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# ACTIVITIES ON AEROSPACE PROPULSION IN THE NETHERLANDS

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CONTENTS

## 1. Introduction

This survey of the activities in aerospace propulsion and gasturbine technology is based on a presentation for the Propulsion and Energetics Panel of AGARD at the Panel Business Meeting in Lisse on June 1, 1984.
Propulsion is one of the vital elements for all aerospace vehicles and it will be clear that although the Netherlands has no aero-engine industry, propulsion in relation to design and operation plays an important role in the Dutch aerospace activities. After a short historical introduction a description will be given of the Netherlands' activities in the propulsion field, covering:
- research laboratories
- industry
- operators
- education.

## 2. History

One of the most remarkable events in Dutch aviation history before World War I was the first flight of the Fokker aircraft "Spider" in 1911, flown by Fokker himself in his native town Haarlem. This aircraft had a German Argus piston engine and a propellor of German design, setting the trend for nearly all aircraft designed in the Netherlands up till now: the use of propulsion systems built outside the Netherlands.
After World War I the year 1919 marked the foundation of three organizations in the Netherlands, which still shape the Dutch aeronautical activities: the Fokker Aircraft Company, the Royal Dutch Airlines KLM and the Dutch Aeronautical Research Institute, now the National Aerospace Laboratory. Fokker and Plesman are well-known pioneers in the world's civil aviation in the period between the two World Wars. A range of Fokker passenger aircraft was built and used all over the world; KLM developed their network of airlines in Europe and to the Far East with Fokker aircraft. After the entry of Douglas in the civil market in the thirties, Fokker continued its tradition as designer and builder of military aircraft.
Moreover some smaller firms with Koolhoven as the best-known, built several military types and smaller aircraft, which we would call today general aviation types. In all these aircraft engines (and propellers) of foreign manufacurers were used from industries like Rolls Royce, Bristol, Hispano-Suiza, Pratt and Whitney, Wright, Hamilton Standard, etc.

After World War II Fokker and KLM rose again literally out of the ashes of their buildings, with the NLR as a more lucky partner with their undestroyed facilities built just before the War. The rebuilding of the Dutch aviation industry was supported by the Government, which founded the Netherlands Aircraft Development Board (now Netherlands Agency for Aerospace Programs, NIVR), with members from industry, operators, research and government. After several types of trainer aircraft Fokker developed, in cooperation with NIVR and NLR, the well-known civil aircraft Fokker F-27 (presently 755 sold, including Fairchild production of 205) and Fokker F28 (presently 217 sold). Fokker became a good customer of Rolls Royce, which company delivered up till now about 1800 Dart engines (with Rotol for the propellers) and 600 Spey engines for these two aircraft types. Furthermore Fokker produced a series of military aircraft under license (Gloster Meteor, Hawker Hunter, Lockheed F104). Currently the General Dynamics F-16 is still in production.
Also after World War II at the Delft University of Technology the education of aeronautical engineers started under the energetic leadership of professor dr. ir. H.J. van der Maas, who was also a long time chairman of the Boards of NIVR and NLR and one of the pioneers of the rebuilding of the aeronautics in the Netherlands.
In this historical overview the single Netherlands aero-engine developed in the fifties should be mentioned: the subsonic ramjets for the small Kolibrie helicopter with remarkable performance, taking into account its operation at the low tip Mach number 0.5-0.6. Test stands for this project were developed at NLR and this was the off-spring for the propulsion research at the NLR as described below. Despite its excellent flight characteristics due to an advanced rigid rotor concept, the Kolibri production was finished after an initial batch, mainly due to the inherent high fuel consumption of its ramjets.
Also two decades ago, efforts have been made to develop some solid propellant rocket motors by Hembrug (now Eurometaal) and the Netherlands gun powder factory in Muiden. Four of these rocket motors have been installed in the prototype of the Fokker F-28 to produce a restoring pitching moment under emergency conditions during deep-stall trials; fortunately they never had to be operated during the test flights. Also application to a guided sounding rocket has been studied. These activities did not result into a production of any scale; the same fate was allotted to the efforts to develop a pulsejet for a small remote controlled drone-aircraft (Aviolande AT-21).
It is told that just after World War II two leaders in aviation in Belgium and the Netherlands - prof. Haus and prof. Van der Maas - made the informal agreement that in rebuilding the aeronautical activities, Belgium should concentrate

on aero-engines and the Netherlands on aircraft. Looking back it can be observed that indeed Holland has been active in aircraft programs, while Belgium has taken its share in the engine field, e.g. by the production of the engines in the military aircraft programs mentioned above and in turbomachinery research.

## 3. Research Institutes

### 3.1. National Aerospace Laboratory (NLR)

In the Fluid Dynamics Division and the Structures and Materials Division of the National Aerospace Laboratory NLR propulsion related research is mainly in fields of:
- aero-acoustics
- engine-airframe integration
- hot-section materials
- operational problems.

Most activities described below are carried out in the laboratory complex in the Noordoostpolder (NOP).

In aero-acoustics theoretical and experimental research is performed on:
- jet noise, concentrated on the reduction of the jet noise by different forms of jet efflux mixing. These investigations are performed in an anachoic wind tunnel, using decomposed hydrogen peroxide for hot jet simulation,
- fan noise generation and suppression. Mathematical and experimental methods have been developed for fan noise prediction, design of acoustic liners and engine duct acoustics. Acoustic liner testing is performed in a special flow-duct facility (fig. 1),
- propeller and rotor noise testing in the large 8 x 6 $m^2$ German Dutch low-speed windtunnel DNW.

The engine-airframe integration is aimed at the development and use of windtunnel-techniques for the simulation of the interaction between airplane and propulsion system. These testing techniques are supported by numerical methods for the calculation of flow fields. Experimental techniques have been developed for:
- testing of separate inlet models in e.g. the High-Speed Tunnel (HST) in Amsterdam,
- engine-simulation with through-flow nacelles, intake simulation by suction and

jet simulation with compressed air or hydrogen-peroxide monopropellant for complete aircraft models in high- and low-speed applications,

-engine-simulation with Turbo-Powered Simulators (TPS). This technique is among others used in the large DNW-windtunnel, supported by a calibration facility, which is designed for calibration of TPS-units under windtunnel conditions (fig. 2 and 3).

Aircraft model testing with turbine-driven propellers has recently been re-activated for the development program of the Fokker 50 with a large scale model in the DNW.

The activities of the Structures and Material Division are mainly aimed at aircraft structures. The unfavourable environmental conditions (pollution, salt, moist) in which especially the Dutch military aircraft are operating, have given rise to research on compressor and turbine blades, including coatings. For this research a hot-testing facility for static testing of turbine blades (fig. 4) and a teststand for compressor blades with hot gas (up to 600°C) and vibration equipment are available (fig. 5).

The NLR also supports the aircraft operators in case of engine problems. For the Royal Netherlands Air Force the compressor-stall characteristics of the General Electric J-85 engine of the Northrop NF-5 have been investigated; presently the NLR is involved in work related to the Pratt and Whitney F100 engine of the General Dynamics F-16 aircraft.

Within the Flight Division of NLR (Amsterdam) the aircraft noise in the environment of airports is part of the work on aircraft operational problems. Computer programs have been developed to estimate the noise exposure contours for airports, while noise monitoring of Schiphol Airport is performed on a continuous base.

### 3.2. Prins Maurits Laboratory (PML)

The PML at Rijswijk is located between The Hague and Delft and is one of the four laboratories composing the National Defence Research Organization, as part of the Organization for Applied Scientific Research in the Netherlands (TNO). The Technological Research Group of PML performs research on weapons, ammunition and explosives. Areas of activities are, among others:

- physics of explosions, gasdynamic phenomena, effect of shock waves in air, detonation waves
- internal ballistics
- terminal ballistics
- vulnerability studies

- risk analyses
- explosion phenomena
- pyrotechnics
- rocket motors.

A short description will be given of the activities of the Rocket Propulsion Section. For more than 20 years this section performs the surveillance testing of solid propellant rocket motors for the Netherlands Military Forces and NATO Agencies. In the area of research the following subjects are covered:

- physical and chemical aging of solid propellants
- combustion instability of solid propellants
- combustion behaviour of solid propellants at subatmospheric pressures
- solid fuel combustion chamber research.

The latter three subjects are part of the joint research program with the Department of Aerospace Engineering of Delft University of Technology (DUT).

Besides the normal laboratory equipment for chemical and physical analyses, mechanical and non-destructive testing and tools for theoretical research, the PML has recently acquired a rather unique indoor rocket test stand for the static firing of rocket motors with a fully automated firing and data acquisition system for rocket motors with a thrust up to 100 kN (fig. 6). Because of the location in a populated area the test stand is fully soundproofed for its environment.

One of the larger research projects of the Rocket Propulsion Section of PML (in cooperation with DUT) is the research on solid fuel/air combustion, as e.g. applied in ramjets. A test-stand is built with a combustion chamber fed by a high-pressure hot air system with a compressor, an air storage facility and a vitiator (fig. 7). The combustion chamber and data-acquisition system are located in the indoor rocket test stand. Inlet conditions of the combustion chamber can be varied between 0,4 - 4 MPa and up to 1000 K. The research is aimed at an improvement of the knowledge of combustion phenomena in turbulent boundary layers, while theoretical analysis supports the experiments. In addition a small hybrid-rocket motor test stand is available. As experimental tool a rather unique continuous burning rate measurement method has been developed, which is based on an ultrasonic pulse-echo technique.

# 4. Industry

## 4.1. Fokker Aircraft Industry

Obviously Fokker as aircraft design and manufacturing industry has strong ties with the aircraft propulsion field. The powerplant is one of the main choices in the aircraft design. In the early fifties Fokker took - at that time - the bold step to select the Dart propeller-turbine for the F-27 instead of the conventional piston engine. The first application of jet propulsion was in the high-subsonic speed trainer Fokker S-14 during the early fifties. Experience on high-speed aerodynamics and propulsion with this aircraft beared fruit to the development of the F-28 in the early sixties, at that time until today, to be considered as the smallest civil jet aircraft for economic regular airline operations. Since then aircraft engines have played a decisive role in studies on follow-up versions of the F-27 and the F-28 or new projects like STOL-F-27 versions, F-29 civil airliner and the MDF-100 project with MacDonnell Douglas. After cancellation of the last project especially the developments in the propulsion field during the last two decades offered a excellent opportunity for improved civil aircraft in the F-27 and F-28 class in combination with advancements in aerodynamics and aircraft systems. After extensive studies the development of the Fokker 50 and Fokker 100 is presently in full swing; fig. 8 and 9 show these aircraft with some of their main characteristics.

The Fokker 50 has two Pratt & Whitney of Canada PW-124 turboprop engines (2400 hp), with much improved specific fuel consumption and engine weight as compared to the Dart engines. The propeller of Dowty Rotol has six blades, which choice was dictated by the requirement of a much reduced noise level in the cabin in comparison with conventional propeller aircraft.

For the Fokker 100 the fuel consumption and external noise will be much reduced in comparison with older aircraft. The two Rolls Royce RB183-03 Tay-engines will contribute to these characteristics by the low jet velocities using a by-pass ratio of 3 with internal mixing of the hot and cold flows. The powerplant of the Fokker 100 is developed in cooperation with Gulfstream, which company use the same engines in the Gulfstream IV-large business jet.

Within the Fokker organization a separate section is engaged with the aero-acoustic activities. This section is among others responsible for the noise-certification measurements of the Fokker aircraft. Other work in the propulsion field is performed in the sections for preliminary design, aerodynamics, performance, structures, systems and airworthiness.

## 4.2. Gasturbine- and component industry

The only firm producing gasturbines in Holland is Thomassen International in Rheden near Arnhem with work force of about 850 persons. Heavy duty and aero-derivative gasturbines are built in association with General Electric, USA for the driving of compressors, pipe line boosters, generators and pumps. The world's largest gas compressor boost station of the Netherlands Gasunie at the large gas field in Groningen has been produced by Thomassen; it has 9 gas-turbines with an output of about 140.000 kW. The firm is manufacturing stationary gasturbines in the range of 10.000 - 100.000 kW for the world market. Efforts have been made to develop a gasturbine of own design, but due to a number of economic factors this project has been terminated.

Other firms in Holland are dealing with gasturbines in many system applications as part of their activities: Gascomij (Cooper Rolls gasturbines), Brown Bovery Netherlands and VMF-Stork. The Mechanical Division of the Philips concern is fabricating the afterburner system of the Pratt and Whitney F-100 engine for the General Dynamics F-16 fighter aircraft, produced by Fokker under license agreement.

In the last decade a small but growing component industry has been activated in the Netherlands, which firms are cooperating in two associations: The Dutch Association Gasturbine (Vereniging Gasturbine, VGT with 10 members) and the Netherlands Aerospace Group (NAG with 30 members). As far as (aero-)gasturbines are concerned the main activities of these firms can be divided into two areas:

- manufacturing, maintenance, repair and/or coating of blades and vanes of turbines and compressors and other hot components as the most expensive and vulnerable parts of the gasturbine,
- fabrication, maintenance and/or repair accessores as fuel pumps, fuel gauging, engine control units, engine instruments, etc, with their test-equipment.

  Fig. 10 lists the firms involved in these two areas, in which several hundreds of people are employed. They can be considered as part of the high-technology industry in the Netherlands, next to the better-known large companies.

# 5. Operators

## 5.1. Royal Dutch Airlines KLM

Like most large airline companies KLM has maintained the engines of most the aircraft in its fleet over the years. In 1969/70 KLM, SAS, Swissair and the

French UTA combined their resources to achieve the best and most economical results in the maintenance of their wide-body jet aircraft, including the engines. The four partners are known as the KSSU-cooperation. From the total inventory of engines in the KSSU-fleet, KLM has the responsibility for the complete engine overhaul of the General Electric CF6-50 C/E and CF6-80 engines (Boeing 747, McDonnell Douglas DC-10 and Airbus A-310).
Facilities for the maintenance of the Pratt and Whitney JT9D (Boeing 747 and Airbus A-310) are available elsewhere in the KSSU-Group. Not only engines of its own wide body fleet (about 120 aircraft) are overhauled by the KSSU, but also engines of many other airlines over the world. Including KSSU affiliate airlines the inventory is about 340 engines (excluding spare engines), which for the types involved accounts for roughly 25% of all engines and 40% of all accumulated engine hours in the world. The shop visits of these engines have shown a rapid growth up to 250 per year, i.e. (roughly) one every working day of the week.
In total 224 General Electric CF-6 engines are involved, which has resulted in an engine shop of KLM at Schiphol Airport, being the largest CF-6 overhaul facility outside the USA.
As well-known the CF-6 engine is modular-built, which has resulted in an average shop-turnaround time of 15 calender days, a remarkable short period of time. Obviously there is a wide spectrum of operating conditions and ages of the engines and KLM has developed an engine parts control program to keep track of the life of the various critical parts in the engine inventory involved. It has been estimated that the concentration of the CF-6 engine overhaul in one shop saves about 17% of the costs, as compared to the situation that each KSSU-partner would have its own CF-6 overhaul shop.
As far as inventory policy is concerned, modern turbofan engines need less spare engine capacity compared with the first generation of these engines. This is the favourable effect of the modular overhaul system and reduced number of shop visits. It makes it also unnecessary to keep spare engines available on out-stations of the network, resulting in cost savings of depreciation, interest and storage.
The KLM Powerplant Overhaul Department has all repair and test facilities in house, which are required for the overhaul of modern jet engines, including a test bench with a thrust-range up to 450 kN (100.000 lbs). The Department's total workforce covers 540 employees.

5.2. Royal Netherlands Air Force (RNLAF)

Currently the Dutch Air Force operates 6 different types of aircraft, ranging from small helicopters to the F-16 fighter aircraft. The total engine inventory is over 600 engines.

For the helicopters (Alouette III, Bölkow 105) and transport aircraft (Fokker F-27) only base-level maintenance is performed by the Air Force and the overhaul is executed by the engine manufacturers outside the country (Rolls Royce, Turbomeca, Allison-England).

The operational requirements of these aircraft are fulfilled by this overhaul policy because of the high MTBO (Mean Time Between Overhaul), which makes a relatively small number of spare engines sufficient.

For reasons of operational readiness the engine maintenance for fighter aircraft is performed by the RNAF at depot level by the "Depot Straalmotoren" (DSM) at Woensdrecht, with a current personal capacity of about 450.

For the General Electric J-85 of the Northrop NF-5 (and formerly the J-79 of the Lockheed F-104G), the preventive maintenance is performed at baselevel, while overhaul and repair of the complete engine takes place at DSM in cooperation with national industries. Gradually this overhaul work is phased out with the aircraft in the coming years.

The maintenance of the Pratt and Whitney F100 engine of the F-16 is organized differently and is based on the modular engine concept (fan, core engine, high-pressure turbine, low pressure turbine, augmentor and gear box). Base level maintenance exists of condition monitoring and if necessary (small) repairs. Major repairs are done separately on engine modules at DSM, while the engine is made service-ready with a spare module at the base. Depot maintenance is scheduled on the basis of temperature cycles and is performed on engine modules only; the maintenance actions are based on the condition of the module (on condition maintenance).

5.3. Other operators

Other aircraft operators in the Netherlands are the charter-airline companies (Martinair, Transavia), Schreiner Aircraft Group (with aircraft operations mainly abroad), and the operators in the category of general aviation. Besides the maintenance on the operational level, these aircraft operators use for the overhaul and repair of their engines the facilities of KLM or maintenance services provided by the engine manufacturers and affiliated firms.

The Royal Netherlands Navy has limited engine overhaul facilities at their bases Valkenburg (Allison T-56, Lockheed Orion) and De Kooy (Rolls Royce Gem, Westland Lynx). The condition of the engines is monitored; changing of engine modules, modification, small repairs and engine testing can be carried out at depot level. Maintenance and repair of the modules is performed by the engine manufacturers. This is also the case for the overhaul of the gasturbines of the naval ships (Rolls Royce M-Tyne and M-Olympus, Turbomeca Astazou).

## 6. Education

On university level the education in the field of aircraft propulsion and gasturbines takes place at Delft University of Technology. Because of the lack of an aero-engine industry as such, the educational activities are of modest scale. In the Department of Aerospace Engineering the teaching and research on aircraft propulsion is related to fundamentals and to subjects as engine performance and installation in connection to aircraft design problems. As such these activities are mainly performed in one of the five sections of the Department: 'Aircraft Design and Performance'; the author is a member of the teaching staff of this section.

As far as research is concerned, two topics are covered by this section:

- noise of general aviation aircraft with propellers, supported by field measurements and theoretical analyses,
- rocket propulsion and combustion, concentrating on combustion problems of solid-rocket propellants and the combustion of solid fuels in high-speed turbulent flow. Both theoretical and experimental research is performed in cooperation with the Prins Maurits Laboratory, where the experimental facilities are located (section 3.2).

In the Department of Mechanical Engineering gasturbine technology is part of the curriculum of the Section Reciprocating Engines/Gasturbines. One of the professors in this section was Professor R. Stuart Mitchell, who retired from the University some years ago and died recently in March 1984. Although no successor has been appointed yet, a small academic staff, headed by Prof.Dr. H.E. Imbach, expert on rotating machinery, continues the teaching and research on gasturbines.

Research topics are performance analysis of gasturbines, characteristics of radial compressors and turbines and condition monitoring of gasturbines. The section has a test facility of radial turbomachinery and some test equipment for

educational purposes.
The maintenance, overhaul and repair activities described in previous sections require also qualified workers at other than academic levels. These are provided by the Higher Technical Institutes (HTS) in the Netherlands: one on aeronautics in Haarlem and several on mechanical engineering in various cities over the country. Technologically skilled craftsmen in aeronautics are educated at the Anthony Fokker School in The Hague. Especially Fokker and KLM are offering on-the-job-training courses for their employees, which also cover the powerplant of aircraft.

## 7. Sources and acknowledgement

This survey has been based on numerous publications and brochures of the firms and institutes mentioned by name in the text. In addition several experts have given information on a personal basis. Without the mentioning of names, the author wishes to thank all persons, who have kindly provided him information or checked the contents of the report, however, without relieving the author of the responsibility for the text presented.

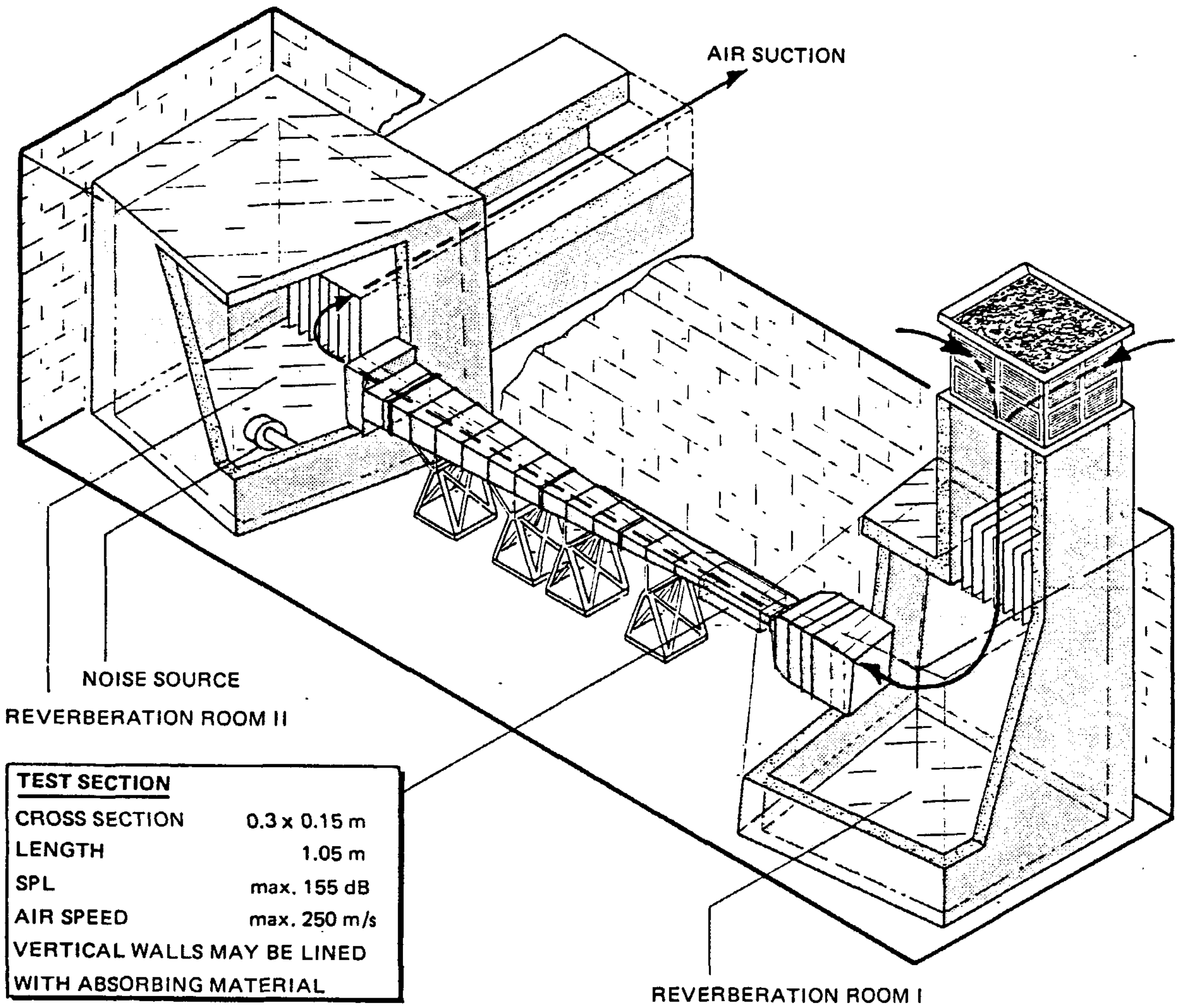



Fig.1 : NLR Flow duct facility.

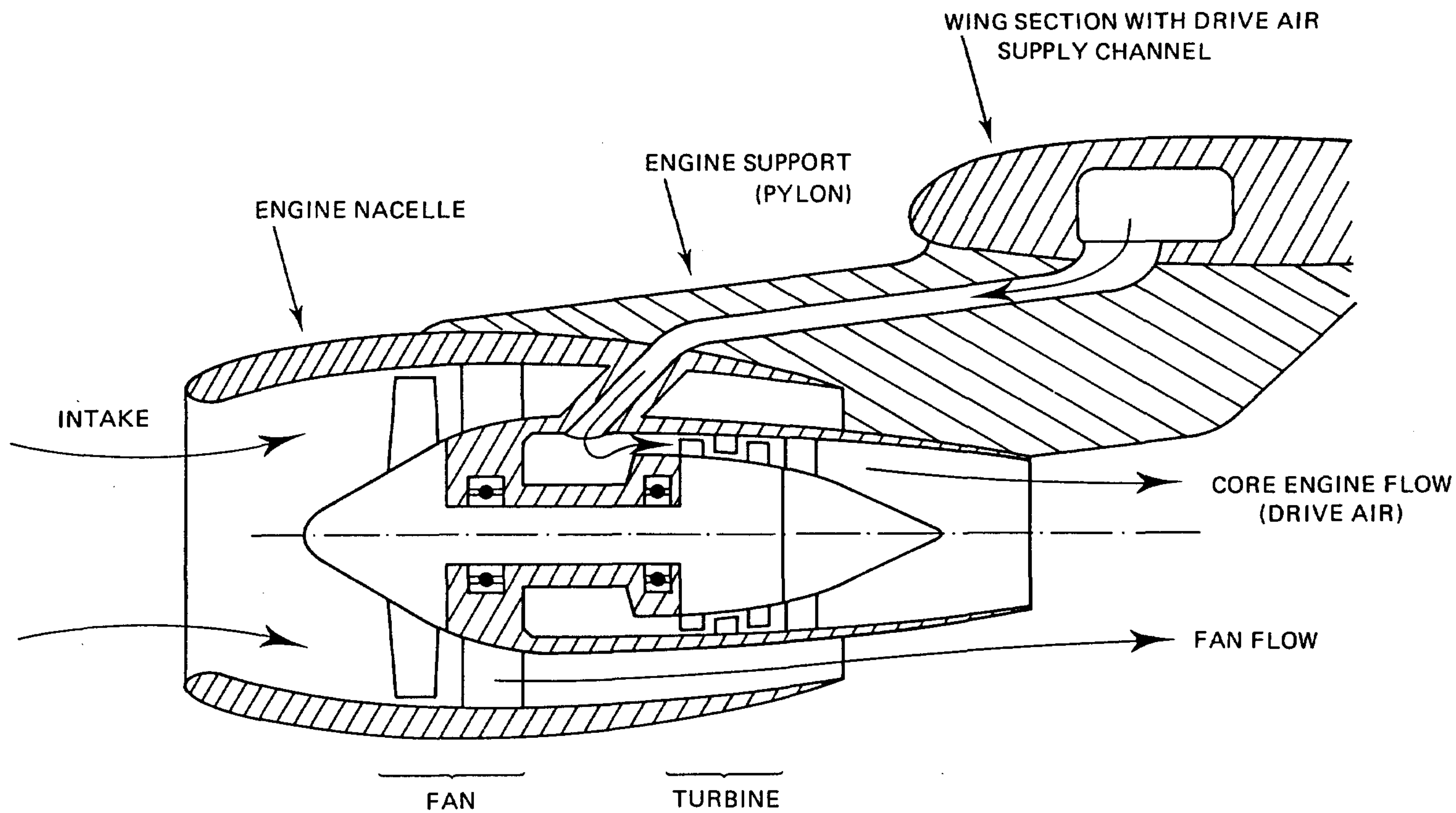



Fig. 2 : Turbo-Powered Simulator (TPS)

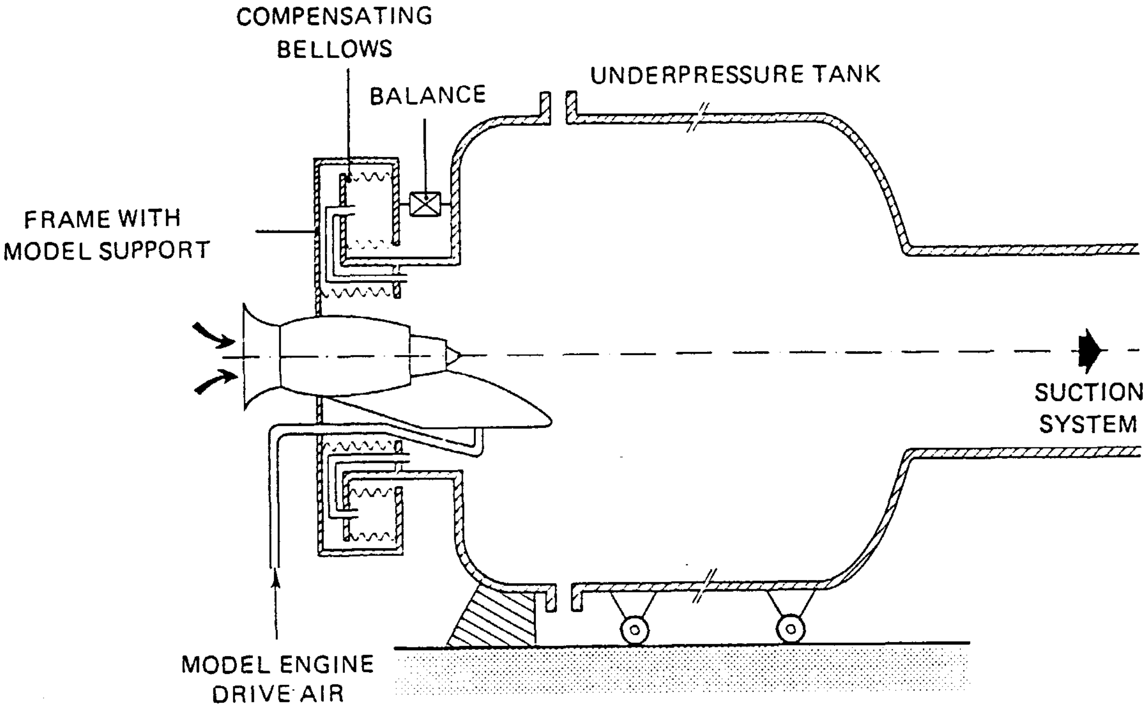



Fig. 3 : NLR thrust calibration facility for model engines.

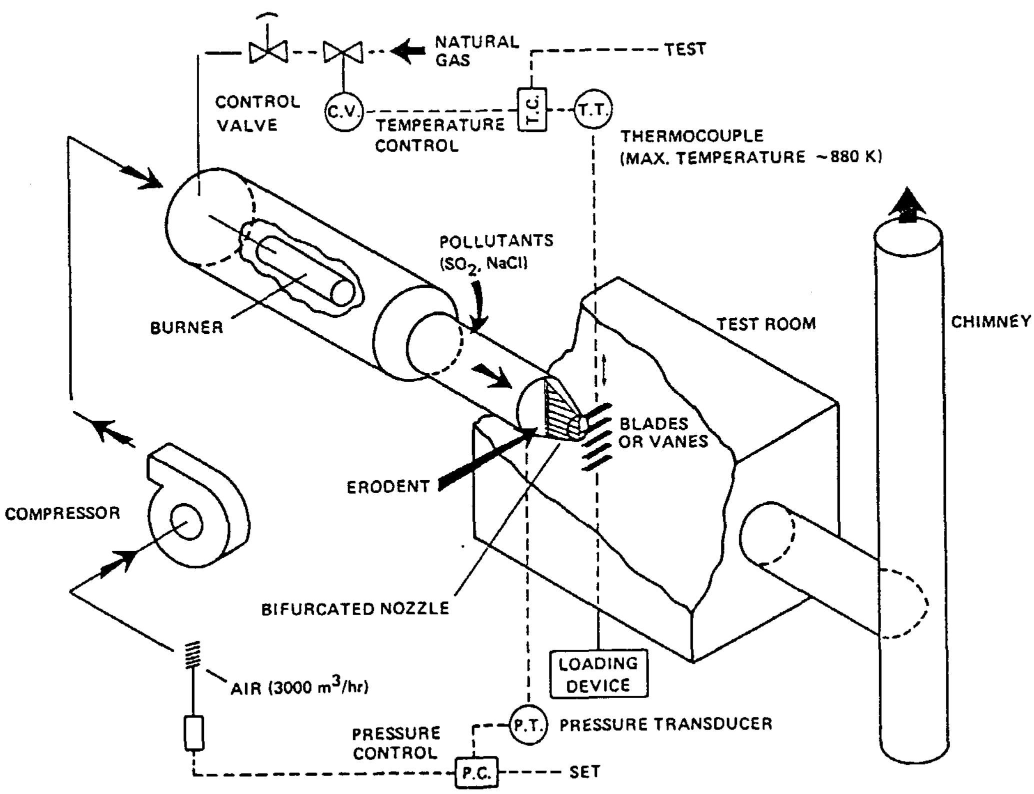



Fig. 5 . Rig for testing compressor parts.

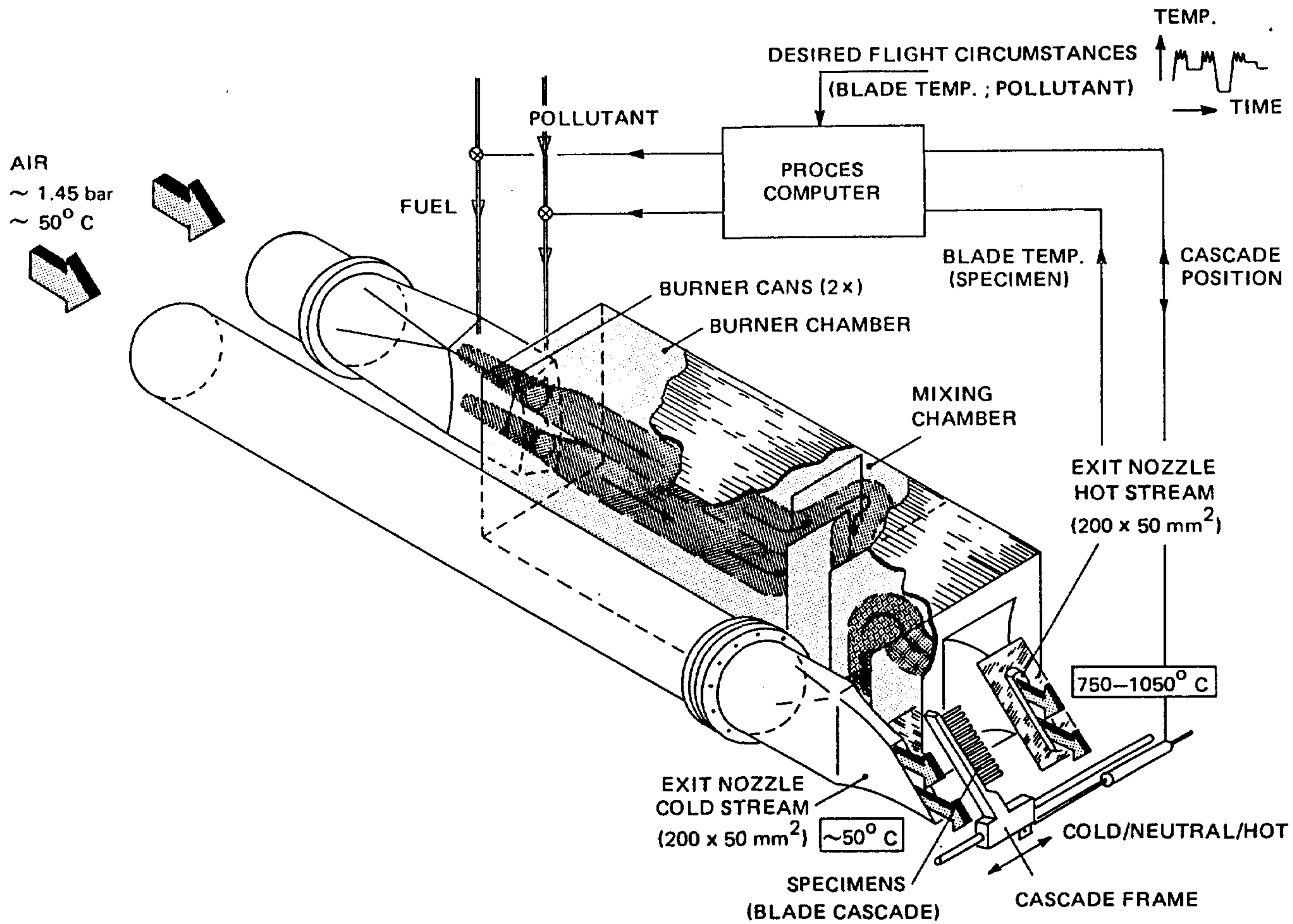
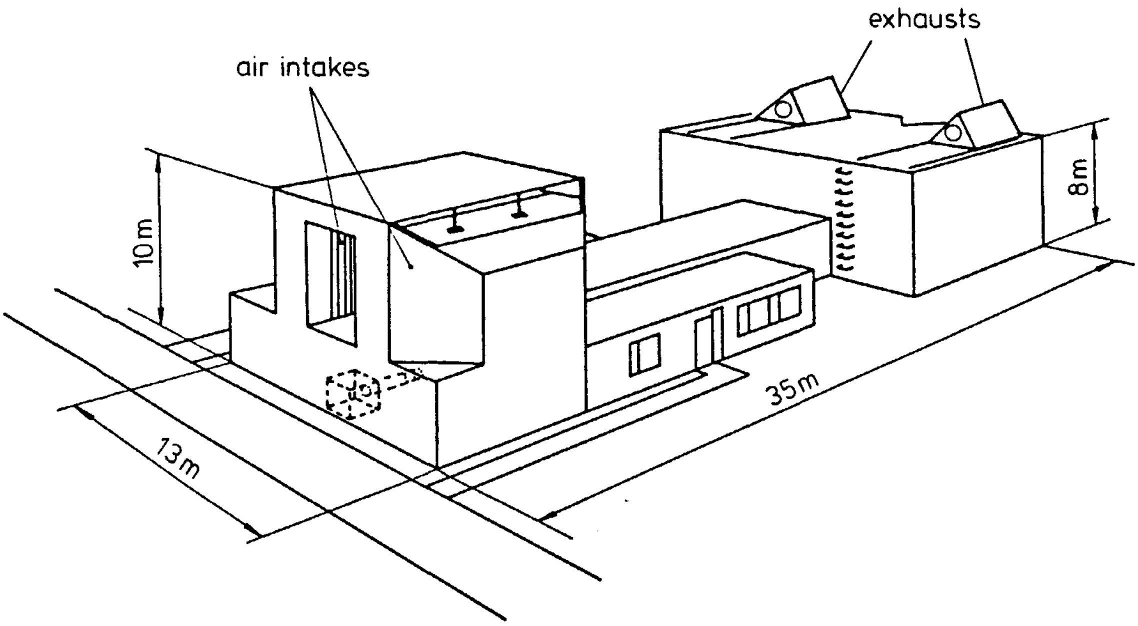
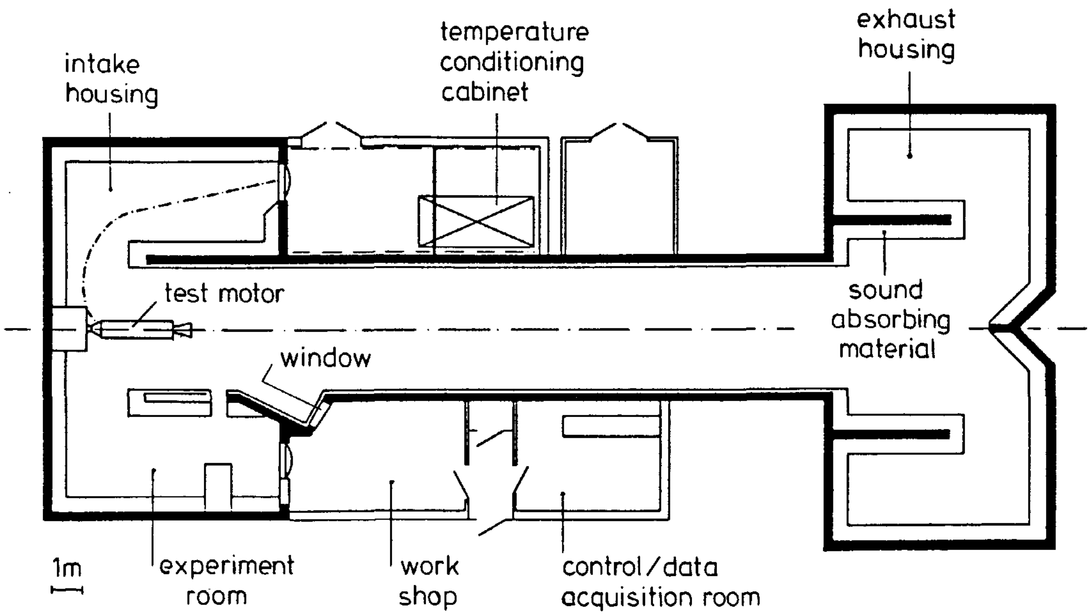



Fig. 4 : Burner rig for testing turbine materials and coatings.




External view




Floorplan

Fig. 6 : Indoor rocket test stand.

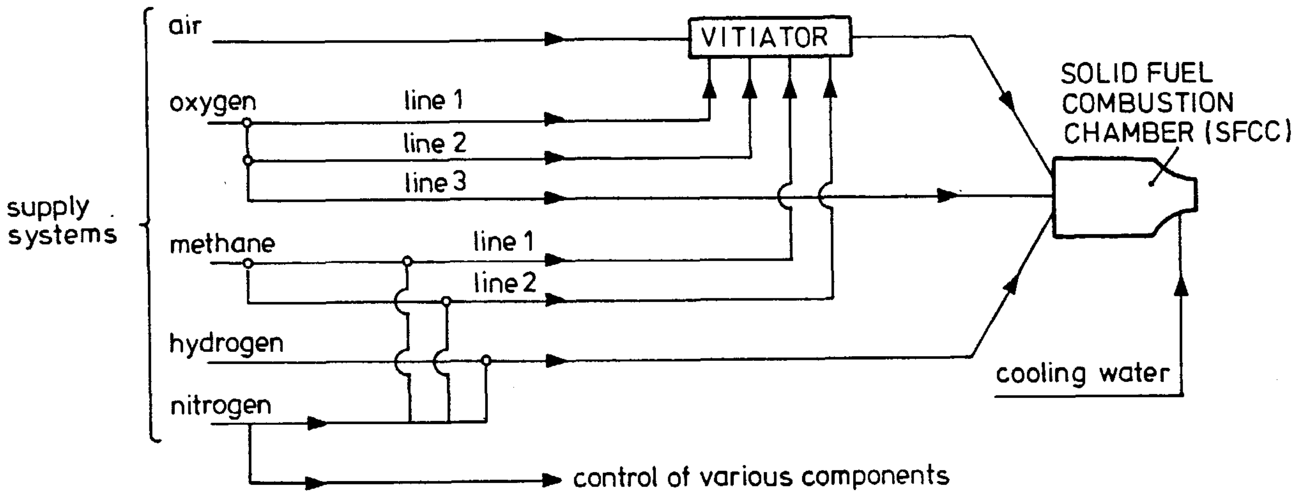
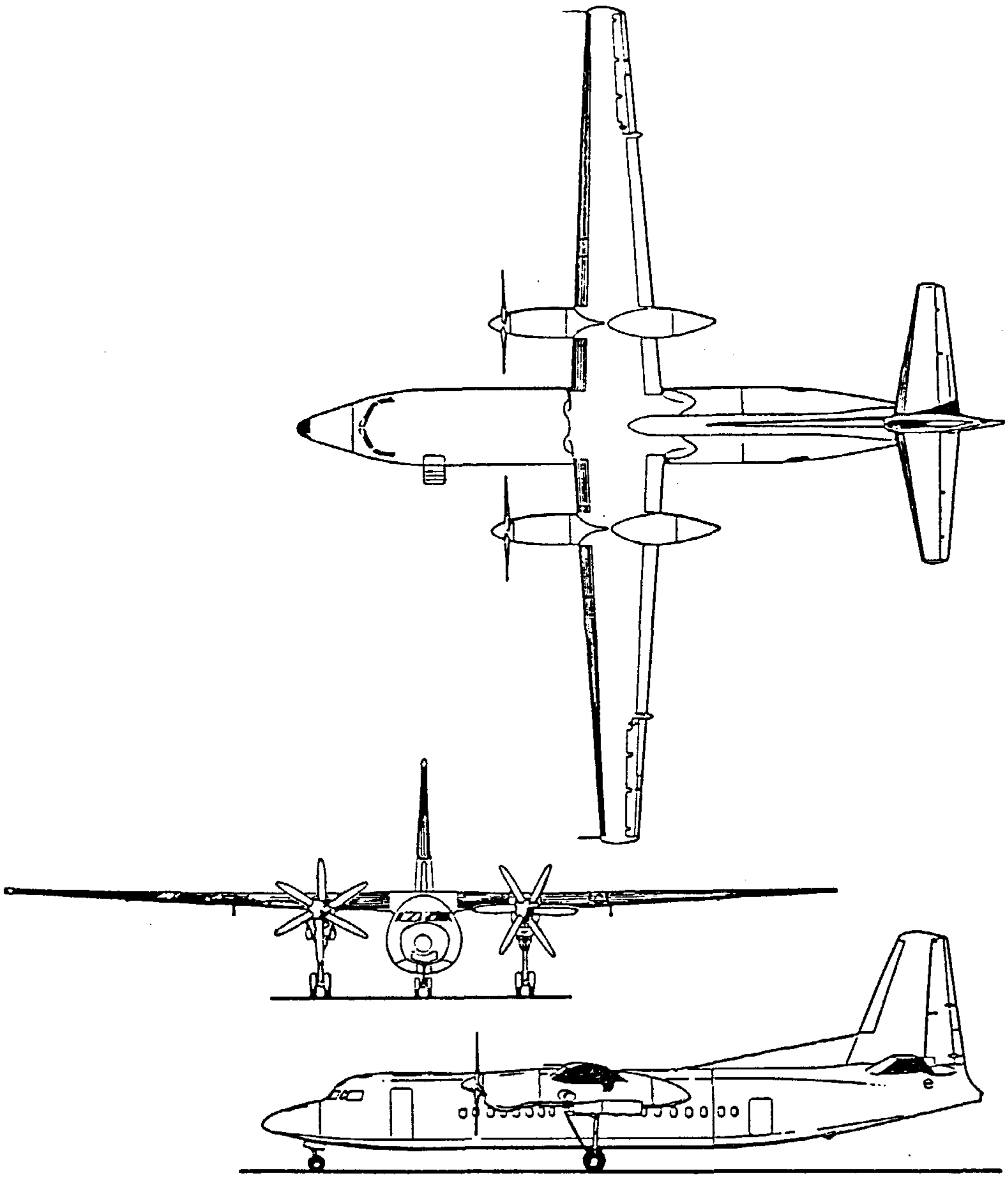
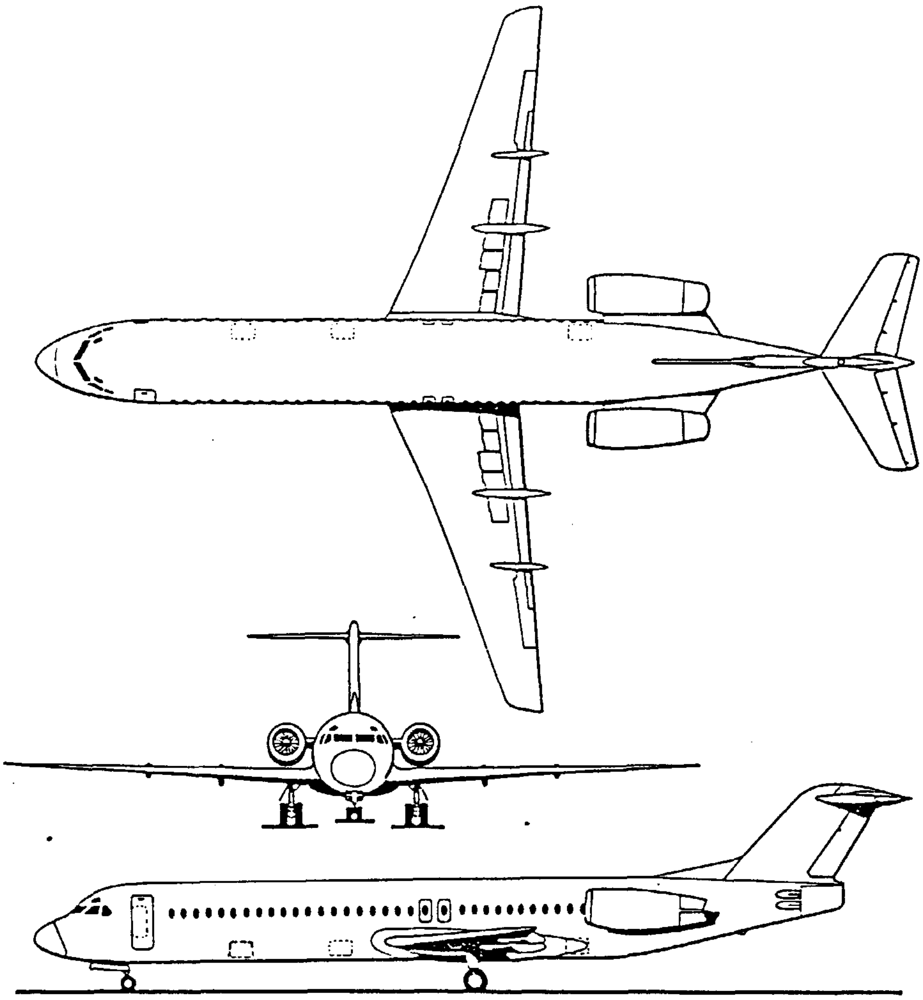



Fig. 7 : Test stand for solid-fuel combustion research.




| | |
|---|---|
| Span | 29.00m |
| Overall length | 25.19m |
| Wing area | 70.00 m$^2$ |
| Maximum take-off weight | 19,000 kg |
| No of passengers | 50 at 32 inch pitch |
| Fuel capacity | 5,136 ltr. |

Fig.8 : Fokker 50



| | |
|---|---|
| Span | 28.08 m |
| Overall length | 35.31 m |
| Wing area | 93.5 $m^2$ |
| Maximum take-off weight | 41,500 kg |
| No of passengers | 107 at 32 inch pitch |
| Fuel capacity | 13,040 ltr. |

Fig. 9 : Fokker 100

| Components | Firms |
|---|---|
| compressor/turbine vanes and blades, combustion chambers and exhaust systems | Bosman Power Source Support, Rotterdam<br>Indivers, Lomm (near Venlo), with<br>- Elbar (industrial gasturbines)<br>- Interturbine Holland (aero-engines)<br>- Eldim (high-precision drilling of holes)<br>Thomassen International, Rheden (near Arnhem)<br>Turbine Support Europa, Tilburg<br>Werkspoor-Sneek, Sneek |
| fuel system components, engine controls and instruments, high-precision engine parts, test-equipment. | Brandt Fijnmechanische Industrie, Amsterdam<br>Dinfa, 's-Gravenzande (near Hoek van Holland)<br>Germefa, Heiloo (near Alkmaar)<br>Hamilton Standard-Stork, Maastricht Airport<br>Simmonds Precision, Zevenaar (near Arnhem)<br>Thomassen International, Rheden<br>Verolme Electra, Maassluis (near Rotterdam) |

Fig.10. Manufacturing, maintenance and repair of turbo-engines components.