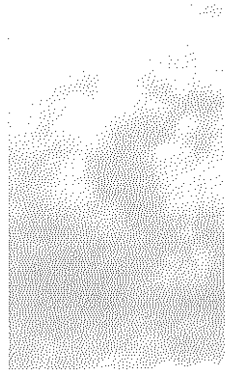
9 From Experimental Aerodynamics to Computational Aerodynamics



The development, construction and operation of wind tunnels and the development of measuring techniques have dominated the activities of the laboratory. Throughout this book several examples are given of aerodynamic tests at NLR.

The **theory of aerodynamics** was from the beginning also an important ingredient in the development of the airplane. Up till about 1900 theoretical aerodynamics was of little use. In fact some even blamed Newton for having contributed to the pessimistic forecasts in the literature before 1900 on the possibilities of powered flight.[1] Once aeronautics became a reality the development of theoretical models and concepts of the flow around practical bodies became very important, e.g. the boundary layer concept, the vortex system around a wing, the use of sinks and sources to construct theoretical models of the flow around closed bodies, etc.

The aerodynamicists of the RSL and NLL stayed abreast with the developments elsewhere and contributed in selected areas as for instance in the area of flutter and unsteady aerodynamics.

Although the physics of fluid flow was reasonably well understood and had been formulated by the Navier-Stokes equations, numerical computations for aerodynamic design purposes had to be simplified because of the complexity of the equations. Even for cases where it was permissible to neglect the viscosity, vorticity and compressibility the calculations were very time consuming. This situation persisted till after the Second World War. During this war the development of analog computers began. There emerged applications in various processes and also in the simulation of flight mechanics problems. Analog computers had a limited application in solving purely aerodynamic problems. That was related to the nature of the fluid flow equations and the associated boundary conditions.

Around 1960, numerical aerodynamic computations started to gain in importance with the arrival of large digital computers. It was the period when high speed aerodynamics also grew in importance at NLR.

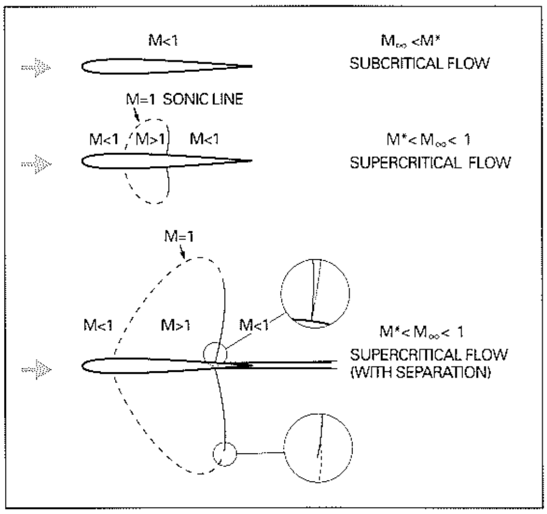
For this Chapter a **selection** is made of theoretical and experimental aerodynamic applications in which NLR played an important role.

[1]Newton had predicted that the force acting on a surface element in a flow was proportional to the square of the sine of its angle of inclination and this would mean that the lift at moderate angles of attack would be very small. Von Kármán wrote in his book 'Aerodynamics', [Ref. 48]: -*"Personally I do not believe that Newton's influence was really so catastrophic. I think most of the people who, in the early period we are talking of, were really interested in flying, and did not believe in any theory."*

Supercritical Wing Technology

The first example is concerned with the contributions of NLR to the development of supercritical wing technology.
During the period after the Second World War the aeronautical world was confronted with the so-called 'sound barrier', the rapid drag increase at high (transonic) speeds and the occurrence of shock waves in the flow around the wings. The shock waves were caused by the supersonic flow over the wings. The formation of shock waves was delayed with increasing speed by changing the sweep angle of the wings. Highly swept-back wings however had aerodynamic and structural disadvantages. Vague ideas arose about other means of delaying the occurrence of shock waves. After having heard about experiments at the National Physical Laboratory, NPL (UK) with so-called 'peaky' airfoils in the late 1950's NLR started around 1960, as the first institute in the world, to develop shock-free airfoils along theoretical lines, that is airfoils with local supersonic flow without shock waves.

The influence of the free-stream Mach Number on the flow around an Airfoil



A critical Mach Number, M*, is reached when the local Mach Number in the accelerated flow over the upper surface of an airfoil becomes 1. At higher Mach Numbers a local region of supersonic flow occurs and that region is terminated by a shock wave through which the velocity reduces from supersonic to subsonic. It is desirable to maintain a relatively large area over the wing of a transport aircraft in which the flow is supersonic (low pressure, high lift) without the adverse effects of shock waves which cause a drag increase, flow separation and through the pressure increase after the shock also a loss of lift.

The question around 1960 was then: Is it possible to design an airfoil which at high subsonic speed would have a large region of supersonic flow over its upper surface and is it then possible to design the airfoil such that the local supersonic flow decelerates to subsonic without a shock wave (so-called isentropic compression)?

The research in this area led to the development of 'shock free airfoils' and 'supercritical wings'.

The Advantages of the Supercritical Wing Technology

It is useful first to indicate the effects of supercritical wing technology on the design of transport aircraft.
The characteristics of supercritical airfoils can be used in different ways. Typically the aerodynamic efficiency of a supercritical wing, expressed in terms of the value of $M \times C_L/C_D$ (Mach Number times the ratio of lift to drag), is 20-30% higher than of a 'conventional' wing.

Around 1960 the research was directed towards increasing the speed of aircraft with a minimum of drag increase. Later, particularly when the fuel cost became a substantially larger part of the operating cost of aircraft, the emphasis shifted towards reduction of fuel consumption through drag reduction and towards reduction of the mass (weight) of the wing, at a given speed.

With supercritical airfoil technology it became possible to increase the wing thickness of a wing with a given sweep angle or to increase the speed. The allowable velocity over the upper surface, before a shock wave occurs, becomes higher, resulting in a higher lift thus making it possible to use a smaller wing area giving less (friction) drag and having a reduced mass.

With a larger wing thickness the construction mass of the wing is less or the wing can be made more slender (higher aspect ratio) which results in a reduction of the (induced) drag.

A schematic presentation is as follows:

Influence of Supercritical Wing Technology:		Effect:
• Drag reduction	»	Less fuel
• Increase of wing thickness	»	Less weight
• Increase of wing aspect ratio (slender wing)	»	Less drag
• Reduction of sweep angle	»	Less weight Higher maximum lift (at low speed)

Typically the design of a transport aircraft wing has changed over a twenty year period as shown below:

	1960-1965	1980-1985
Aspect ratio (wing span divided by mean chord)	7	11
Sweep angle	32°	16°
Efficiency expressed in $M \times C_L/C_D$	11.6	14.2

The gain in efficiency was 22.5% over this period. Obviously the designer has a complicated optimization problem when designing a specific aircraft. He must - besides many other factors - optimize the combination of wing thickness, aspect ratio, sweep angle, etc. As an example, for an aircraft in the Fokker 100 class an overall reduction in fuel consumption of about 15% was obtained by applying supercritical wing technology. This is of course independent of the fuel savings that have been realized by the engine manufacturers and the reduction of the construction weight by further optimizing the structural design and the application of advanced materials.

In the 1960's the problem of transonic flow was actively studied at several locations. NLR was very much involved in this development. Tracing the exact course of events and the many interactions between the laboratory and the industry is beyond the scope of this book. There was, much later, an exercise in Europe to fight the application of a NASA patent for the supercritical wing technology in several European countries. Prof. Ir. E. Obert of Fokker produced an extensive report for AICMA, the Association of European Aerospace Material Manufacturers, to counteract the NASA patent application.[2]

The highlights of the contributions of NLR to the supercritical wing technology can be summarized as follows:

- Nieuwland's development of a class of symmetrical shock-free transonic airfoils ('Quasi-Elliptical Airfoils'), [Ref. 49];
- Spee's demonstration of the stability of shock-free flow over a supercritical airfoil, [Ref. 50[3], 51];
- Boerstoel's extension to a wider class of lifting supercritical airfoils;
- Slooff's design of an integrated series of supercritical airfoil profiles, later applied to three-dimensional wing designs;
- The development of inverse methods by Slooff and his associates.

[3]The results of the investigations on the transonic flow around airfoils at NLR were presented - together with papers of Labrujère, Slooff, Loeve, Han and Kramer of NLR presenting the theoretical and experimental results in transonic aerodynamics then achieved - at a Symposium of the AGARD Fluid Dynamics Panel (September 1968, Paris) on Transonic Aerodynamics.
In 'A Brief History' of the International Council of the Aeronautical Sciences, ICAS, 1980, J.J. Green, past President of ICAS, recorded as one of the highlights of the Sixth ICAS Congress held in München in 1968:
-"An important paper by B.M. Spee and R. Uijlenhoet of the National Aerospace Laboratory, Amsterdam, gave experimental confirmation of the shock-free transonic flow around quasi-elliptical airfoil sections, the theoretical possibility of which had been suggested in G.Y. Nieuwland's paper delivered at the Fifth ICAS Congress held at London in 1966."

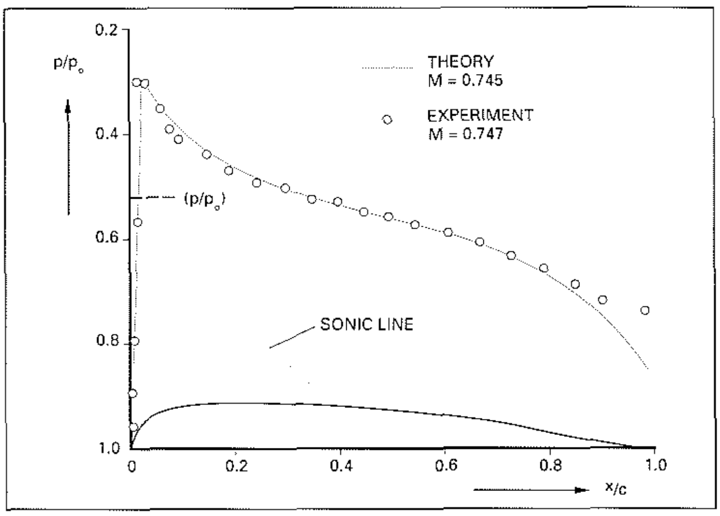
One of the first practical applications at NLR was a contract from NASA to design two-dimensional airfoils for the rotor of a Bell helicopter.

During the 1970's a very close cooperation developed between Fokker (Prof. Blom and Prof. Obert and their design group) and NLR, to turn all these elements into real design tools.

It is interesting to quote from a paper by Nieuwland, (Ref. 52), in which he looked back at his early work:

> "--- *Around 1955 a whole body of theoretical literature, some of it of great mathematical sophistication, was written to explain why certain theories nobody had ever applied in real situations, but presumably yielding transonic flows without shocks around airfoils, could not ever be expected to work. One of the reasons advanced was that in such flows, weak time-dependent disturbances would come to a standstill, coalesce, and let the basic flow collapse into one with a shock. In 1961 we began to become interested in the application of difference methods for subsonic and eventually transonic flows. It was thought that to this end, comparisons with exact subsonic solutions would come in handy, but these were not then available. It was decided to construct such solutions on the basis of the challenged theories in the subsonic case and perhaps have one transonic example computed to observe the collapse in a wind tunnel, expecting to observe an interesting experiment. Soon it became abundantly clear why nobody had cared to carry out computations: the theories were either not applicable in realistic situations, or not correct, and gave rise to tremendous computational problems. These were duly sorted out, the first results were given in 1964, a completely revised theory announced at the 1964 ICAS Congress, and the definite results were published in 1967, [Ref. 49].*
> *From one point of view the transonic experiments were disappointing. Nothing happened, i.e. experimental agreement with theory was near perfect.*"

Symmetrical quasi-elliptical Airfoil

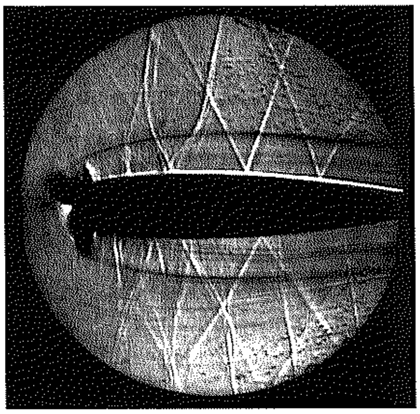


Around 1964 Herbert Pearcey had experimentally developed shock-free transonic flows around airfoils at the National Physical Laboratory, NPL in the UK.

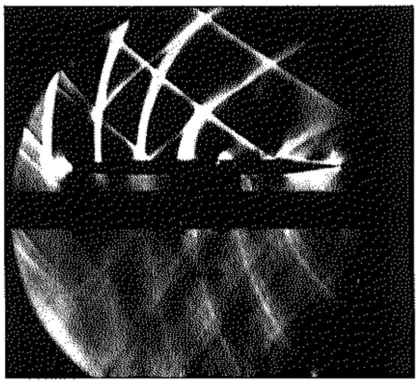
> -"*The theory gave rise to an interesting experimental study of the stability of these flows, in which even not so weak travelling waves were shown to fail in blowing up the flow pattern, [Ref. 50].*[4]
>
> *Experimental verification for lifting airfoils was obtained in early 1969. Here of course boundary layer effects are more prominent.*

[2]Compared to other laboratories - and industry - the aeronautical research laboratories score poorly in the application of patents. In fact the experience at NLR with patents is not very encouraging. The few cases for which a patent was applied were not very profitable. The main role of an engineering laboratory like NLR appears to be to generate ideas, confirm them by theory and experiments and then transfer these ideas to the industry, the aircraft users and operators.

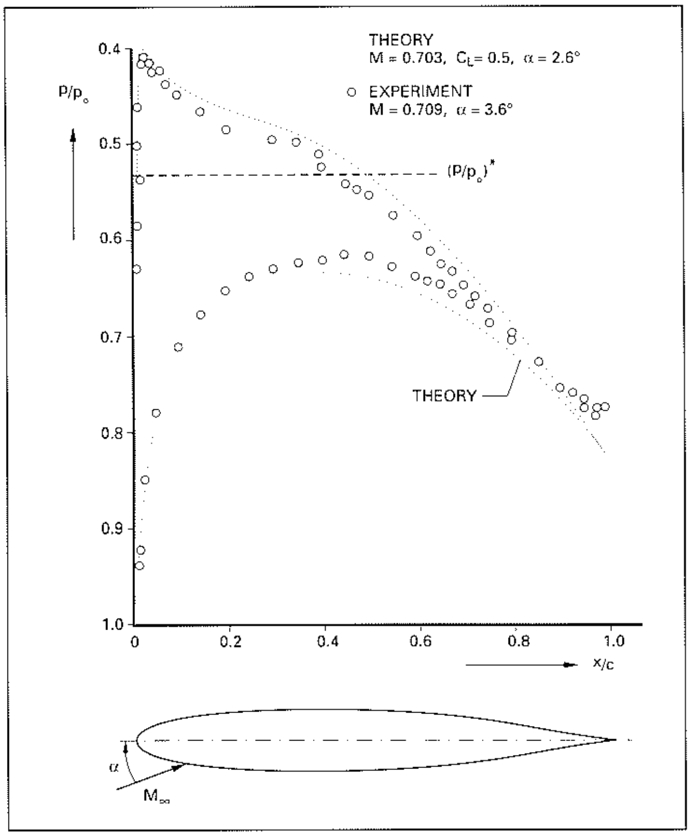
[4]In this dissertation for his Doctor's degree, Spee pointed out that the time-dependent instability arguments advanced previously, were essentially based on one-dimensional considerations but that in reality a turning effect due to the spatial (two- or three-dimensional) velocity gradient permitted disturbance waves to propagate through the local supersonic region without coalescing into a shock wave.



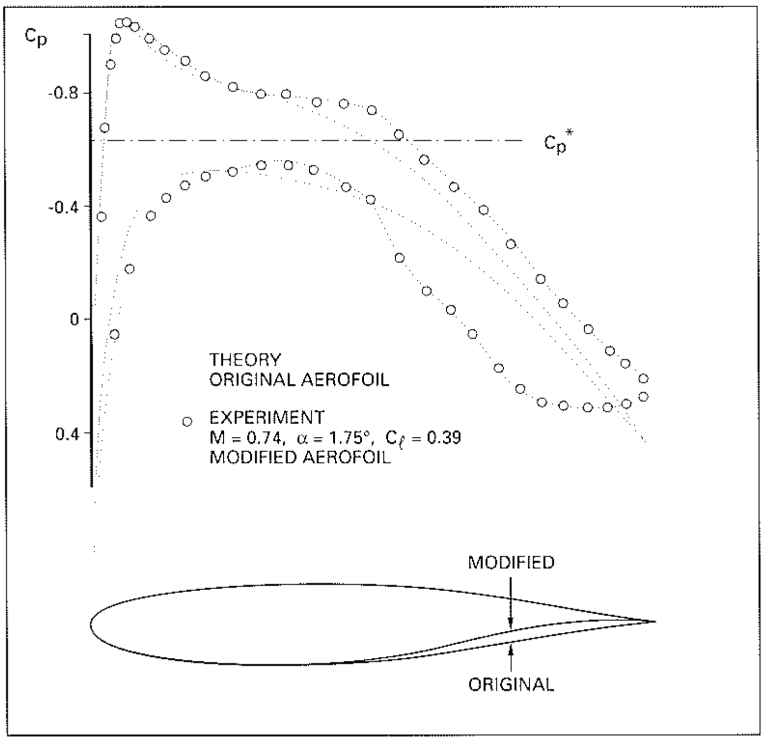
Wave propagation through transonic flow



Wave generation by cavity flow



Lifting quasi-elliptical Airfoil



Modification of Airfoil to increase lift

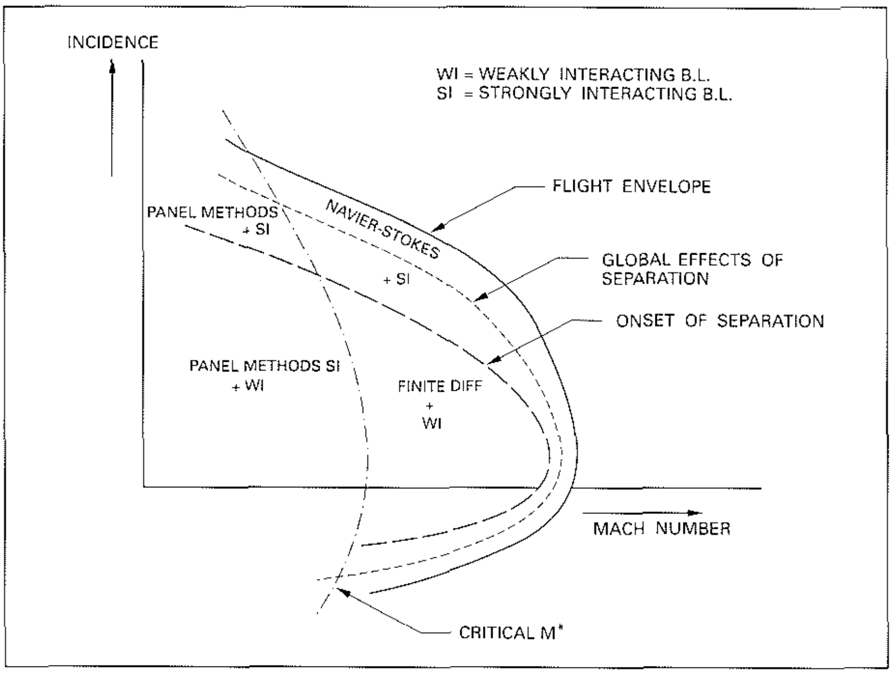
From a practical point of view this is not a particularly good airfoil, there being too little loading over the rear. Such airfoils were theoretically produced by a competing theory of the same scope developed around 1969 at New York University, the rear-loaded airfoil being found in a somewhat involved iteration process. As the significance of the shock-free designs for airfoil development had by then been shown amply, the transonic airfoil project was restarted at NLR in 1969 as a purely development directed effort. The first aim was to develop a semi-analytical modification procedure, which would add rear-loading to the original analytical airfoils. This idea proved to be completely successful."

After Nieuwland's contributions, showing that it was theoretically possible to design shock-free transonic airfoils and Spee's proof that these flows were stable, Boerstoel of NLR further developed methods to design lifting transonic airfoils. Thereafter methods were developed for real three-dimensional wings by Slooff and his associates.

These activities were carried out in the period 1960-1970 when the digital computer gradually became of age and when it became possible to compute the aerodynamic forces on complete wings and aircraft configurations.

The coverage of Computational Fluid Dynamics (CFD) methods for the flight regime of a typical transport aircraft with a high subsonic cruising speed around 1985 is shown in the Figure below. The methods indicated on the left refer to computational methods based on potential flow. With separate boundary layer computations adequate predictions could be obtained. Moving to the right in this figure the solution of the full Navier-Stokes equations becomes necessary. The margin of uncertainty was resolved by wind tunnel experiments and design experience. The ideal situation of a computer program system which uses the full Navier-Stokes equations to compute the pressures and temperatures on an aircraft had not been achieved in the early 1990's.

Coverage of CFD (Computational Fluid Dynamics) methods of a typical flight envelope for a subsonic aircraft around the year 1985



One of the major problems is still the physical modelling of turbulence including the transition in the boundary layer (the flow very close to the surface) from a laminar to a turbulent flow. However with the present computational schemes, in which experimental information is embedded, aircraft designs (not only the wing but the whole aircraft) can be optimized far better than before the era of large digital computers.

The aircraft designer now has the tools with which he can very rapidly, in minutes or hours, visualize the effect of a series of changes in his design. Intermediate and final checks with wind tunnel tests are still necessary and will be in the foreseeable future, but the result is that the aircraft design is of higher quality.

Another important aspect of Computational Fluid Dynamics (CFD) developed by Slooff and his associates is the use of the so-called inverse method, i.e. a method to determine the shape of an airfoil for a given (desired) pressure distribution.

Prof. Ir. H. Bergh, who was Head of the Aerodynamics Division of NLR, wrote a paper in 1980 with the 'case history' of the NLR contributions to the development of the supercritical wing theory. The following extract shows the sequence of events and the way in which the work was managed and financed.

Basic Research (1960-1972)

Since this basic research, described above, was of a fundamental nature it was financed out of the Government subsidy for in-house research - NLR's own resources.

Development of Computational Methods

For this theoretical research it was necessary to develop advanced computational methods. These methods would have a broader application and NIVR was asked to finance part of this work. During the 1960's computational methods were developed with which symmetrical airfoils at zero angle of incidence (1964) and non-symmetrical airfoils at incidence (1967) could be computed.

Experimental Investigations

An important question was: Is transonic flow over these theoretically developed (quasi-elliptical) airfoils also physically real? To find the answer to this question NLR carried out wind tunnel experiments in the period 1963-1968, financed from its own research budget, to investigate the stability of the flow around this type of airfoil. A wave generator was developed which produced two-dimensional disturbances of known amplitude and frequency for superposition on the main flow. It was shown that the shock-free flow generated over the new airfoil did occur and that the flow was stable. After this success NIVR awarded a contract to NLR for further wind tunnel experiments. The result of those investigations was that the differences between theory and experiment were negligible and thus such profiles could be applied to practical wing design.

International Contacts

During the period of 1960-1968 NLR stayed in contact with NPL and RAE, (UK), where the investigation of the 'peaky airfoils' was continued and with laboratories in the USA where the 'NASA Supercritical Airfoil' was being developed. Since that time the term 'supercritical airfoil' has been used to identify the collection of airfoils which displays at transonic speed no or only weak shock waves.

Practical Applications / Feasibility Studies

The airfoils developed so far did have the desired properties as far as the shock-free flow was concerned but they were not yet suitable for incorporation in an actual wing. During the period 1969-1973 feasibility studies were carried out in cooperation with Fokker in order to arrive at wing designs which could be incorporated in a civil transport aircraft.
This work was largely financed by NIVR. It involved an intensive experimental program and improvements in the computational methods. These investigations were also related to the off-design behavior of the airfoils. This led to the design capability of the NLR/Fokker-team (probably before anywhere else) for airfoils without or with weak shock waves, which also had favorable characteristics at off-design conditions.
During this period the emphasis shifted from increasing the speed to the reduction of the fuel consumption of airliners.

Project-Oriented Research (1973-1978)

Application to an Aircraft Wing

During the period of 1973-1978 the following step of applying supercritical airfoils into a wing design was undertaken.
Experience with numerical flow simulation had been gained through contracts financed by the Royal Netherlands Air Force and the laboratory's in-house research program. The laboratory had relatively large computer programs for the design of wings but they were only applicable to subsonic flow. In early 1973, NLR developed ideas for designing, semi-empirically, supercritical wings and after discussions with Fokker, NIVR initiated contracts to NLR and Fokker to develop design procedures.

The Design Procedure

The NLR design procedure for supercritical wings was based on the fact that the aerodynamic properties of a wing are more directly determined by the pressure distribution than by the wing

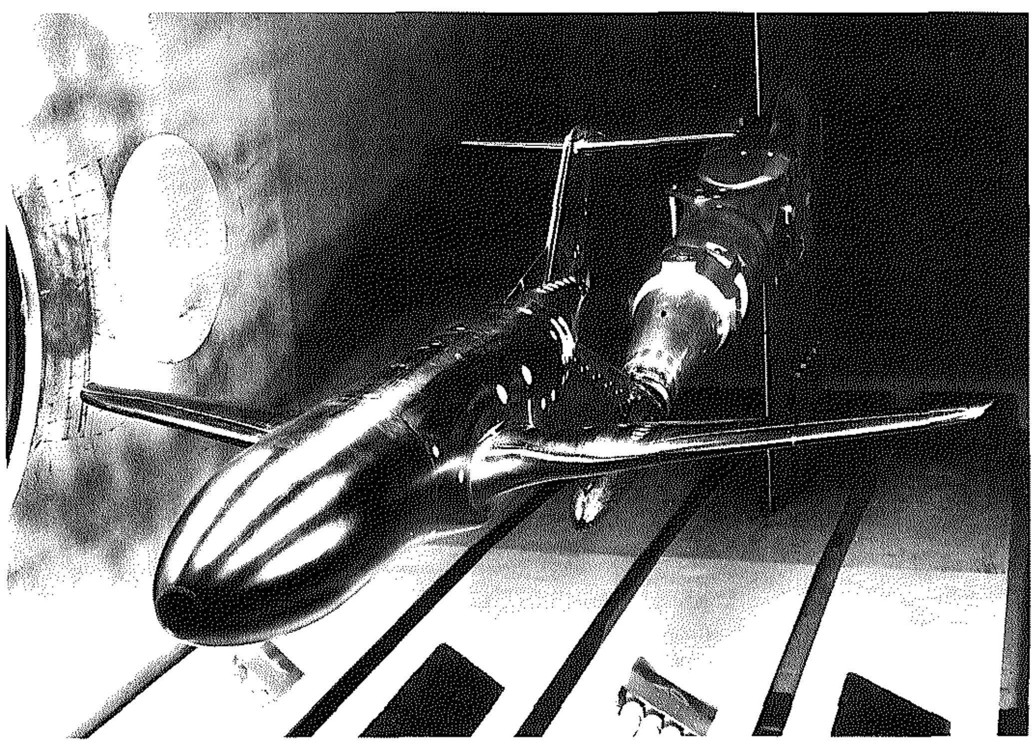
geometry. The pressure distribution of a wing, chosen for the cruise condition of the aircraft, (the design pressure distribution), determines the aerodynamic characteristics of the wing at the design conditions but also at the off-design conditions.
With this approach the problem is: to determine the relation between the design pressure distribution, the off-design properties and the wing geometry. The fixation of the design pressure distribution from the desired aerodynamic properties calls for a profound technical insight and experience of the design team to relate the design characteristics to the properties of the wing at off-design conditions.
After having determined the design pressure distribution, there is the clearly defined problem of finding the wing planform which can be solved if the proper tools for the 'inverse problem' are available. This may lead towards wing forms which are not acceptable from a structural point of view. The construction introduces additional constraints leading towards a wing design with a pressure distribution slightly deviating from the desired one.

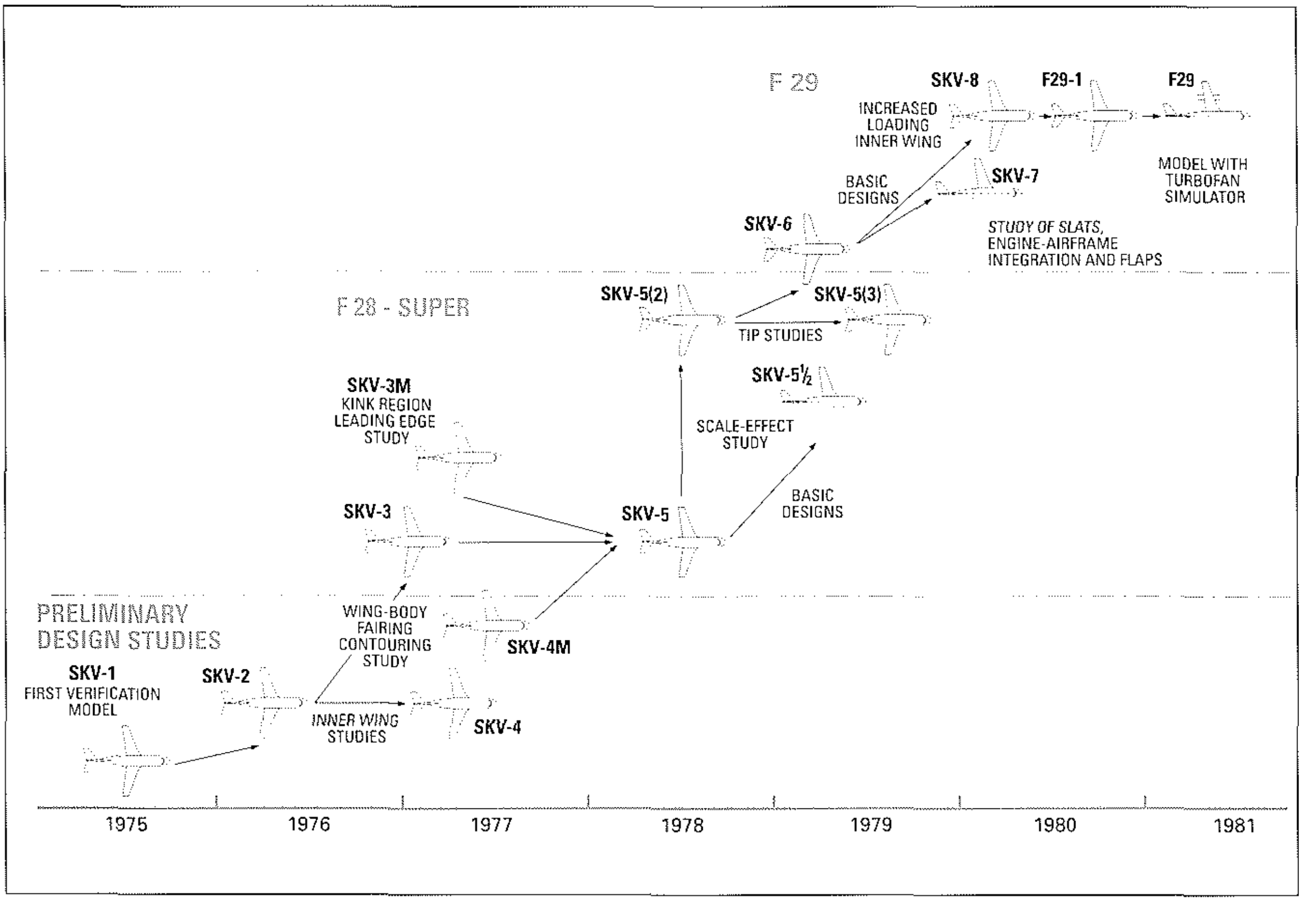
When this design procedure was formulated in 1973 it was not entirely clear what the desired pressure distribution would have to be and also the tools for the second step in the design process, the determination of the wing geometry which would produce that pressure distribution, were only partially available and so the design process was to a large extent still empirical. Nevertheless in the second half of the 1970's the method had been refined to such an extent that satisfactory solutions could be obtained.

Experimental Investigations

In 1975 the first wind tunnel tests were carried out in the High Speed Wind Tunnel HST, on a wing-body combination to verify the design procedure.
These tests showed that the design procedure worked satisfactorily and that the technology of supercritical wing design would introduce great economic advantages. During the period of 1975-1977 several wing-body configurations were designed and tested in the wind tunnel in close cooperation with Fokker, in support of the Fokker F28-Super project.

An early Supercritical Wing-Fuselage configuration, SKV-1, in the High Speed Wind Tunnel HST





Supercritical Wing investigations in the High Speed Wind Tunnel HST, Period 1975-1981

Investigations on Flap Systems

Parallel to this research in the HST, experiments were carried out in the Low Speed Wind Tunnel LST 3 x 2 M², on supercritical wings with flap systems designed by Fokker. It appeared that aircraft with supercritical wings and properly designed flap systems would have considerably better take-off and landing characteristics than aircraft with 'conventionally' designed wings.

Instationary Flow / Vibration Research

Starting in 1975 research was carried out on the effect of instationary air forces on supercritical wings and on the vibrational behavior of these wings. Initially investigations of the aerodynamic characteristics of oscillating supercritical airfoils and airfoils with oscillating flaps were carried out in the Pilot Tunnel of the HST (PHST) and then a method was developed to predict the instationary air forces on supercritical wings and its effects on elastic wings. The design method was verified by flutter test in the HST with a specially designed half-model of a supercritical wing-body configuration.

Basic Research / Feed-Back

Already starting in 1973 and parallel to this Project-Oriented Research, financed by the NIVR, several more basic research projects were carried out. These projects were also largely supported by NIVR through its 'General Research Program'. They concerned the development of computer programs for wings at transonic speed which could replace some of the semi-empirical elements in the design procedure and methods for the calculation of the instationary flow over wings.

Development (1979-1984)

Development of the F29 (1979-1980)

During 1978-1979 Fokker started the development of a new civil airliner, first announced as the F28-Super and later called F29, as the design evolved further. The experimental work at NLR was determined to a very large extent by the specific needs of the Fokker design team.

Development of the MDF 100 (1980-1982)

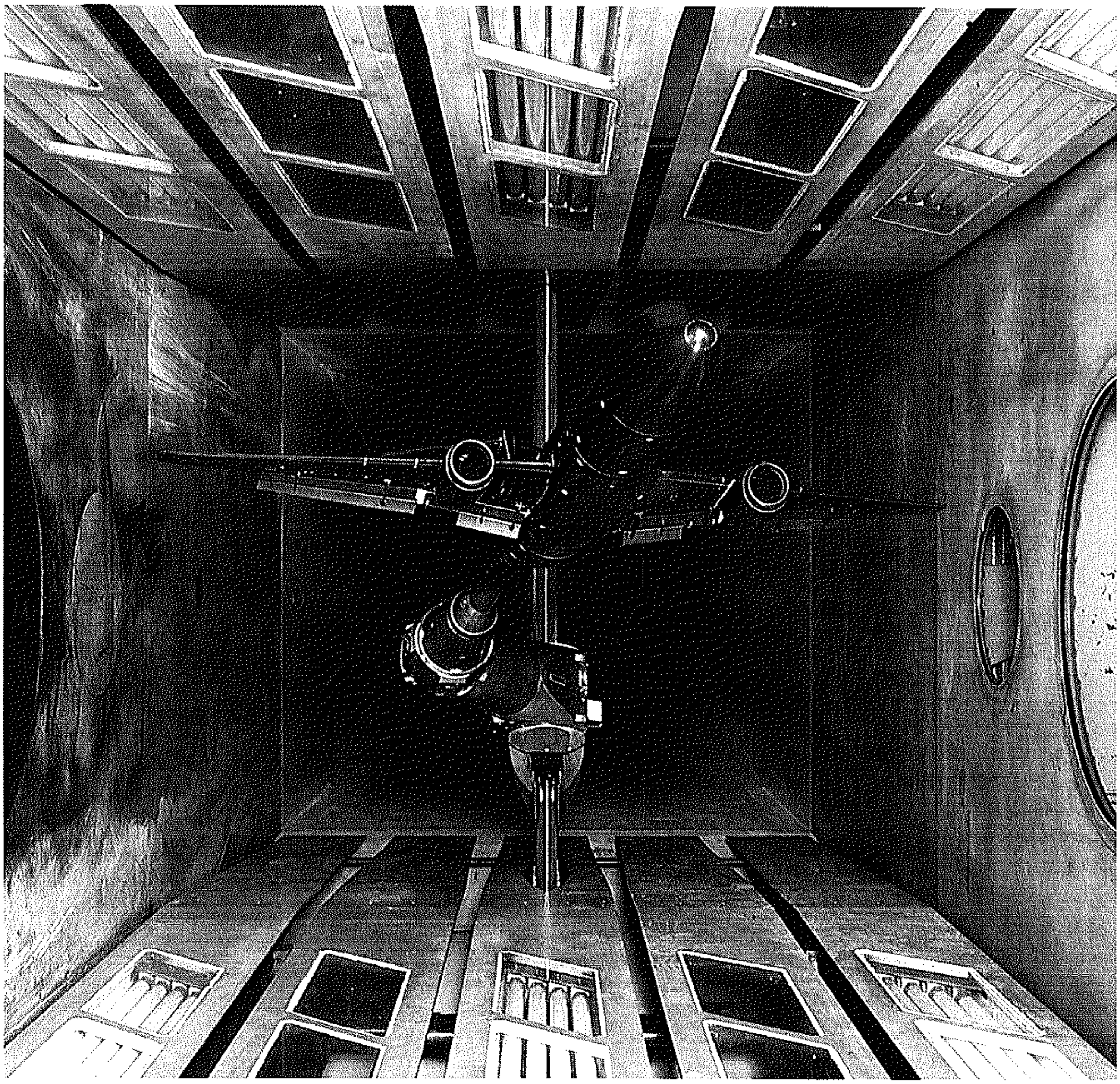
During the early 1980's Fokker and McDonnell-Douglas cooperated in a joint design project which became known as the MDF 100. This led towards a further intensification of the aerodynamic design activities. Although it was a joint project in which the best engineering capabilities of the partners were combined, it also had an element of competition since the partners were faced in detail with each other's design capabilities. In February 1982 the project was canceled for other than purely technical reasons. The Fokker/NLR-team certainly had gained confidence through this confrontation.

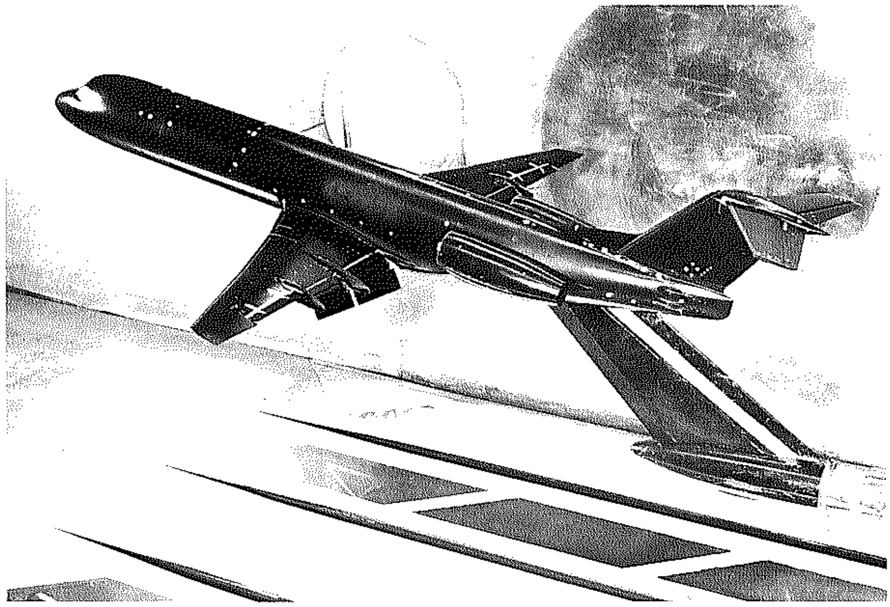
For the Fokker/NLR-team there was an important change in that the engines of the MDF 100 were planned under the wing instead of at the rear of the fuselage as had been the case since the F28 and the subsequent Fokker design studies.

Development of the Fokker 100 (1983-1984)

The supercritical wing technology and the aerodynamic computational capability developed at NLR since the 1960's had been applied in several European and American contracts and in various projects carried out for the Royal Netherlands Air Force, but the Fokker 100 was a case in which all the

Model of the Fokker F29 mounted in the test section of the High Speed Wind Tunnel HST

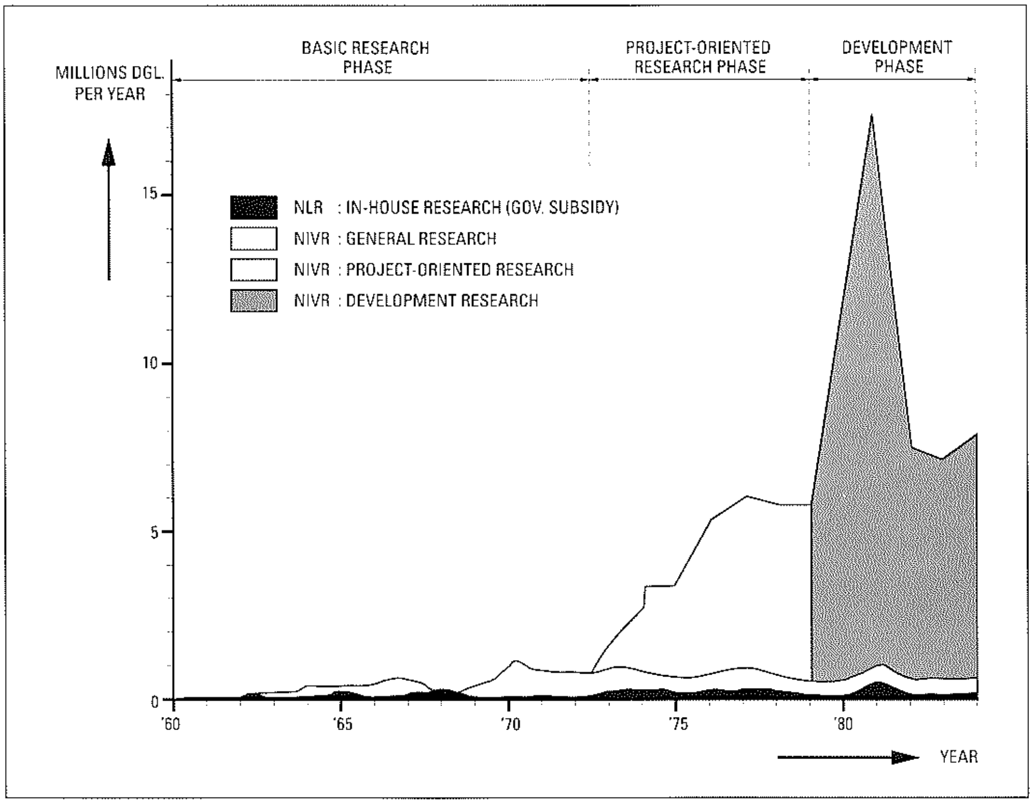




Test of a model of the Fokker 100 in the High Speed Wind Tunnel HST

experience gained was applied to a civil airliner. The design of the Fokker 100 wing was constrained by certain production and economical considerations. One of the constraints was that the design of the wing torsion box (the center part of the wing) of the F28 had to be retained. External form changes of the leading edge and trailing edge of the wing and of the wing tip could be accommodated. With the design methods available and the experience gained in the F29/MDF 100 projects, it was possible to design in a very short time an optimal supercritical wing within the constraints set by the Fokker designers.

The expenditures at NLR related to the development of Supercritical Wing Technology



The Cost of this Innovation Process

The annual expenditures at NLR involved in "Supercritical Wing Technology" during a period of over twenty years are as shown. (Quotation marks are used here since the cost involve besides the 'supercritical' part the development of computer programs, the manufacture of wind tunnel models and the wind tunnel tests).

The first phase of the process - Basic Research, 1960-1972 - was funded at a level of DGL. 300,000 per year till 1968 and DGL. 400,000 per year till 1974.

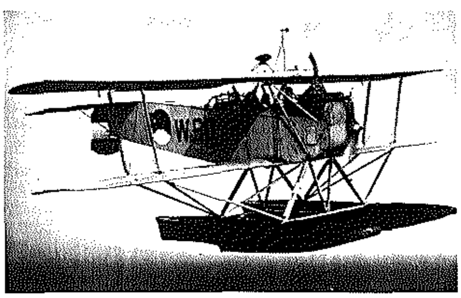
The Project-Oriented Research was funded at a average level of DGL. 3,750,000 during the period of 1973-1978. The higher cost level was associated with the use of more expensive equipment (wind tunnels, computers) and the design and manufacture of wind tunnel models.
During the Development Phase - 1979-1984 - the expenditures increased very rapidly to the level of DGL. 10 million per year. During that five year period Fokker went through the evolution of the designs of the F29, the MDF 100 and finally the Fokker 100. Had the design goal in 1980 been the Fokker 100, the total expenditures would probably not have been much less.

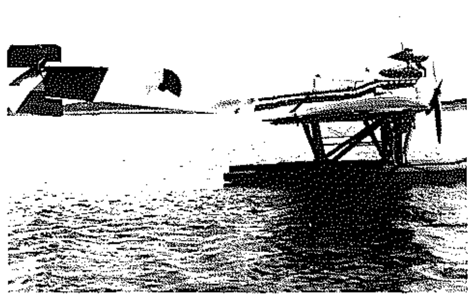
Flutter

As a second example of NLR contributions to theoretical and experimental aerodynamics the solution of the Flutter problem is selected.
Flutter is an aero-elastic phenomenon in which the elastic and the inertial forces interact unfavorably with the unsteady aerodynamic forces generated by the oscillatory motion of the structure itself. Flutter occurs when the oscillatory motion is reinforced and this can lead to destruction of the structure.

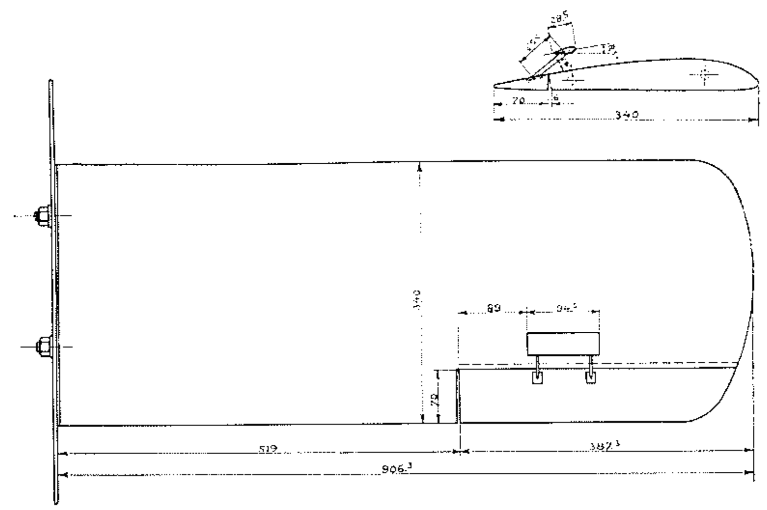
The elastic and the inertial forces are determined by the properties of the aircraft or parts of the aircraft such as wings, ailerons, flaps and tail surfaces. That is the structural part. The aerodynamic forces due to the oscillatory motion form the aerodynamic part and so flutter is an aero-elastic phenomenon. In general two or more structural vibration modes are involved - for instance bending and torsion of a wing - which, under the influence of the unsteady aerodynamic forces, interact with each other such that the vibrating structure extracts energy from the passing air stream. This leads to a progressive increase of the amplitude of the vibration and this may lead to a structural failure.

Flutter played an important role in the development of the airplane or rather it was a major hurdle to be overcome by many aircraft designers, often without the designers being aware of the phenomenon. Collar contributed the failure of S.P. Langley's flying machine (launched with a catapult from a house-boat on the Potomac River, USA) to aero-elastic problems: *"...It seems, therefore, that, but for aero-elasticity, Langley might have displaced the Wright brothers from their place in history...", [Ref. 53].* Note that Mr. Langley's attempt to fly his airplane took place on 8 December 1903, nine days before the Wright brothers' first powered flight.
In 1916 F.W. Lanchester et al. reported on the problems of a Handley Page biplane bomber, where a combination of vibrations of the tail plane with the torsional vibrations of the fuselage caused the fuselage to twist as much as 15 degrees, [Ref. 54]. They probably carried out the first analytical investigations of aero-elastic stability.


The Van Berkel WA aircraft

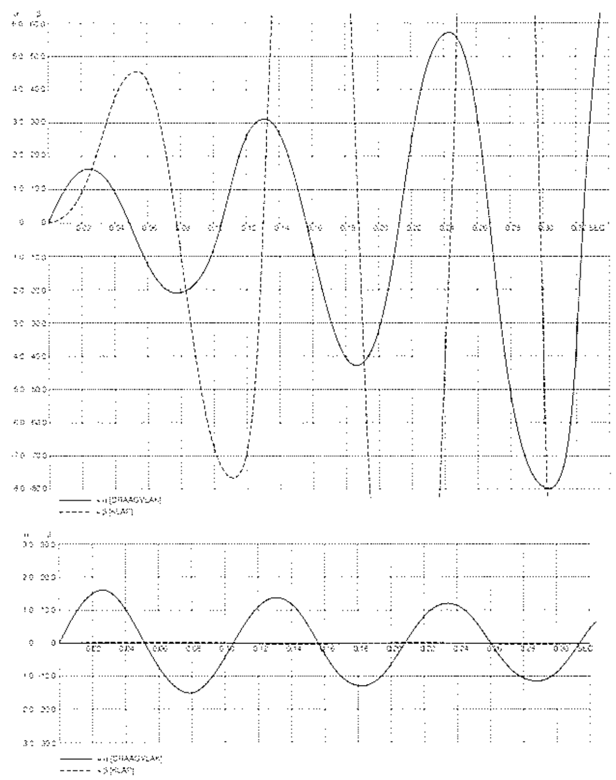

The Van Berkel WB aircraft

[5](See page 94) The story of the Van Berkel aircraft is summarized in [Ref. 7]. During the first World War the purchase of aircraft from abroad was very difficult and so the Government looked for national companies to manufacture aircraft. One of those was, the 'N.V. Maatschappij tot vervaardiging van snijmachines volgens Van Berkels Patent' (Company for the manufacturing of food cutting machines according to Van Berkels' Patent) at Rotterdam. The export of cutting machines and commercial weighing scales was restricted due to the war and since this company had an excellent reputation, the Government awarded it a contract to produce aircraft for the Navy. On 18 April a German aircraft, a Hansa-Brandenburg W-12, was captured after having made an emergency landing near the isle of Rottum, in the North of The Netherlands. The aircraft was still in perfect condition and Van Berkel was asked to copy this aircraft. That is how the Van Berkel WA model was created. The WB model was definitely a different aircraft as indicated above. Both models served with the Navy till 1933 in The Netherlands and in the Netherlands East Indies. In the early 1920's Van Berkel terminated the aircraft division due to lack of orders and presumably since its 'core business' was more profitable.



The experimental arrangement of a Wing-Aileron Wind Tunnel Model

In The Netherlands, in the early 1920's violent unstable oscillations were observed on the wing of a Van Berkel WB semi-cantilever monoplane of the Royal Netherlands Navy. The Navy had purchased six aircraft of this monoplane equipped with floats; the aircraft were delivered in 1921 and 1922. Earlier Van Berkel had received an order from the Navy for some 40 biplane aircraft, designated Van Berkel WA, which were delivered between 1919 and 1924. The introduction of a single wing version (the WB) with a 360 HP Rolls Royce engine compared to a 180 HP Mercedes engine on the WA, changed the aircraft to such an extent that flutter conditions occurred.[5] Ir. Von Baumhauer and Ir. Koning of the RSL investigated various possible causes for the problem. A wind tunnel test was carried out on a half wing with an aileron and coupled oscillations were observed. This two degrees of freedom system (bending of the wing and rotation of the aileron) showed unstable oscillations due to aerodynamic forces. It was shown that the problem could be eliminated by moving the center of gravity of the aileron towards the center of rotation (through mass balancing of the aileron). In the first instance wing torsion was neglected in the experiment and also in the analysis. The Figures show the principle of the experimental set-up and the results of the calculations for this two-degrees of freedom vibrational system, for the case of an unbalanced aileron and a balanced aileron, [Ref. 55].



The oscillations of the Wing-Aileron system, without and with Aileron Mass Balancing

Although this was not the first time flutter had been observed and studied, it was certainly the most effective - and elegant - analysis and experimental investigation of aerodynamic flutter.

The above referenced report of Von Baumhauer and Koning was dated August 1923. Unfortunately this did not mean that from then on all aircraft in The Netherlands were free of flutter. Flutter accidents occurred when aircraft were flown under extreme conditions such as on 15 January 1932 when a Fokker D.XVI ended in a crash after the pilot carried out a series of tests to determine whether or not wing vibrations would occur in a steep dive. From the brief RSL report it does not appear that the pilot was aware of the flutter phenomenon and Von Baumhauer, after having reviewed the evidence of the accident, had to recommend to provide the ailerons with balance weights [Ref. 56], some ten years after he and Koning had carried out their pioneering investigations!

The basic mechanism of flutter was now uncovered. This laid the foundation for an enormously fruitful series of investigations and a school of experts on unsteady aerodynamics and flutter

developed at NLL/NLR. Major contributions were made by Timman, Van de Vooren, Greidanus, Bergh, Tijdeman, Zwaan and several others.
In 1956 Dr. Ir. A.I. van de Vooren of NLL became a part-time Professor of Unsteady Aerodynamics at the Technical University Delft before he became a full-time Professor of Applied Mathematics at the University Groningen, September 1958. Ir. H. Bergh continued the lectures at Delft and later a special Chair on the subject of Aero-Elasticity was created, first occupied by Prof. Ir. H. Bergh and from 1985 bv Prof. Ir. R.J. Zwaan of NLR.

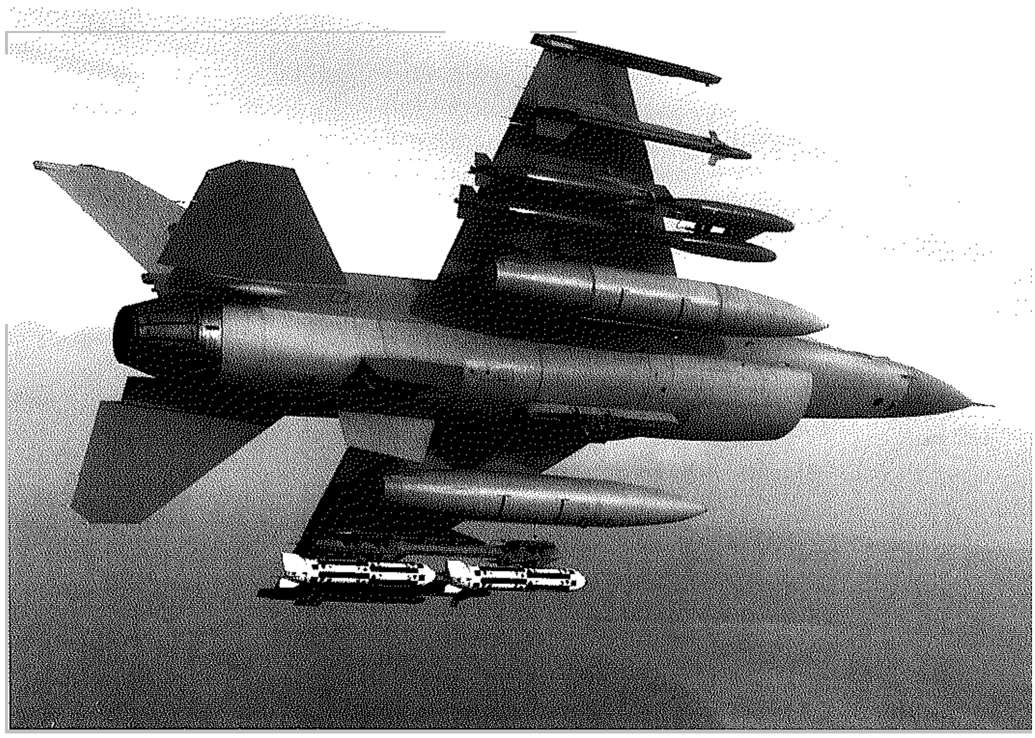
When high speed aerodynamics became more important at NLR the emphasis shifted over the years via the calculation of the aerodynamic coefficients of airfoils in oscillatory motions and many intricate experiments, to transonic phenomena. Detailed investigations of oscillatory motions of shock waves over airfoil surfaces at transonic speeds were carried out and methods were developed to determine the safe boundaries of the combination of speed and angle of attack, [Ref. 57][6].

A very fruitful area of application of unsteady aerodynamics is the investigation of flutter behavior of fighter aircraft with external stores. During the life-time of these aircraft many different stores and combinations of stores under the wings and the fuselage are used. Each configuration has to be cleared for safe operation, that is the range of operation (speed, altitude, angle of attack, mass, etc.).

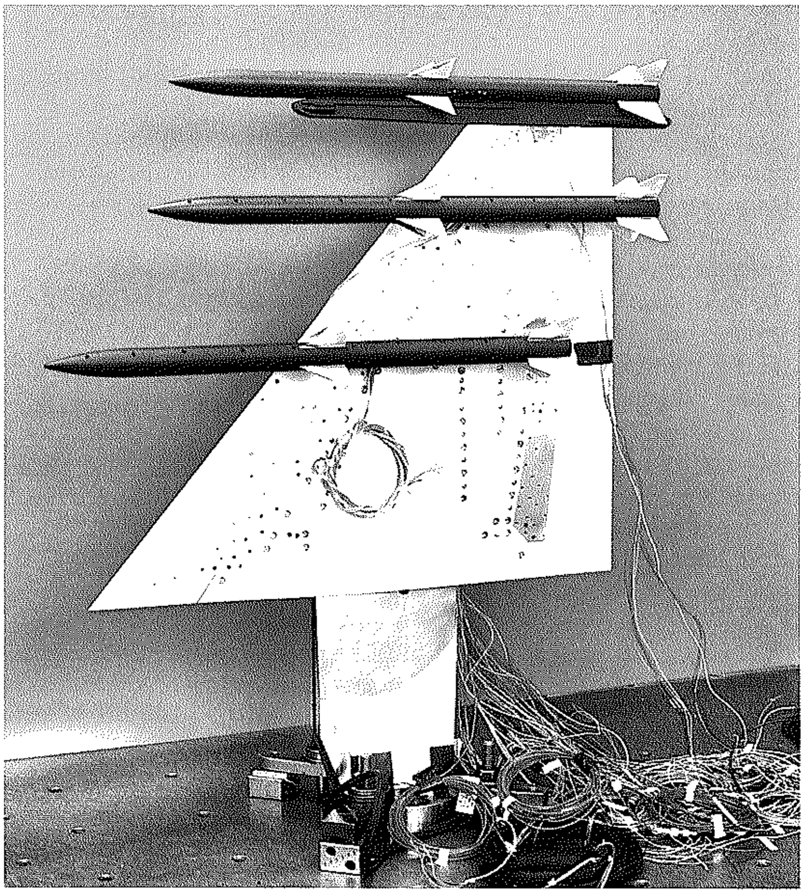
A summary of more recent investigations carried out by NLR on several aircraft of the Royal Netherlands Air Force and foreign Air Forces, [Ref. 58] shows that there was and still is a need for careful testing whenever the external configuration of a fighter aircraft is changed.

An additional problem is that high performance fighter aircraft carry out 'high g' maneuvers at transonic speed (high accelerations due to rather abrupt maneuvers) causing separations of the air flow

Example of a Fighter Aircraft carrying a variety of stores



[6] When Prof. Dr. Ir. H. Tijdeman - who worked at NLR for 25 years before he became Professor of Technical Mechanics at the University Twente in 1986 - defended his Doctoral dissertation at the Technical University Delft he posed the proposition: - The prominent position NLR has achieved in the field of aero-elasticity is for a substantial part due to the fact that the Aero-elasticity Department is part of the Aerodynamics Division and not of the Structures and Materials Division, as in most other aeronautical laboratories.



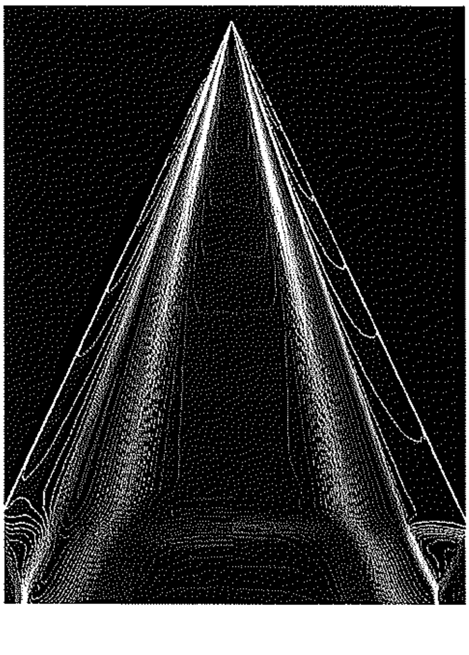
Model of a wing for investigations of Limit Cycle Oscillations (LCO)

over the wing. This type of flow causes aircraft buffet and in some cases transonic nonlinear oscillations of limited amplitude. This is known as Limit Cycle Oscillations (LCO). These oscillations may affect the performance of the aircraft and of the pilot. It is therefore necessary to determine the allowable limits of the amplitude and frequency of these oscillations and the limits of operation of the aircraft with various external stores combinations.

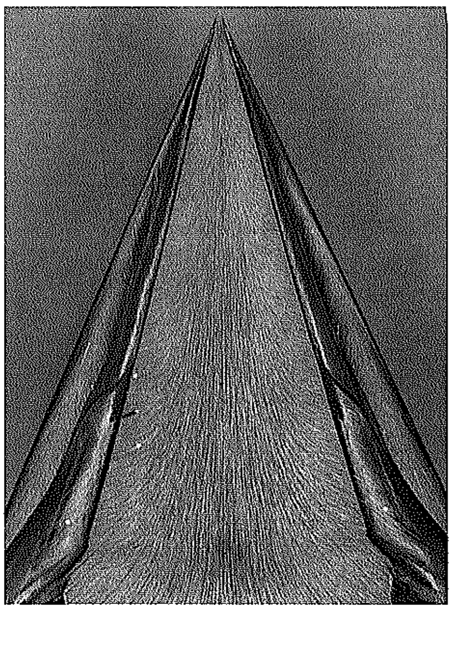
During the 1980's NLR (in cooperation with the USAF and General Dynamics) carried out a series of experiments on an oscillating delta type wing with sharp leading edges and strakes. Detailed pressure and force measurements were made and with the aid of a stroboscopic laser light sheet the behavior of vortices, emanating from the leading edges and strakes was studied so that comparisons could be made with numerical calculations, both at low speed and at high speed.
The knowledge and experience gained at NLR with aircraft aero-elasticity has been applied over the years to a large number of other engineering structures, including many bridges, tall structures such as chimneys, and offshore oil and gas platforms.

Over a period of many decades theoretical analysis and wind tunnel tests on scale models have been made for all new major bridges in The Netherlands and also in some other countries. Combined with the measurement of the vibration frequencies and amplitudes on the full-scale bridges, a considerable body of knowledge and experience has been built up in this field.

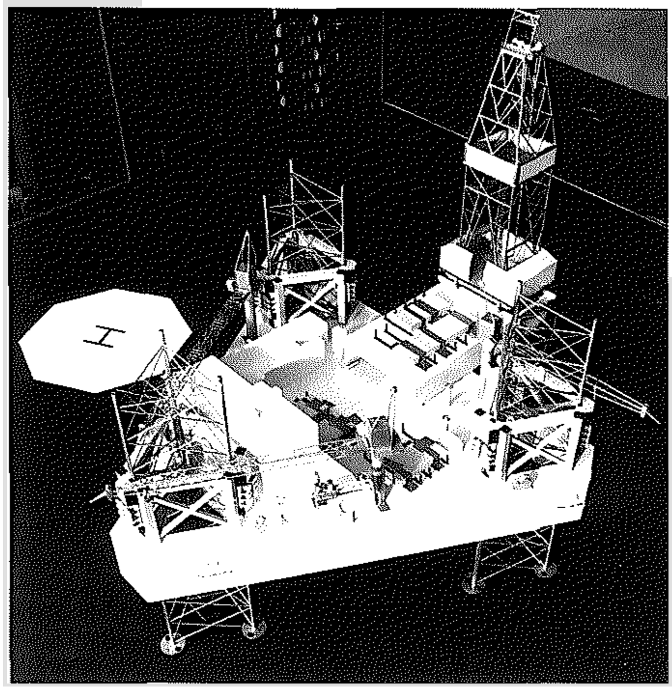
Isobar pattern on upper wing surface calculated by NLR's Euler method on the Supercomputer of NLR



Visualization of flow on upper wing surface in the High Speed Wind Tunnel HST



Wind tunnel model of a Bridge



Wind tunnel model of a typical Offshore Structure

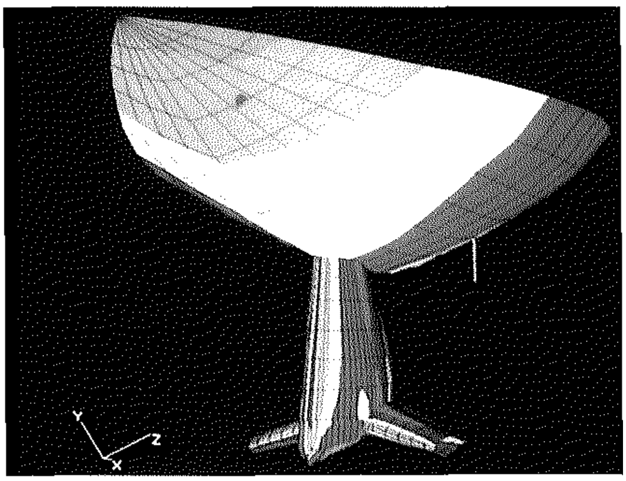
The Winning Keel

For the **third** example of NLR contributions to aerodynamics the design of a keel for a sailboat is chosen. In fact it is not aerodynamics but hydrodynamics. Although the NLR contribution was rather limited in terms of man-hours it is an interesting example of applying knowledge and experience gained in aeronautics to non-aeronautical problems.

In 1983 the 'AUSTRALIA II', owned by Alan Bond, won the America's Cup in the 12-meter yacht race at Newport, R.I., USA. This race, organized by the New York Yacht Club, had always been won by Americans, since its very beginning, 132 years earlier.

The success of the AUSTRALIA II was attributed to a new and revolutionary keel design. The keel was provided with end plates or 'wings', giving the yacht considerably better side force and drag characteristics than yachts with conventional keels. It resembled an inverted T-tail as used on some types of airplanes.

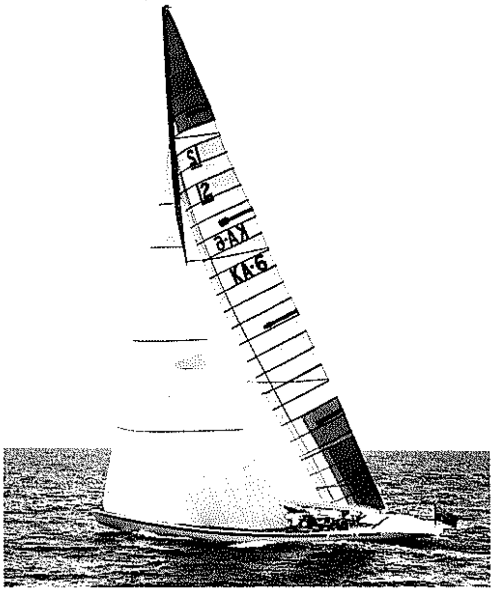
Example of a Computer Grid used to calculate the hydrodynamic forces on the Keel of the 'AUSTRALIA II'



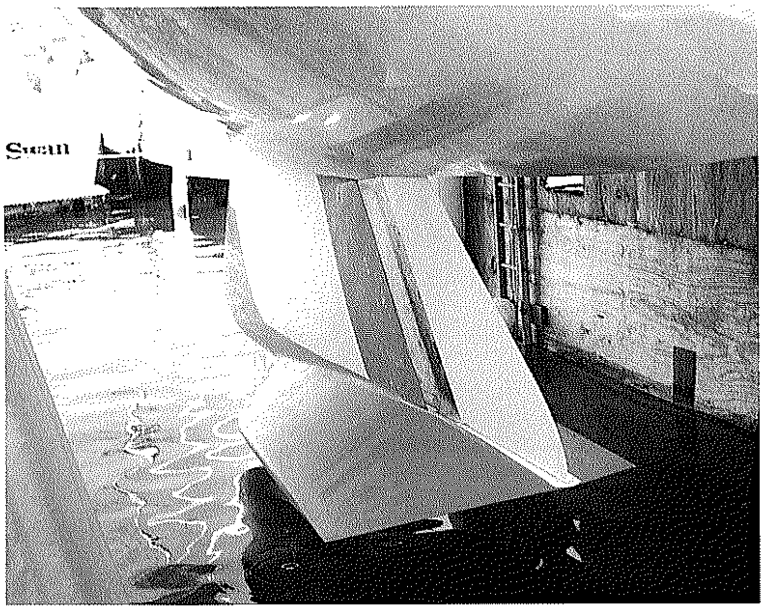
The main keel is inversely tapered with little or no sweep, a rounded forward tip and trapezoidal, downward sloping winglets at the rear half of the foot or 'tip' of the keel. In an integrated ship design the concept results in a more slender hull with a smaller wetted area, [Ref. 59].

This type of winged keel was conceived in 1980 by Ir. J.W. Slooff, who was then Chief of the Theoretical Aerodynamics Department at NLR and a cruising yachtsman.[7] He had been developing computational methods and computer programs for aircraft design purposes. In fact his Department contributed greatly to and worked closely with the Fokker design team in several aircraft design studies and research projects, some of which involving winglets - small surfaces mounted at the tip of a wing. He also cooperated with

[7] Ir. Slooff was appointed part-time Professor of Aerodynamics at the Technical University Delft and Head of the NLR Fluid Dynamics Division in 1986.



The 'AUSTRALIA II'



The Keel of the 'AUSTRALIA II'

Dr. P. van Ossanen of the Netherlands Ship Model Basin, MARIN, at Wageningen, in a Study Group for Advanced Ship Design for the Royal Netherlands Navy.

It was in the Spring of 1981 when Ben Lexcen, Mr. Bond's designer, was supervising model tests at MARIN, when the concept of the winged keel was discussed with him. The result was that NLR received a contract to carry out computer simulations of the flow over a number of hull-keel configurations using the NLR lifting potential flow computer programs. The calculations confirmed that the side force and resistance characteristics of the winged keels were superior to those of conventional keels. This was verified by model tests in the towing tank of MARIN in the summer of 1981. After sizing and fine-tuning the design of the AUSTRALIA II the final result was that in 1983 the America's Cup went to Australia.

Early in 1983 rumors circulated that the Australians had a revolutionary design with a 'Dutch connection' and MARIN and NLR were approached by competitors with offers for contracts. However the agreement with the Bond Syndicate was that no information would be released and that similar work would not be carried out for possible competitors till after the race. It was also questioned whether this was an original Australian design, which seemed to be part of the rules of the New York Yacht Club.

Unlike 'normal' sailboat races of a certain class, where all participating boats must have the same dimensions, the rules of the New York Yacht Club for the 12-meter racing yachts stipulated a certain number of design parameters which can be varied according to a certain formula. The parameters relate to length and beam of the hull, the depth of the keel, the displacement, the mast height, the sail area, etc. The yachts are specifically designed for the race: specified trajectory and location with an expected wind force, sea state, wave height and patterns.

The impact on the design practice of yacht designers was enormous. During the preparations for the 1987 race in Australia, 17 syndicates all resorted to computer modeling and analysis. The team of the STARS & STRIPES, the winner of the 1987 America's Cup competition, wrote, [Ref. 60]:

> -*"It was our ambition first to duplicate and then to exceed the AUSTRALIA II achievement...... Although we dreamed up and modeled several other keel appendages, none proved to be as promising as a refinement of Lexcen's design...."*

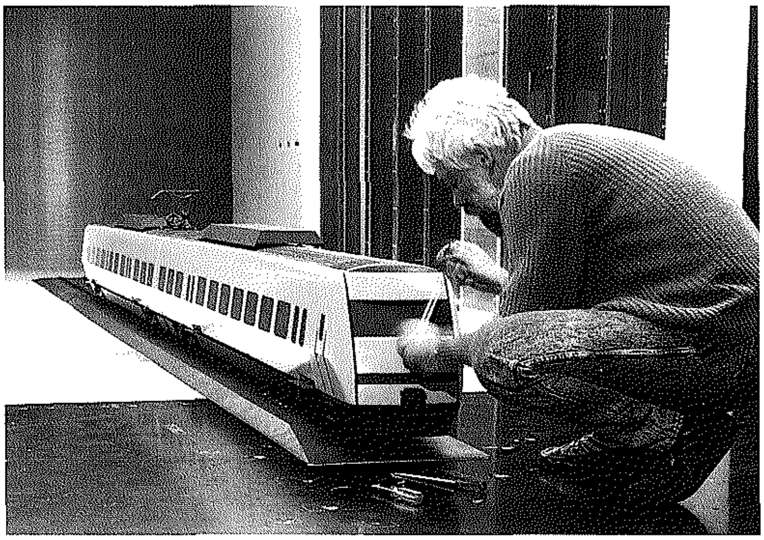
What more can one desire than such praise from a competitor!

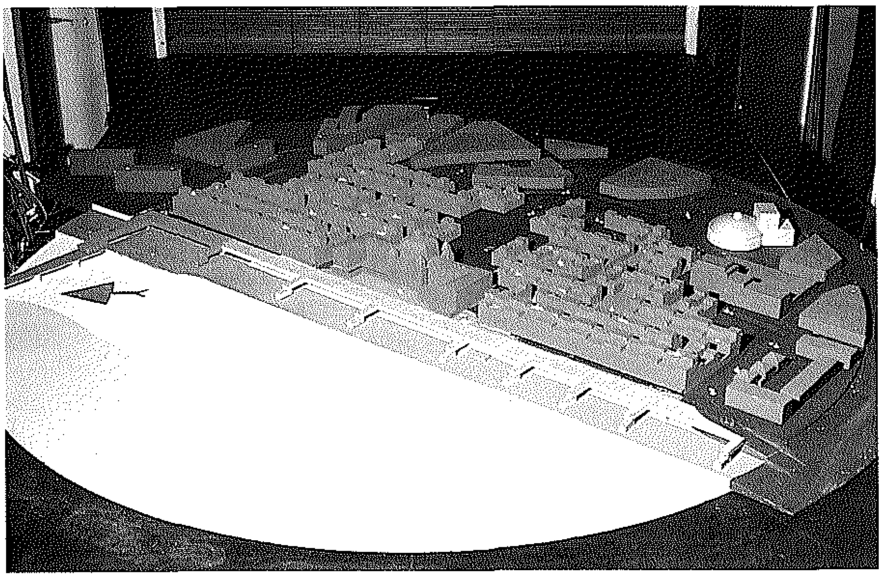
Jan de Vries, World Champion Motorcycle 50cc, in the Low Speed Wind Tunnel LST, 1971

Examples of Non-Aeronautical Tests

There seem to be endless possibilities for the usage of wind tunnels. In Chapter 3 some examples of non-aeronautical tests were given. This type of activity continued to this day. In some areas a considerable expertise was built up, e.g. the simulation of the wind climate around high-rise buildings and built-up urban areas, and the smaller of the two low speed tunnels in Amsterdam, the LST 1.5 x 1.5 M² with an open test section was used almost exclusively for this type of testing. After the termination of the two low speed wind tunnels in Amsterdam and the transfer of all experimental low speed aerodynamics to the NOP, the new LST 3 x 2.25 M² in the NOP continued to carry out non-aeronautical testing and the DNW was used for larger scale (and more expensive) tests. The photographs present typical non-aeronautical tests.

Model of a Train being prepared for tests in the Low Speed Wind Tunnel LST 3 x 2.25 M²





Model for an Urban Development Plan in the Low Speed Wind Tunnel LST (Kurhaus Scheveningen)

10. The Supersonic Facilities

During the period 1946-1948 a small supersonic wind tunnel was built at NLL. The tunnel had a test section of 3x3 CM², a Mach Number range of 1.4 to 4.0 and the tunnel was driven by a compressor.[1] It was mainly used to gain experimental experience with supersonic flow and to develop optical instrumentation. It was then intended to build a supersonic wind tunnel with a 40x40 CM² test section which would also be driven by a compressor.

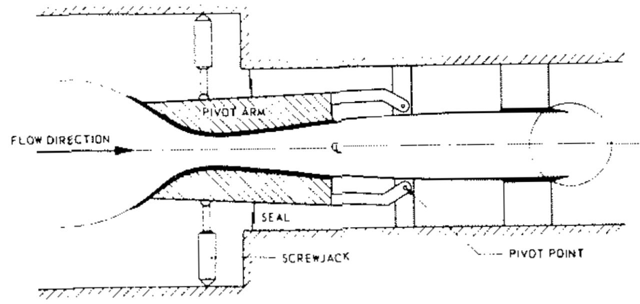
After the Second World War, Dr.-Ing. S.F.A.H.P. Erdmann, who had been employed at Peenemünde, the German Army establishment where the V-2 was developed, came via a stay in the UK to NLL in Amsterdam. He gave an important impulse to the experimental techniques, while several others, among whom Dr. R. Timman, developed the theoretical knowledge. Shortly after the modernization and expansions at NLR had to be stopped, (Chapter 5), Dr. Erdmann decided to accept a position in Sweden at the KTH, the Royal Technical University at Stockholm. But after the resumption of the expansion plans in 1952, when it was also decided to proceed with a supersonic facility, he returned to NLL. On 1 November 1954, after having worked five years in Sweden he resumed his work at NLL.

The supersonic blow-down facility that was ultimately built was larger than the one originally planned; it became the 1.20x1.20 M² blow-down tunnel SST, supplied with air from a large 40 atmosphere pressure vessel. The Mach Number range is 1.2 to 4.0 and the maximum Reynolds Number is 100 million, which is quite unique in many respects.

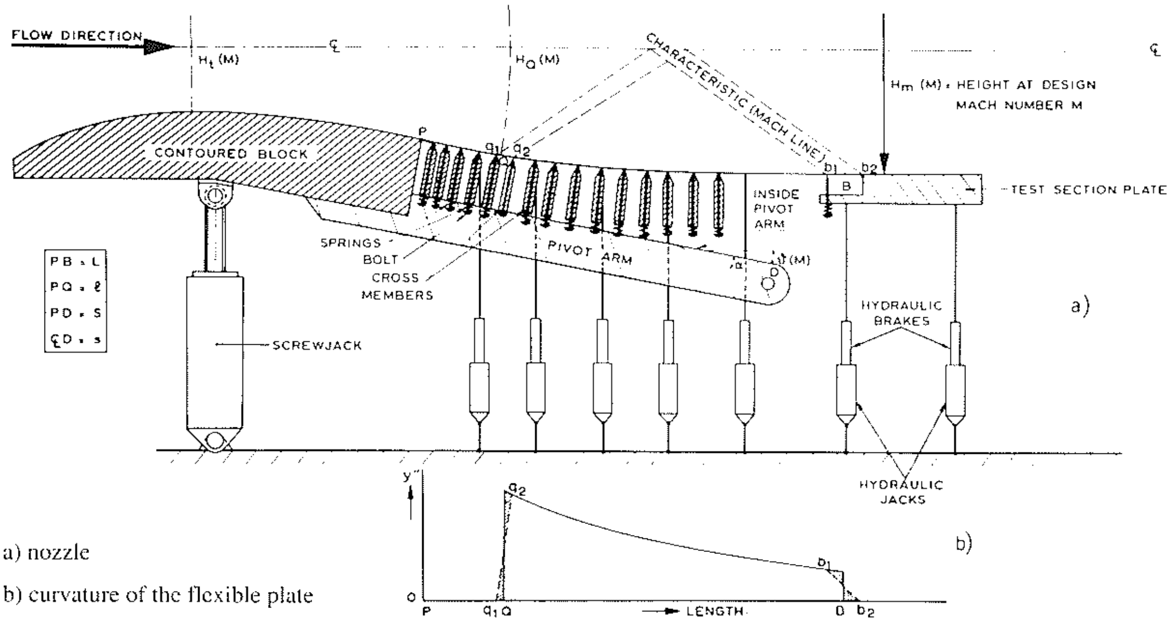
One of the problems facing the designer of supersonic facilities was to design a flexible supersonic nozzle which could be adjusted continuously so that a uniform Mach Number (or velocity distribution) across the test section was achieved at all Mach Numbers. This could be done but it required the walls of the nozzle, the part before the test section, to be adjustable for each Mach Number. This was achieved by having the top and bottom walls consist of flexible plates with a large number of jacks which had to be adjusted each time the Mach Number had to be changed. This resulted in a very expensive and complicated system.

The alternative was to design nozzle blocks for each Mach Number. Initially this last solution was chosen by several laboratories but it meant that when the Mach Number had to be changed the nozzle block had to be replaced which was very time consuming, apart from the problem of designing, manufacturing and storing many nozzle blocks. To avoid the complications of having separate nozzle blocks, the Swedish engineer Rosén had devised a nozzle with throat blocks attached to flexible plates whereby only the throat blocks had to be

Sketch of the Rosén Nozzle for a Supersonic Wind Tunnel



[1]The 3x3 CM² tunnel was later transferred to the Aeronautical Engineering Department of the Technical University Delft where it served as a demonstration facility for students.



a) nozzle

b) curvature of the flexible plate

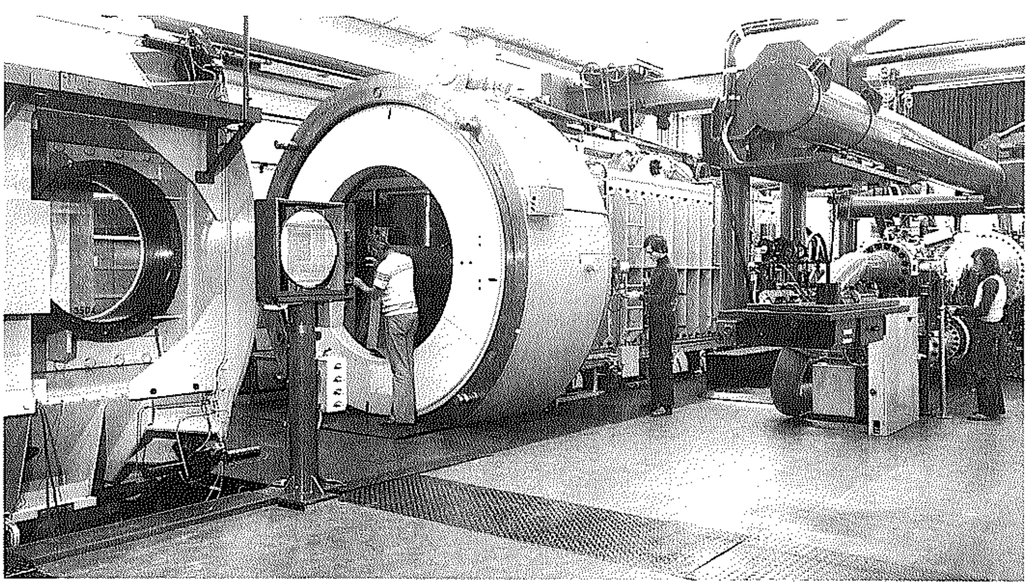
The NLR (Erdmann) Supersonic Nozzle Design

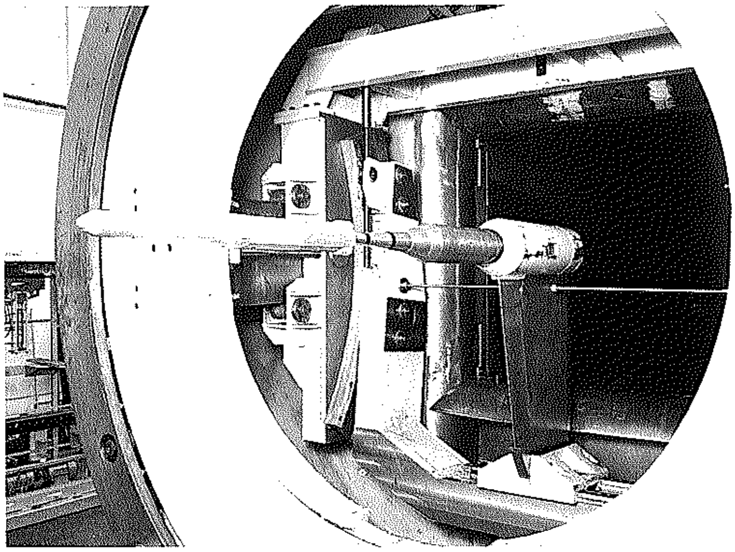
adjusted. (The 'throat' is the narrowest part of the nozzle; it is where the Mach Number becomes one and after the throat the flow expands into the supersonic regime.) For a larger Mach Number range this still required many adjustments to achieve a reasonable Mach Number distribution across the test section.

Dr. Erdmann devised a system whereby the additional corrections were achieved by means of a series of pre-adjustable 'cross members' and a limited number of jacks, [Ref. 61]. The Mach Number uniformity was better than 0.0015 M over a Mach Number range of 1.2 to 4.0 in the 1.2 x 1.2 M^2 facility, the SST, and in the smaller 0.27 x 0.27 M^2 facility, the CSST, up to M=6.0. The C stands for continuous; with the large compressor and air storage vessel this smaller tunnel can run almost continuously.

The large blow-down supersonic facility, the SST, became operational in 1963, four years after the transonic facility, the High Speed Wind Tunnel, HST.

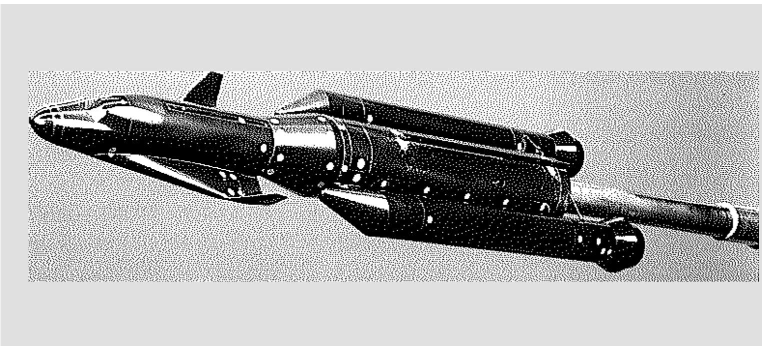
The Supersonic Wind Tunnel SST with the Continuous Supersonic Wind Tunnel CSST in the rear



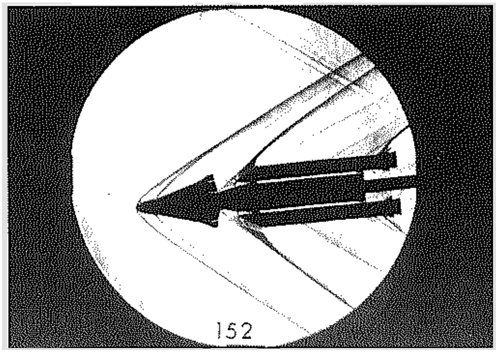


A model of an ELDO Launcher in the Supersonic Wind Tunnel SST

All this finally resulted in a capability with which The Netherlands through NLL/NLR was in a position to contribute substantially to the development of the ELDO series of launchers and later to the development of the Ariane rocket launchers and the Hermes vehicle.
The SST was designed such that the same model (same size) could be used in the HST and in the SST. Thus it is possible to use the same model for testing continuously from subsonic speeds up to Mach Number 4 with an overlap around Mach Number 1.2. This feature proved to be very effective; not only for the ELDO and Ariane rocket series but even more so for the French-British Concorde, various fighter aircraft and missiles.



A combination of a Hermes Re-entry Vehicle and an Ariane 5 Launcher model in the Supersonic Wind Tunnel SST



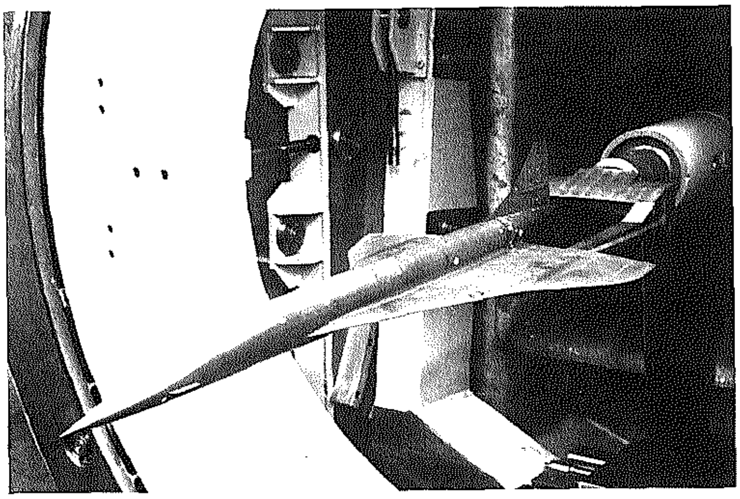
Schlieren photograph of the combination Hermes/Ariane 5 at Mach Number 2

The flow quality of both the HST and the SST was high by any standard. Also much effort was spent to increase the productivity of the two tunnels and the data handling equipment was periodically upgraded.
NLR was proud of the fact that the Concorde aerodynamic data obtained in the HST-SST wind tunnels compared very well with flight data and that the tunnels were often used for the final check of the aerodynamic data to confirm aerodynamic data of the Concorde obtained elsewhere.

Only fifteen Concorde supersonic airliners were produced in spite of the fact that it was technically a very successful project. The main reasons for this limited production were the drastic increase in fuel costs and the increased concern about the environmental effects: pollution, noise, supersonic bang, possible effects on the ozone layer, etc. These developments were not foreseen in the 1960's when the aircraft was conceived. Nevertheless there is now a considerable experience in supersonic airline operation: close to twenty years of trans-Atlantic operation of 150,000 passengers per year. A successor with a reasonable price per passenger-kilometer would find a growing market! It is not surprising then that major aircraft manufacturers (Aérospatiale, Boeing, British Aerospace, Deutsche Aerospace-DASA and McDonnell Douglas) have been studying for some time the possibility to design and develop the next generation of supersonic airliners. Some of the major aerospace research laboratories also have active research programs to tackle the problems mentioned above.

It is conceivable that the SST, still one of the best supersonic wind tunnels, will play a role in the development of the next generation of supersonic airliners around the turn of the century.

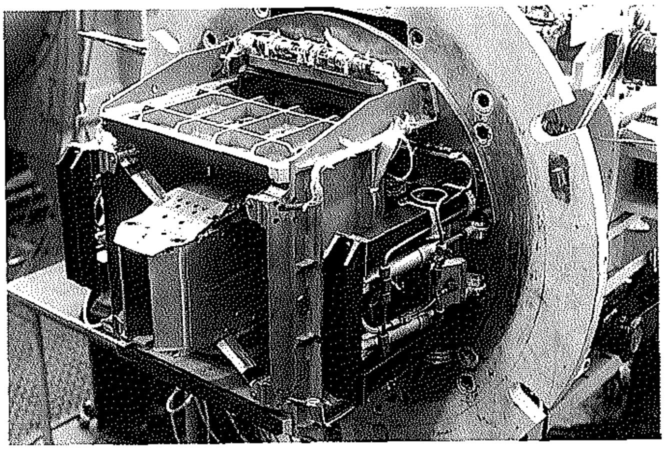
The French-British Concorde tested in the Supersonic Wind Tunnel SST



In this Chapter only the name of Dr. Erdmann was mentioned in connection with the development of the SST, but it must be clear that many experts contributed to this achievement. Dr. Erdmann who had been a part-time Professor at the Technical University Delft since 1960, became a full-time Professor of High Speed Aerodynamics at Delft in 1969 till he retired in 1983.

During the 1970's, when testing at high Reynolds Numbers at transonic speed became more and more important, Ir. J.P. Hartzuiker developed the idea of placing an insert in the SST test section. It was a kind of supersonic inlet with transonic flow inside. The advantage of the scheme was that a high stagnation pressure (and thus a high Reynolds Number) could be achieved, the pressure level of the air storage vessel being 40 atm. Pilot tests were carried out in the smaller supersonic blow-down tunnel, the CSST, and it was shown that this was a feasible idea. However due to technical complications and high pressure of other (contract) work, this insert was never developed for the SST and so it remained an interesting idea.

Pilot tests in the CSST of an insert for the SST to achieve high Reynolds Numbers at transonic speed



11. Aero-Acoustics

Aircraft and especially aircraft propulsion systems produce noise. During the early days of aeronautics that noise was pleasing to most people, but as time progressed and the production of noise increased both due to the introduction of more powerful jet engines and the increase of air traffic it became a nuisance, particularly around airfields.

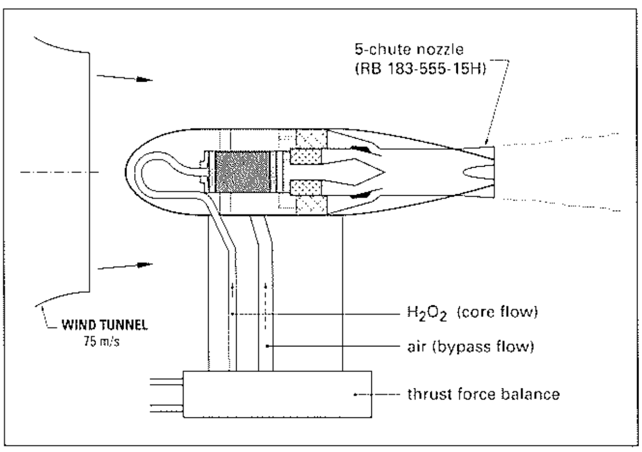
Additionally during the 1970's and 1980's the problem of aircraft noise became important around military airfields and in certain areas in Europe in connection with the low level high speed training missions of fighter aircraft.
The high intensity aero-acoustic noise loading caused by the high speed jet exhaust also had an impact on the fatigue life of the adjacent aircraft structure.

The first real noise problem for NLL itself was probably when it was confronted with complaints of the neighbors in Amsterdam about the noise produced by the ramjets in the rotor test stand for the Kolibrie helicopter, (Chapter 12). That installation was subsequently moved from Amsterdam to the Noordoostpolder.
Another noise problem was the noise produced by the HST, the transonic wind tunnel in Amsterdam. That problem was solved by building a sound absorbing structure around the steel structure of the wind tunnel in 1966.

Those noise problems were not the reason for starting aero-acoustic research for aeronautical development. During the 1970's and more so during the 1980's the governmental rules on aircraft noise became more strict and this led NLR to the development of the necessary research tools to support the aircraft industry.

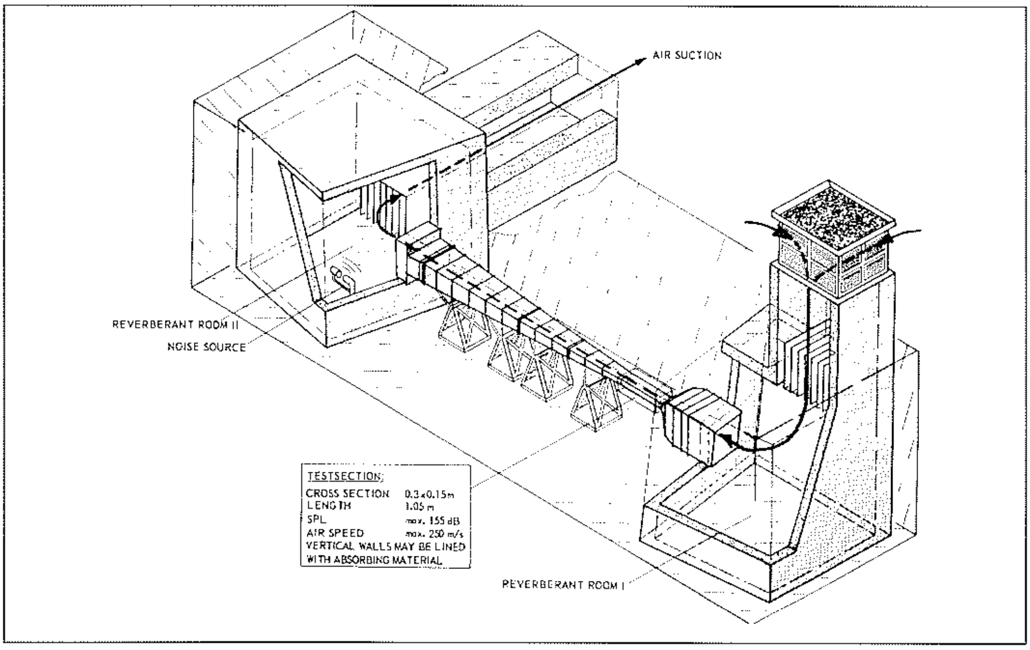
The major source of aircraft noise is engine noise. Since The Netherlands did not have an aircraft engine industry it was not immediately clear that it would be necessary to allocate much of the NLR resources to this problem. It did become of interest when the Fokker F28, based on the technology of the 1960's, ran into the problem of noise restrictions at some airport locations. The static thrust stand, at one time developed for testing the Kolibrie rotor tip engine and for experiments with hybrid rockets, was converted into an acoustic test stand for measuring the exhaust noise of jet engine models. Model tests on an **internal exhaust mixer** for the Rolls-Royce Spey engines of the Fokker F28 led to a substantial noise reduction. The mixer was immediately implemented by Rolls-Royce. This stimulated further work on jet engine intake and exhaust noise, on the border line of the activities usually assigned to the aircraft industry and engine manufacturers.
Several exhaust configurations were investigated in this test stand in which the hot gas core was simulated by supplying the model with hydrogen peroxide.

A test arrangement for simulating the mixing of the hot core gas with the cold by-pass air of a By-pass Jet Engine to measure the noise generated by various Mixing Devices



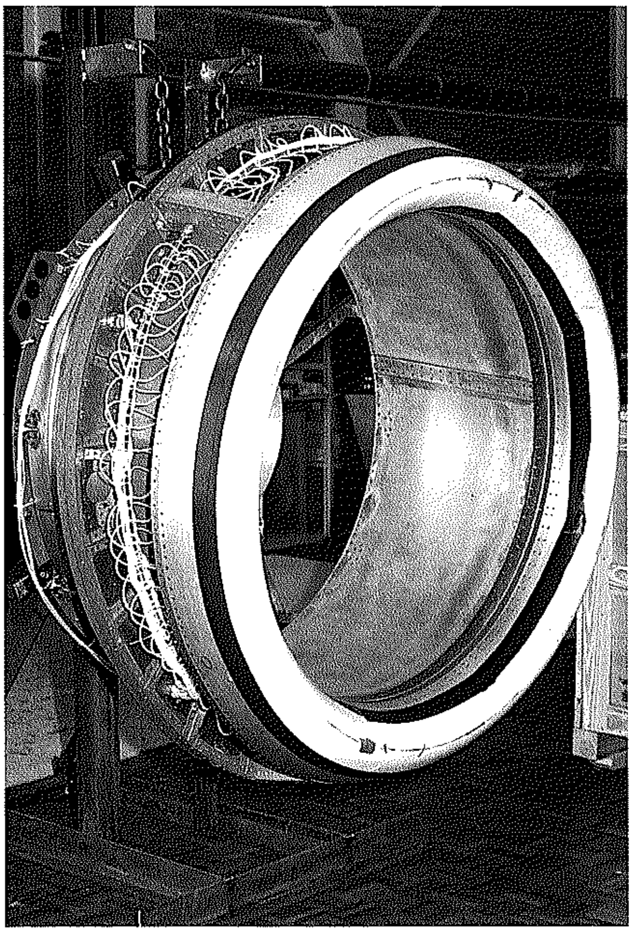
The following development was related to the reduction of the **fan noise** at the intake of jet engines. This research gained momentum around 1975 when various configurations for the next generation of civil airliners were being studied. An extensive analysis and experiments on the intake noise brought about the need for a facility to test the acoustic properties of sound absorbing materials for application as linings for jet engine intakes. It became clear that realistic tests of sound absorbing materials required a special facility

The Acoustic Flow Duct Facility for measuring the noise attenuation characteristics of Acoustic Liner Materials



An instrumented Engine Inlet of the Fokker 100 for flight testing

in which the material was embedded in a wall along which the intake flow was simulated. At the downstream end of this flow duct a powerful noise source (powerful loudspeakers) was located, simulating the fan noise of the engine. By measuring the sound level before and after the portion of the wall in which the test article (sound absorbing liner) was mounted an impression could be gained of the effectiveness of the liner material to suppress the fan noise.



With this facility it became possible to compare effectively the acoustic absorption properties of various liner materials. This capability also stimulated the research into the mechanism of sound absorption. One result was the development by the industry of a new sound absorption material, Perfolin.

Having gained experience in determining the acoustic properties of liner material, NLR was in a position to contribute to a series of flight tests carried out by Fokker on the engine inlet duct - made by Grumman - for the Fokker 100.

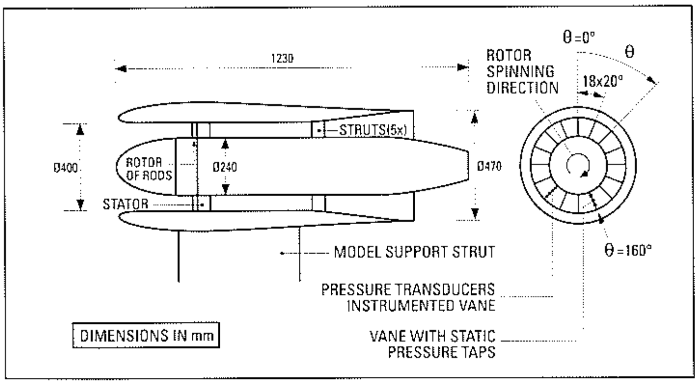
Contributions to the understanding of propeller noise were made at NLR as early as 30 years ago when a theory of propeller noise was presented by Van de Vooren and Zandbergen, [Ref. 62]. More recently Schulten of NLR provided a theoretical background for fan noise calculations, [Ref. 63]. A basic experiment with a specially designed model, [Ref. 64], was used to provide experimental data.

The theoretical and experimental capability was gainfully applied to civil aircraft development and in the support of tests carried out in the DNW.

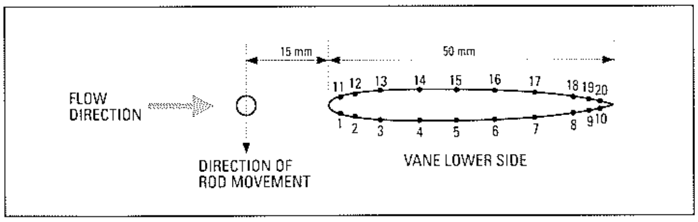
With these aero-acoustic studies and experiments, a considerable experience had been gained in this field by the mid-1970's. It is therefore not surprising that it was clear to the aerodynamicists that any future large scale facility for aircraft model testing should be suitable for aero-acoustic experiments. The facility under consideration at NLR was a large

A wind tunnel model for basic studies of the Fan Noise of a High By-pass Jet Engine

Cross-sectional view of fan noise wind tunnel model



Pressure measurement stations at stator vane



low speed wind tunnel with a test section cross-sectional area of 8x6 M². At the NOP a wooden 1:10 scale model of the design had been built. That pilot facility came into operation in 1972 and by 1974 the investigations had shown that this design resulted in a very high flow quality.

In the UK, Dr. John Williams of the Royal Aircraft Establishment, RAE, had been studying the noise problem in wind tunnels for quite some time and he had generated ideas to reduce the background noise in wind tunnels. In 1976 he summarized the state-of-the-art in [Ref. 65]. Based on his work and that of others it was then decided to make the LST 8x6 suitable for aero-acoustic testing of aircraft and engine models. This tunnel design was the basis for the German-Dutch Wind Tunnel, the DNW, which was designed in detail and constructed during the period of 1976-1980. The acoustic features of the DNW proved to be extremely valuable, (Chapter 18).

12. Helicopters

The origin of the helicopter might be traced back to the ancient Chinese, whose 'flying tops' were recorded as early as the 4th Century B.C., [Ref. 66]. In a sketch made in 1483 Leonardo da Vinci introduced a lifting screw, which is now regarded as the origin of the modern helicopter. It was however not till around 1900 that the first attempts were made to turn these ideas into a flying machine and not till the 1940's that helicopters became practical flying machines. This Chapter deals with the involvement of the laboratory in the development and applications of helicopters in various ways.

The Von Baumhauer Helicopter

When the RSL was founded Ir. A.G. von Baumhauer (1891-1939) was a designer with the aircraft factory Trompenburg. He joined the RSL in 1921 and when the RSL became the foundation NLL in 1937 he moved to the Netherlands Department of Civil Aviation, RLD. At RSL he headed for some time the Engine Department and also became Deputy Director. On 18 March 1939 Ir. Von Baumhauer and Mr. P. Guilonard, Technical Director of the KLM, died in an accident with a Boeing 307 Stratoliner while on a test flight near Seattle, USA.

Ir. Von Baumhauer was an exceptional engineer and scientist. While a student at the Technical University Delft he became interested in aeronautics and worked at the small aerodynamics laboratory of Mr. A.P. Kapteyn, [Ref. 8] and Chapter 2. When he came to the RSL he was 30 years old and he had accumulated a considerable aircraft design experience with the aircraft divisions of the factories Trompenburg and Van Berkel. In 1920 he had already sketched the first outline of a helicopter in his notebooks.

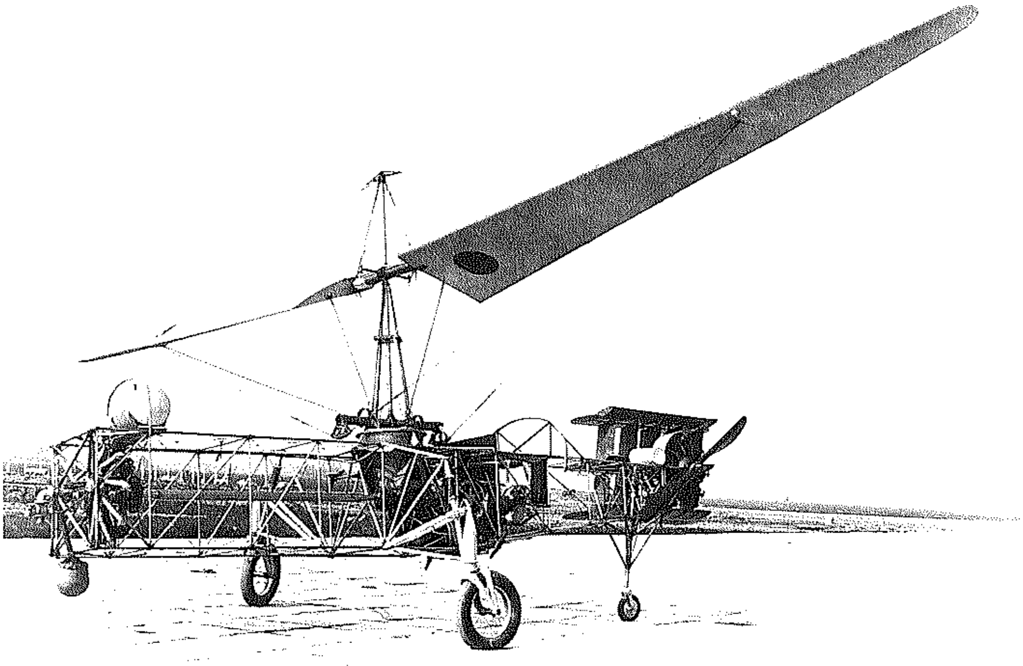
He was a typical inventor, often rapidly shifting his attention and he did not always conform to the requirements of the organization, which made it sometimes difficult for his colleagues. One of his colleagues at that time, Prof. Van der Maas, remarked to the author that Ir. Von Baumhauer never wrote proper reports - a strict requirement at the RSL. That may have been true from the point of view of the RSL, but Von Baumhauer did keep a very extensive diary, starting on 15 March 1906, when he was only 14 years old, [Ref. 67].

During the period 1924-1930, while employed at the RSL, Ir. Von Baumhauer experimented with a helicopter of his own design. In 1922 the British Air Ministry had offered a prize of £50,000 for the design and construction of a helicopter[1] with demanding requirements, including vertical autorotation and landing from a height of 500 feet. Apparently this stimulated the start of the Society 'De Nederlandsche Helicoptère' of which Ir. Von Baumhauer became the technical advisor. The Society received support from industry and government. The construction of the helicopter started in the Fall of 1924 and in June 1925 the first tests began at Soesterberg.

Von Baumhauer's helicopter (total weight 1195 KG), lifted off the ground for the first time on 17 September 1925, and early in the Spring of 1926 Capt. Van Heyst of the Army Air Force, LVA, flew the helicopter for five minutes.

[1] It is reported that the British Air Ministry withdrew this prize in 1926 since there had been too many accidents in trying to meet the requirements.

The experimental Von Baumhauer Helicopter, Period 1924-1930



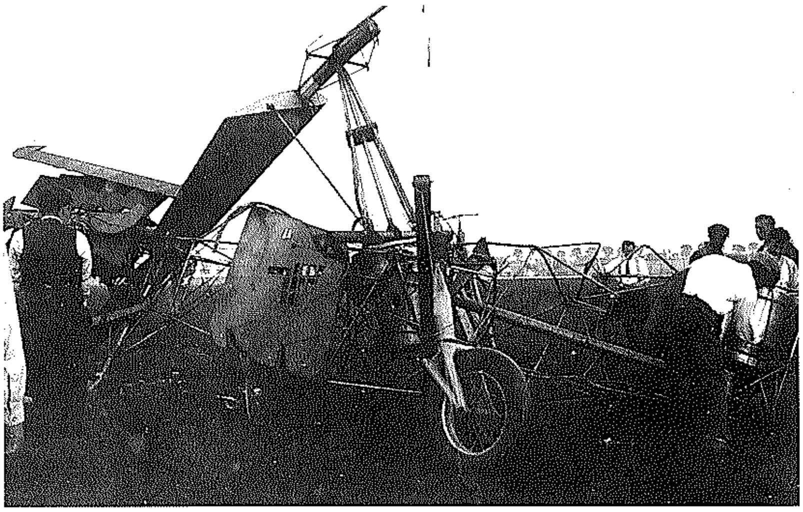
The 15.4 M diameter main rotor of the helicopter had two blades with a large chord (1.2 M at the root). The rotor blades were constructed of four spars and many ribs and each blade weighed 54 KG. The rotor was provided with a collective pitch control and a swash-plate for cyclic pitch control, much the same as present day helicopters. Power was initially provided with a 160 HP rotary Ober Ursal engine, later replaced by a 200 HP Bentley Rotary BR2. The power was transmitted to the rotor through a worm-wheel gearing arrangement. The main rotor turned at the rather low speed of 100 RPM and the tip speed of the blades was correspondingly low at less than 300 KM/HR.

Another important novelty was the introduction of a tail rotor, driven by first a 40 HP Anzani motor and later by an 80 HP rotary Thulin motor. There were five vertical tail surfaces and three horizontal tail surfaces operating in the slip stream of the tail rotor, providing directional and longitudinal control respectively.

All-in-all the Von Baumhauer helicopter resembled the helicopters of to-day. However it was not very reliable mechanically and the machine was heavy and complicated through the use of a separate tail rotor engine.

From October 1926 the tests took place at Schiphol Airport, and several RSL employees participated in the flight testing. Many flights were made by the engineer-pilot Ir. J.C.G. Grasé of the RSL (see Chapter 6). There were several structural failures due to excessive vibrations and after each flight repairs had to made.

The Von Baumhauer Helicopter after the crash on 29 August 1930



It is reported that in 1930 Jhr. P.J. Six flew freely over the whole of Schiphol Airport, albeit in a somewhat uncontrolled manner. Unfortunately on 29 August 1930, a blade failure occurred a few meter above the ground. The pilot was unharmed but the helicopter was totally lost.

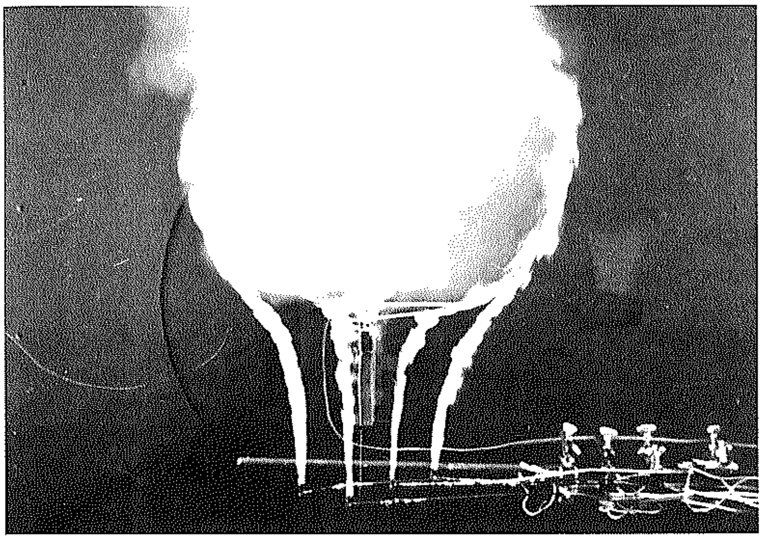
After the crash the project was terminated due to lack of funds.

With this helicopter with **collective pitch control**, the **swash-plate for cyclic pitch control** and the **tail rotor** valuable contributions were made to the development of the helicopter of to-day.

Rotor Aerodynamics

Shortly after the Second World War there was a great interest in helicopters. Ir. J. Meyer Drees, who had already started studies of the flow through rotors while working towards his degree (he graduated Cum Laude in 1948) at the Technical University Delft in Prof. Burgers' laboratory, came to NLL in 1949. He completed there a series of wind tunnel tests on a simple rotor model with smoke visualization. Through these experiments he gained an excellent understanding of the flow through rotors with and without vertical and horizontal speed and also of the transition of powered flight to the state of auto-rotation.

A sample of the flow through a Helicopter Rotor



Ir. Meyer Drees analyzed the longitudinal and lateral non-uniform distribution of the induced velocity in the rotor plane. He set up a schematic and a manageable simplification of the fixed and free line vortices of the blades. This led to a calculation method to take into account the uneven distribution of the induced velocity encountered by a blade during rotation. His paper describing this work was awarded the La Cièrva Memorial Prize in 1949 for the best author under the age of 35 (Meyer Drees was 26); it was published in the Journal of the Helicopter Association of Great Britain, [Ref. 68].

Another contribution to the understanding of rotor aerodynamics was made by Prof. R. Timman, at that time employed in the Flutter Department of NLL, when he analyzed the unsteady aerodynamic lift on rotor blades, in particular as affected by the free vortices shed by the blades at earlier rotations below the rotor plane, [Ref. 69]. The result, in the form of a modified Theodorsen function, was useful in explaining certain flutter regimes that had been observed. Theodorsen's work was related to propellers.

A 16 mm movie was made at NLL of the flow through a rotor, showing the changes in flow pattern with changes in forward and vertical speed and under auto-rotation conditions. Many copies of this film were used in various countries to gain a better understanding of the flow through helicopter rotors.

The 'Kolibrie'

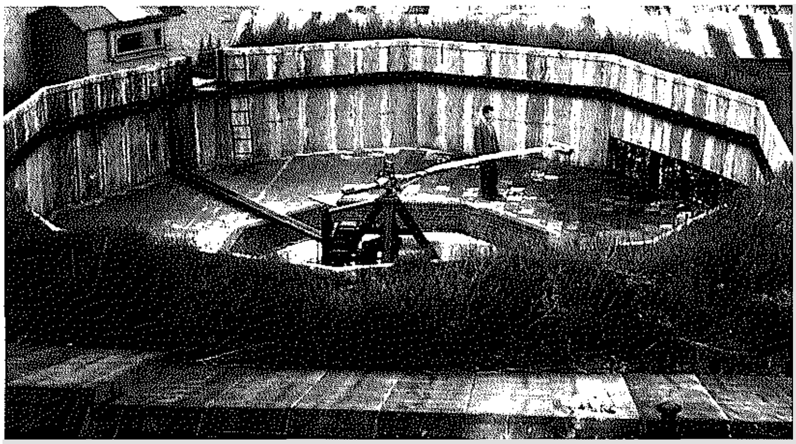
A second helicopter development in The Netherlands took place during the period 1950-1960 under the technical leadership of Ir. G.F. Verhage and Ir. J. Meyer Drees, (who went to Bell Helicopters in 1959 where he later became Vice President of Technology) with Mr. R.J. van Harten (later Deputy Director KLM Helicopters) as the test pilot. A more complete story is given in [Ref. 70].

The initiative came from a group who formed the Foundation for Development and Construction of an Experimental Helicopter (Stichting tot Ontwikkeling en Bouw van een Experimenteel Hefschroef-vliegtuig, SOBEH) in 1951. After an experimental period the Netherlands Helicopter Industry, (Nederlandse Helikopter Industrie NHI), was formed in 1955 in which the companies Aviolanda (fuselage), Kromhout (rotor head and engines) and Fokker (rotor blades) participated.

In 1954 the research related to helicopters justified the formation of a Helicopter Department at NLL, headed by Ir. L.R. Lucassen.[2] There were now several helicopter activities in which the NLL became involved.

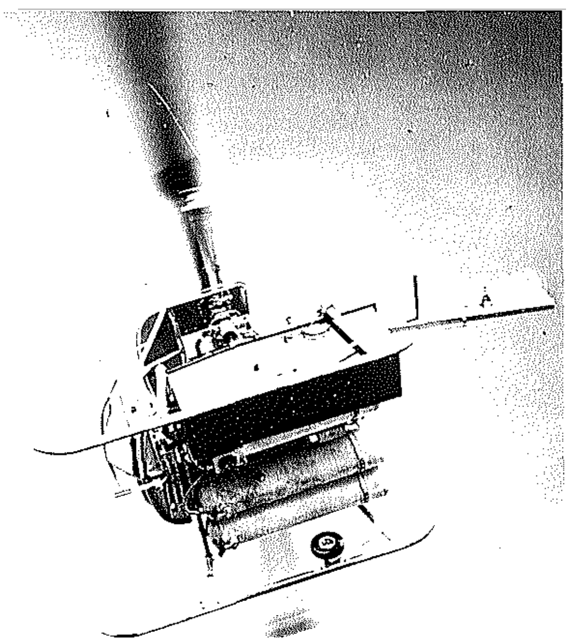
The Kolibrie had a number of novel features. The two rotor blades had ramjet engines at the tip and the blades were self-adjusting. In 1948 Ir. Verhage, employed by the PTT, showed theoretically how a blade with torsionally flexible pockets could lead to low induced power required, by striving towards a uniform induced velocity through the rotor plane. (The idea was based on the fact that a uniform induced velocity along the span of a wing results in a minimum induced drag for a given lift condition.)

The Rotary Test Stand at NLR Amsterdam



The NLL built a rotary test stand for the ramjet tip engines. This test stand was located at the laboratory at Amsterdam. The complaints of the neighborhood about the noise were one reason to accelerate the search for new premises, (Chapter 26). That test stand was the first facility to become operational at the NOP in 1958. Another facility was erected to study the combustion in the ramjet. NLL was very much involved in the development of this helicopter through analysis, experiments and of course also through the fact that some of the NLL personnel participated directly in the project development group.

The Kolibrie Helicopter



The Kolibrie had some unusual characteristics. Since the power was provided by the tip ramjets, leaving no reaction torque at the fuselage, only a small tail rotor was required. The high kinetic energy of the rotor made it possible for the helicopter to take-off and land safely within seconds in the event of engine failure during take-off. The 'unsafe' altitude regimes which are characteristic for normal helicopters - the altitude at which it is not safe to transfer to the mode of autorotation for an emergency landing, typically 10 to 100 meter - were eliminated. A disadvantage of the Kolibrie was the noise. Also the fuel consumption was quite high. An external starting motor was required to produce the initial velocity for the ramjet engines to work. A small series of the Kolibrie was built. The applications were finally mostly in the agricultural sector, e.g. crop spraying.

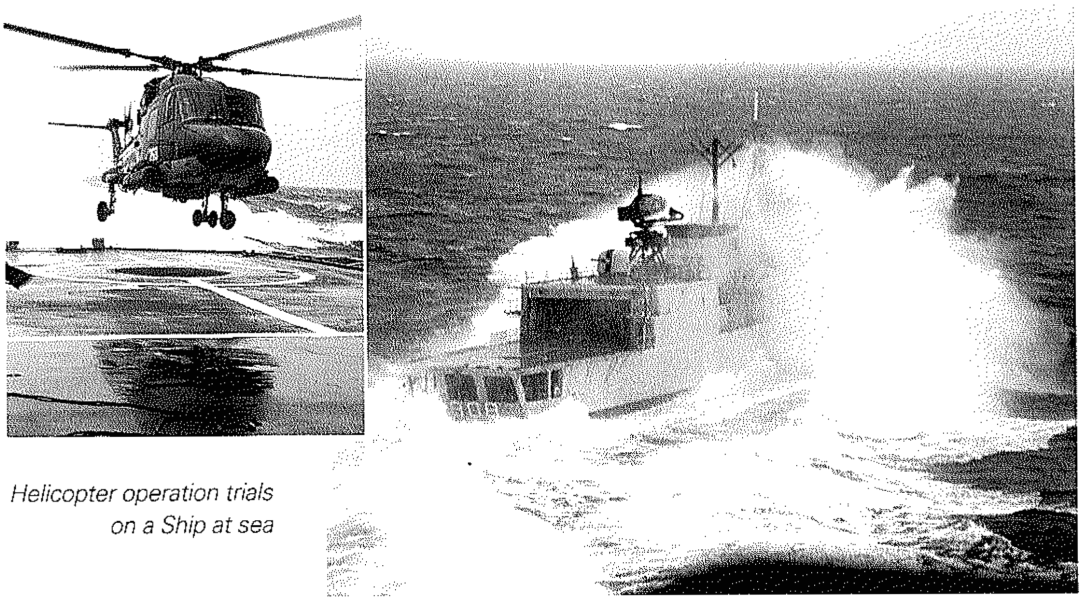
Helicopters on ships

An interesting aspect of helicopter operations is the problem of the qualification of the ship-helicopter combination. The problem is to determine the safe operating limits and the procedures for specific ship-helicopter combinations at various wind and sea state conditions. NLR developed qualification methods, in close cooperation with the Royal Netherlands Navy. Starting with take-off and landing tests on land, under various weather conditions, the qualification tests have to be carried out with helicopters at sea under various sea states, wind force and wind directions. Usually this type of operation is much more complicated than landing on and take-off from land or even from an oil platform in

[2] In 1943 Ir. Lucassen was the first to receive the Diploma of Aeronautical Engineer at the Technical University Delft.

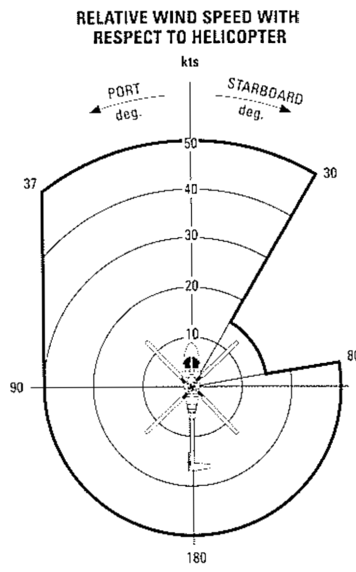
the open sea. Apart from the fact that the ship motion in a storm makes the operation more difficult, there is also the problem of the 'wind climate' on a ship, that is the large-scale turbulence caused by the superstructure of the ship. This wind climate on a ship is determined in a wind tunnel using scale models of the ship.

This capability to determine the safe operating limits, built up with the assistance of the Navy, has been applied for the qualification of several helicopter-ship combinations for Navies of many countries. Typical operating limits for a particular combination are indicated in the Figures below, [Ref. 71 and 72].

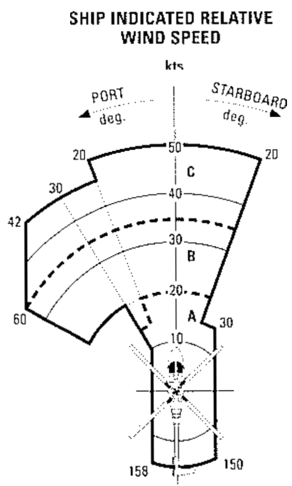


Helicopter operation trials on a Ship at sea

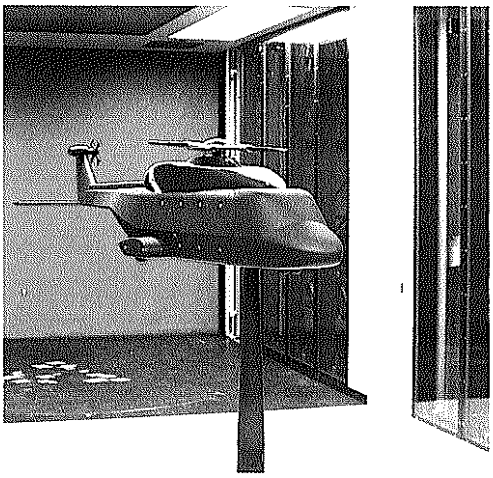
The Operating Limits of a Helicopter-Ship combination for take-off and landing during shore-based operations and at sea



PERCENTAGE OF MAX. TAKE-OFF AND LANDING MASS: 100



LIMITS OF HELICOPTER MASS AND SHIP MOTION			
AREA	PERCENTAGE OF MAX.TAKE-OFF AND LANDING MASS OF HELICOPTER	AMPLITUDE OF SHIP MOTION (STAND.DEVIATION) PITCH deg.	ROLL deg.
A	95	1.0	3.5
	98	0.5	0.5
B	98	1.5	3.5
C	98	2.0	1.5



Other Helicopter activities

Dr. J.P. Jones, Technical Director and Chief Engineer of Westland Helicopters once said that helicopters were perfect vibration machines. They were very noisy machines and aerodynamics, apart from the aerodynamics of the rotor, seemed of little importance to the designers of helicopters. Most helicopters were developed without any wind tunnel test during a period when the designers of aircraft already paid much attention to the external shape of their aircraft. But during the last twenty years, as the speed of helicopters was increased, this seems to have changed.

Aerodynamic testing of the fuselage of the NH-90 Helicopter in the Low Speed Wind Tunnel LST

The NH-90

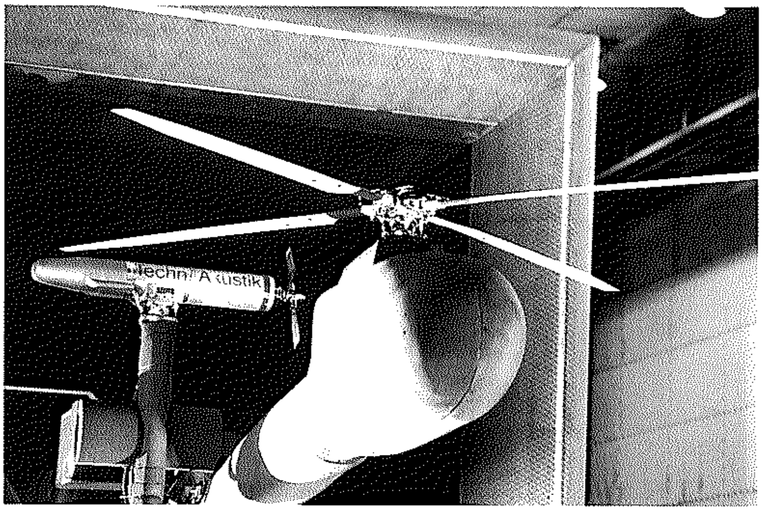
After an extensive series of studies and evaluation of several available and planned helicopters, the Governments of Germany, France, Italy and The Netherlands decided to undertake the development of a helicopter for the Navies and the Armies, mainly for transportation of troops and equipment. For this helicopter an initial requirement of over 700 has been identified.

A mock-up of the NH-90 Helicopter

Apart from aerodynamic model testing NLR contributed to the development of this helicopter by assisting the Netherlands industrial participants (Fokker, DAF-SP) in the project team. The experience gained in evaluating helicopter operations under difficult circumstances provided a valuable basis for participation in the NH-90 project.

Rotor Noise

At the instigation of the US Army a very extensive series of experimental investigations was carried out in the 1980's in the DNW. The aim was to study the noise produced by helicopter blades. The DNW, with its unique acoustic testing capabilities, was the ideal facility to carry out such investigations. The program was carried out by the US Army, NASA, and several American helicopter companies. DNW was strongly supported by the DLR Helicopter Group of Braunschweig.
NLR engineers contributed through project support to DNW. This extensive international program definitely established the value of the aero-acoustic testing in wind tunnels.



A noise test on a rotor and tailrotor combination of a Helicopter in the German-Dutch Wind Tunnel DNW

13. The Free Flight Test Range

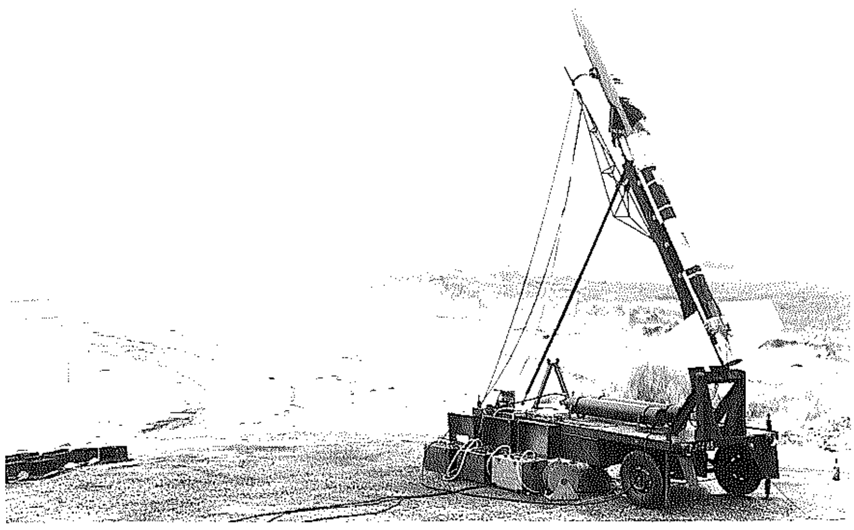
On 1 July 1953 several organizational changes took place at NLL. Three new Departments were formed: a Combustion Department, a Helicopter Department and a Free Flight Model Testing Department. It was characteristic for the situation, a year after the laboratory had received the approval to continue with the expansion plans, which had been interrupted for a period of 28 months and during which the personnel was reduced by one third. It was an organizational adjustment to accommodate the initiatives that had been taken during the previous years.

Free Flight Model Testing

In several countries free flight model testing had been used to study aerodynamics and stability and control characteristics with the aid of free flight models, launched by rockets. Particularly at transonic and supersonic speeds there was a need for reliable data which could not (yet) be obtained in wind tunnels. Another motivation for pursuing this technique was to gain practical experience in launching rockets and in guidance and control techniques.

During 1954 some free flight models were launched by NLL with boosters made available by the Commission for Experimental Testing of the Army ('Commissie van Proefneming'). The launchings took place at the North Sea coast near Petten, in the Province Noord-Holland. The flights took place at night with models illuminated with flares and tracking was done with optical cameras. The first models fired were simple bodies of revolution of the shape of the NACA RM-10 model. This model was adopted by AGARD as a standard for testing in wind tunnels and data were being collected from various wind tunnels and from free flight tests. The drag coefficients in the Mach Number range of 0.9-1.5 obtained from these first free flight tests compared reasonably well with published data. Encouraged by these results the technique was developed further.

The Rocket Launch installation at the beach

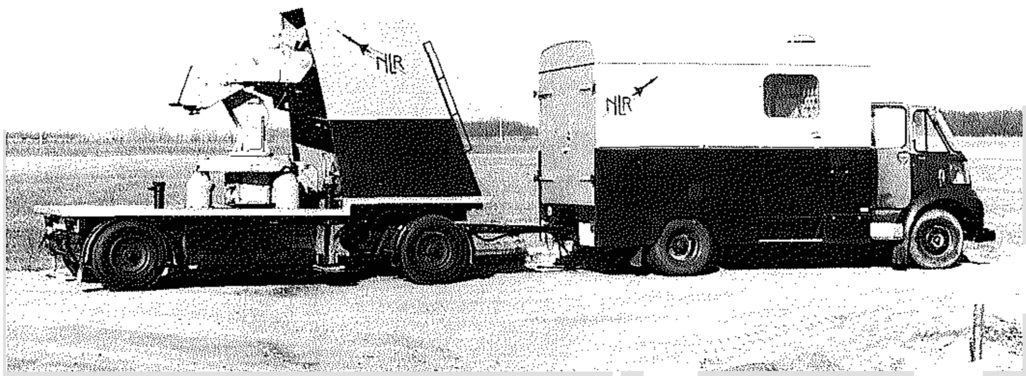


The free flight model activities started at the laboratory in Amsterdam but soon after 1957, when the new laboratory in the Noordoostpolder began to take shape, the activities were moved to the NOP.

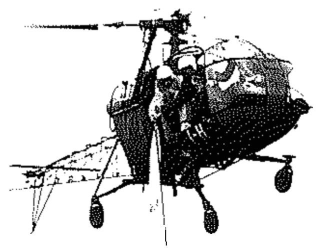
The Mobile Rocket Launcher of NLR

During the following years more elaborate models were built, which were provided with programmed control surfaces and telemetry for on-board measurements. Roll stabilization and longitudinal control and stabilization systems were developed and the ground equipment was extended with a Doppler radar, an automatic tracking radar, telemetry receiver and transmitter stations. All the equipment was mobile, including a mobile rocket launching installation and a control station. The preparation of the launching campaigns took place in the NOP and then the crew and equipment moved to the launch site for a particular campaign.

Part of the Mobile Ground Equipment



The Flying Models were recovered by helicopter from the mud-flats at low tide



When the models became more sophisticated and costly it was decided to develop a parachute recovery system which had the additional advantage that malfunctions could also be better analyzed.

A semi-permanent launch site was acquired at the North of the Isle of Texel. Permission was obtained to use an area with a diameter of about 17 KM, East of Texel, as a test range. This area, consisting of tidal mud flats which become largely dry during low tide, was very suitable for recovering both the models and the boosters.

During this development there was a close cooperation with the industry (Fokker, Philips, the munitions and gun powder industry) and the Air Force and the Army. Much of the development was sponsored by the NIV.

By 1965 the need for free flight model testing at transonic and low supersonic speed had diminished. The quality of wind tunnel testing techniques had improved considerably and, world wide, free flight model testing was only used for special tests such as ballistic tests around Mach Number 20. The last launching by NLR took place in June 1966. With the experience of more than eighty launches and the development of the equipment an interesting capability had been built up. There was no immediate interest and support in The Netherlands to develop guided missile techniques, for which the experience would have provided a good background.

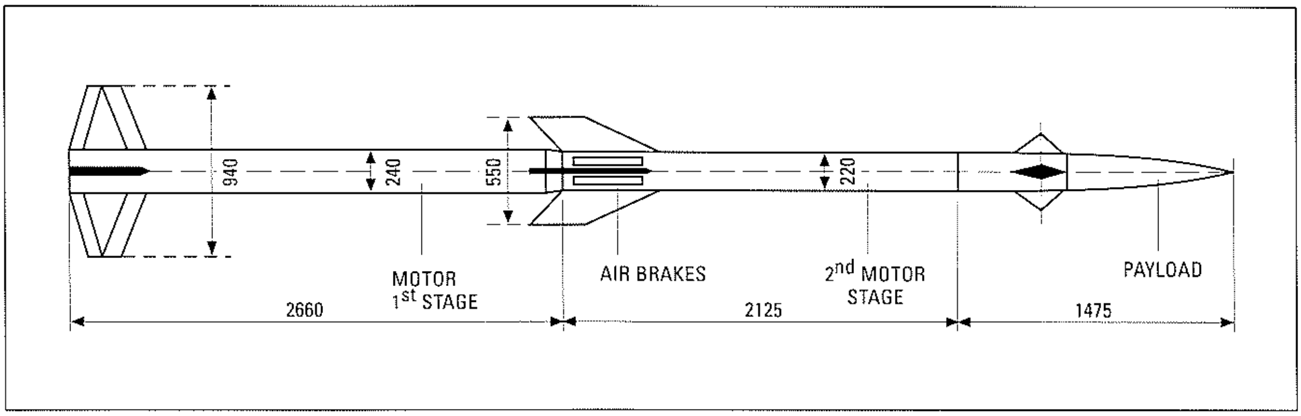
The development had been funded partially out of the NLR subsidy and by the NIV. A few tests were carried out for customers but with other higher national priorities this was not sufficient to maintain the capability in the long run. The experience gained did provide a basis for participation in various tasks in the international context of ELDO - the European Launcher Development Organization.

A Sounding Rocket System

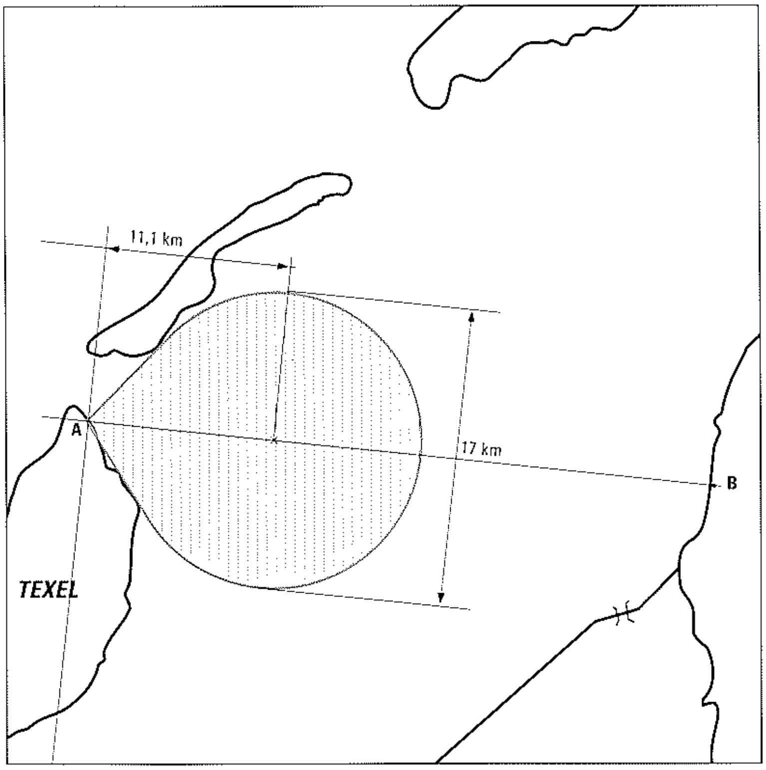
Following this period (1954-1966) of free flight model testing an attempt was also made to apply the knowledge and experience gained very directly. A feasibility study was carried out for a two-stage sounding rocket for high altitude research with a **very small impact dispersion**. There was a desire to launch high altitude research rockets in areas where only a limited area for impact on the ground is available. It was argued that the major factor contributing to the impact dispersion of vertically launched and spinning sounding rockets is the influence of the wind and some form of compensation for the deviations from the nominal flight path due to the wind had to be provided.

A two-stage rocket system was designed for a small impact area of 17 KM diameter. This was the test range of NLR East of the Island of Texel. Based on this impact area an apogee of 150 KM was chosen for a system with horizontal velocity control. The rocket had a total mass of 285 KG and a gross payload of 33 KG (net payload 15 KG).
The first stage was unguided and designed such that it would always impact within the designated area. The second stage would only be ignited after it had been determined that the horizontal velocity was within certain boundaries. If this were not the case or if during the sustained flight of the second stage a failure of a vital component would occur, a safety system (air brakes on the second stage) would be activated so that the rocket would impact in the designated area.
The second stage was controlled in such a way that during the powered flight - up to an altitude of 30 KM - the horizontal velocity component had to stay within certain, safe, boundaries. The position and velocity of the rocket were to be measured with a tracking system and the horizontal velocity would be continuously compared with the desired horizontal velocity. The effect of the wind on the impact dispersion was thus compensated during this controlled part of the flight.
It was shown that for such a guided sounding rocket the radius of the area in which the impact occurs with a probability of one million-to-one was 6.3 KM as compared to 21 KM for attitude stabilized rockets and 63 KM for unguided, uncontrolled rockets.

Sketch of a guided Sounding Rocket



The projected impact area of the guided Sounding Rocket at the Test Range at Texel



The systems study was carried out in the period 1967-1969 when there was an interest in high altitude sounding rockets with small impact dispersions. They were of interest even for the rocket launching base Kiruna in the North of Sweden, an area with a very low population density.
The Committee for Geophysics and Space Research of the Royal Netherlands Academy of Sciences (Geofysica en Ruimte Onderzoek Commissie, GROC, van de Koninklijke Nederlandse Akademie voor Wetenschappen, KNAW) gave partial financial support to the feasibility study of this system.

The study included a market survey, carried out with the Space Division of Fokker, and potential partners from Germany and Sweden. Unfortunately the market for sounding rockets had stabilized and no definite development plans materialized for this interesting idea which was basically developed by Ir. G. Boersma, [Ref. 73], who worked at the Space Division of NLR. Elements of this idea were applied later in other sounding rocket systems.

14. Space Activities

The beginning of the Space Age was marked by events during the International Geophysical Year (the IGY as it became known). The planning of the IGY (1957-1958) started in 1954. It was an international venture in which scientists in various countries planned to study and collect data on the earth and its environment on a world-wide scale.

A comprehensive international sounding rocket program was planned to collect data on the earth's atmosphere. The USA program included the launch of a satellite for which a US Navy proposal, the Vanguard, was chosen. The USSR, participating in the program, surprised the world by launching the first artificial earth satellite - Sputnik 1 - on 4 October 1957, exactly 40 years after the beginning of the Communist Revolution. The impact of this event on the world was enormous.

Although the USA responded rapidly by launching the Vanguard within a few months, the USSR seemed to be well ahead of the rest of the world. Only two years later in 1959 - again on 4 October - the USSR launched a spacecraft (Luna 3) to orbit the moon and it transmitted the first pictures of the far side of the moon. The USA set up a broad space program and much of the Western World profited from it.

The rest of the story is well known. The USA organized a great space program, culminating in the first manned landing of Apollo 11 on the moon on 20 July 1969.

Much of the technology for space flight was available, particularly through the development programs of guided rockets and ballistic missiles. There had been a great interest in space flight in many countries but outside the military there were no organized space programs. The contributions of The Netherlands were very modest[1]: there was no industrial rocket activity.

However at the universities there were several very active groups of astronomers interested in employing the new technical means which were becoming available through the development of space flight technology. On 2 March 1960 the Royal Netherlands Academy of Sciences - the KNAW - formed a Committee for Geophysics and Space Research, the GROC[2], which was to coordinate the space research carried out by the astronomers in The Netherlands. Through this Committee The Netherlands was represented internationally and this Committee also had the task to manage the government funding for space research carried out by the universities. The GROC consisted mainly of the Astronomy Working Groups of:

- the University Utrecht (Solar and Stellar Space Research under Prof. Dr. C. de Jager),
- the University Leiden (Cosmic Rays under Prof. Dr. H.C. van de Hulst),
- the University Groningen (Photometry under Prof. Dr. J. Borgman) and
- the Working Group on Satellite Geodesy of the Technical University Delft (under Prof. Ir. G.J. Bruins).

[1]One noteworthy contribution was Prof. Dr. Ir. J.M.J. Kooy's book which he wrote with Prof. J.W.H. Uytenbogaart in 1946: 'Ballistics of the future'. This elaborate work on space mechanics served as a standard space flight dynamics textbook in many countries in the period after the Second World War. This book was written for the most part during World War II when Prof. Kooy observed the launchings of the V-2 rockets near his home in The Hague. During many years he contributed to the space flight literature, i.a. the stability of lunar orbits, and he contributed to the International Astronautical Federation, the IAF, as Chairman of the Netherlands Astronautical Society.

[2]This Committee operated very successfully and managed, amongst others, all the aspects of the instrument development and the scientific experiments of the ANS and the IRAS satellites mentioned in this chapter. Prof. Dr. H.C. van de Hulst of the University Leiden was its Chairman till the Committee was replaced by the Space Research Organization of the Netherlands - SRON - on 10 June 1983.

The GROC Working Groups participated in several rocket and balloon campaigns and flew experiments in American (NASA) and European (ESRO) satellites. The instruments were designed and developed by the university laboratories with assistance of the industry and other technological laboratories.

In 1960 several European countries, among which The Netherlands, decided to form the European Space Research Organization - **ESRO** - to carry out space research by means of high altitude rockets and satellites. ESRO became effective in 1964 and through this organization the Netherlands' astronomers were able to participate in several projects.

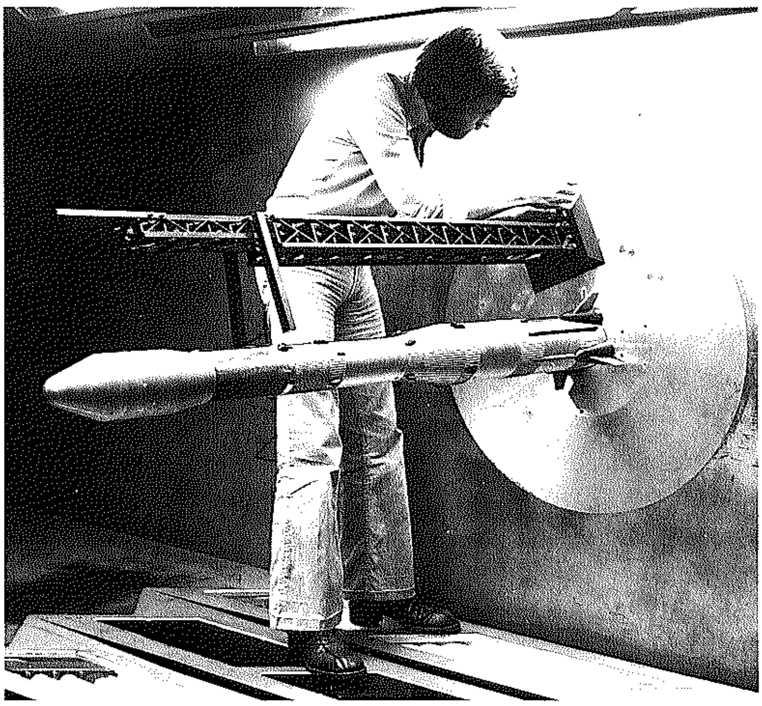
ELDO Programs

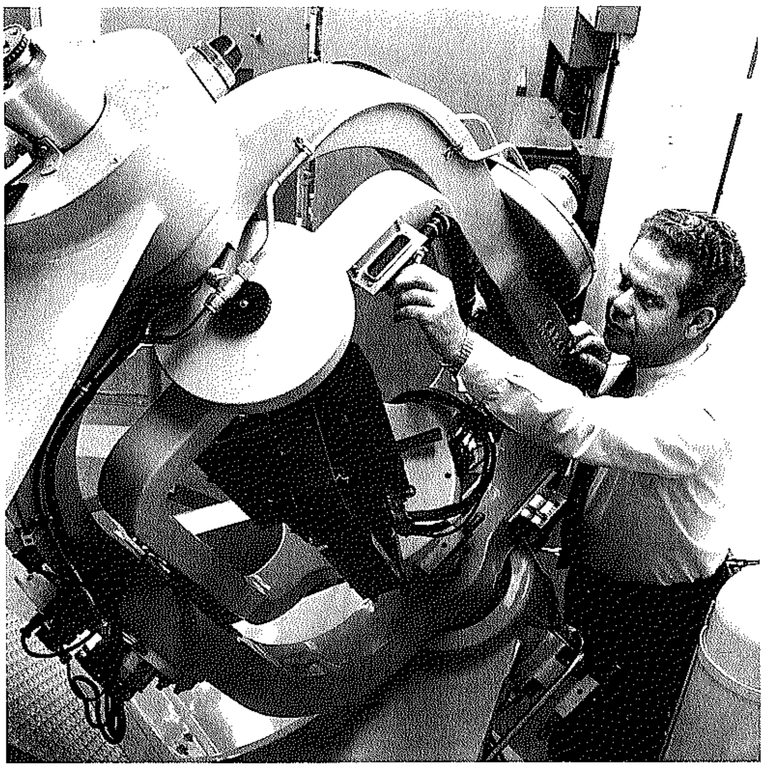
In the period 1960-1961 the UK started to discuss with France the possibility to develop a satellite launching system in Europe. The UK had decided to stop the development of the (military) strategic rocket the 'Blue Streak'. The Blue Streak was proposed as the first stage of a three-stage rocket to be launched from Woomera, Australia. In February 1961 an agreement was reached and a year later, April 1962, seven countries signed a convention to design, construct and launch rockets for spacecraft. The new organization was called **ELDO**, European Launcher Development Organization. There was a global division of work:

- The UK : the Blue Streak (first stage), guidance equipment;
- France : the Coralie (second stage), already under development;
- Germany : third stage, still to be developed;
- Italy : experimental satellite;
- Belgium : ground guidance station, various equipment items;
- Australia : launching facilities at Woomera;
- The Netherlands : the development and manufacture of telemetry equipment, program units and ground installations (Philips), systems testing of the attitude reference system and later the inertial guidance system (NLR).

NLR also carried out a large part of the aerodynamic wind tunnel testing and the analysis of aerodynamic data.

An experiment in the High Speed Wind Tunnel HST to determine the effects of high ground winds on ELDO and Ariane Launchers





A major task of NLR was to carry out ground testing of the Attitude Reference and Programme Unit - ARPU - and to develop the protocols for the launching of the rockets. This ARPU had a gyroscopically stabilized platform providing a reference frame from which the attitude of the rocket was derived.

The ground testing system, located at NLR-NOP, consisted of a hydraulically controlled rocking table with three degrees of motion on which the reference unit was mounted. Thus the rotational motions of the rocket were simulated. The hydraulic cylinders, actuating the motion of the platform, were controlled by an analog computer on which the equations of motion and the characteristics of the rocket steering mechanism were simulated. The signals from the reference platform on the rocking table were fed back to the analog computer. The reference platform was placed in a closed loop. It was thus possible to simulate a complete launch and to carry out the testing at a systems level.

Laboratory test on a stabilized Attitude Reference Platform Unit of an ELDO Launcher

In later versions of the ELDO rockets the gyroscopically stabilized platform was replaced by an inertial system using accelerometers. For this inertial system NLR also carried out the systems testing before shipment to the launching site. The inertial sensors, very sensitive accelerometers, were provided with signals derived from the analog computations, to simulate the accelerations that would be sensed during an actual flight.

It is interesting to note here that, at that time, the speed of digital computers was not fast enough to process the equations of motion and the control equations in real time. Initially fully analog computation was used, later a hybrid (analog-digital), but a fully digital computer could not cope with the real time requirements.

For the last ELDO flights the launching site was moved from Woomera (Australia) to Kourou (French Guyana) near the equator, favorably located for launching satellites into a geostationary orbit.
NLR employees also participated in the testing before launch and in the actual launching procedure. The design and operation of this test system was a very useful experience for the laboratory.

Unfortunately, although the guidance system worked perfectly during all ELDO launches, during the period of 1962-1973 no fully successful launch was achieved. This is not the place to analyze the reasons why this experiment in international cooperation was not successful,[3] but a major reason was undoubtedly that the participating countries acted quite independently, the central management was weak and there had not been a joint systems study. The development of various versions of the launchers, the Europa I, II and III, was continued till 1 May 1973 when it was decided definitely to terminate the activities.

However for NLR:

> The experience gained and the laboratory facilities for guidance and control testing laid the foundation for the participation in many ESA satellite projects, usually under contract from a (foreign) main contractor.

[3]A first attempt to analyze the failure of ELDO is made in [Ref. 74].

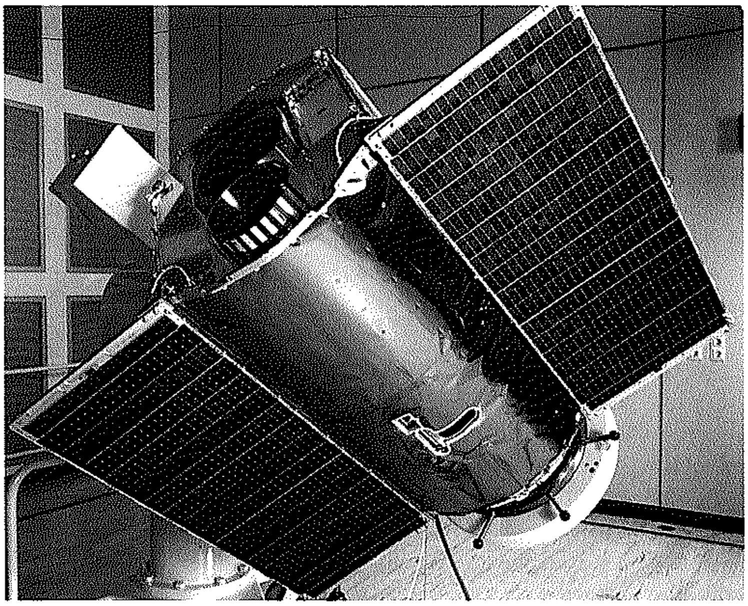
Other organizations in Europe had similar experiences. Apparently ELDO was an (expensive) experiment in international cooperation that did not work out too well but from which valuable lessons were learned.

At the initiative of France the development of the Ariane launcher was started, and in 1972 it was decided to form the **European Space Agency - ESA**, combining the activities of the former ESRO and ELDO organizations.

During the ELDO/ESRO period NLR carried out several other interesting tasks. One of these was a full mission analysis for the projected **ELDO-PAS** satellite (Perigee-Apogee Satellite). This was a system which would carry a payload, launched from Kourou near the equator, into an elliptical orbit with the apogee, the highest point, at the altitude for a geostationary orbit from where the satellite would be injected into a geostationary orbit. This was a useful experience when later NLR was given the task of the ground operations of the ANS.

Fokker, Philips and NLR jointly carried out the task to develop the attitude control system, including the sensors, for the ELDO-PAS satellite under contract from an Italian consortium which was to develop the satellite. Although this satellite was also canceled when the ELDO operations were terminated, the project did provide valuable experience for the industry and NLR for the development of the first Netherlands satellite, the ANS.

The Astronomical Netherlands Satellite - ANS

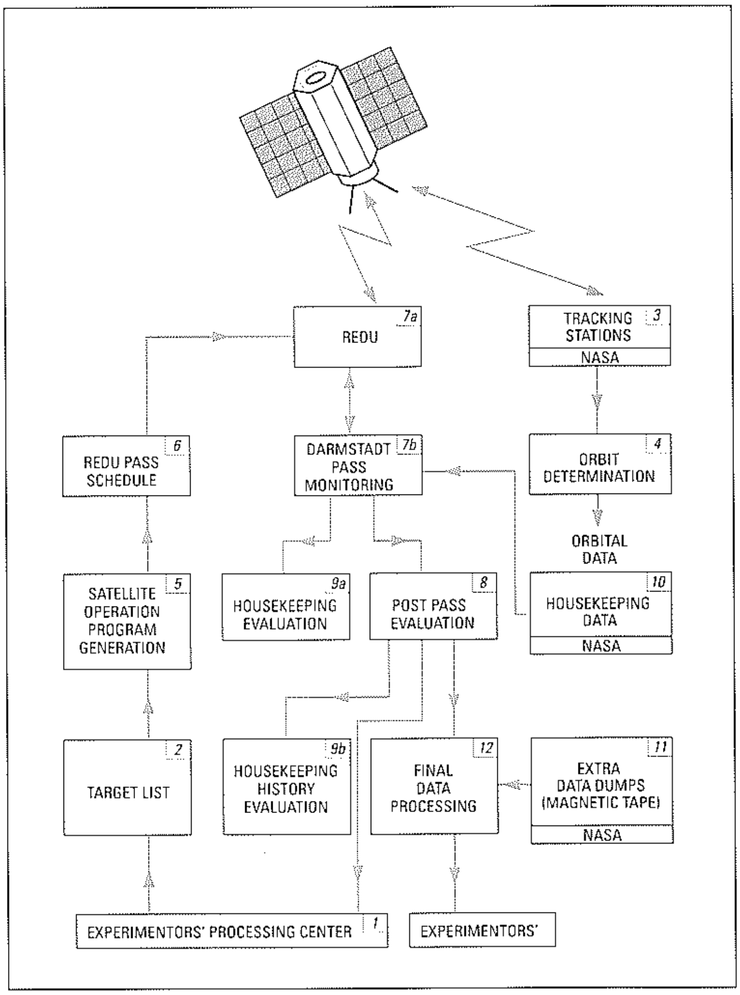


The Astronomical Netherlands Satellite, ANS

In 1966 representatives of Fokker and Philips presented a proposal to the Minister of Economic Affairs for the development of an astronomical satellite. The proposal was the result of a close cooperation between the industry and two of the GROC Working Groups: the Kapteijn Observatory of the University Groningen and the Laboratory for Space Research of the University Utrecht. The Dutch astronomers had taken advantage of flight opportunities on American (NASA) and European (ESRO) satellites, but their scientific standing and their ambitions exceeded the limited opportunities. The ANS was to make a complete survey of ultra violet and X-ray sources in the sky. For this the satellite had to be placed in a special near-polar, so-called sun-synchronous, orbit. By a judicial choice of the orbital parameters the plane of the satellite can be made to rotate at the rate of one degree per day, making use of the oblationes of the earth. The satellite can then almost continuously be exposed to the sun and the telescopes in the satellite, when always pointing outward, will have viewed the whole sky after 6 months.

The ANS project was approved in early 1969. The industrial consortium Fokker-Philips obtained the cooperation of General Electric, USA, as an advisor. The ANS project was presented to NASA and NASA offered to launch the satellite with a Scout rocket from the Western Test Range. NASA also sponsored an additional experiment from the Massachusetts Institute of Technology, MIT, Cambridge, Mass. for incorporation in the satellite.

The overall program management was entrusted to NIVR. It acted as the official representative of the Netherlands Government and concluded the contracts with the industry and the agreements with the American partner.



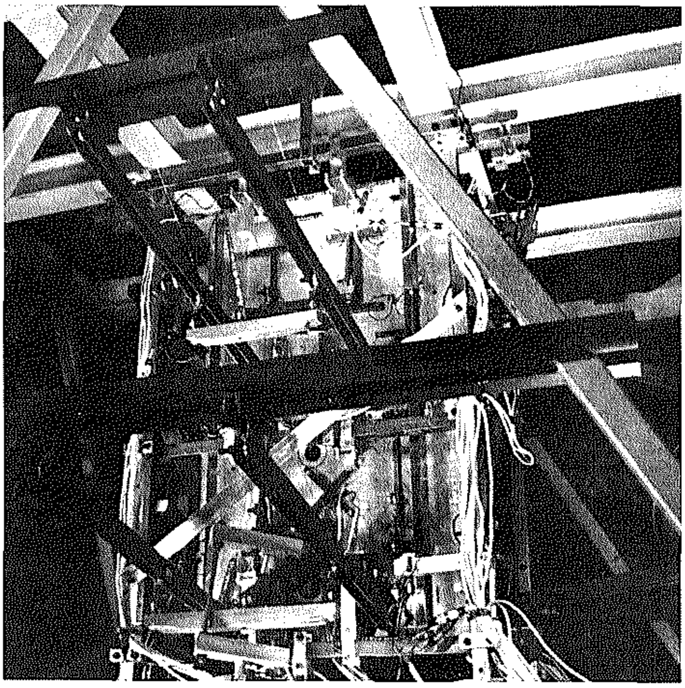
The satellite was unique in that it employed for the first time an on-board computer which could be programmed from the ground. Twice a day the data collected were transmitted to the Operations Center and also twice a day the computer was loaded with a new observation program.

The ANS satellite was launched by NASA with a Scout rocket from the Western Test Range, California, on 30 August 1974 and was kept in operation till 12 December 1975. It was turned on again during a brief period, 1 March 1976 - 19 April 1976, to observe some special X-ray sources.

The major task of NLR in the development and operation of this satellite was to develop and test the computer programs for the ground operations, the software for the execution of the scientific measurements, and the programs to control the on-board computer. Finally software was developed to translate the observations into useful astronomical data. The ground operation took place at the European Space Operation Centre, ESOC, Darmstadt, Germany. A team of 12 experts was involved. This team was stationed at Darmstadt from the middle of 1973 till the end of the operation.

Diagram of the ANS Orbital Operations

The NLR crew operating the ANS Satellite from the European Space Operations Centre (ESOC) at Darmstadt, Germany



Static test of the Sandwich-construction of the frame of the ANS Satellite

The development and operation of the ANS satellite was extremely successful. The teams participating were small compared to international standards. The participants were very capable and enthusiastic, the lines of communications were short and there was a minimum of 'red tape'. The total expenditures on the Netherlands side were DGL. 81.5 million, including DGL. 16 million paid by the industry and excluding DGL. 12 million born by the experimenters for their instruments. These amounts are given here because for many involved in space activities they were so unbelievably low for the development of such an advanced system.

The ANS satellite was technically very advanced as is evident from the following data:

• Height	123	CM
• Width	61	CM (solar panels folded)
	144	CM (solar panels deployed)
• Depth	73	CM

• Mass breakdown:

Instruments	42.3 KG
Structure	40.3 KG
Attitude Control System	14.6 KG
Power Supply	10.5 KG
On-board Computer	7.8 KG
Telecommunication System	3.5 KG
Remainder	21.0 KG
Total	140.0 KG

• Sensors: 13 in all (coarse, intermediate and fine solar sensors down to 0.01° accuracy, star trackers (Plumbicon), magnetometers)

• Actuators: yo-yo system for de-spinning, reaction wheels, magnetic coils

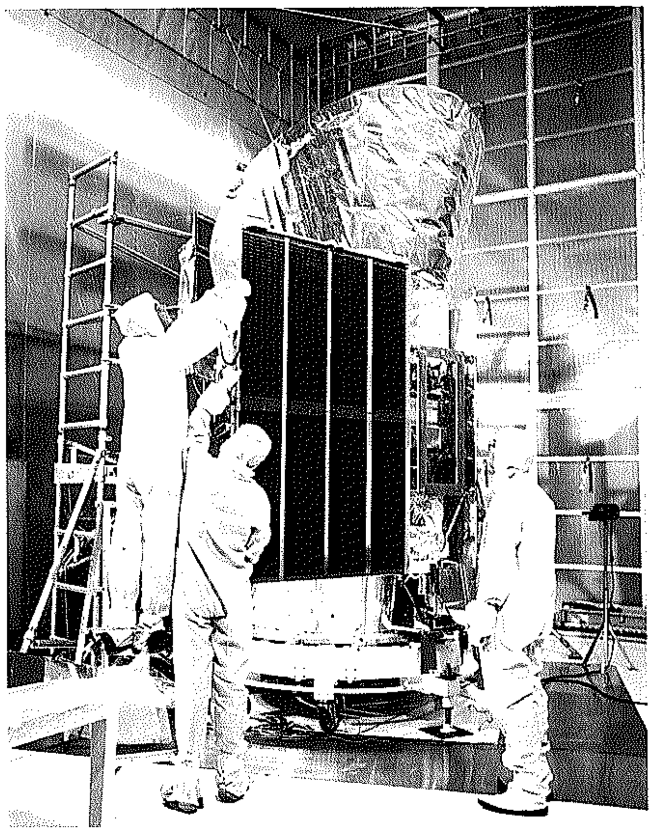
• On-board Computer:

Mass	7.8 KG
Power consumption	8 Watt

Task: *data storage and execution of 12 hours observation program*
attitude control
data handling

Apart from the fact that the ANS project provided the astronomers with a wealth of data, it 'qualified' the industry as full fledged spacecraft developers and indeed it did help to acquire several interesting contracts. The problem of the relatively small size of the contribution of The Netherlands in the European context remained and it did not lead towards contracts in which the Dutch industry was given the overall system responsibility as was the case in the ANS project. It was therefore not surprising that proposals were made for a second national satellite. Again the astronomical community of The Netherlands and the industry proposed a satellite, now of a much larger size than the ANS.

The Infra-Red Astronomical Satellite - **IRAS** - was a cooperative effort of The Netherlands, the USA and the UK. The plans of the Dutch astronomers to survey the sky for infra-red sources resulted in the design of the IRAS satellite by a consortium of Fokker and HSA (Signaal) - a division of the Philips Company where Philips had concentrated its space activities. This design was presented to NASA. In a similar way as with the ANS satellite the plans were merged with American plans into the IRAS satellite. This satellite, which was much larger than the ANS (mass of 1080 KG as compared to 140 KG for the ANS), was launched by NASA - on 26 January 1983 - with a Delta rocket from the Western Test Range, California, USA, as the ANS, in a near-polar sun-synchronous orbit.



The Infra-Red Astronomical Satellite, IRAS

The Netherlands contribution included the systems design, manufacturing of the structure, integration and a large part of the instrumentation. The USA contributed a major part: the liquid helium cooled (at 4°Kelvin = -269°C) part of the infrared telescope.

The operation of the IRAS was terminated on 22 November 1983, when the helium was fully used. The satellite was also operated from a sun-synchronous earth orbit (near polar) and it was designed to survey the complete sky in six months, the orbital plane rotating one degree per day. It more than accomplished its mission.
The IRAS Ground Operations took place from the UK, under the responsibility of NLR and in close cooperation with the Rutherford Appleton Laboratory, at Chilton in England.

The contributions of NLR to this most successful satellite project included a variety of tasks such as:

- testing of the Attitude Control System in the laboratory,
- the integration and systems responsibility for the Ground Check-out System and assistance in testing of the electrical systems,
- the Ground Operations and its preparations,
- the development of Data Reduction Systems for the enormous stream of data, in close cooperation with the University Groningen.

The final results were compiled in the IRAS catalogue which provided basic information taking astronomers many years to analyze.

IRAS was a much larger project than the ANS satellite and several more companies and organizations in The Netherlands contributed to the development of this satellite. Also the contribution of NASA was much larger, not in the least due to the large cryogenic vessel containing the infrared telescope.

After the successful completion of this mission several more studies were carried out for application satellites in which The Netherlands would have overall systems responsibility. These included a study together with Indonesia for a remote sensing satellite specially designed for tropical conditions. But although the industry - and NLR and other laboratories in The Netherlands - did obtain many more highly interesting research and development contracts, mostly from ESA, a new 'national' satellite project did not appear feasible.

Nevertheless, the two 'national' satellite projects, the ANS and the IRAS, had provided the industry, and also NLR, with a good background for future research and development in space technology.

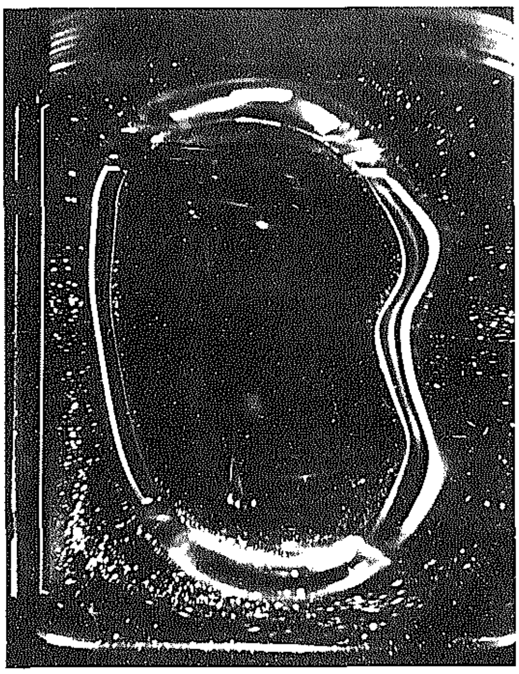
Testing the Attitude Control System of IRAS at NLR

For NLR the participation in these two satellite projects also resulted in a solid basis for the development of several other information systems, (see Chapter 16).

Fluid Dynamics and Heat Transport in Space

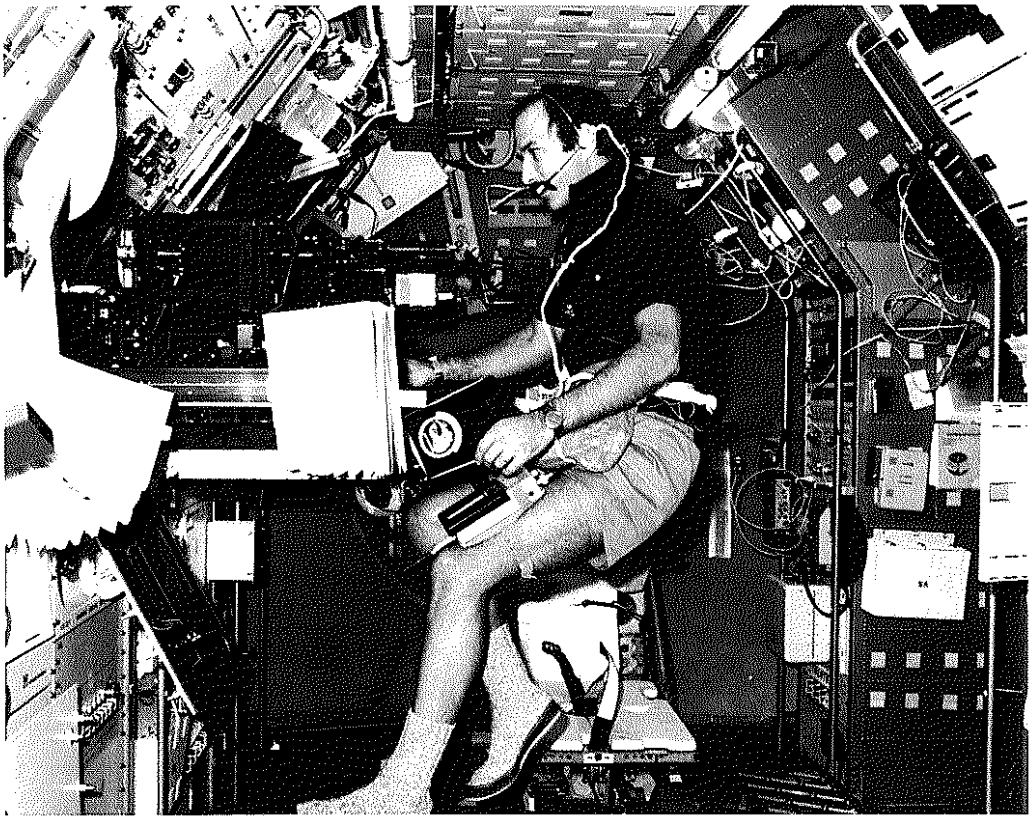
The advent of the NASA Space Shuttle Transportation system and the European participation with the Spacelab created the opportunity for scientists of the ESA countries to prepare experiments under near zero-gravity conditions. There are several groups in The Netherlands participating in this program, e.g. in the area of biology, physiology, metallurgy.
The Spacelab is essentially a laboratory, built for ESA by the European industry, which can be mounted in the NASA Shuttle vehicles. The original idea was that ESA would regularly provide (a few times per year) Spacelabs, fully instrumented to carry out a series of experiments in space, and that NASA would fly the Spacelab with American and European astronauts performing experiments. Unfortunately, for various reasons, only a few Spacelab flights have been carried out.

NLR carried out experiments on the behavior of fluids in partially filled containers. The first preliminary experiments were carried out during parabolic flights with the Hawker Hunter laboratory aircraft but there it was only possible to achieve a period of about 15 seconds under '0-gravity' conditions. These experiments were later complemented by participation in 'zero-g' flights organized by ESA in a Caravelle and an American KC-130.



Fluid in a container under Weightless Conditions during a zero-g flight with the Hunter Laboratory Aircraft

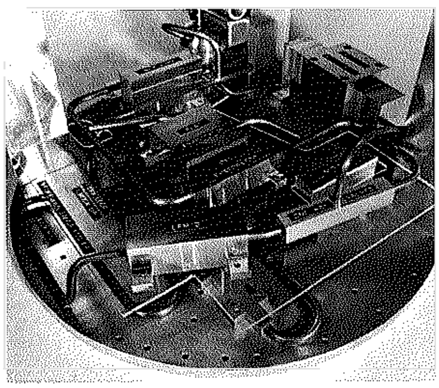
The Dutch ESA Astronaut Dr. Wubbo Ockels carrying out an experiment in Spacelab with the Fluid Containers of Dr. Vreeburg of NLR



During the first operational flight of the NASA Space Shuttle (STS 5) in November 1982, a small demonstration model of the NLR experiment was carried during that flight. In November 1983 (launch date 28 November, flight duration 10 days) the NLR experiment was carried in the first Spacelab flight and again in the first German (D1) Spacelab flight in November 1985[4] (launch date 30 October, flight duration 7 days).
During these flights the NLR experimenter, Dr. Ir. J.P.J. Vreeburg, interacted with the Dutch astronaut Dr. W.J. Ockels[5] and the German astronaut Dr. U. Merbold via a TV connection with the ground station. The experiments were of great importance to refine the theoretical work of Dr. A.E. Veltman and others of NLR on the behavior of fluid under 0-gravity conditions.
In preparation of other Shuttle flights NLR participated in the design of a Fluid Physics Module.
Also preliminary experiments during the ballistic part of the flight with ESA high altitude rockets and a proposal and a design for a so-called 'Wet Satellite' were made.

Another aspect of the behavior of fluids under zero-gravity conditions is the transport of heat in pipes filled with vapor and fluid. Through the mechanism of vaporization on one end and condensation on the other end of a tube, heat can be transported through a spacecraft. This subject has been studied by NLR over a period of several years. The potential is very great, especially for large space systems.

Mock-up of an experiment with a Two-Phase System for heat transport to be carried out in Spacelab



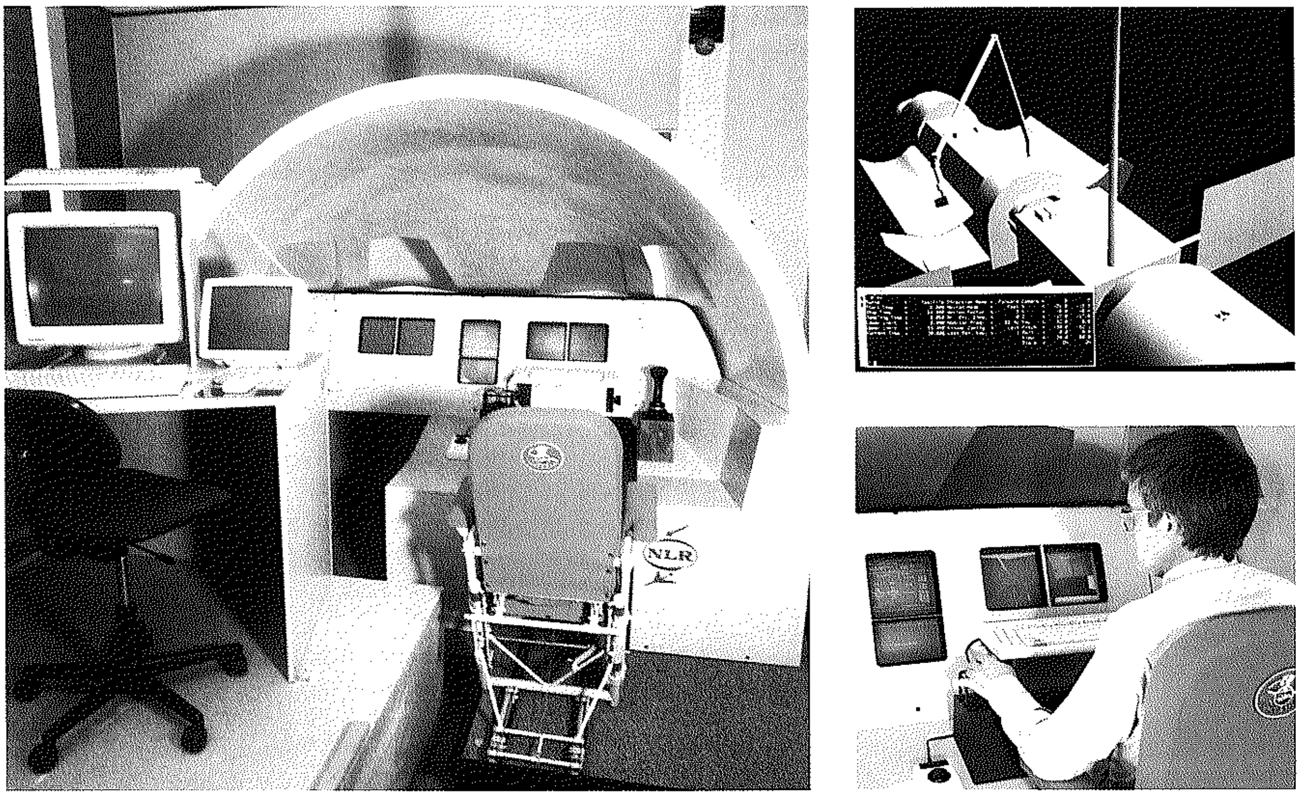
In 1994 a two-phase experiment will be flown as a 'Get Away Special' in a NASA Shuttle flight. This experiment designed by NLR with the assistance of four industries, will provide experimental data on the behavior of the vapor and fluid and the capillary pumping system under 0-gravity conditions. The beauty of heat transport systems like this is that there are no moving parts.

[4]The D1 Spacelab was carried by the Shuttle 'Challenger' which met with a fatal accident on 28 January 1986, shortly after launch. The events following this accident resulted in a long delay of flights with the NASA Shuttle and this also meant that the flight opportunities for this type of testing were almost nonexistent for a long time.

[5] In 1993 Dr. Ockels, employed as an ESA astronaut, (the first astronaut from The Netherlands) became part-time Professor in the Aerospace Engineering Department of the Technical University Delft.

Space Robotics

In connection with the NASA plans of developing a Space Station and the European participation in this station, the ESA organization started studies for the **Hermes** shuttle which was to be launched by an advanced version of the Ariane launcher: the **Ariane 5**.
Hermes is essentially a small manned shuttle, launched by the Ariane and returning to earth in a manner similar to the NASA Shuttle. This concept was developed in the early 1980's, mainly by the French industry, and adopted by ESA in 1987. Since that time many technical and political changes took place, in Europe, the USA and the former USSR. When this book was written, the future of the Space Station and the Hermes vehicle was not clear.
For NLR the project did result in its involvement, together with Fokker Space & Systems, of studies of a Hermes Robot Arm (HERA). For this space manipulator a simulation facility for training purposes was developed.



The Space Simulator of the Hermes Robot Arm (HERA)

This project formed the basis for several space robotics studies, often in cooperation with other companies and organizations in Europe. The ultimate application of these studies is uncertain, but it is clear that space robotics in manned and unmanned vehicles will increase in importance. Through exercises like these, valuable experience is being gained in the development and application of mathematical algorithms for the manipulation of robots.

At the beginning of the 'Space Age' it was clear to the Chairman of the Board, Prof. Van der Maas and the Director, Ir. Marx, that NLR had much to offer in the area of technology (aerodynamics, flight mechanics, guidance and control, structures, systems testing, etc.) and in turn, NLR had much to gain by participating in space technology projects. They both spent a considerable amount of their time to become acquainted with the problems at hand and they also became very much involved in the national and international discussions. Prof. Van der Maas convinced one of his prize students, Ir. P. Kant, to join NLR even before he graduated. He was employed by NLR on 4 October 1959 and first sent to Cranfield in the UK to take a guided missile course. After that Kant acted more or less as a personal assistant to Ir. Marx for several years. He worked at the

Flight Division but reported mostly directly to Ir. Marx. Since there was no national space technology program, they concentrated on the ELDO organization. Under the guidance of Ir. Kant NLR built up the capability for the systems testing of the guidance and control system for the ELDO launchers. In later years the reputation Ir. Kant[6] had gained and the connections he made formed a solid foundation for NLR to operate in the European context.

One aspect of the task of NLR in the area of space was to advise the Ministry of Education and Science, the Ministry of Economic Affairs, and also on occasion the Ministry of Foreign Affairs. This requirement diminished in the 1970's when the NIVR was given the task to supervise space programs and when the Ministries became better equipped to handle technical matters.

Since a separate Space Department was formed at NLR in 1967 a rather extensive spectrum of subjects has been treated. In almost all cases this took place in close cooperation with other NLR Divisions, other laboratories and the national and European industry often stimulated by the opportunities offered by ELDO/ESRO/ESA and other international organizations involved in some aspects of space.

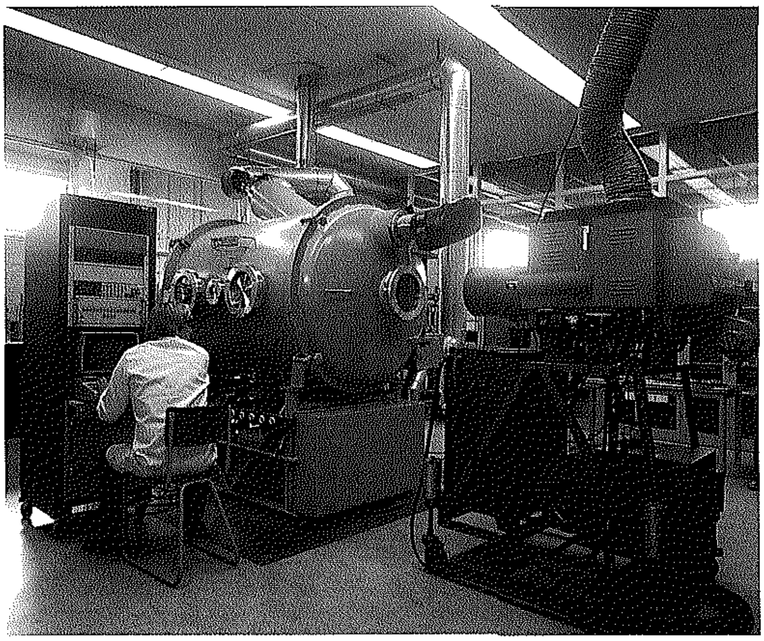
The subjects for in-house research had to be selected very carefully, which was not always easy since the forecast for medium term applications (always a good guideline for engineering research) was quite uncertain in the national and the international context. Also the more or less traditional division between the tasks of the aircraft industry and the laboratory did not always apply, since for the space industry the emphasis was far more on research and development than on design and production as it was in aeronautics.

Test Facilities

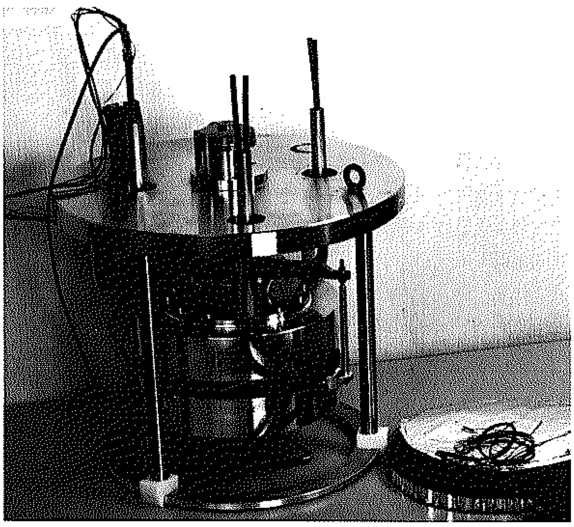
Finally the matter of test facilities deserves attention. Traditionally the aeronautical laboratories operated special test facilities of sufficient size to carry out experiments in support of the industry, the Armed Forces and other government organizations (wind tunnels, structural test facilities, flight simulators, laboratory aircraft). The development of these facilities is usually subsidized by the governments: they are to be available for government and industry. Since the ESRO/ESA central test facilities were being built up in The Netherlands (the ESTEC laboratories at Noordwijk) and since it was not to be expected that the national requirements would justify the construction of large space technology facilities, it was clear that NLR's role in space technology would not be exactly the same as in aeronautical technology.

With these constraints NLR did purchase a space chamber in 1966 and added a solar simulator later, but the size (1 M diameter and 1.5 M long) was such that full-scale space simulation for satellites was not possible. The facility is however very useful for more basic engineering research.

The Space Environmental Simulator with Solar Simulator of NLR



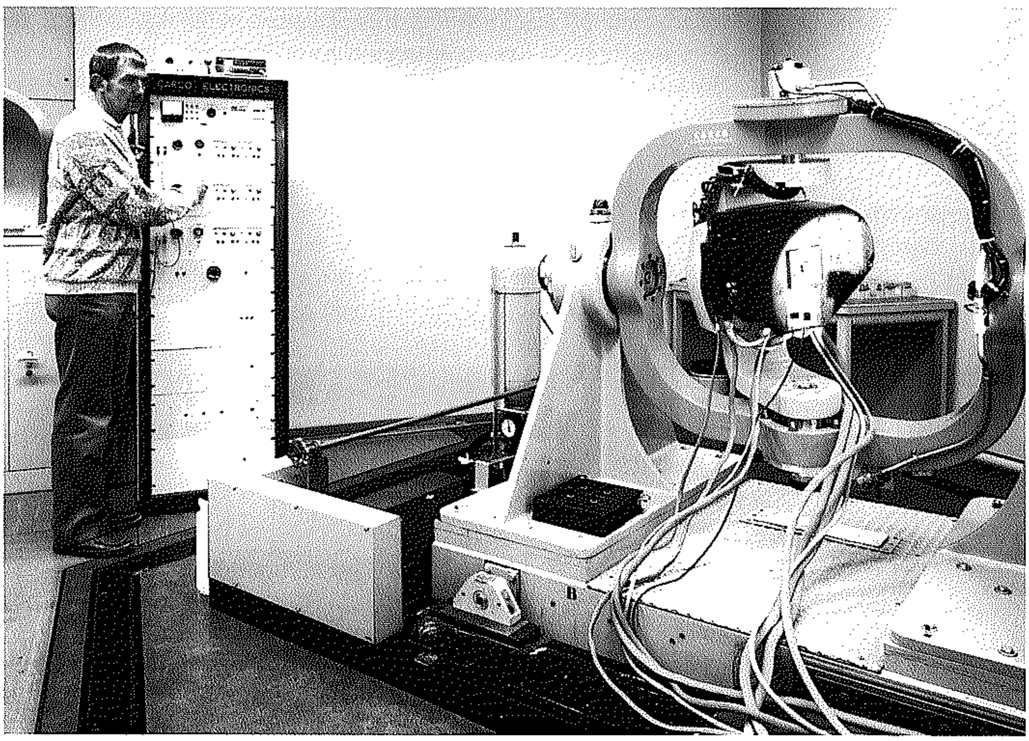
[6]On 21 June 1985 Ir. Kant was involved in a very serious car accident. After a long period he did recover remarkably well. However it was not possible for him to continue as Head of the Space Division of NLR - a demanding position he had held since 1971. Ir. C.A. Schmeitink succeeded him.



Experimental set-up to measure the heat conduction of sandwich-constructions in the direction perpendicular to the plates under vacuum conditions

The Guidance and Control Laboratory of the Space Division was initially developed specially for the ELDO program. It was partially financed by ELDO. During its thirty years of existence several more motion tables and other simulator equipment were added. The laboratory was engaged in the systems analyses and testing of many European satellite attitude control systems, among others for the SAX and ISO satellites.

Testing the Attitude Control System of the European Communication Satellite OLYMPUS



15. From Slide Rule to Supercomputer

For many decades the slide rule[1] in various forms - linear or circular - was the symbol of an engineer. More accurate and larger computations were often carried out with the aid of mechanical or electro-mechanical desk calculating machines. Since the 1940's electronic computers developed very rapidly and the effects of computers on science, engineering and business and on almost every human activity, are well known.

It would seem that a special chapter on this subject related to the activities of NLR would not be different from historical chapters of any other organization. However aeronautics (and since the 1960's particularly space technology) was a major stimulant for the development of computer technology. At NLR, as at other aerospace laboratories, the latest developments of computers were applied whenever the human and financial resources could be made available.

We have now reached a state where in many organizations every employee has available a computer. This is certainly so in many university departments and in research laboratories. The word 'computer' now often has a meaning which is quite different from what it meant some decades ago. It must be recognized that the majority of computers is used as advanced word processors and filing systems, but at the same time the capabilities of the now standard personal computers (PC's) are orders of magnitude larger than the digital computers of only a few years ago. That is not only due to the spectacular development of the computer hardware but also due to the continuing development of software. Computers have become an integral part of education at schools of all levels and therefore the story of the application of computers at NLR is less impressive to younger than to older readers, who will undoubtedly remember their first struggles with computers.

Numerical Calculations in the 1930's and later

The aeronautical engineering sciences were faced from the beginning with the problem of carrying out large scale numerical calculations to obtain e.g. the pressure distribution around airfoils and wings, the oscillatory motions of aircraft due to atmospheric and pilot induced disturbances and of course the stress calculations of the complicated wing and body structures of airplanes. It is now difficult to imagine that it took several man/woman months to carry out an accurate calculation of even the first few periods of a purely symmetrical longitudinal motion of an aircraft. This made it almost impossible to calculate in detail the stability and control characteristics of an aircraft by numerical methods.

The numerical methods were reduced to calculations in tabular form and then handed to the Numerical Calculation Office, where ladies carried out numerical calculations, using simple hand operated calculators.

The Numerical Calculation Office in the 1930's

[1]The slide rule is now almost archaic and unknown to the current generation. A slide rule is - according to Webster's Dictionary - a device for rapid calculation, consisting essentially of a rule having a sliding piece moving along it, both marked with graduated, usually logarithmic, scales.

Usually the same numerical calculation was carried out by two different persons or groups to eliminate human errors. This (double check) procedure was also used for the reduction of the vast amount of data produced by flight tests and wind tunnel tests.

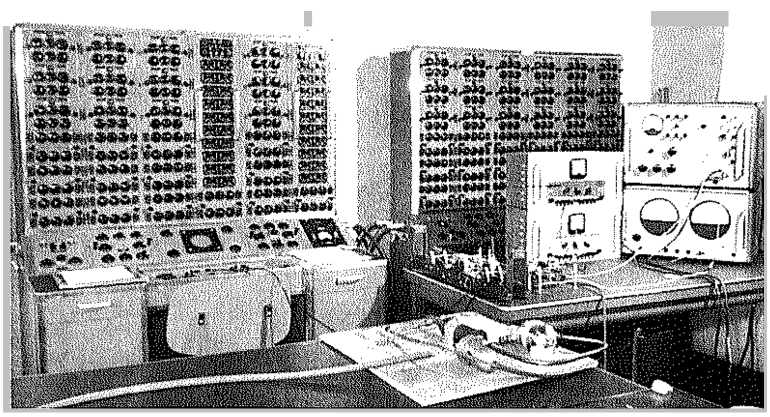
During the 1940's and 1950's the Flight Department and the Aerodynamics Department started to incorporate elementary computational components as they became available. However it was not till the mid-1960's that the application of computers penetrated all corners of the laboratory. In the issue of 'De Ingenieur', commemorating the 50th Anniversary of the NLR in 1969, [Ref. 1], there is only a short description of the computational facilities although at that time a central computer facility had been established. During the 1970's this activity became a dominating factor in almost all research activities.

The Numerical Calculation Office, started as a part of the Flight Department, grew from a complement of about 20 in the 1950's to some 70 personnel in the early 1970's when digital computers were really incorporated in the laboratory and further to more than 150 in the 1990's when the supercomputers were introduced. The introduction of computers definitely did not lead to fewer jobs at NLR!

Before describing some of the highlights of the digital computational facilities at NLR it is of interest to pay attention to the analog computational facilities. In the early 1950's these were the only computational facilities commercially available and of practical engineering use. Particularly in North America computer systems and elements of systems became available with which motion systems could be simulated. Shortly after that the first digital computers became available. For some time the analog computers were favorite for engineering applications and in the beginning it seemed that digital computers were only useful for accounting purposes. The access to the digital computer was cumbersome at first - card punch machines, separate interfaces, often difficult to handle outputs, etc. - but that soon improved. The speed, and the input and output mechanisms, of digital computers improved rapidly and for most applications analog computers were replaced by digital computers.

Analog Computers

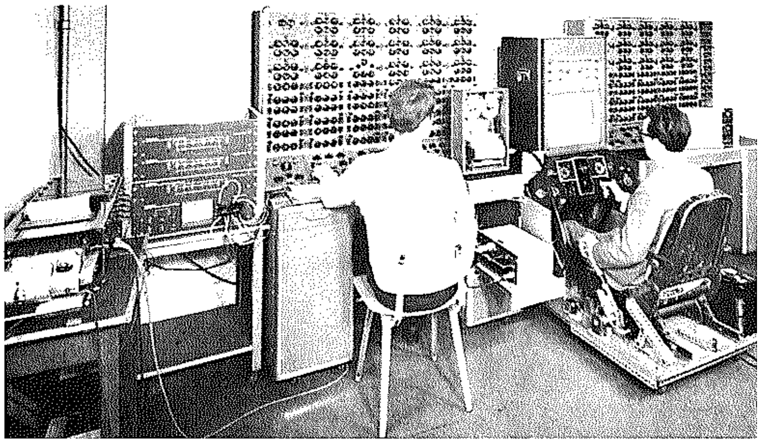
At NLR the Flight Department stimulated the application of analog computers. In 1955 a Short analog computer was installed at NLL. The first interest was in the use of analog computers 'in the loop', that is computers directly connected to hardware whereby the analog computer solved continuously the equations of motion, as illustrated by an application in the mid-1950's.



An early application of an Analog Computer to simulate the flight of a Free Flight Model at NLL, 1956

The analog computer was used here to simulate the flight of a free-flight model (solving continuously the equations of motion) and it was connected to the electro-pneumatic servo control system of the model.

When reliable and accurate integrators, function generators and multiplier units, etc. became available analog computers were used mostly for this type of arrangements. It became possible to 'fly' an airplane in the laboratory by connecting a control stick and engine controls to the analog computer which would then solve rapidly the programmed equations of motion and present the new flight status to the 'pilot'. Thus the analog computer not only opened the possibilities of obtaining rapidly solutions to the equations of motion but it also provided the possibility to study the response of an aircraft with the pilot in the loop. The road was opened to sophisticated flight simulation in the laboratory.



Application of an Analog Computer to simulate the flight mechanics of V/STOL aircraft at NLR, 1963

The most important applications of analog computers at NLR were in flight simulators for aircraft and in the testing of guidance and control systems for rockets, (Chapters 6 and 14).

The main advantage of analog computers over digital computers was the speed of computation at the desired accuracy. Most of the applications were with a pilot in the loop or hardware in the loop which had to be tested in real time. Only in a limited number of cases, analog computers were used for purely computational problems. Although most analog computers were relatively easy to use, the number of applications diminished when the capacity and speed of digital computers grew very rapidly in the 1960's and 1970's. This was accompanied by the development of more efficient and user friendly computer codes.

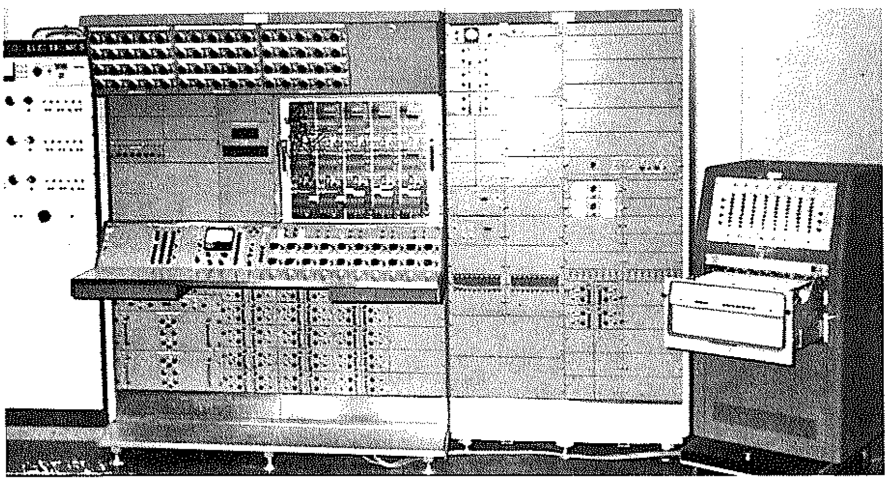
In the beginning of the 1960's Vertical and Short-Take-Off and Landing (V/STOL) aircraft became an important subject of study[2]. A simulator was developed by the Flight Division to study the flight characteristics and the requirements for aircraft in that category. This was a so-called fixed base flight simulator, meaning that the cockpit did not move, in contrast to the moving base flight simulators as described in Chapter 6.

Another major application of analog computers was the simulation of the flight of the ELDO (European Launcher Development Organisation) rockets. The simulation was set up to test the guidance and control system of the ELDO launchers, (Chapter 14).

That simulation system, gradually refined and extended, was converted into a 'hybrid system' in 1972. Hybrid in this context meant that the system consisted of a digital part and an analog part. The analog part was used for those elements of the computation that required a fast response which could - at that time - not be met by digital computation. This was also an application with actual hardware in the loop - an inertial platform of the Europa Launcher. An EAI 640 digital computer provided via the EAI 680 analog computer the inputs to the moving (rocking) table on which the inertial platform was mounted, (see Chapter 14).

The analog computer systems were used also for other purposes by individuals in the laboratory on an ad-hoc basis. The idea - in the late

[2]Much attention was paid to V/STOL aircraft designs since it was believed that it would help solve the noise problem around airfields and particularly since there existed various schemes to open up airport facilities at or near city centers. An example is the trial operation between Montreal and Ottawa in Canada in the early 1970's. Fokker also studied the prospects of adapting the Fokker F27 Friendship to short take-off and landing operations to and from city centers. In fact the subject was so prominent that the studies for the new low speed wind tunnel of NLR, (Chapter 18), were motivated to a large extent by the requirements of V/STOL aircraft. Obviously any aircraft having that additional capability will be heavier than its counterpart operating from a 'normal' airfield and the fuel consumption will be higher. After the first 'energy crisis' the market did not seem ready for civil V/STOL aircraft and city-center to city-center transportation. Subsequent further development of the existing main airports and the improvements in ground transportation pushed back further the application of civil V/STOL aircraft.



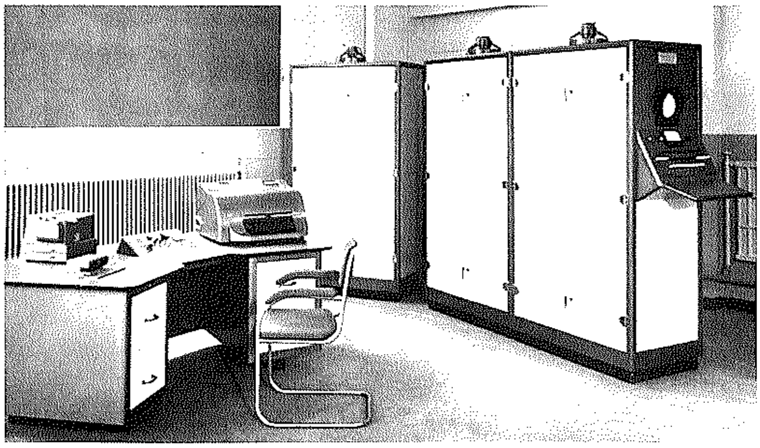
The PACE Analog Computer used in the Guidance and Control Laboratory at NLR-NOP

1960's - to concentrate the analog computer activities (aircraft, space flight and others) in one building at the NOP never came to fruition. This was of course also influenced by the fact that the ELDO operations ceased and the analog computers of the Space Division were used for different purposes.
As time went on it became more efficient to instal dedicated computer facilities for a particular research installation.

Developments like this made it difficult to chart a long-term plan for computational facilities, in a period where the computers themselves developed very rapidly. The development of computers - not a part of the NLR research program - has a great influence on the long-range planning of the laboratory. For decades it was a major problem that required the full attention of the Management.

Digital Computers

In **1954** it was reported that Mr. Th. Burgerhout, then Head of the Computation Office, carried out numerical calculations on boundary layers over a swept-back wing at the Mathematical Center of the University Amsterdam (ARRA computer). These and similar trial calculations resulted in ordering the first digital computer for the laboratory. It was the **ZEBRA** (= Zeer Eenvoudige Binaire Reken Automaat = Very Simple Binary Calculation Machine), installed at the laboratory in Amsterdam in **1958**.

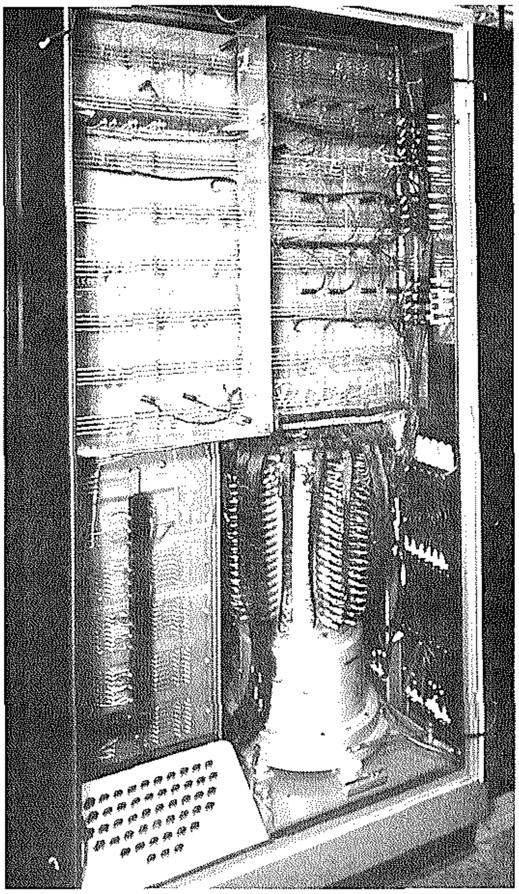


The first Digital Computer ZEBRA installed at NLL-Amsterdam in 1958

ZEBRA Operator Panel. The small scope showed the contents of accumulators and counters in binary form, suitable to follow the progress of the program execution

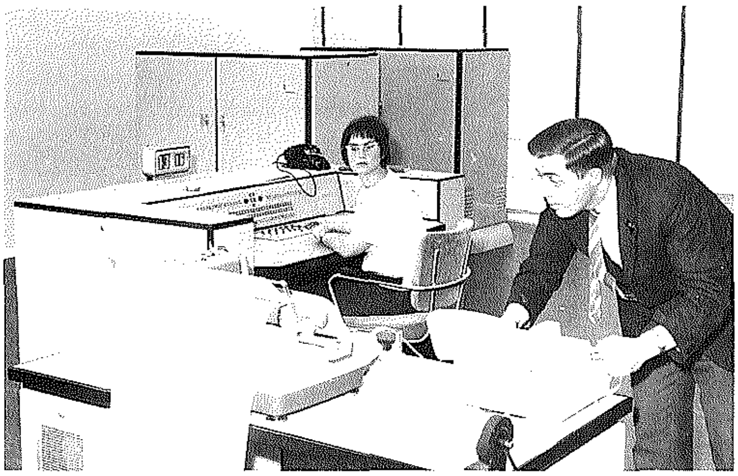
The ZEBRA machine was developed by the Netherlands PTT. As the name implied, it was a very simple machine but it was the start at NLR of the 'computer era'.
The name of the Computation Office was changed - it became the Mathematical Problems and Numerical Calculations Department and under the leadership of Dr. E. van Spiegel[3] this Department used the computer for a large variety of numerical problems: data reduction for flight tests and wind tunnel tests, the development of nozzle contours for wind tunnels, the development of numerical methods for aerodynamic force calculations, pressure distributions and forces on oscillating airfoils, etc. The computer was used almost continuously. Wind tunnel data reduction took up a very large part of the available time. The personnel included eight university graduates in 1959 as compared to only one a few years earlier.

[3]Dr. Van Spiegel headed this activity from 1957-1960 till he was appointed Professor of Applied Mathematics at the Technical University Delft (1960-1977). In that position he served NLR as an Advisor in the NLR Computer Committee, concerned with the planning and purchase of large-scale computers and as a member of the Sub-Committee for Applied Mathematics and Informatics of the Scientific Committee, till he became Director-General for Science Policy of the Ministry of Education and Science.



The read and write heads on the Drum Memory of the ZEBRA

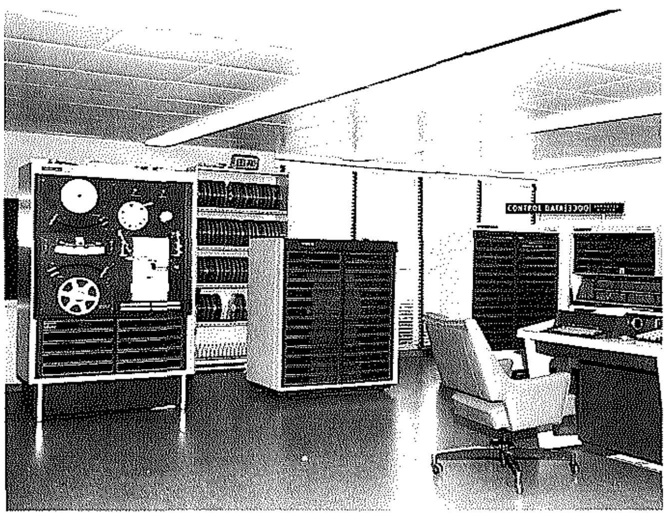
The Electrologica Digital Computer X-1 installed at the NLL-NOP in 1962



In **1962** the ZEBRA was replaced by an **Elliott 803b** computer. This computer was mostly used for the data reduction of wind tunnel and flight tests.

Also in **1962** a digital computer of **Electrologica** (The Hague) **X-1** was installed at the NOP. The number of numerical computations at NLR had expanded considerably and the Department - now headed by Dr. Ir. J.P. Benthem[4] - also made use of three other ZEBRA and two X-1 computers located at other institutes in The Netherlands. By then there were also two analog computers in full use at NLR.

The Central Computer Control Cata CDC-3300 installed at the NLR-NOP in 1967



The X-1, the more general purpose computer in the NOP, was succeeded by a Control Data Corporation **CDC-3300** in **1967**. At NLR this was the end of computers made in The Netherlands. The computer industry had developed very rapidly and there were only a few computer manufacturers left on the market for large-scale scientific computations.[5]

The next major operation was the installation of a **CDC-1700** computer at Amsterdam in **1971**. It had a fixed line connection with the CDC Computer Center at Rijswijk, near The Hague, for the data reduction of wind tunnel tests and flight tests. The older Elliott computer had become unserviceable and - apart from the capacity - the transportation of data tapes by car to the NOP became too cumbersome; there was not yet a fast line connection available between the NOP and Amsterdam.

[4]Dr. Benthem stayed in that position till 1970 when he went to the Technical University Delft where he later became Professor of Applied Mechanics (1979-1986). For a while it seemed that with the introduction of every new computer generation NLR contributed a professor to the universities. Fortunately for NLR, after Ir. W. Loeve took this position, this brain drain process has been discontinued.

[5]This did not mean that the capability of producing advanced digital computers was lost in The Netherlands. Only a few years later Philips produced the first on-board satellite computer for the ANS satellite, followed later by the on-board computer for the IRAS satellite. These were marvelous computers but they were special purpose - one of a kind - developments.

It is often difficult to identify important mile stones in organizations like NLR where there is a continuous development of ideas which sometimes come to fruition instantly and sometimes much later or - unfortunately - never result in any particular action. In retrospect the period **1970 -1972** may be noted as a mile stone in the application of computer technology at NLR. On 1 June 1970 Ir. W. Loeve became Head of the Scientific Services at NLR.
Since the major re-organization in 1967 (Chapter 22) Ir. J. Boel, Deputy Director, had been Head of this group on an interim basis. This Group of Scientific Services also included the Space Technology Department which later also became a separate Division.

The Group of Scientific Services included:
- Applied Mathematics and Data Reduction
- Electronics
- Library, Documentation, Photography and Reproduction

The last activities of the Group were later separated and became the responsibility of Ir. W.F. Wessels. The computer activities and all the interactions with the rest of the laboratory became the responsibility of Ir. Loeve.

One could argue that all these organizational aspects are of less interest than the actual work carried out by the personnel. While that is certainly true, it was also important that the computer activities were represented directly on the Management Team. After all this was the body where the - often heated - debates took place about the deployment of manpower and the financial resources.

It was clear that in order to support the aerospace community and to stay abreast with developments in other countries, strategic plans had to be developed, even though the financial means were limited. There were plans to extend the computer networks in The Netherlands and NLR extensively investigated the possibilities to establish connections with the national network(s) for which the plans were then in progress. The Ministry of Education and Science stimulated this and in fact there was a Committee which had to sanction new (major) computer acquisitions in which government funding - directly or indirectly - was involved. Discussions took place with universities and other engineering laboratories which received government subsidies.

Finally it was decided by NLR to install a large Central Computer at the NLR-NOP site, operating independently from other computers in The Netherlands. The arguments were, i.a.:

- NLR would use the facility to its full capacity after a short introduction period (a few years);
- security could not be guaranteed when the computer was part of a national network;
- the networks in The Netherlands were still not reliable and cumbersome in use;
- it was expected that the cost effectiveness would be greater for a separate computer.

In the Spring of 1972, after having discussed the matter extensively at the Board meeting, Prof. Gerlach, the Chairman of the Board of NLR, took the bold step of ordering a Control Data Cyber 72 system. This step was bold, not in the sense that he did something for which he did not have the mandate, but because several Board members and people in other organizations were still not in agreement and felt that the NLR computers should be part of the national network (which did not yet really exist) and that the main computer should be located somewhere else. It turned out to be a wise decision to place the contract.

Reporting on computers is often very dry and uninteresting. The Annual Report of NLR of the year **1973** says: *"As a result of the installation of the new Central Computer (CDC Cyber 72), a large number of programs was converted from the CDC-3300"*. In reality this involved hard work of many people who had to work under constant pressure of internal and external users who really did not care about the details of the introduction of the new computer system.

In 1974 a 48 kHz line connection was established between the laboratory in Amsterdam and the Cyber in the NOP. There were also fixed lines introduced with the Fokker computer system. Although the first (quick look) data reduction of wind tunnel tests became gradually more and more possible on - relatively inexpensive - local computers, more extensive analysis, using a data base compiled in the Central Computer, took place via terminals of the Central Computer. For quite some time the data reduction of the flight tests took place at the Central Computer in the NOP. A real computer network was developed.
The ideal was: no matter where one would be working within the laboratory or outside the laboratory if connected to the network, it would not make any difference as far as the access to the Central Computer is concerned.
There was on the one hand the tendency to channel all computations to the Central Computer but on the other hand gradually a new generation of engineers and scientists moved in. They were educated in the 'computer age' and less dependent of the expertise of the personnel operating the Central Computer. This also coincided with the advent of less expensive smaller computer systems with which many day-to-day problems could be solved.
This new generation also understood better the advantages and possibilities of large scale computers and so the net result was - besides a considerable increase in special purpose and personal computers - also an increasing demand on the central computing facilities. This development at NLR was of course not unique. By 1978 there were 22 terminals directly connected to the Central Computer, including one from Fokker. The 'standard' data reduction associated with the various experimental facilities was mostly carried out on dedicated computers directly linked with the test facilities.

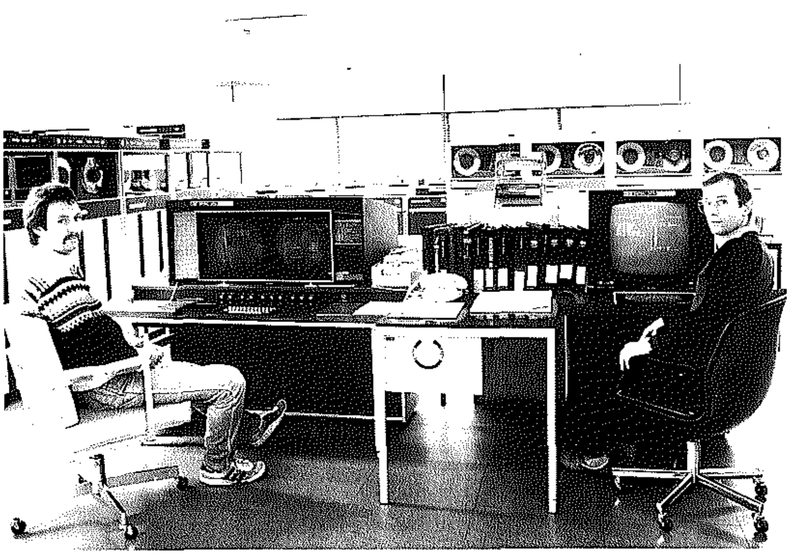
In 1980, when the Informatics Division was formed (Chapter 16), 18.5% of the total NLR personnel of 760 was employed in this Division. The employment of the then five Divisions - that is excluding the Administrative, Technical, and General Services - was:

Aerodynamics	151
Flight	125
Structures and Materials	46
Space	26
Informatics	140
Total Divisions	488

The personnel employed in the Informatics Division thus was 28.7% of the personnel directly employed in the Divisions.

In 1980 the Cyber 72 was further extended to make it equivalent to a Cyber 73-configuration and the number of computer terminals was further increased.

The Control Room with the Control Data Cyber 73 and Cyber 170-855 installed at the NLR-NOP in 1982



During 1981 the demand for computer capacity rose very rapidly, mainly due to design activities at Fokker and also in connection with project studies carried out jointly between Fokker and McDonnell-Douglas. Terminal connections with the CDC computer Cyber-176 at Brussels and the CDC computer Cyber-760 at Rijswijk were implemented. During the following year the internal capacity was adjusted when a Cyber 170-855 was installed at the NOP and the computer speed was increased by a factor of 12, while the throughput became 4 times larger. In 1983 the line connection between the laboratories in Amsterdam and the NOP was increased from 50 kbits/sec to 150 kbits/sec.

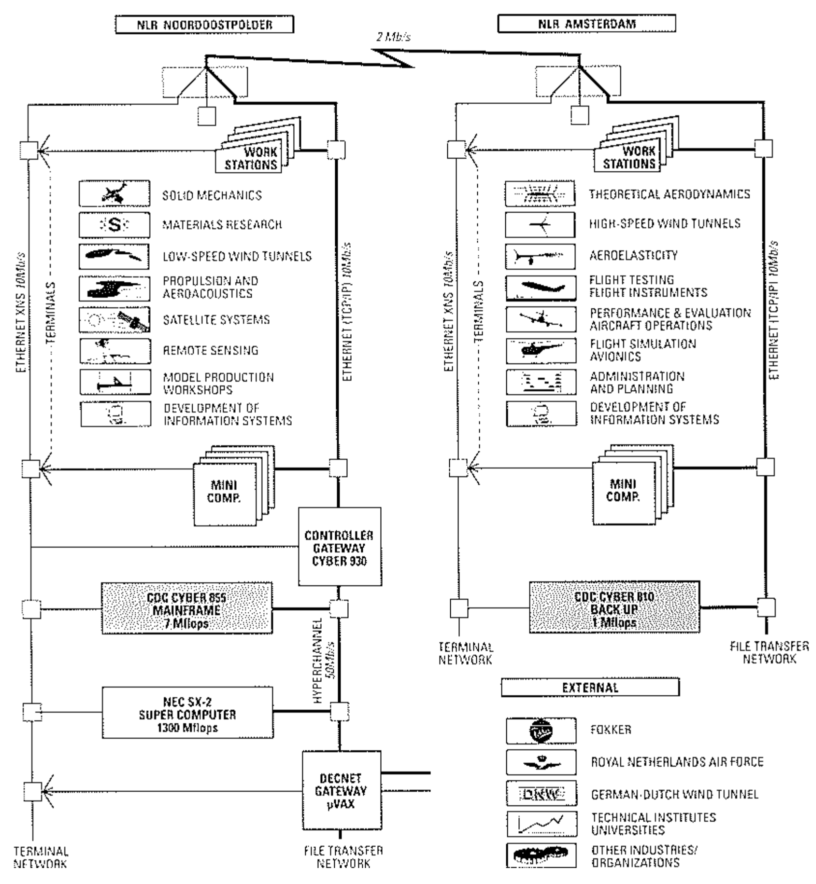
The hardware of that computer configuration was extended periodically during the following years: the Central Computer memory was doubled till 32 Megabytes and several disc memories were added. This continuing story of hardware extension must be supplemented by the story of developing data base management systems specifically geared towards aerospace applications.
A first attempt was made to design a software infrastructure - a Computer Aided Engineering (CAE) infrastructure - to include aerodynamics, flight mechanics, structures, etc.

Besides the software developments associated with data handling, data reduction and the handling of engineering design data in general, there were also other software activities in which the NLR contributed. Specific examples are:

- the development of Expert Systems and Artificial Intelligence Systems for aeronautical applications;
- data compression, in particular for satellite and remote sensing applications;
- cryptography with a variety of applications;
- the participation in a national effort to develop an Information System for the solution of the Navier-Stokes equations (ISNaS).

The latter refers to numerical methods to solve the basic equations of motion of fluids, hopefully finally to its full extent. These partial differential equations have been used for over a hundred years with various degrees of simplification. It is assumed that full solution of these equations might finally be possible when digital computers become available with several orders of magnitude larger computing speeds and memory than the present supercomputers. Wind tunnels will then remain the installations in which the basic physical phenomena are studied, but they will also serve as installations to produce the final physical check at selected operating conditions.[6]

Schematic of the Computer Network with the NEC SX-2 Supercomputer installed in 1987



[6]This prospect of numerically solving the full Navier-Stokes equations, with real physical turbulence models - that is to be able to calculate truly the flow around aerospace vehicles without any simplifying assumptions - was an element in the discussion as to whether or not a European high Reynolds Number transonic wind tunnel facility, costing hundreds of million of guilders, should be constructed. Finally it was decided to construct the ETW (European Transonic Wind Tunnel, Chapter 19). This is the only facility in Europe (and for that matter the only real production facility in the world) producing the correct Mach Number and Reynolds Number combination for aircraft operating at transonic speeds and it will - at the very least - provide physical checks of numerical computations for decades to come.

Supercomputers

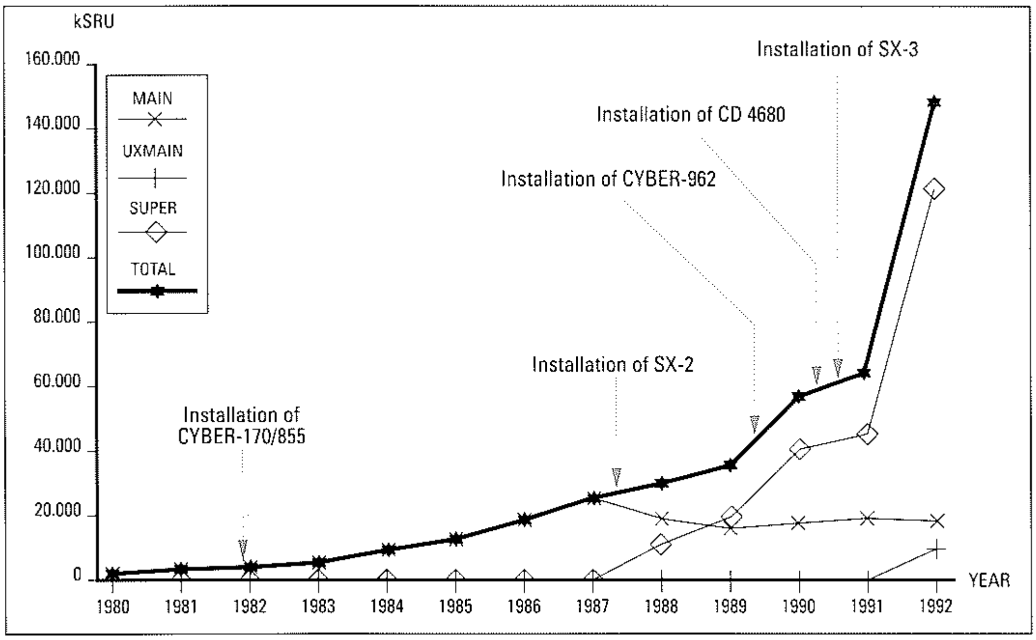
In the 1980's there were several aerospace centers employing so-called supercomputers. NLR, one of the smaller aerospace laboratories in Europe, had made use of supercomputer facilities elsewhere for some time. Based on this experience and in view of the increasing demand the computer network was extended in 1987 with a Japanese supercomputer, the NEC SX-2.

The conversion of existing programs to this computer was relatively easy and on 6 April 1988 the Minister of Traffic and Public Works officially started the operation of this supercomputer.

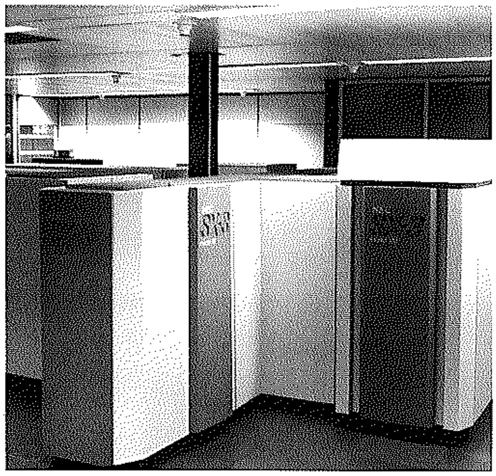
Mrs. Drs. N. Smit-Kroes, Minister of Traffic and Public Works, officially started the operation of the NEC SX-2 Supercomputer on 6 April 1988

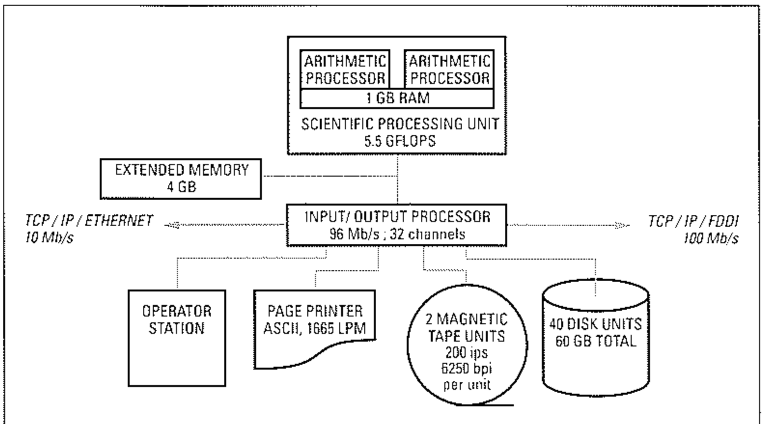
The use of the Central Computer had grown enormously, as indicated in the Figure where the production during the 1970's an 1980's is shown - expressed in units of computation per year.

The use of the Central Computer Facilities at NLR



This computer was also made accessible to universities and other groups in The Netherlands through a Working Group Supercomputers (WGS) which had obtained a budget from the Ministry of Education and Science for carrying out large scale computations by university groups.

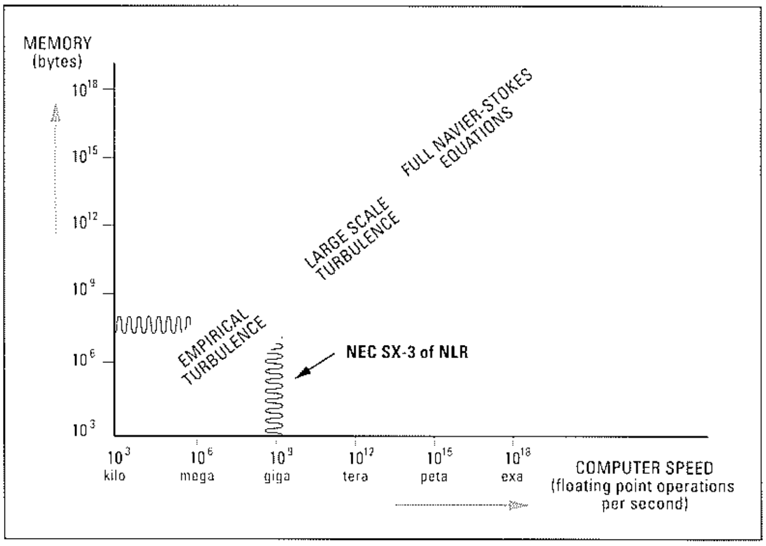




Configuration of NLR's NEC SX-3 Supercomputer 1993

The NEC SX-3 Supercomputer installed in 1991

During the following years, 1990 and 1991 the computer network was further extended and a variety of new, outside, users became involved. The Cyber 855 in the network was replaced by a Cyber 962 and a contract was signed to replace the NEC SX-2 by a NEC SX-3/12. This configuration was installed in 1991, without any loss in productivity during the installation period.
This computer has a speed of 2.75 Gigaflops (one Gigaflop is 1000 million floating point computer operations per second), a central memory of 512 Megabits and an extended memory of 1 Gigabits. In 1993 the maximum speed and the central memory of the SX-3 were doubled. An extension of the computer, increasing the speed to 22 Gigaflops, is likely to be introduced later. The computer is embedded in the NLR computer network covering both the laboratories in the NOP and Amsterdam.



When considering the developments as sketched above, the question arises when the end is in sight. From the point of view of the aerodynamicist there is still a long way to go. In the Figure, after [Ref. 75], an estimate is given of what would be required in terms of computer speed and memory to solve the Navier-Stokes equations for complete practical airplane configurations within a reasonable time frame (hours).

The final solution may be found in massively parallel computing systems, combined with some orders of magnitude increase in speed and memory capacity. This will introduce complicated communication software of the various subsystems.

Estimates of required Computer Speed and Memory for the calculation of the flow around an Aircraft with and without any simplifying assumptions

Great strides have been made and with the present programs in the hands of capable aerodynamicists realistic design calculations can be made. Indeed Computational Fluid Dynamics (CFD) is now a very essential element in all efforts to refine the aerospace vehicle designs in spite of the fact that the ideal computer installation is still far away.

16. Information Systems

The name of the Scientific Services was changed into Informatics Division on 1 July 1980, (Chapter 22). The word Informatics, not extensively used in English and translated from the Dutch word Informatica, means in the context of the activities of NLR:

Information Technology related to Aerospace Systems

The change from a Service into a Division meant that this group gradually had developed from a pure service, mostly for internal support, to a group with its own 'products' and customers as the other Divisions had.

The Scientific Services comprised four Departments:

- Electronics;
- Mathematical Models and Methods;
- Numerical Mathematics and Application Programming;
- Computing Center and Systems Programming.

These Departments were retained when the name was changed into Informatics Division.

Practically all the information systems mentioned in this and other Chapters were not developed exclusively by the Informatics Division. They often resulted from activities started in other Divisions, but in most cases the Informatics Division became involved.

The work of the Electronics laboratory, which had started in the Flight Division, had evolved from building and repairing instruments into dealing with electronic systems, not only for internal use such as for the laboratory aircraft and the wind tunnels, but also electronic systems for aerospace applications.
A major development undertaken by the Electronics laboratory was the development of the DR28, the Digital Recorder for the flight testing of the Fokker F28 Fellowship, which flew for the first time on 9 May 1967.

Similar developments took place in the other Departments of the Scientific Services. By 1980 a considerable part of the activities of these Services was related to the realization of Information Systems. Those were systems whereby specific aerospace knowledge was essential. Examples at that time were:

- a Ground Operation System for the IRAS satellite;
- an Operational Management Information System (OMIS) for the Royal Netherlands Air Force;
- a System for Measuring, Recording and Processing Flight Test Data (MRVS);
- a Receiver and Data Reduction System for Weather Satellites (KOSMOSS) for the Royal Netherlands Meteorological Institute (KNMI);
- a Data Reduction System for Remote Sensing Data (RESEDA).

In all cases close cooperation in project teams was necessary with members of the more 'classically' oriented Departments of the other Divisions.
Often there was - and still is - some degree of competition between the various Departments and project leadership for the development of aerospace information systems is not always placed within the Informatics Division. This is understandable since the degree of specialized knowledge and operational background experience differs from system to system. Similar considerations apply when computer programs have to be developed and whether the Central Computer or a local

computer should be used. Needless to say that during the last decades many changes took place as a new generation, grown up with the use of computers, moved in and the costs of computers decreased drastically.

It is worth noting here that, when the proposal to change the name of the Scientific Services into the Informatics Division was discussed, some members of the Scientific Committee NLR/NIVR pointed out that it was important for the laboratory to maintain a group of engineers and scientists (typically 8 to 12) active in applied mathematical methods, the Department **Mathematical Models and Methods**. Traditionally this Department had been concentrating most of its efforts, but not all, on applied mathematical problems related to fluid dynamics. As part of a Division concentrating on information systems in a somewhat broader sense it was felt that there would be some spin-off to other applications in aerospace.
The Department of **Numerical Mathematics and Application Programming** supports practically all other Departments in the laboratory with their numerical problems, while the Department **Computing Center and Systems Programming** is responsible for the Central Computer and the Computer Network, (Chapter 15). The experience gained with the specification, acquisition and operation of large-scale computer systems is in itself valuable and has been applied to the design of other information systems.

The development of aerospace information systems has thus become a major product during the last 25 years of the 75 years history of NLR. The examples of the systems given below - designec during this period - are the result of merging the knowledge and experience gained in aerospace technology and the efficient use of (large-scale) computers.

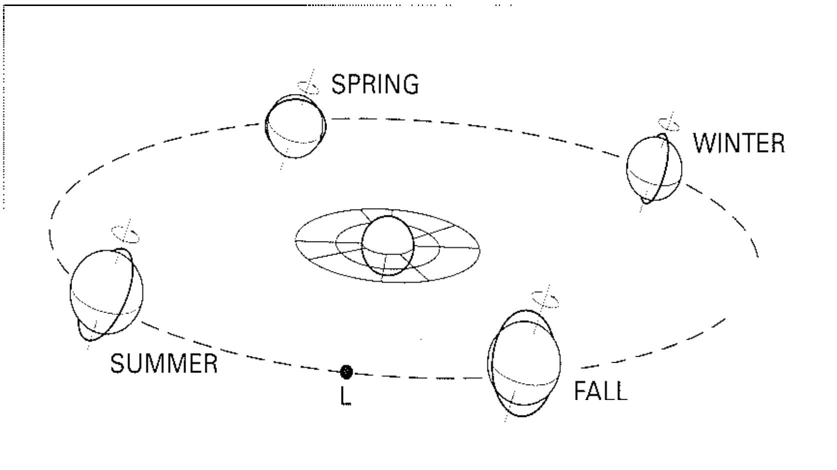
Satellite Ground Stations

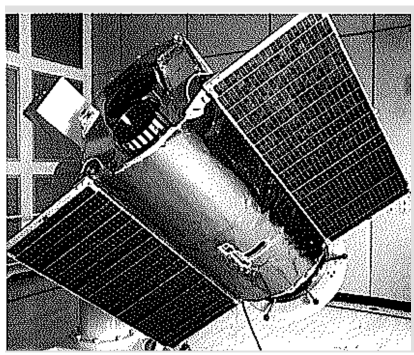
The ANS Ground Operations

The Astronomical Netherlands Satellite, a cooperative effort between The Netherlands (NIVR) and the USA (NASA), was launched on 30 August 1974 by a Scout rocket into a near-polar, sun-synchronous orbit, (see also Chapter 14). The satellite was designed for a six months period of operation, but when it had surveyed the complete sky, the operation was extended a few times till the operation was definitely terminated in April 1976. It was conceived by Dutch astronomers and designed and developed by an industrial consortium formed by Fokker and Philips. It carried an UV-telescope (1500-3300 °A) and soft and hard X-ray experiments, including an American experiment.

NLR developed the computer programs for the operations of the ANS during its mission. The operations were carried out by an NLR team headed by Ir. M. Lamers - of the Space Division - from the European Space Operations Center, ESOC, at Darmstadt, Germany and in close cooperation with that center. This satellite with a mass of only 140 KG was completely computer operatec from the ground station. A small on-board computer (power consumption 8 Watt, mass of 7.8 KG), developed by the Physics Laboratory of Philips, was

The near-polar, Sun-Synchronous Orbit of the ANS Satellite



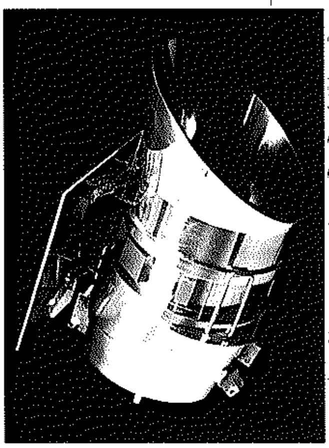


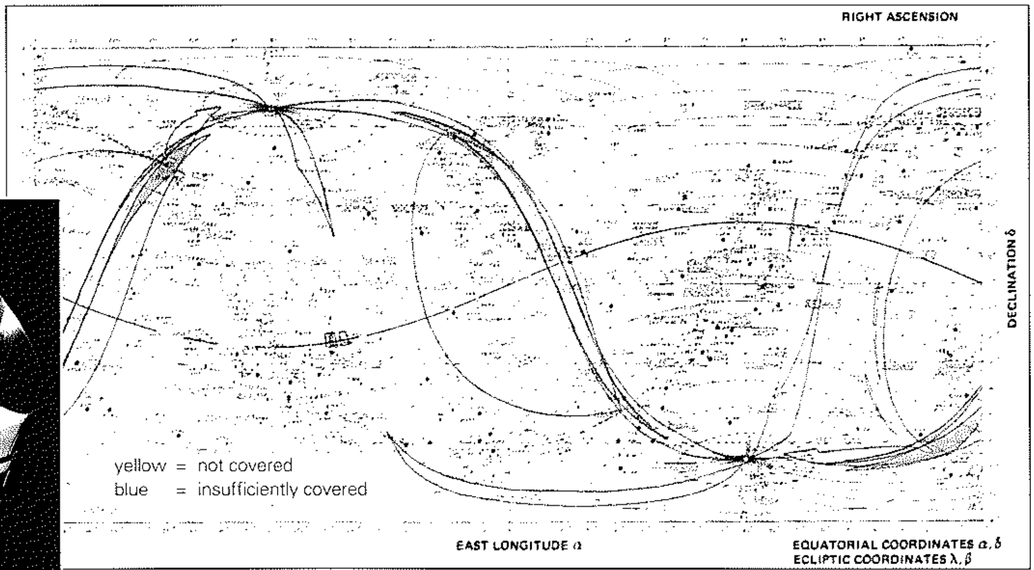
employed to control the satellite and to store the data which were read out at the ground station every 12 hours. The computer was programmable from the ground and instruction packages for the observation program for the coming period were transmitted daily. This almost directly interactive system was a novelty in unmanned satellites at that time.

The IRAS Ground Operations

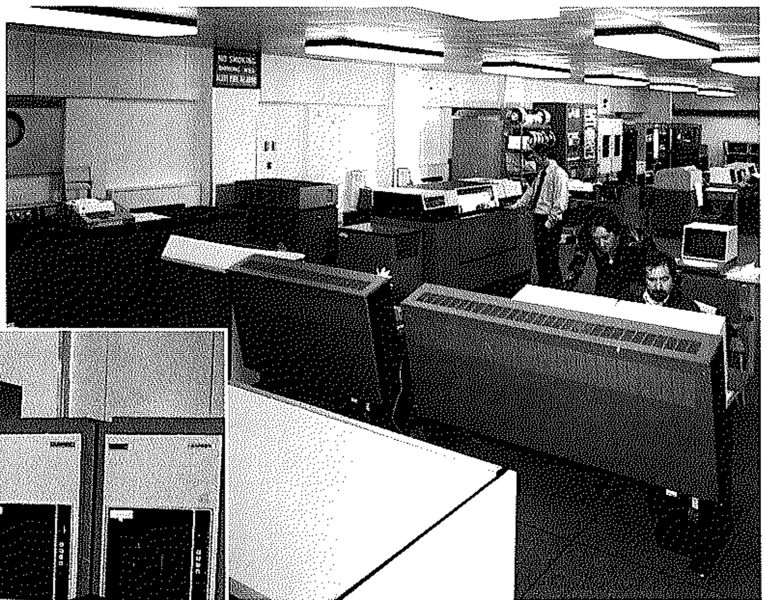
For the second 'national' satellite, the Infra Red Astronomical Satellite - IRAS - a similar task was carried out by NLR, (Chapter 14). The operations took place in 1983 from the Rutherford Appleton Laboratory at Chilton in the UK by a crew of NLR in close cooperation with the British.

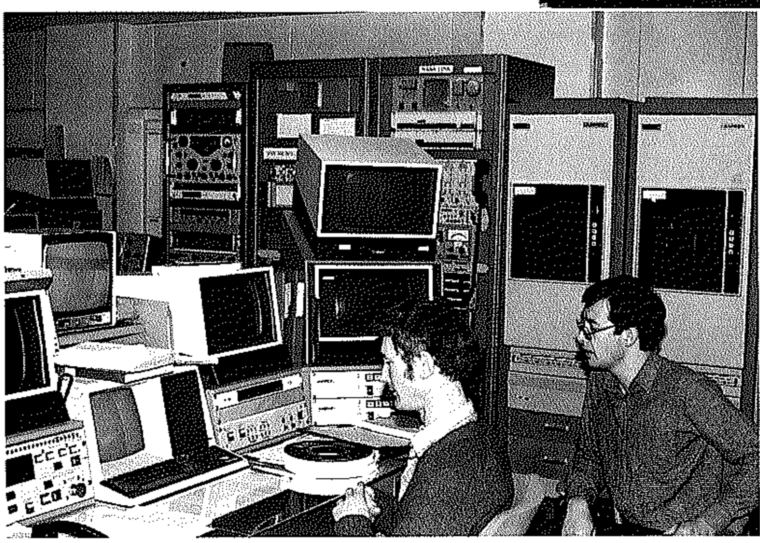
The IRAS Satellite and the Coverage of the Sky



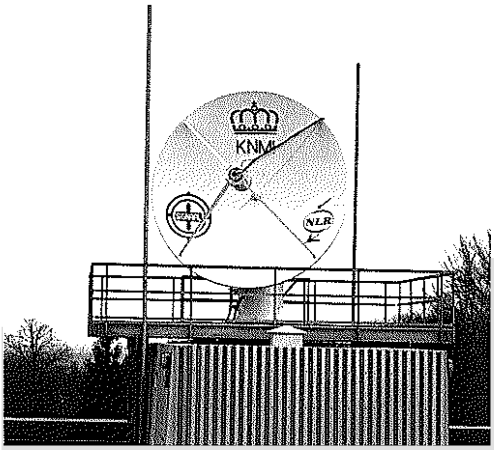


The IRAS Satellite Operations Control Room, Chilton, UK





NLR-personnel carrying out Satellite Operations of IRAS at Chilton, UK



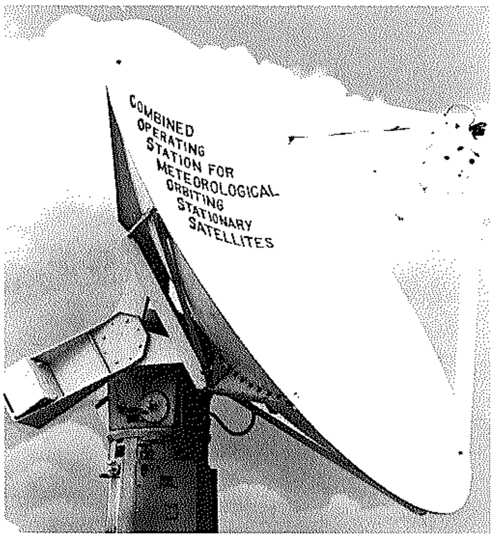
The KNMI Ground Station KOSMOSS

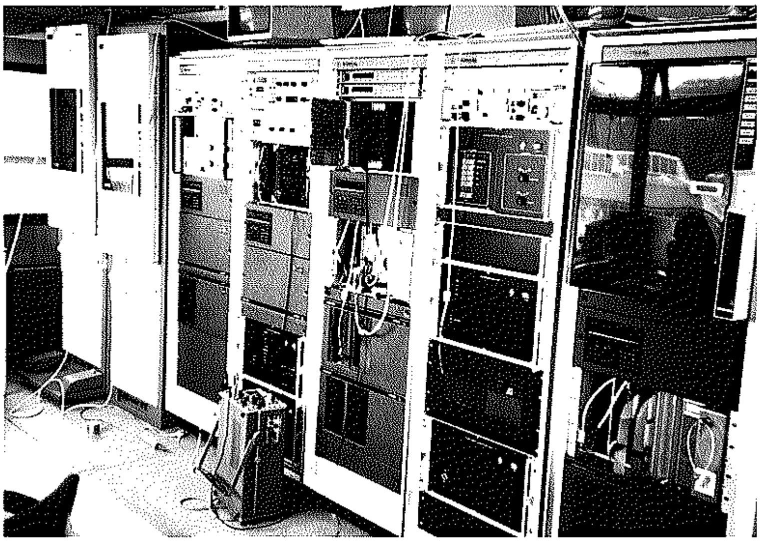
The acronym **KOSMOSS** stands for KNMI (Royal Netherlands Meteorological Institute) Ontvangst Station voor Meteorologische Omloop- en Stationaire Satellieten, a receiving station for meteorological satellites. Signaal, then a Division of the Philips Company, was selectec by the Ministry of Traffic and Public Works to design and manufacture a satellite receiving station for meteorological purposes. NLR was responsible for the data handling, the automatic control and the associated subsystems. The experience gained at NLR in handling aircraft and satellite remote sensing data and the experience with the astronomical satellites ANS and IRAS formed an excellent basis for the contribution to the development of this weather satellite ground station.

The Antenna of the KNMI Weather Satellite Receiving Station, KOSMOSS

The Indonesian Weather Satellite Station COSMOSS

(Combined Operating Station for Meteorological Operating Stationary Satellites). This Ground Station, located near Jakarta, Java, was again developed by Signaal and NLR, whereby NLR was responsible for the data handling and data reduction system. It was particularly geared towards the Indonesian requirements suitable for handling of data from the American NOAA low orbit satellite and the Japanese Geostationary Meteorological Satellite, (GMS). This station began operation in 1987. Apart from the then common information about the weather development, this station was also to be used for geophysical phenomenon such as the observations in connection with volcanic eruptions and also the measurement of the water temperature of the oceans.





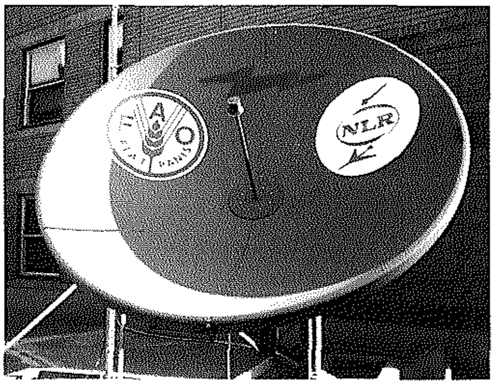
The Antenna of the Indonesian Weathei Satellite Receiving Station. COSMOSS

Ground Station equipment of COSMOSS

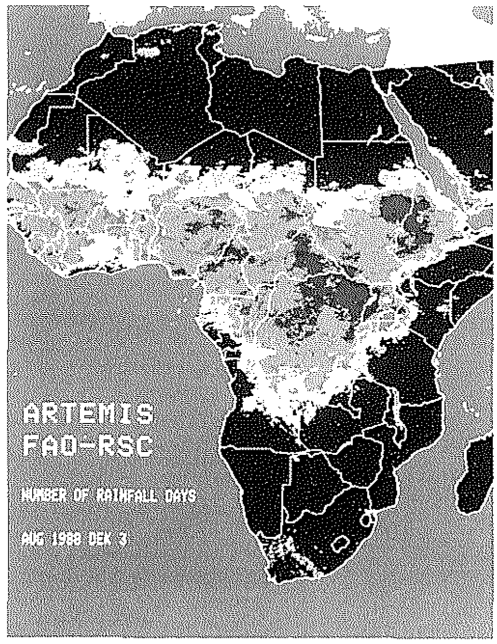
Mr. Bleekrode of NLR amidst students of the introductory course for COSMOSS

The ARTEMIS[1] Ground Station

In 1985 NLR reached an agreement with the Food and Agriculture Organization (the FAO) of the United Nations to develop a ground station for receiving and processing remote sensing data of Northern Africa, in particular the Sahel area. The project was a cooperative effort between the FAO, the NASA Goddard Space Flight Center and universities in the UK and The Netherlands, whereby the Netherlands Government Department of Development Cooperation assisted in financing the project.
One of the objectives of this project was to monitor the soil conditions (moisture content), the vegetation and the temperature development over a large area and to predict the probability of insect (locust) plagues. Systems like this offer a real possibility to apply aerospace technology in tackling large-scale world problems. The Figures below give an impression of the system and the type of gross information.



The Antenna of the Africa Real Time Environment Monitoring using Imaging Satellites Ground Station, ARTEMIS, of the FAO, Rome



A photograph of Africa with 'gross' information of Agricultural Data

Although the NLR contributions to all the above satellite information systems was vested in the Space Division, the involvement of the Informatics Division was extensive. This was a fertile arrangement since often similar implementation problems were encountered after having defined the requirements and the preliminary design of the system.

Flight Test and Monitoring Systems

While during the early days flight testing brought about the development of specific measuring techniques and the development of specific instrumentation, during the last 25 years the emphasis was on the design, development, construction and operation of complete flight test systems. The following two examples illustrate this.

Flight Test System

A major effort of the Flight Division was the development of the system for the measurement of flight parameters, the registration and the data handling during the 1980's. In close cooperation

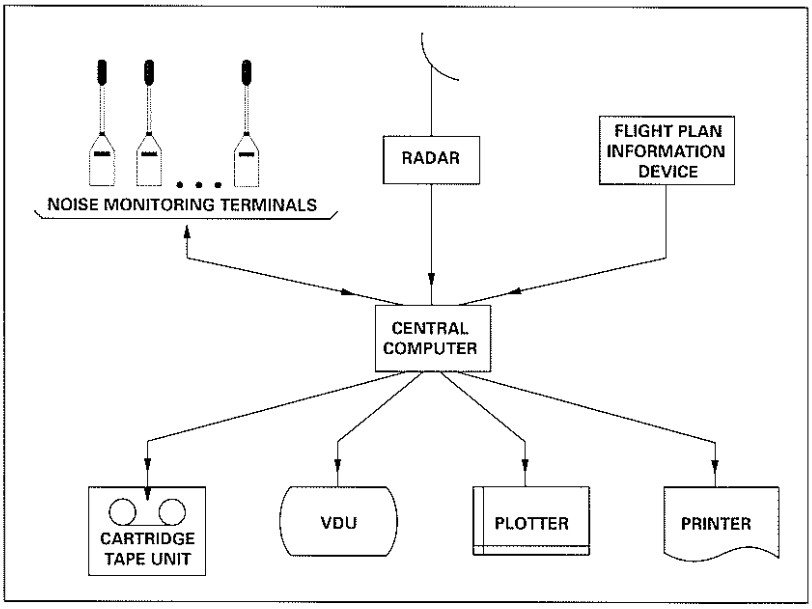
[1]ARTEMIS stands for Africa Real Time Environment Monitoring using Imaging Satellites. The proliferation of acronyms to designate systems and activities is often annoying to those who are not part of the often limited group directly associated with the system. In this case the name is not inappropriate. Artemis, in classical mythology a Greek goddess identified with the Roman Diana, was a deity of the woods and a special goddess of women and childbirth. Her celebrated temple is located in Ephesus, Turkey.

with the Fokker Aircraft Company a system was developed with the ultimate goal to flight test the Fokker 50 and the Fokker 100. A clear division of tasks between the two organizations was agreed. Many of the elements developed at NLR were tested with the NLR laboratory aircraft, the Queen Air and the Metro II. Some of these developments were applied to other projects in which NLR participated, (see Chapter 6).

Flight Track and Aircraft Noise Monitoring System (FANOMOS)

An example of a system of a much smaller scale than the above mentioned systems is the Flight Track and Noise Monitoring System developed by the Flight Division for Schiphol Airport, at the request of the RLD, the Netherlands Department of Civil Aviation. It is a system to monitor the flight path of aircraft during take-off and the first part of the flight in the vicinity of Schiphol Airport.

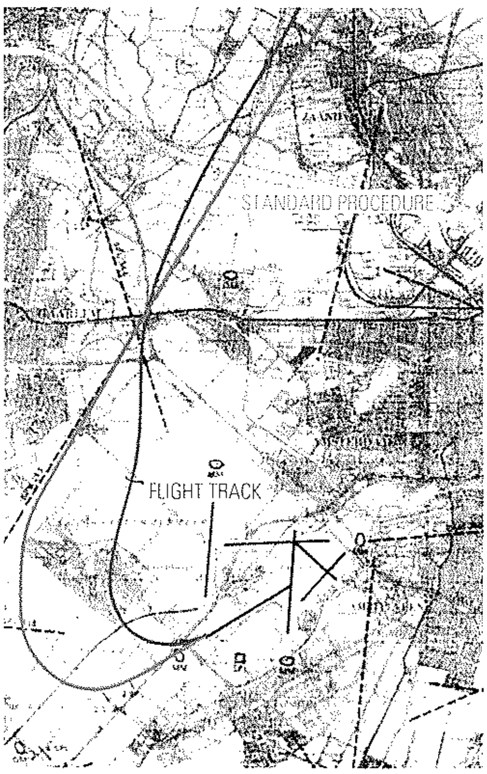
Schematic of the FANOMOS Flight Track and Aircraft Noise Monitoring System

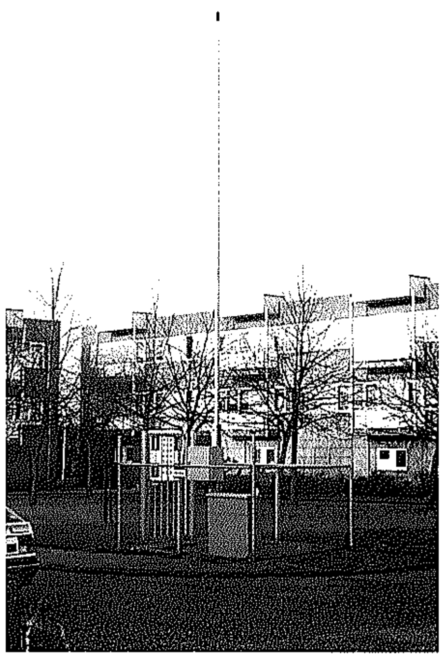


With this system the Airport Authorities are able to determine the deviation of the actual flight path from the prescribed path, dictated by environmental requirements. It gives the Airport Authorities the possibility to warn or penalize the offenders. The system was combined with noise monitoring stations located around the airport and thus a true environmental control station was developed.

Subsequent to the application at Schiphol Airport several European Airport Authorities ordered their specific version of this system and applied it successfully, i.a. the airports of Maastricht, Oslo, Zürich and Manchester.

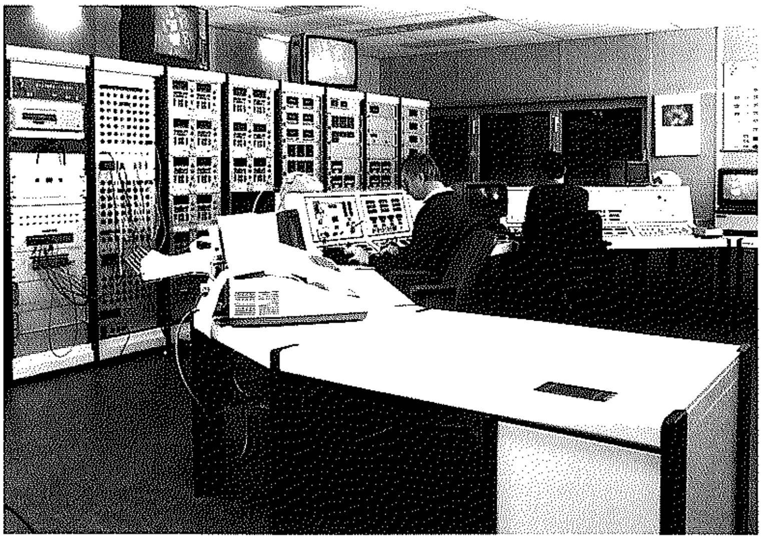
The Flight Track and Aircraft Noise Monitoring System - FANOMOS - installed around and at Schiphol Airport





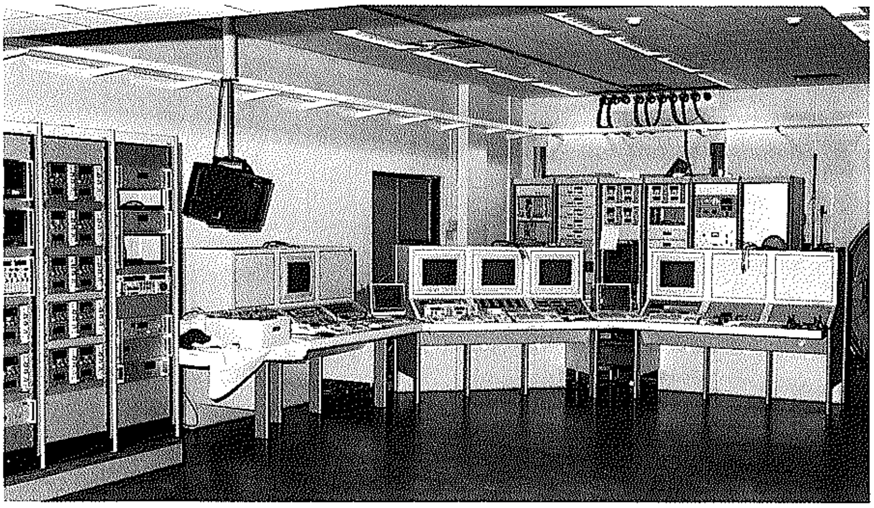
Wind Tunnel Data Recording and Data Handling Systems

From the beginning of wind tunnel operations at NLR most of the wind tunnel data handling systems, including the wind tunnel control systems, were developed in-house, as has been the case also in other aeronautical laboratories. In fact there is usually a constant development activity to meet the demands for special testing. Occasionally this capacity was applied to provide other institutes with a wind tunnel data handling system.
In most cases the actual manufacturing was contracted to the industry.



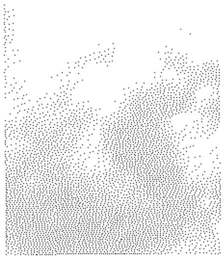
The Control Desk and Data Handling System of the Low Speed Wind Tunnel LST at NLR-NOP

The renewed Control Desk and Data Handling System of the High Speed Wind Tunnel HST at NLR-Amsterdam



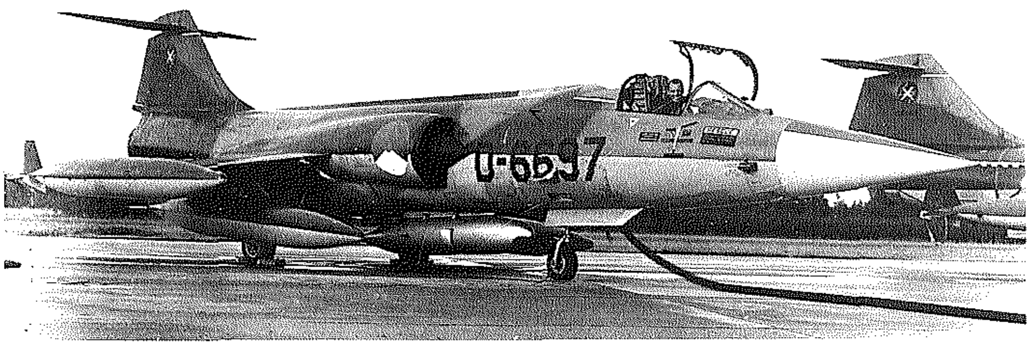
17. Remote Sensing

The remote sensing activities are closely related to the development of information systems as described in the previous Chapter. Based on the NLR capabilities to carry out accurate flight tests, the development and integration of instrumentation systems and the handling and reduction of large quantities of data, remote sensing became an activity in its own right. It finally resulted in a separate Department in the Space Division, since the major remote sensing systems were space related.

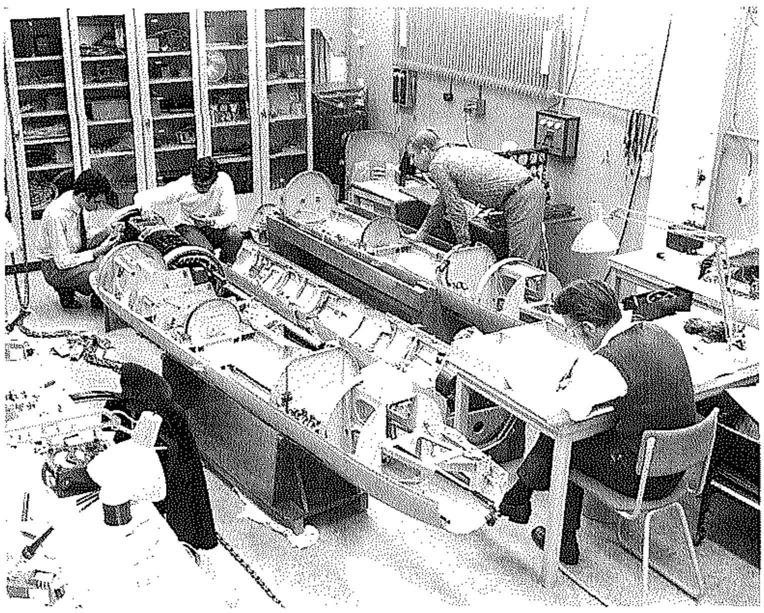


In the 1960's an infrared reconnaissance system was developed for the Royal Netherlands Air Force. An infrared line scanner (8-14 micrometer wave length) was installed in a 'pod' mounted under the reconnaissance/fighter aircraft. In The Netherlands Lockheed F-104 Starfighters were used for this purpose. The pod, developed by Fokker and NLR, contained equipment developed by Delft Instruments (formerly known as 'Oude Delft'). The task of NLR was to assemble the system, to test it for airworthiness and to carry out flight tests with the laboratory aircraft. This infrared reconnaissance system, called Orpheus, was used by the Air Forces of The Netherlands and Italy.

An Infrared Reconnaissance Pod mounted under an F-104 Starfighter of the RNLAF



Installation of Sensors and Recording Equipment in a Pod to be mounted under an aircraft for Remote Sensing flights



This system was later used for civil applications. A governmental working group for the application of remote sensing, called NIWARS, was formed. During the period of 1971-1977 this working group sponsored a large number of experiments, involving many groups who had a potential interest in the application of data obtained by remote sensing.
The equipment was mounted in a pod under the laboratory aircraft.

Remote sensing activities can be divided into four areas:

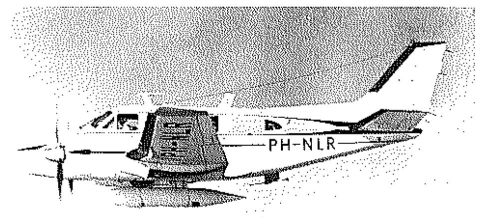
(a) the development of the instrumentation;
(b) the operation of the instrumentation platforms (first for aircraft but later also in the context of ESA satellites);
(c) the registration and reduction of the data;
(d) the interpretation and utilization of the data.

NLR contributed to the first subject (a) through assisting in the development of the instrumentation, to adapt it to safe and reliable flight operations and to package the instrumentation in the pods mounted under the Queen Air and the Metro II laboratory aircraft.

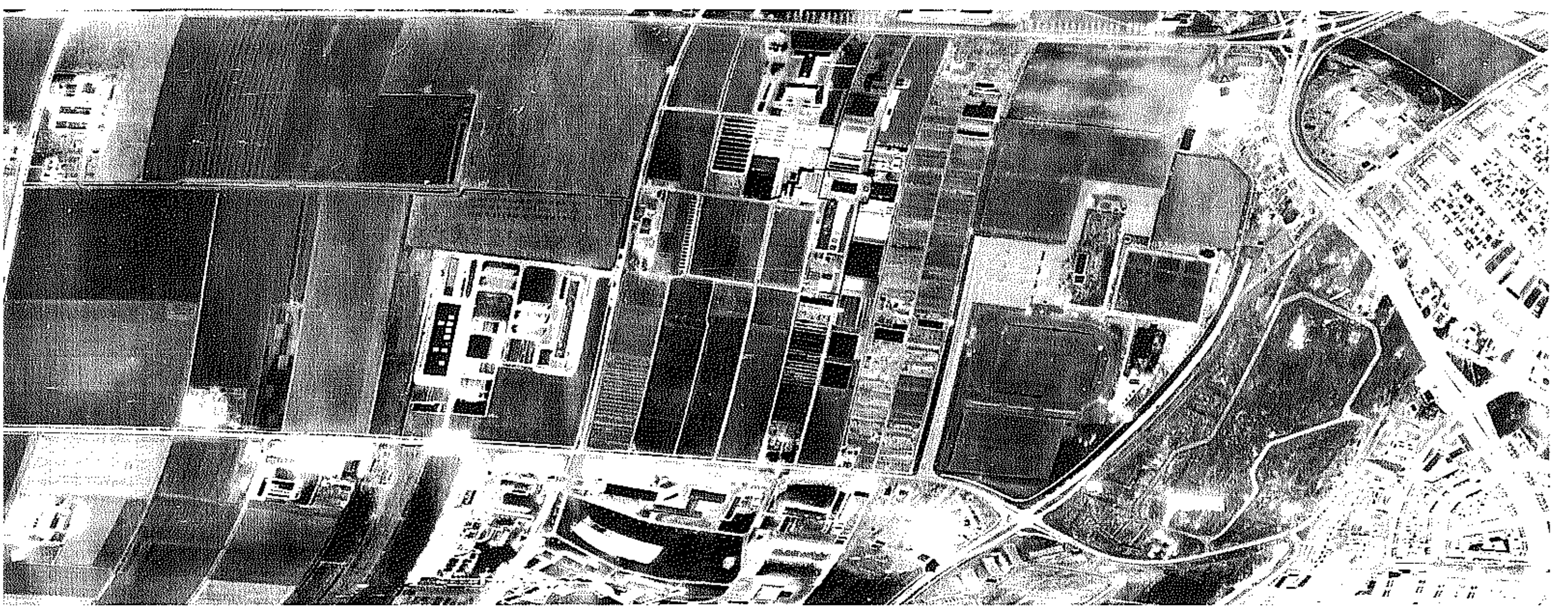
The second item (b) is concerned with the execution of flight tests. This often includes very accurate navigation and recording of the aircraft position and that was an area in which NLR could contribute.
Many flights with the laboratory aircraft were carried out for a variety of applications such as to observe the discharge of cooling water, to locate pollution at rivers and at the North Sea, to locate features under the earth surface which result in small temperature differences at the surface (ancient foundations, seepage through dikes), etc.

The participation of NLR in the registration and reduction of data (c) led to the development of a Remote Sensing Data reduction and data handling station (RESEDA). This station became a national center for handling remote sensing data for a wide variety of purposes, including land use

The Orpheus Pod mounted on the Queen Air Laboratory Aircraft

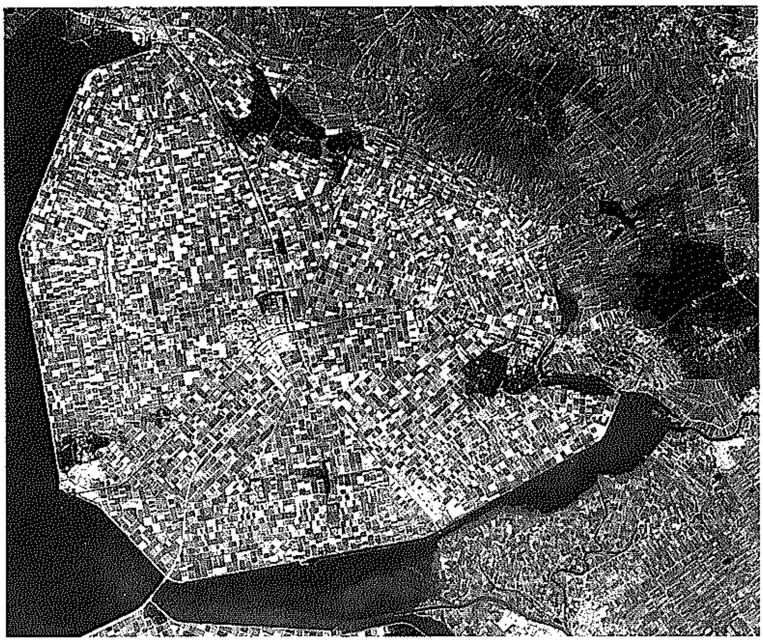


An early Infrared photograph (1973) of an agricultural test area, made in cooperation with the Agricultural University Wageningen, using the pod-mounted equipment on the Queen Air Laboratory Aircraft



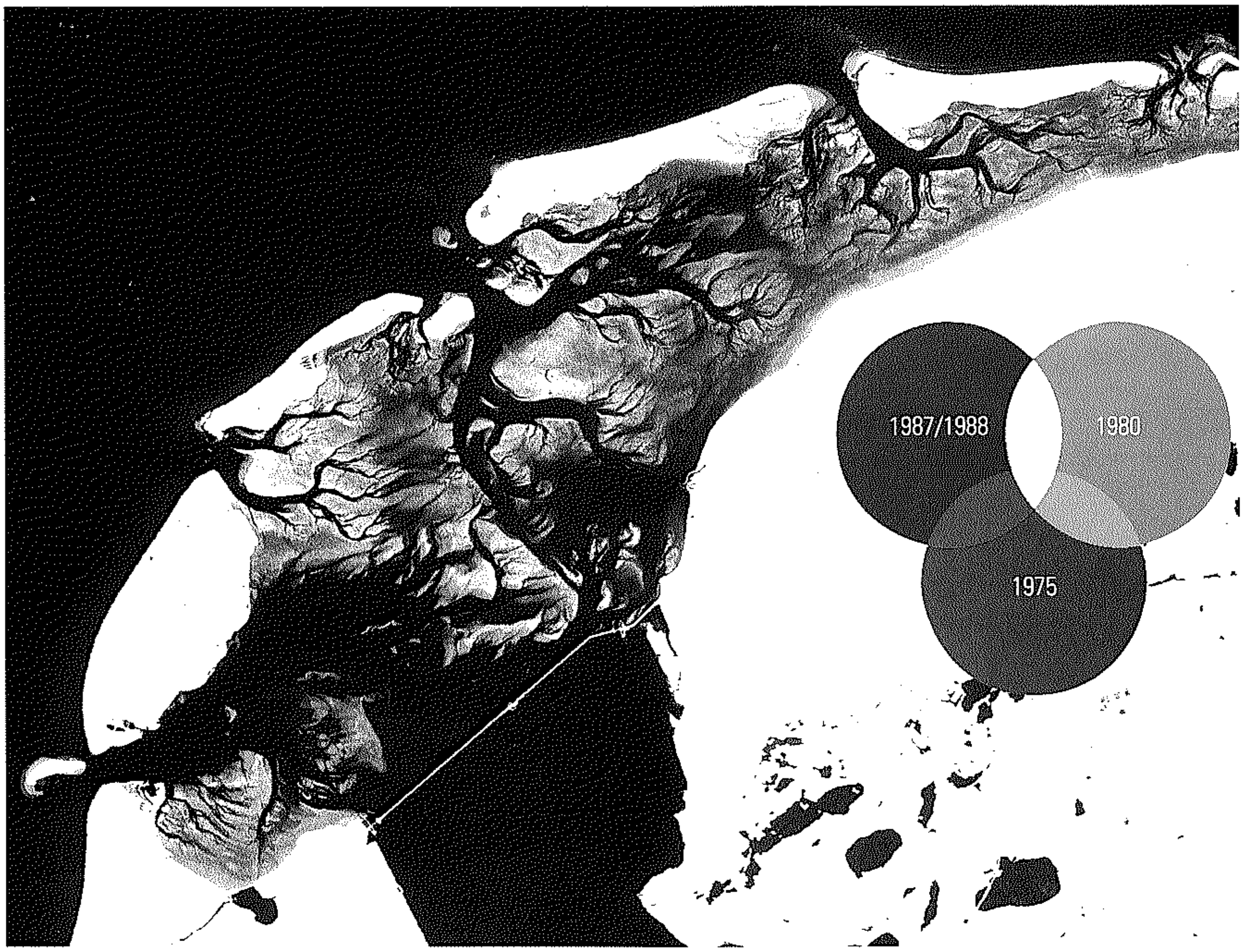
management, hydrology, cartography, etc. The station started its activities at the Flight Division in Amsterdam but was later transferred to the Space Division in the NOP.

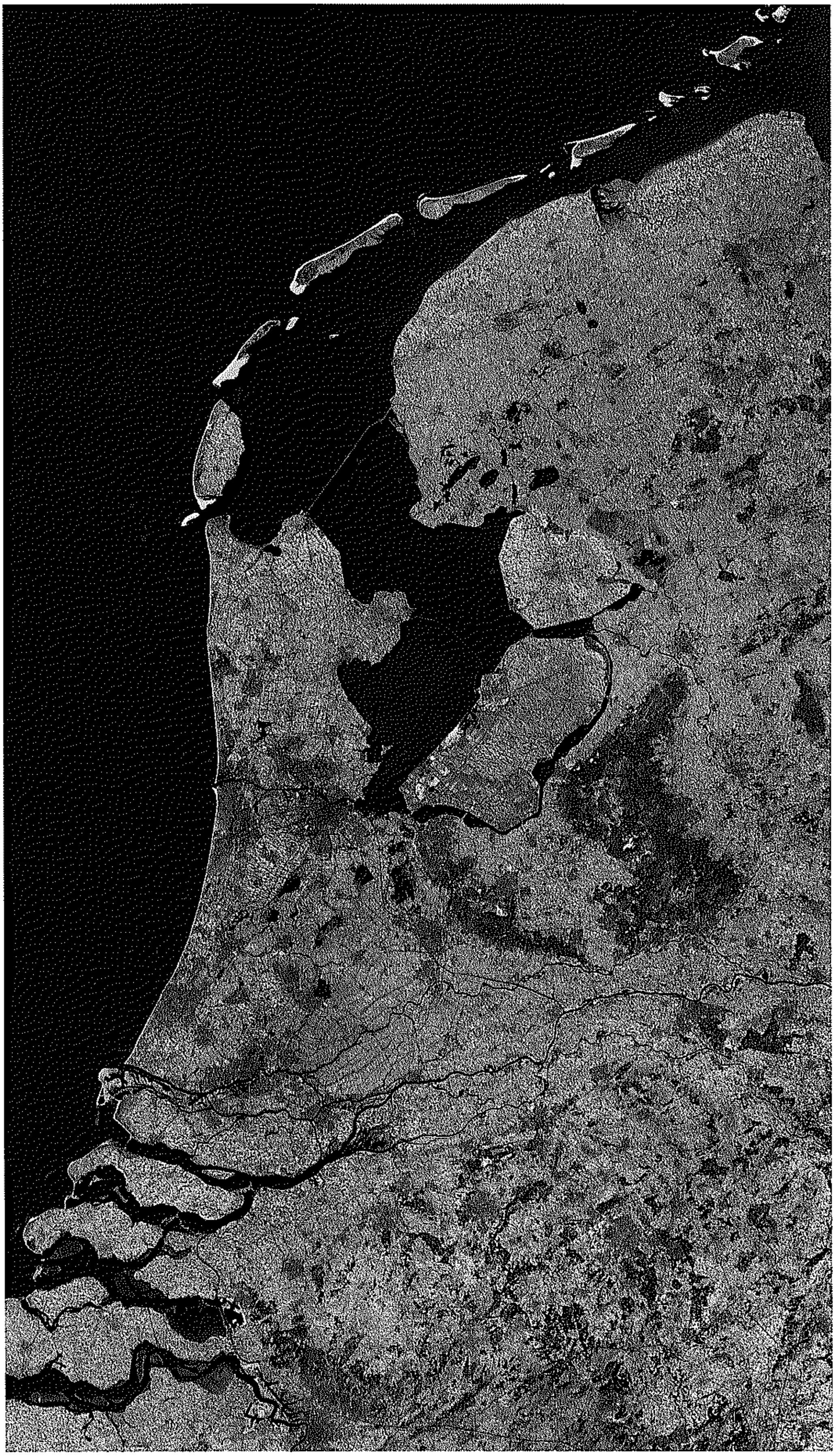
Through this activity NLR also became the logical place to deal with the satellite remote sensing data as they became available from first the NASA/NOAA satellites and later on a regular, commercial, basis from the French SPOT satellites. NLR became an agency for the utilization of the products of SPOT IMAGE, the French company charged with the sale of remote sensing data obtained with the SPOT satellite. The actual commercialization of remote sensing pictures was carried out by companies producing geographical maps and pictures. The task of NLR became to handle the digital information produced by the satellites.



A photograph of the Noordoostpolder, derived from data obtained with the SPOT Satellite, 1986

A composite photograph of the Frisian Islands and the Wadden Sea, taken by the Landsat Satellite over a period of 13 years (1975-1988)



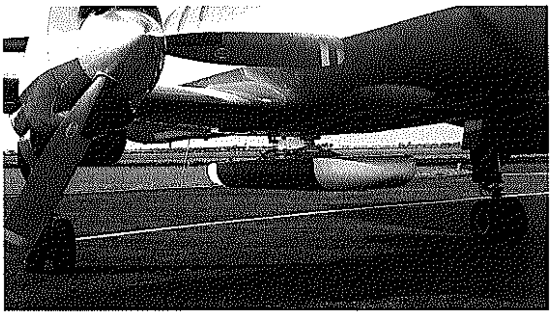


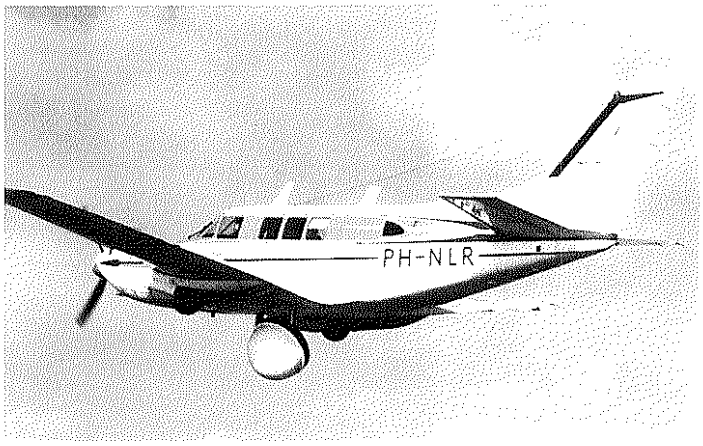
A photograph of The Netherlands taken by the Landsat Satellite, 1989

This became a major activity and NLR made contacts with a different part of the scientific community. The interpretation and utilization of the remote sensing data (d) is not a task of NLR but through the handling of large amounts of remote sensing data it is not surprising that a certain expertise was built up.

A Side-Looking Airborne Radar (SLAR) installed under the Queen Air Laboratory Aircraft

After the experiments with remote sensing equipment in the visible and infrared regime had met with some success, similar tests were carried out to investigate the applicability of RADAR for remote sensing purposes. A Side-Looking Radar System (SLAR) was mounted under the laboratory aircraft. NLR's role was again to integrate the instrumentation, to carry out flight tests, to register and carry out the data reduction and presentation.

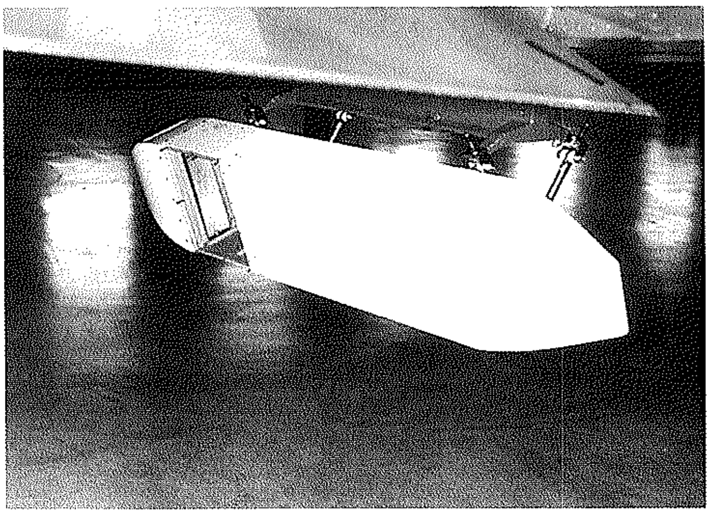




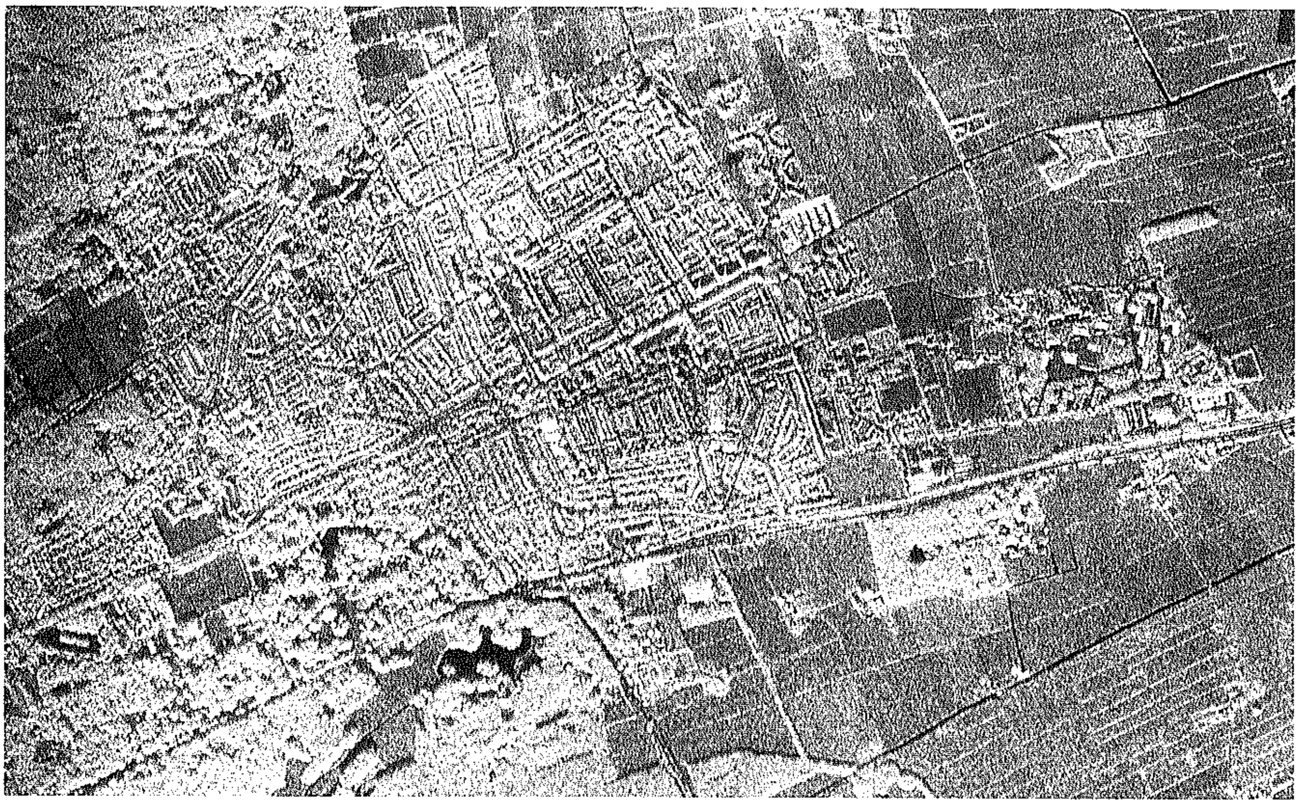
A Scatterometer mounted under the Queen Air Laboratory Aircraft

After the initial experience with the infrared equipment (Orpheus), inherited from the Royal Netherlands Air Force, and the radar experiments with the SLAR, obtained from the UK, several more advanced instruments were developed by the Technical University Delft and TNO. In the framework of the national remote sensing program, funded by the government, an advanced airborne phased array radar system for remote sensing purposes, PHARS (Phased Array Synthetic Aperture Radar), was developed. The Technical University Delft developed a multi-band wave scatterometer. Because of its size, NLR had to develop a complicated retractable mechanism to suspend the sensor underneath the Beechcraft Queen Air laboratory aircraft.

The Phased Array Synthetic Aperture Radar (PHARS) mounted under the Metro II Laboratory Aircraft

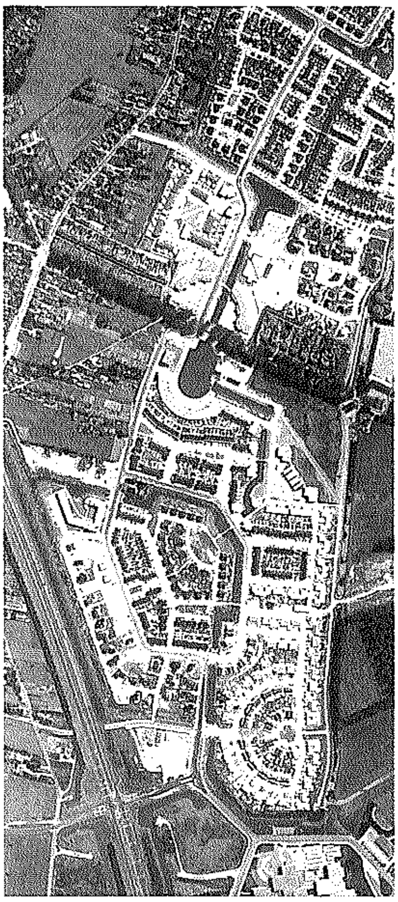


During many years a phased array synthetic aperture radar was mounted under the Swearingen Metro II laboratory aircraft. Nominal resolutions of about 5 meters were achieved. Several of the flight tests carried out by NLR were concerned with providing basic ('calibration') data for the European Remote Sensing Satellite, the ERS-1.



A Radar picture of Wassenaar derived from PHARS-data, 1990

In the mid-1980's TNO built a CCD (Charged Coupled Device) Airborne Experimental Scanner for Applications in Remote Sensing with eight bands in the wavelength range of 400 to 1050 nanometer.



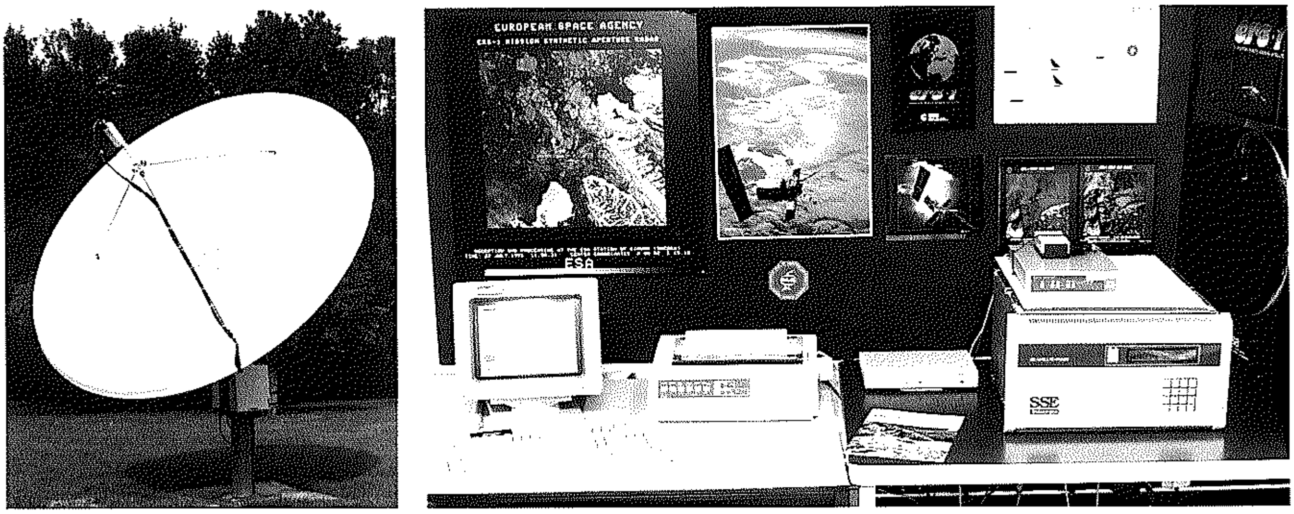
A photograph of a Dutch village taken by the Optical Sensor System CAESAR on board of the Metro II Laboratory Aircraft, 1991

With the above mentioned instruments many flights were carried out in the framework of national and international programs in such diverse fields as:

- observation of wave patterns at sea;
- detection of pollution at sea;
- detection of floating ice masses in the Baltic Sea;
- monitoring agricultural growth patterns;
- monitoring of wooded areas;
- detection of the degree of moisture in the soil;
- surveys of sites of archeological interest.

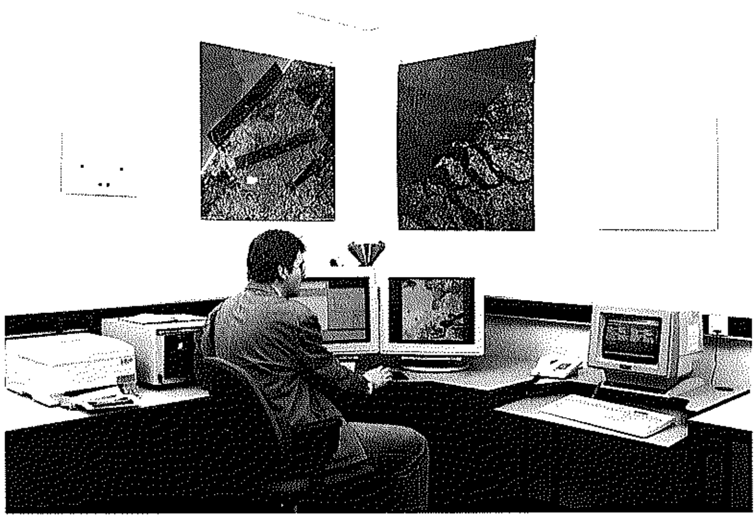
The number of applications seems endless.

In July 1991 the ERS-1 (European Remote Sensing satellite) was launched and in September 1991 a receiving station for Synthetic Aperture Radar (SAR) data was installed at the laboratory in the NOP.
This station is part of a network of stations through which fast - almost real time - access can be obtained to SAR data via the main receiving stations of ESA at Fucino (Italy) and Kiruna (in the North of Sweden).



The ERS-1 Satellite Receiving Station at NLR-NOP

Image of Zeeland composed from ERS-1 satellite data, 1992



The second generation Remote Sensing Data handling station (RESEDA II) at NLR-NOP

18. The German-Dutch Wind Tunnel - DNW

The German-Dutch Wind Tunnel, DNW, was the result of two project proposals: the Dutch NLR Low Speed Wind Tunnel LST 8x6 and the German DLR (then called DFVLR) tunnel called 'Grosser Unterschall-Kanal, GUK' (see also Chapter 27, where the genesis of the DNW is shown in relation with the DRG Aerotest Group and the AGARD LaWs Group).

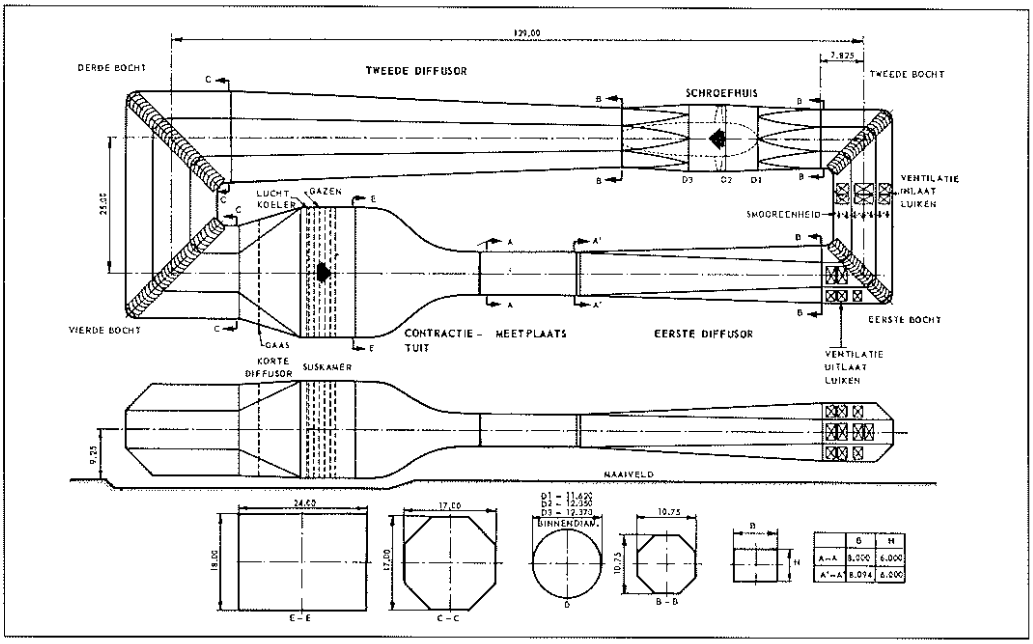
How the Low Speed Wind Tunnel LST 8 x 6 M² was developed

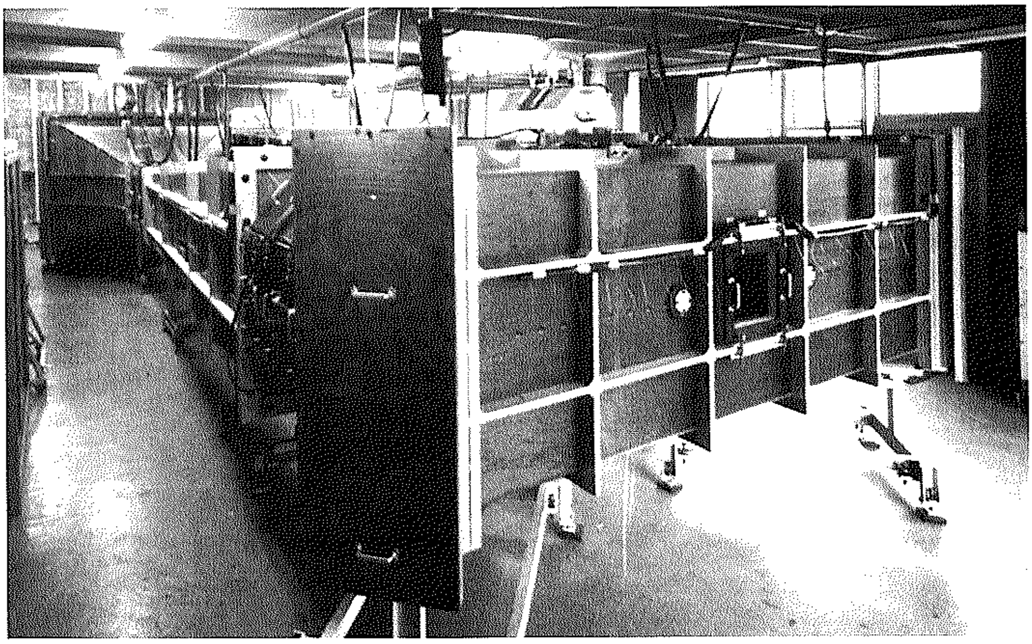
The two low speed wind tunnels at NLR, with test sections of 3x2 M² and 1.5x1.5 M² and maximum speeds of respectively 70 and 35 m/sec were designed in the period 1935-1938, and some 30 years later the need for more modern facilities became urgent. There were new technical requirements that could not be met by the older wind tunnels.

World-wide predictions indicated that there was a necessity to develop aircraft with short take-off and landing distances. This idea was inspired by the desire to take-off and land in the middle of cities and by the need to increase the capacity of existing airports and the requirement to reduce the noise around airports. Fuel costs did not yet dominate the operational cost of aircraft and it was expected that the additional power needed for shorter take-off lengths - and thus greater mass and fuel consumption of the aircraft - would be acceptable.

In 1963 studies were started at NLR on the elements of a low speed wind tunnel which would allow the testing of models for Vertical or Short Take-Off and Landing, V/STOL aircraft.
A special aspect of testing V/STOL aircraft models of a fair size in relation to the test section dimensions was the problem of how to cope with the downwash effect which is much larger than with conventional aircraft models of the same size. Much attention was paid to the contraction

The Airline design of the LST 8x6, 1971



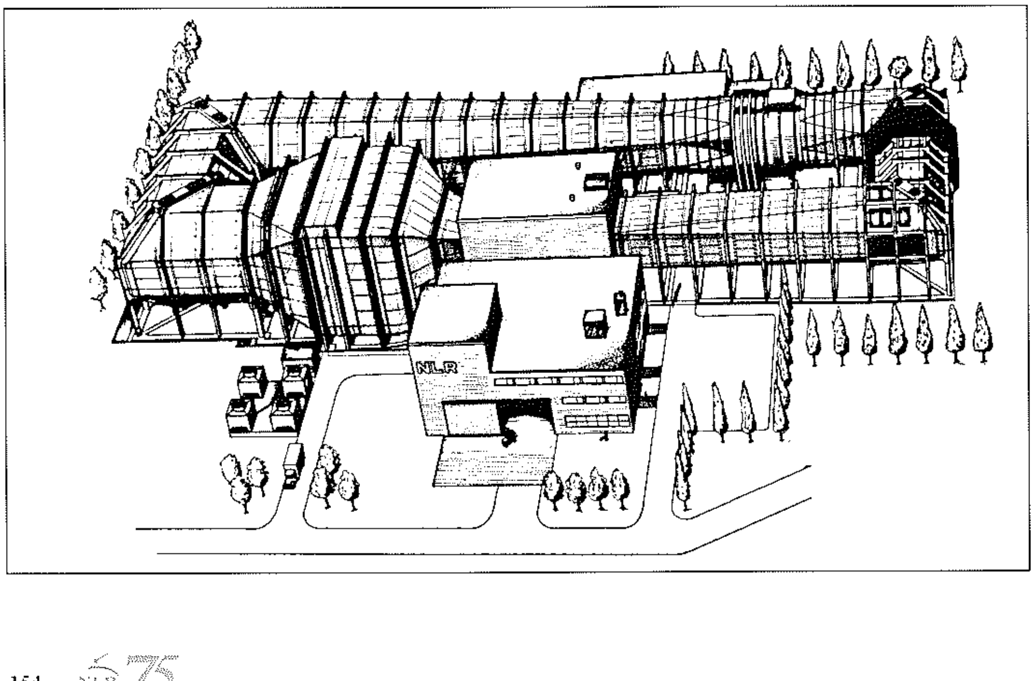


The wooden Pilot Tunnel of the LST 8x6

section before the test section and the diffusor after the test section which had to designed such that highly non-uniform flows emanating from the test section would not cause flow separation in the diffusor and introduce flow instabilities in the wind tunnel circuit.

The project studies were initiated in 1963 but only limited manpower and funds were available during the first few years. In 1968 the design studies had progressed so far that external engineering consultant firms and an architect could be engaged for the preliminary design and cost estimates. One of the studies was concerned with a comparison of using steel or concrete for the tunnel circuit.

Over a number of years various elements of the wind tunnel were studied in great detail and finally in 1971 a 1:10 scale model of the tunnel - the Pilot Tunnel with a test section of 0.8×0.6 M^2 - was built in the laboratory in the NOP. This high quality wooden pilot tunnel, built in-house by the Modelshop carpenters in a very short time, proved to be of great value. It was used in the first place to check the aerodynamic design of the LST 8x6 and to make final corrections to the design of the circuit and the propeller. Later it was used intensively when an aero-acoustic test section was incorporated in the plan and when various decisions on modifications resulting from the merger of the LST 8x6 with the GUK project had to be taken in a very short time. Some of the change proposals were implemented in the Pilot Tunnel practically overnight.
The result of all this was an aerodynamic circuit design that was nearly perfect and, as far as can be ascertained, still is the best design of a circuit of this type of low speed tunnel. It is basically the same as that of the DNW, it was used for the Indonesian Low Speed Tunnel - the ILST - at Serpong, near Jakarta and it was applied to the NLR 3×2.25 M^2 LST built later at the NOP when the two



Artist view of the LST 8x6

older tunnels at Amsterdam were closed[1]. This circuit design was used as a basis for all foreign designs for low speed wind tunnels advanced since that time.

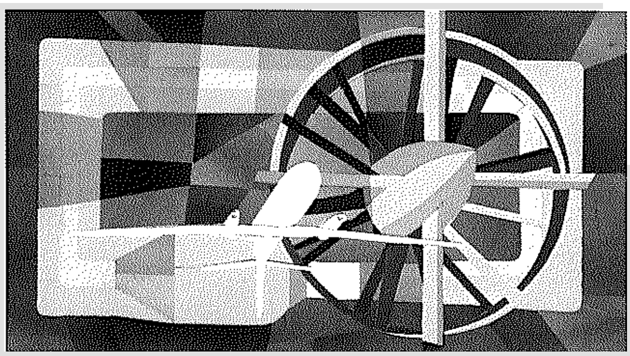
The design was a collective effort, including the Canadian firm DSMA, but it can basically be attributed to the NLR team in which Spee, Mannée, Van Ditshuizen and Runge played a major role. Dr. Ir. B.M. Spee had become the project leader of the LST 8 x 6 at the end of 1969 and he and Ir. J. Mannée jointly headed the Incompressible Aerodynamics Department from 1 April 1970 where most of the design work was carried out. In 1971 there was a project plan which was first submitted to the Scientific Committee. The Committee fully appreciated the technical quality of the proposal and the importance of this type of tunnel for aircraft development in the coming decades and it whole-heartily approved the project. Subsequently the Board of NLR decided at its meeting of 8 June 1971 to submit the LST 8 x 6 proposal to the Government.

Then there followed a period in which several discussions were held with Ministers and their senior civil servants. The estimated cost of the project at that time was about DGL. 45 million and it was argued by NLR that it would be equally cost effective as the large transonic wind tunnel, the HST. This meant that the costs of operating the facility and the annual additional investments (refurbishment and improvements) would be covered by the annual revenues. However the initial investment was to be financed by a government subsidy. It was also the period when the international Aerotest exercise was carried out, (see Chapter 27). The final Aerotest Report (published in January 1973) also included a market analysis for wind tunnels in the various categories. NLR had contributed to this analysis and concluded that a large wind tunnel such as the LST 8 x 6 would have an excellent chance to be fully occupied in the predicted market.

Finally the Government budget for 1975, submitted to Parliament in September 1974, contained an amount of DGL. 1 million extra funding for the LST 8 x 6 to start external engineering design contracting. So far all the activities had been funded from the annual general subsidies for in-house research and capital investments but these were too small to fund a major installation such as the LST 8 x 6. Therefore the initial sum of DGL. 1 million as an extra subsidy, an ear-marked line item in the Government budget for this project, was a major milestone. It was reasonable to assume that the project would be funded by the government during the following years. At that stage the encounter with DFVLR took place, (see Chapter 27). The project had now gained momentum.

During the preceding period the Chairman of the Board Prof. Gerlach and the General Director Ir. Marx had met with various Ministers to convince them of the merits of the LST 8 x 6 project. The Minister of Finance had said: -*"If you are convinced that this is such an economically viable project, why don't you borrow the money?"*. To borrow an amount of money of the same order as the then annual income was difficult to accept for a financially vulnerable institute such as NLR. The deliberations finally ended in a proposal of the government providing half of the funds for the LST 8 x 6 and NLR borrowing the other half. The loan was guaranteed by the government and that was great for

[1]The two low speed tunnels at Amsterdam, constructed during the period 1939-1940, were vertically placed and the tunnel circuits were made out of concrete as integral parts of the building. Around 1980, when the design studies for the LST 3 x 2.25 in the NOP were on their way (the tunnel was completed at the end of 1983) the Directors of NLR felt that the old integral structure could not serve any useful purpose and they were ready to demolish that part of the building. There was however an urgent need for meeting rooms and also the space used for the canteen was planned to be used as office space in Amsterdam. The personnel faced with the constant demand for meeting rooms and canteen room came up with a plan to convert the wind tunnel structures into a restaurant, meeting rooms and storage space. In particular Ir. W.F. Wessels and Mr. G. Lipsius pressed for such a plan and they convinced the Directors that this would be an interesting [illegible] that it would not cost to much [illegible] kept the project management in their own [illegible] have [illegible] to be the settling chamber of the LST 3 x2. Meeting rooms were constructed on top of the wind tunnel circuits and there was even room for a small laboratory museum.



Stained glass window in the former Sett[illegible] f the LST [illegible] NLR-Am[illegible] the money lenders. NLR was running the risk that in the event NLR had problems in paying the annual installments, deductions from the annual subsidies for research and capital investments could be made in financially difficult times for the government. Convinced of the economic viability of the project, NLR did accept this condition, albeit reluctantly.

The transition LST 8x6 + GUK = DNW

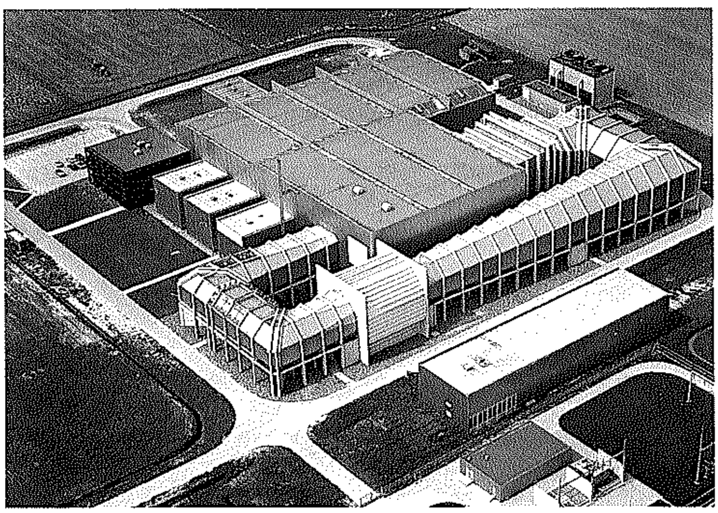
When in October 1974 the proposal of DFVLR to explore the possibility to merge the German and the Dutch low speed wind tunnels was considered, the reaction on the NLR side was positive. The first subject to deal with was to obtain government approval since on both sides government funds were involved. There was an exchange of letters between Mr. T.E. Westerterp, the Minister of Transport and Public Works of The Netherlands, and Mr. H. Matthöfer, Minister of Research and Technology of Germany. The first formal meeting between government representatives took place in May 1975, when it was clear that an effective joint facility was feasible.

In October 1974 it was already clear that the Netherlands government would favor a cooperation with Germany and NLR and DFVLR began to study each other's plans in the Fall of 1974. A joint Technical Working Group was formed to study the LST 8x6 and the GUK proposals and the projected requirements from the German and the Netherlands aircraft industries and of course the prospects of attracting wind tunnel test contracts from other countries. A second Working Group was formed to deal with the financial and legal details of the cooperation.

On the German side the aircraft industry contributed substantially in the Technical Working Group. On the Netherlands side this was less so, mainly because the aircraft industry had during the post World War II period already reached an understanding with NLR that the construction and operation of wind tunnels was a task (and risk) of NLR. Through the composition of the Board of NLR, in which Fokker was represented by its Technical Director, Fokker felt that its voice was clearly heard. This did not mean that Fokker had a dominating voice in the Board but at least the industry could count on their opinion weighing heavily. In Germany the situation was somewhat more complicated: there were still three major aircraft industries, VFW, MBB and Dornier and due to the stoppage of aeronautical activities after the Second World War, DFVLR had not yet gained such a status that the industry would fully delegate its interest in major aerospace facilities to DFVLR. The Managing Board of DFVLR and the German Ministry of Research and Technology were well aware of this. It took NLR some months to understand fully that situation but after that a solid basis for the technical discussions was established.

During 1975 completely satisfactory solutions were found for all the technical, administrative and organizational problems and as of 1 January 1976 a joint DFVLR/NLR project team started to operate in good faith, assisted by consulting engineering firms, although the official paperwork still had to be finalized.

Aerial view of the German-Dutch Wind Tunnel, DNW



The Foundation DNW

A Foundation under Dutch law - named **'Stichting Duits-Nederlandse Windtunnel/Stiftung Deutsch-Niederländischer Windkanal'** or DNW for short - was founded on 30 June 1976 by DFVLR and NLR. The first pile was driven in the ground on 1 July 1976.

An area of 10 HA of the NLR grounds at the NOP was made available for the DNW. The major principle of the cooperation is **'parity'**, meaning that DFVLR and NLR, the two parent organizations, contribute equally and share the responsibility equally. The DNW operates as an independent Foundation, does its own marketing and carries out aerodynamic investigations on a contract basis. It can request technical support from the parent organizations.

The two parent organizations are the shareholders, and carry the final financial responsibility for the Foundation.
The Board of DNW is composed of two members of DFVLR, two members of NLR and two members each representing the German and Dutch government. The positions of Chairman and Vice-Chairman rotate among German and Dutch Board members of the parent organizations.
The DNW being located in The Netherlands, the Director is of German and the Deputy Director of Dutch origin. During the Construction Phase however the Project Director was Ir. F. Jaarsma of NLR (He had succeeded Dr. Spee who became Deputy Director of NLR on 1 March 1976) and the Deputy Director was Dr.-Ing. M. Seidel of DFVLR.

The Board (and the Directors) of DNW are advised by an Advisory Committee consisting of representatives of the aircraft industry, the aerospace research establishments and the universities of both countries. This Committee advises the Board on future trends in aircraft development with particular emphasis on relevant large investments and acquisition strategies.

The personnel of DNW is detached from the parent organizations as much as is practical. DLR and NLR provide technical and administrative support to DNW. This support makes it possible to extend the capabilities of DNW far beyond what would be possible with its personnel complement of about 50. Examples of technical support are:

- the support of DLR with experts and equipment in the area of rotor/helicopter testing;
- the support of NLR in calibration of turbo powered model jet engines;
- the support of DLR and NLR in model design and manufacture and the support in aero-acoustic testing.

With almost 15 years of operational experience DNW has proved to be an excellent wind tunnel. It has been employed in the development of a variety of projects including European and American aircraft projects, helicopter projects and also automobile and truck testing.

Some Technical Aspects of the DNW

The design and construction of the DNW have been described in [Ref. 76]. A comprehensive review of how the capabilities were developed and how the customers used the wind tunnel is given in the Anniversary Volume Ten Years of Testing at DNW 1980-1990, [Ref. 77]. In this Chapter attention is paid to the unique specifications and how these were fixed in a relatively short time.

For the LST 8x6 project the air speed in the test section and the size of the test section were mainly determined by requirements to simulate the flow over complicated flap systems at the leading edge and the trailing edge of aircraft wings and the possibility of simulating propulsion systems in aircraft models at a practical scale. The achievable Reynolds Number (high enough so that extrapolation to full-scale can be carried out with confidence) and Mach Number (particularly for the flow over flaps) played an important role. The same considerations played a role in the design of the large low speed tunnels which were planned in France, the UK and Germany.
In The Netherlands and in Germany the concept of an 'atmospheric tunnel' was chosen (as opposed to the 'pressurized tunnels' in France and the UK) based on i.a. the ease of operation when carrying out propulsion tests and acoustic tests.

The LST 8x6 design incorporated throttles in the first cross leg after the test section and ventilation hatches before and after the throttles. It was thus possible to exchange the air in the tunnel after it had been contaminated by exhaust gases of engines or by gases used for flow visualization. With the throttles closed during a test, the tunnel is basically an open jet tunnel, suitable for full-scale engine testing. This feature was also incorporated in the DNW.

There were also provisions for an engine exhaust system - an airscoop - for carrying out tests with (full-scale) combustion engines installed.

The Aero-acoustic Aspects

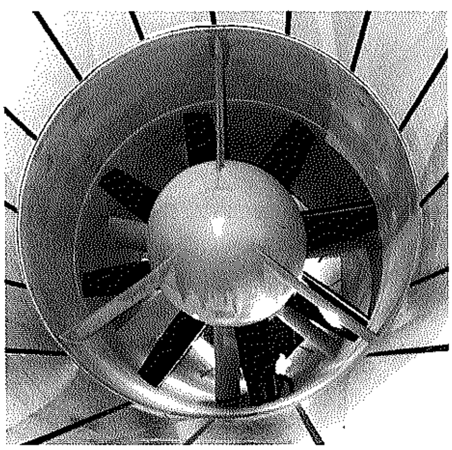
The LST 8x6 concept was mainly based on the expected need of testing models of aircraft of the V/STOL and CTOL (Conventional Take-Off and Landing) types of national and foreign customers. A major aim was to obtain a high flow uniformity in the test section and also a very low level of turbulence. The result was a wind tunnel with a very low aerodynamic background noise level as was shown by tests in the 1:10 scale Pilot Tunnel. Having achieved this and in view of the growing importance of noise reduction of aircraft, studies were made of the requirements for aero-acoustic testing in wind tunnels.

There was of course also the problem of noise of the tunnel itself and its effect on the community, the tunnel being projected in the rural area of the NOP where the background noise, certainly at night, is about as low as one can imagine. But with a tunnel circuit constructed out of concrete slabs, extra insulation around the propeller, the electric motor mounted inside the hub of the fan and a very low internal aerodynamic noise this was not expected to be a problem - and later this proved to be true.

During the time when the Government approval was pending and when the merger with the German GUK project was discussed, several additional measures were considered and experimental studies were carried out. The NLR engineers realized that with such a low background noise level in the tunnel (also a minimum chance of flow separation in the circuit) here was a chance to make the tunnel not only capable of measuring rotor noise, jet engine intake and exhaust noise but also airframe noise, which would become important for large aircraft at some time in the future. On 24 February 1975 one of the NLR Directors discussed the matter with Mr. Hayden of the American acoustic firm Bolt-Beranek-Newman. The result was that Mr. Hayden and his associates studied in detail the various noise sources in the wind tunnel and carried out experiments in the Pilot Tunnel. By May 1975 several measures were incorporated in the design of the tunnel, many of which were considered earlier. These included:

- a design for attached flow over the 8 fan blades and the 7 stator vanes located downstream of the fan operating at a constant pitch angle;
- a 15° sweep of the leading edges of the stator vanes and the nose cone support of the drive system;
- direct drive by a low speed electric motor to avoid gear box noise, low tip speed of the fan (about 150 m/sec at top speed);
- a very smooth interior surface finish;
- acoustic treatment of the corner vanes of the first and fourth corner after the test section;
- an open test section configuration of 8x6 M^2 with a very large hall around it with acoustic absorption wedges on all four walls;
- a specially designed collector after the test section with acoustic treatment to be used in the open jet configuration.

The Fan of the DNW; the electric motor is installed in the hub



In addition to these measures provisions were made for carrying out aero-acoustic testing at this scale, including mounting systems for arrays of microphones.

These features were all incorporated in the final design of the DNW.

Other Special Features

The merger of the GUK and the LST 8x6 design proposals resulted in the addition of inserts in the 8x6 M^2 test section at the vertical walls so that a test section of 6x6 M^2 was obtained. This would increase the maximum speed from 90 m/sec to 130 m/sec. It was an addition which would be particularly suitable for certain flutter tests.

The GUK plan also included a 9.5x9.5 M^2 test section with a maximum speed of 55 m/sec, particularly suitable for testing helicopter configurations.

The availability of the Pilot Tunnel proved to be very effective in 1975 to determine very rapidly if the addition of these two test sections was feasible, using the basic circuit lay-out of the LST 8 x 6. It proved to be possible to design a transition section for this 9.5 x 9.5 test section and still retain a high flow quality in the test section.

Both the GUK and the LST 8 x 6 design proposals incorporated an external six-component balance and a sting support for balances mounted internally in the model. The model support was made such that flare-out maneuvers during the landing stage could be simulated. This meant that the sting support could move the model from the test section top to the test section floor at the appropriate speed.

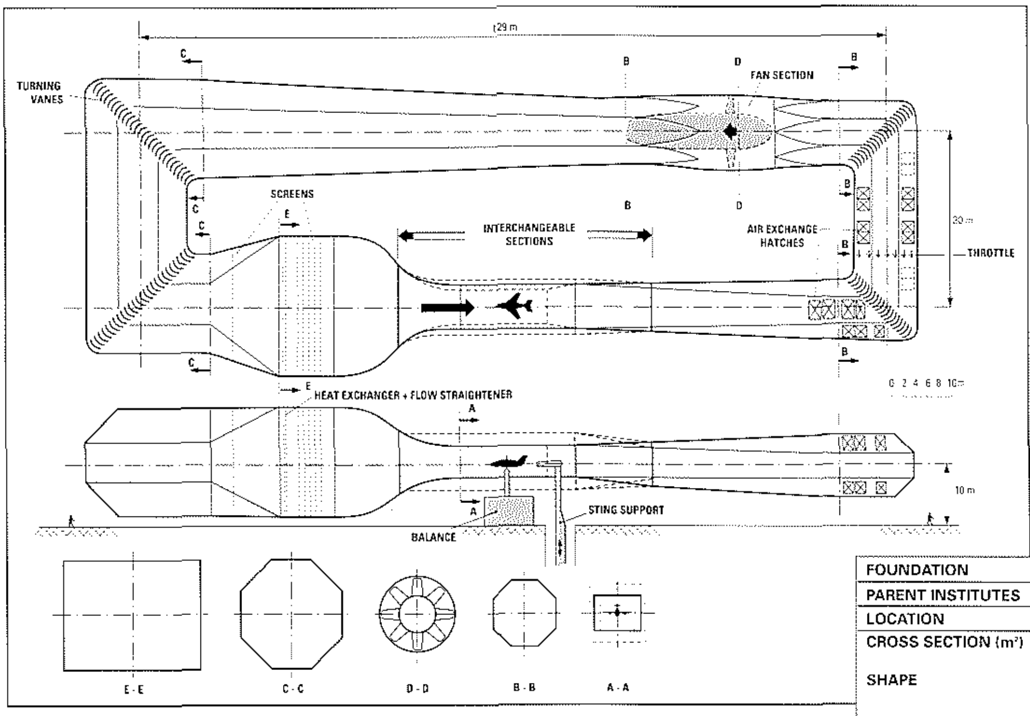
Another feature of both proposals which was incorporated in the DNW was a Moving Belt Ground Plane. In essence it is a rolling floor in the test section to simulate better the flow conditions near the ground. Normally the boundary layer built up along the tunnel walls will influence the flow around the tests vehicle when it is placed close to the tunnel wall. This Moving Belt is useful when simulating the flow around an aircraft (or a truck or car) when it is flying close to the ground.

Apart from the data handling systems, the control systems of the installations, etc. mention should be made of the High Pressure Air System which supplies air from storage vessels with a volume of 50 M^3 at 280 bar. This system is capable of supplying air continuously at 6 kg/sec and up to 35 kg/sec intermittently at 100 bar. The system also supplies the calibration stand for the TPS model engines at NLR (TPS - Turbo Powered Simulators, see Chapter 7).

The DNW as it was built

As related above, the Construction Project Team started on 1 January 1976 and the first pile was driven in the ground on 1 July 1976. On 2 May 1979, less than three years later, the wind tunnel was turned on for the first time. It then took about a year of commissioning and calibration before the tunnel could be declared operational.

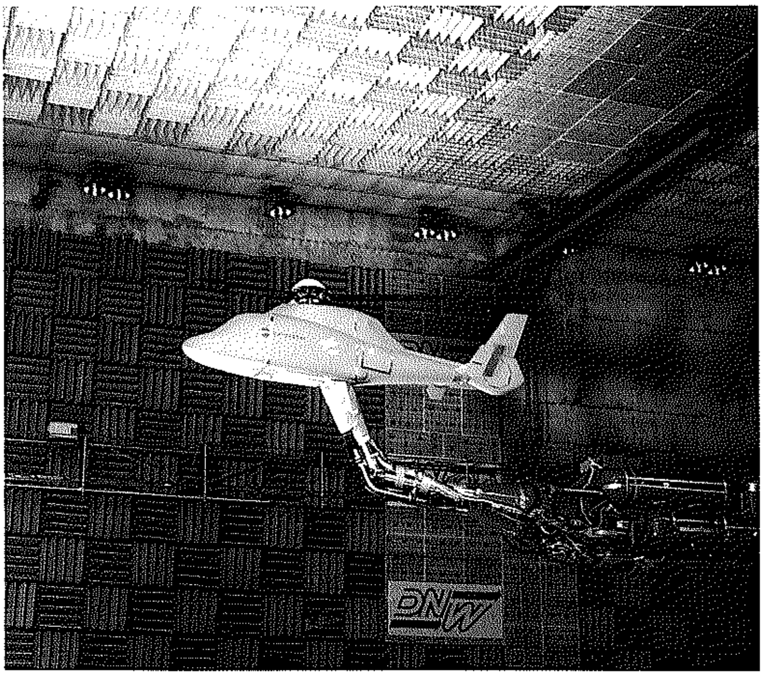
The final result of this cooperation of DFVLR and NLR, the DNW, is shown in the illustrations.



The Airline of the DNW

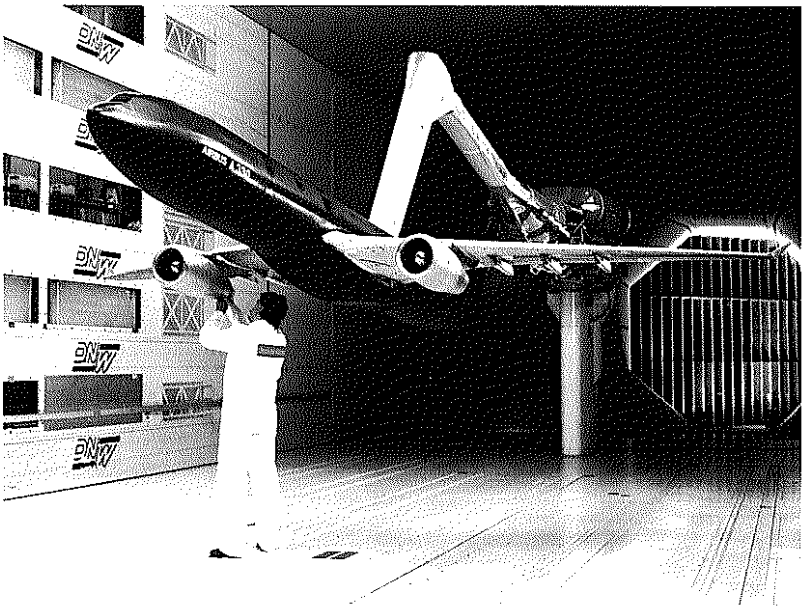
FOUNDATION	DNW		
PARENT INSTITUTES	DLR NLR		
LOCATION	NOORDOOSTPOLDER		
CROSS SECTION (m^2)	9.5x9.5	8x6	6x6
SHAPE			
OPERATION MODE (c=closed; o=open)	c	c + o	c
MAX. VELOCITY (m/s)	62	116 open:85	152
PRESSURE (bar)	1	1	1
MAX. Re.NUMBER ($x10^6$)	3.9	5.1	5.8
YEAR OF OPERATION	1980		

The Main Dimensions of the DNW



Acoustic test of a helicopter (Eurocopter) in the open jet test section of the DNW. Note the acoustic lining of the test hall

A model of the Airbus A 330 - wing span 5.7 M - mounted in the DNW

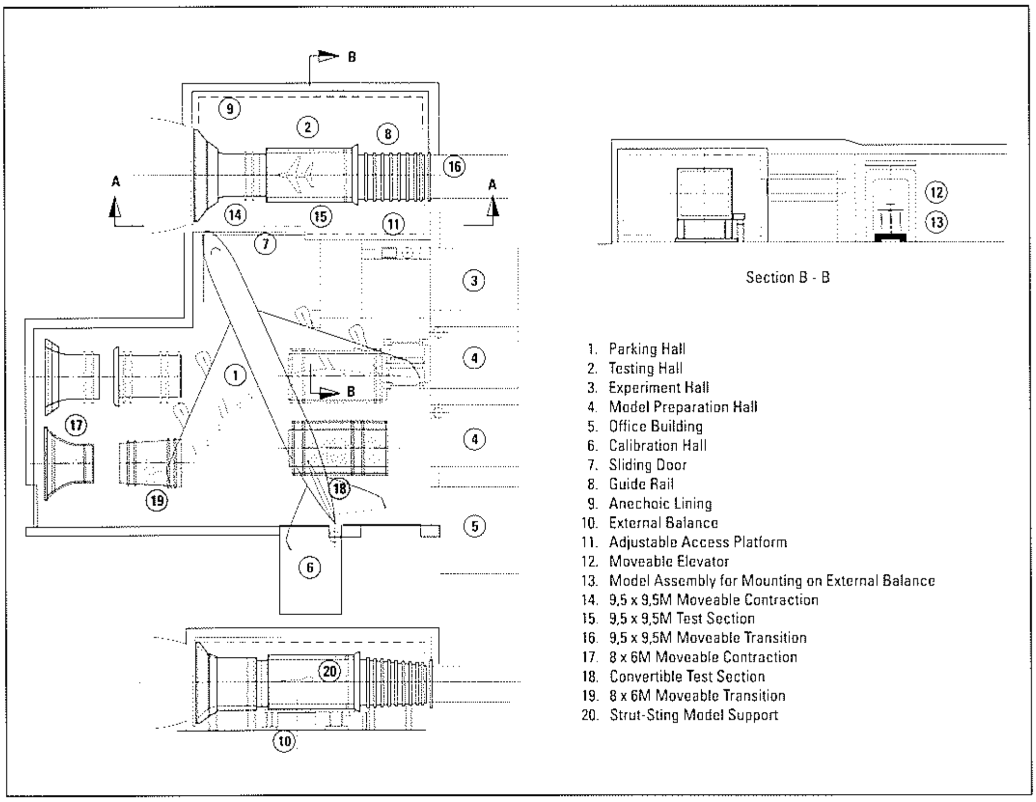


Deep-stall test of the Fokker 130 in the DNW

The incorporation of the various test section configurations resulted in exchangeable components over a length of 40 meter, weighing up to 280 ton. The large external balance had to be moved to and from the calibration room. The handling of large wind tunnel models required special handling equipment. The solution was found in an air cushion system. The photographs and figures show the extent of the storage and transportation system and the size of the parking hall compared with the size of a Boeing 747.

It is obvious that the DNW is a facility of a considerably extended scope when compared to the original LST 8x6 or the GUK proposals. The investment level was also higher than each of the two partners had initially envisaged around 1970 for its own facility, but the combined effort led to a truly unique installation in all respects. The final investment amounted to DGL. 125 million as compared to the estimated amount of some DGL. 85 million which each of the two tunnels would have cost at the actual construction period.

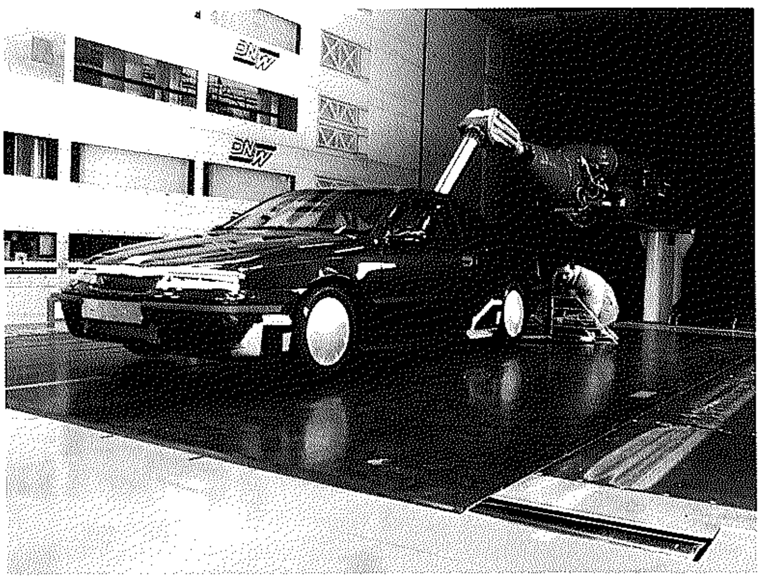
The interchangeable Test Sections and the Parking Hall of the DNW. For comparison a Boeing 747 is sketched in



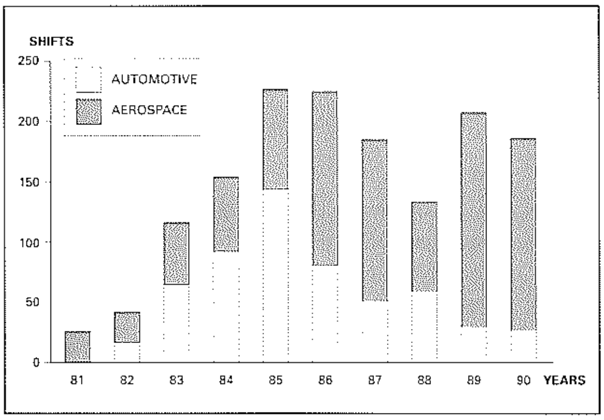
The architectural and landscaping features received praise from various quarters, which is unique for a technical installation of this type. Without exception all the contractors did their utmost to make this endeavor a success.

As with any large facility of this type the initial period of operation was difficult. The cost involved in designing and manufacturing wind tunnel models for testing in DNW are high and aircraft manufacturers are reluctant to invest in this without having a guarantee, based on proven performance, that the relatively high cost of the model and the daily wind tunnel rates are cost effective. Through the cooperation of the German Ministry of Research and Technology (Bundesministerium für Forschung und Technologie, BMFT) the German firm VFW produced a generic Airbus model which was used to demonstrate the capabilities of DNW. This proved to be convincing in the long run but nevertheless there was initially a period in which it was difficult to achieve full occupancy. Fortunately it was also the time when automobile manufacturers showed an increased interest in the aerodynamic characteristics of their vehicles. During the first half of the 1980's automobile testing increased to close to 150 shifts per year in the DNW. Thereafter it declined since many automobile manufacturers built their own wind tunnels. Testing of full-scale cars was relatively easy in the DNW as shown in the illustrations. Over a period of several years practically all types of European cars were tested in the DNW. These were mostly short duration tests (one or two shifts) but they served as a standard for the automobile industry.

Test of an Automobile in the DNW, using a Rolling Floor (Moving Belt) to simulate the behavior of the car on the road



Three-component force measurements in the DNW 9.5 x 9.5 test section on a Truck under yaw (cross wind) conditions



During the initial years of operation, when DNW had to prove its usefulness to the aircraft industry, many Cars and Trucks were tested in the DNW

Directors of the DNW since the foundation in 1976

During the Construction Phase:	• Project Director	
	Ir. F. Jaarsma	1976 - 1980
	• Deputy Director	
	Dr.-Ing. M. Seidel	1976 - 1980
During the Operational Phase :	• Directors	
	Prof. Dr.-Ing. J. Barche	1980 - 1985
	Prof. Dr.-Ing. H.B. Weyer	1985 - 1987
	Prof. Dr.-Ing.habil. H.U. Meier	since 1987
	• Deputy Directors	
	Ir. J.W.G. van Nunen	1980 - 1982
	Ir. A.H. Runge	since 1982