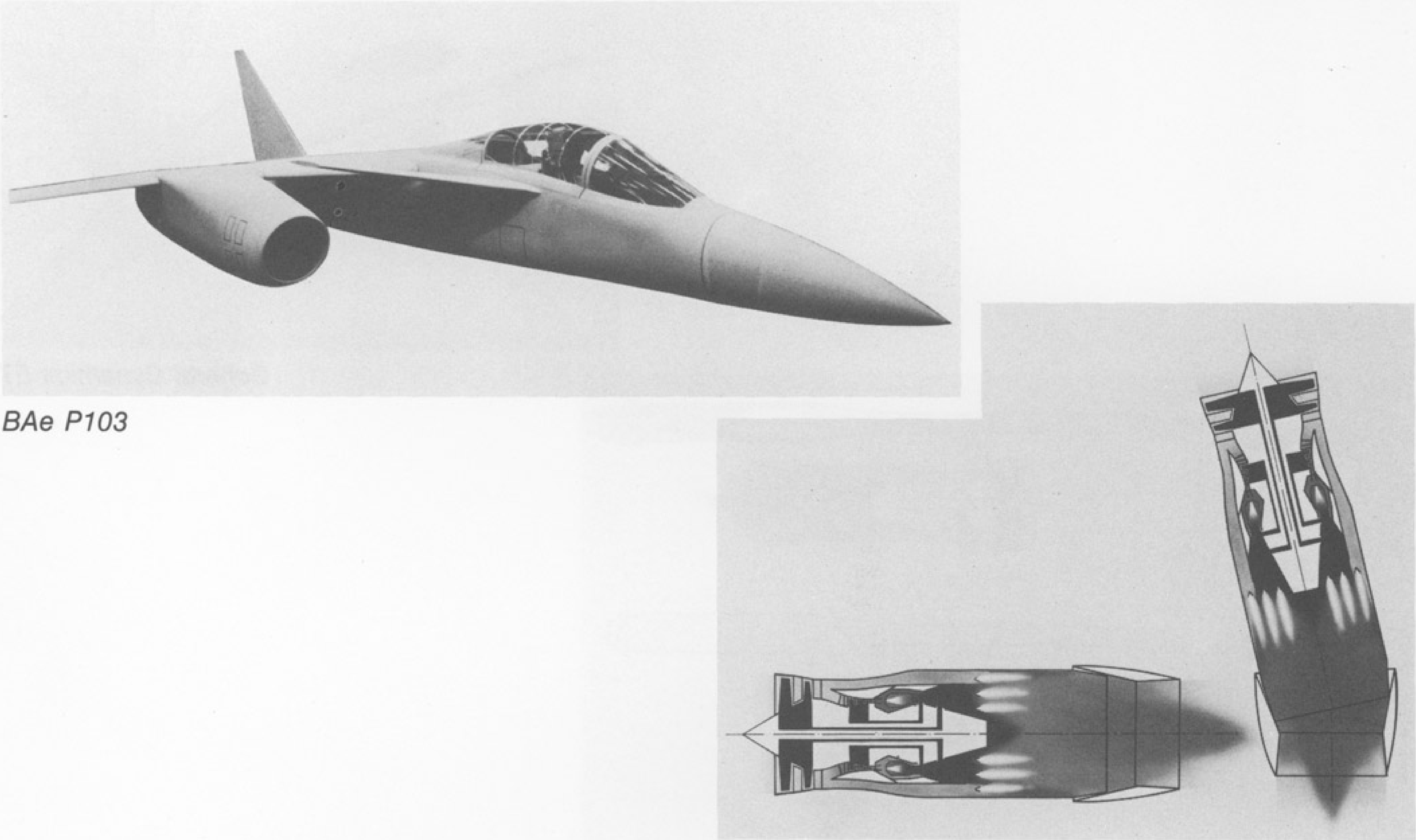
Ejector lift

The ejector lift concept is similar to that of 'RALS' but has a much lower temperature and pressure exhaust flow and thus a more benign ground footprint.

This design has compressed fan airflow diverted through ducts to a series of ejectors in the wing structure. The ejectors are nozzles that exhaust the high pressure fan air entraining more flow through wing passageways to augment thrust and hence produce lift for vertical take-off and landing.

In forward flight the ejectors are closed off and folded into the wing to reduce drag. The entire engine flow, mixed or separate, is then fed into a nozzle where it can be reheated for supersonic operation.

Supersonic V/STOL



BAe P103

Tilt nacelle

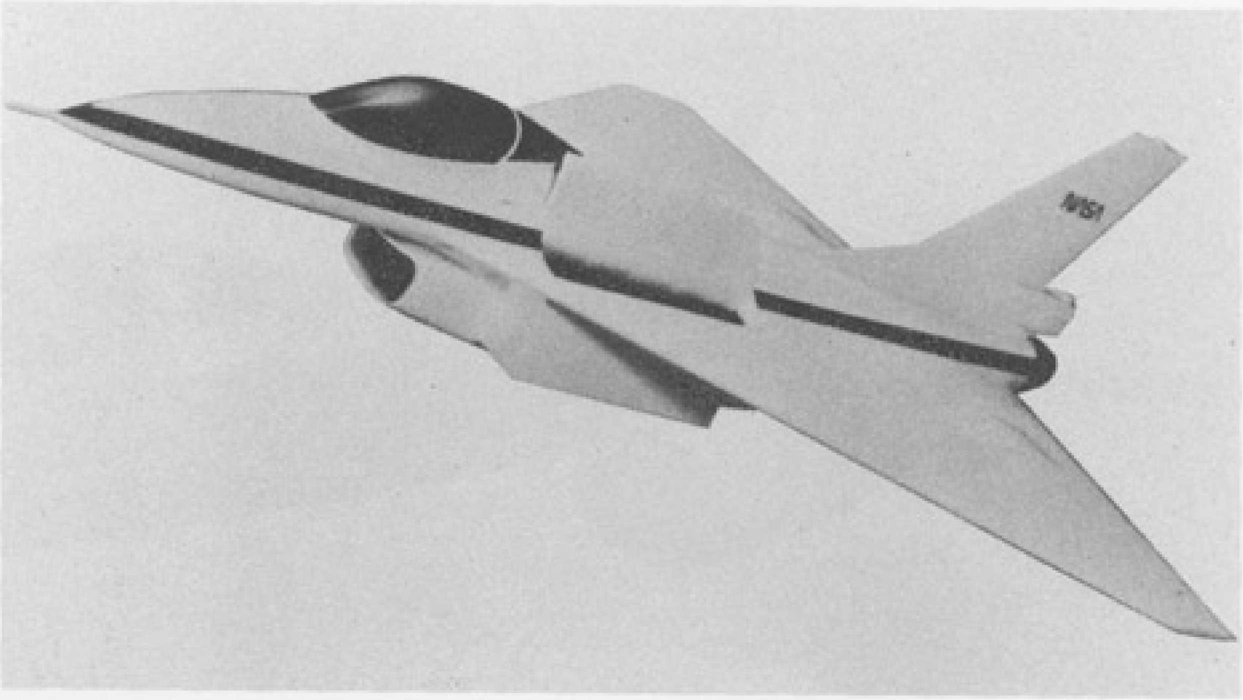
The tilt nacelle is another method of providing maximum thrust over the full range of required vector angles. It was originally proposed and test flown on the German VJ101. It could make use of an engine designed for conventional take-off and landing (CTOL) aircraft.

British Aerospace has conducted studies on tilt nacelle V/STOL aircraft; the P103 as it is designated is a twin-engine combat aircraft designed for the close air support role.

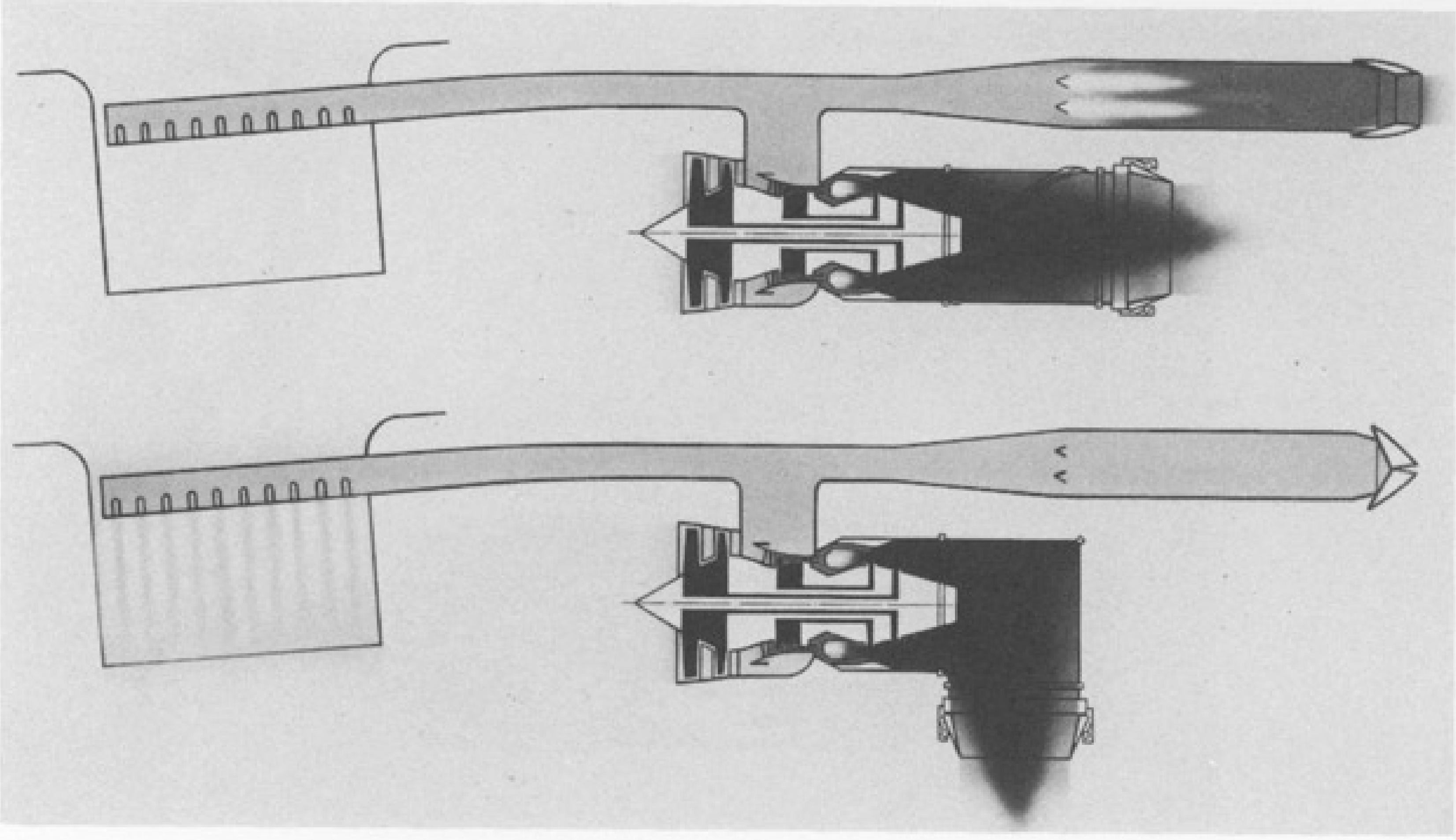
The proposed engines for the P103 are developed versions of the Turbo-Union (Rolls-Royce, MTU, and Fiat) RB199 which powers the Panavia Tornado.

The P103 would reduce thrust loss associated with compressor bleed for the reaction control system by vectoring and differential throttling of the main engine thrust.

Supersonic V/STOL



General Dynamics E7



Ejector lift

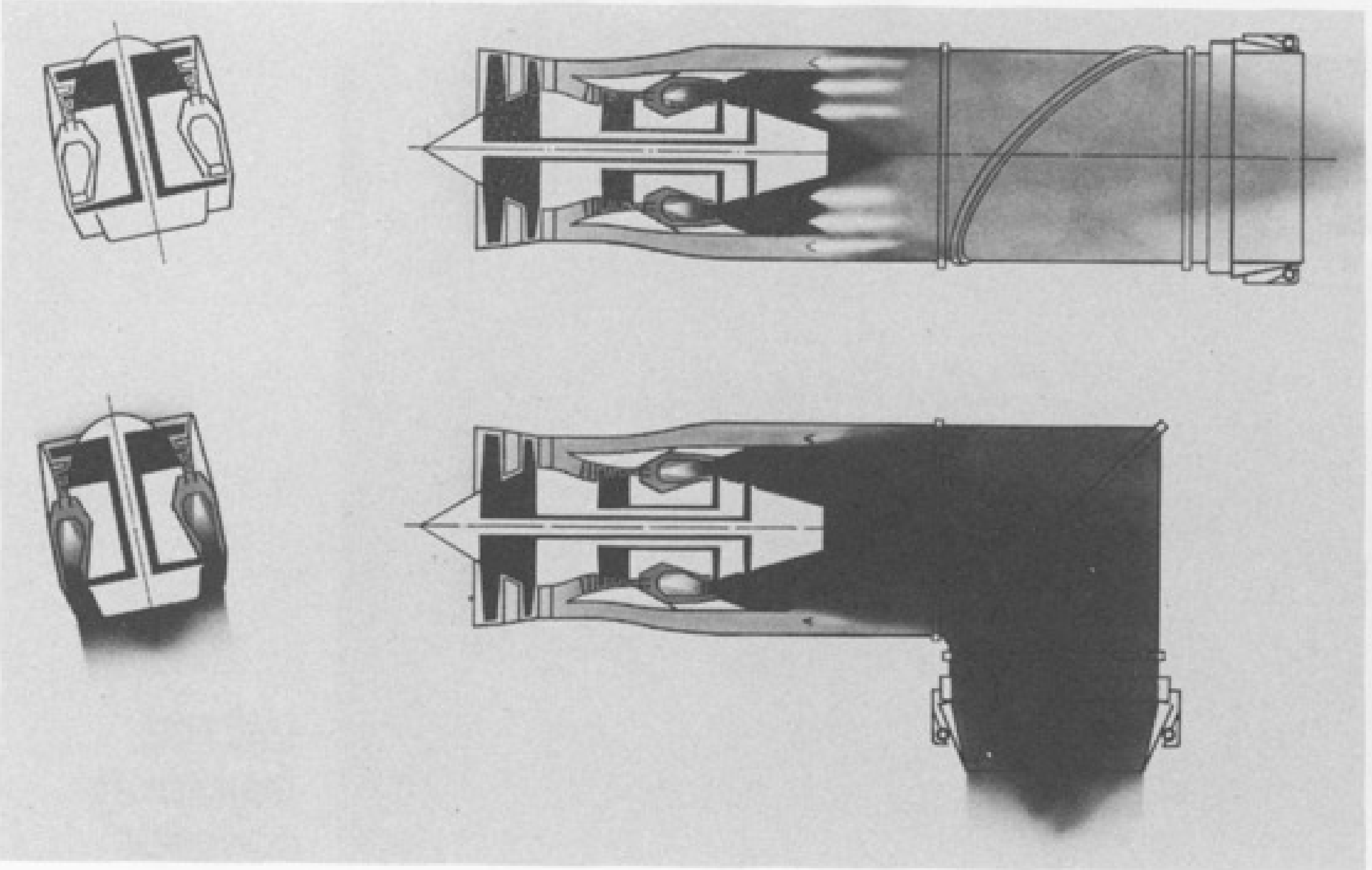
The ejector lift concept is similar to that of 'RALS' but has a much lower temperature and pressure exhaust flow and thus a more benign ground footprint.

This design has compressed fan airflow diverted through ducts to a series of ejectors in the wing structure. The ejectors are nozzles that exhaust the high pressure fan air entraining more flow through wing passageways to augment thrust and hence produce lift for vertical take-off and landing.

In forward flight the ejectors are closed off and folded into the wing to reduce drag. The entire engine flow, mixed or separate, is then fed into a nozzle where it can be reheated for supersonic operation.

Supersonic V/STOL

General Dynamics 218V



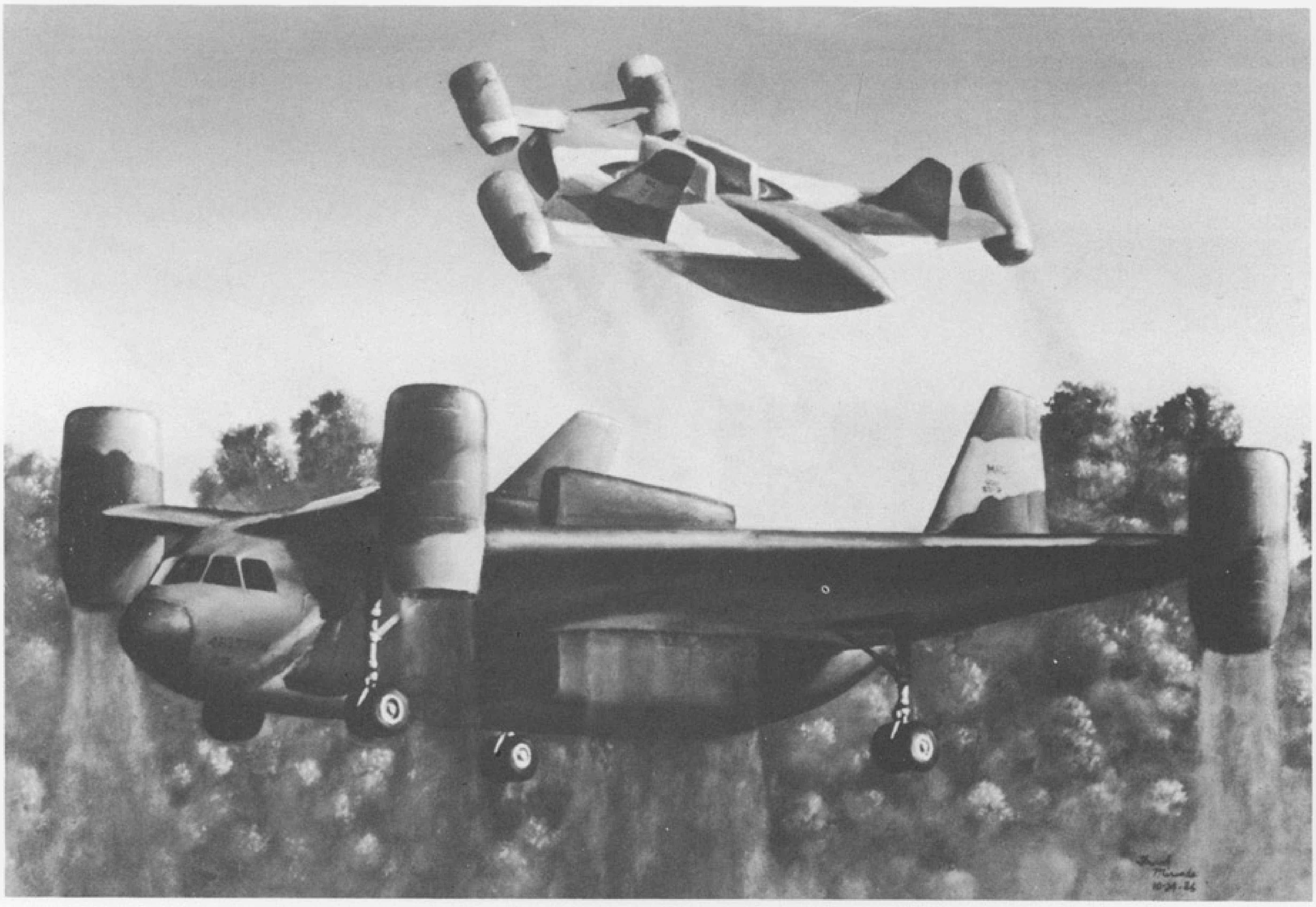
Lift and lift/cruise engines

In the western world Rolls-Royce is the only engine manufacturer with extensive experience in developing specialist lift engines. The RB108 and RB162 engines were developed by Rolls-Royce in the 1960s specifically as lift engines.

More V/STOL test vehicles and experimental aircraft have flown powered by Rolls-Royce lift engines than by any other propulsion source.

The lift plus lift/cruise system can be tailored exactly to meet the thrust requirements for both jetborne and wingborne flight and thus offers one of the lightest V/STOL aircraft to perform any task.

V/STOL transport



V/STOL transport concept

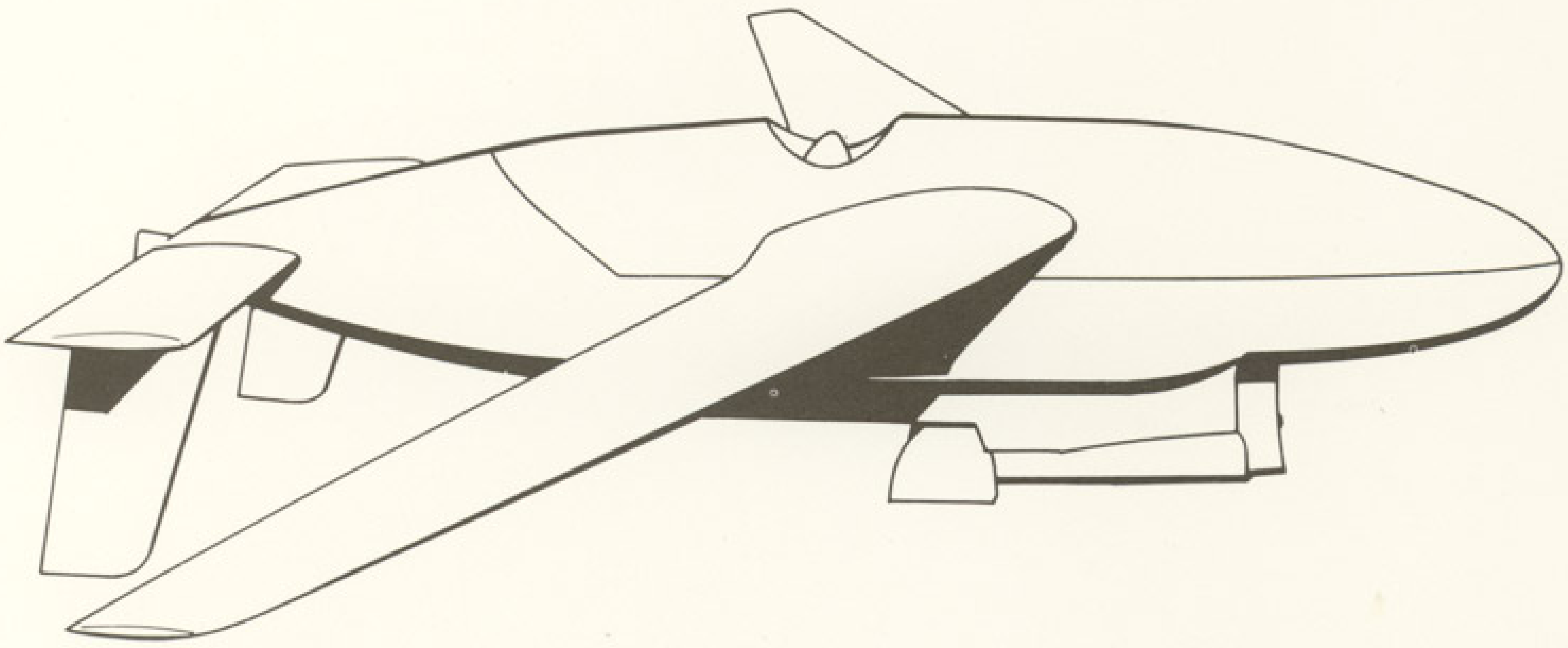
V/STOL transport

The requirement for V/STOL transport aircraft arises from a variety of scenarios. The support of V/STOL fighters at dispersed sites could be achieved by such transports; troop and equipment deployment and recovery from behind the forward line of troops could be by V/STOL transport. This may allow a faster and larger deployment to crucial areas than at present possible using helicopters.

Interest exists in Navy circles for small multi-purpose V/STOL aircraft that can be used for resupply, airborne early warning, and anti-submarine warfare.

Rolls-Royce are studying turbofan lift engines for a future V/STOL transport.

VTOL Remotely Piloted Vehicle



The Grumman Corporation is developing a shipborne vertical take-off and landing remotely piloted vehicle to operate in a defensive surveillance role. The concept is for a twin-tailed 9800 lb aircraft powered by a lift engine and a lift/cruise engine.

The RPV should be capable of cruising at 210 knots for 14 hours at altitudes between 27 000 and 37 000 feet.

Designated the D754 the proof of concept RPV is configured around a Rolls-Royce RB162-81.

Grumman is already flying a 7 foot span model of the D754 using a ducted-fan piston engine and has successfully hovered the aircraft.