Table of Contents

75 Years of Aerospace Research in The Netherlands

A Sketch of the National Aerospace Laboratory NLR

1919 - 1994

The Names

R.S.L. = N.L.L. = N.L.R.

The RSL was officially founded on 5 April 1919.

R.S.L. = Rijks-Studiedienst voor de Luchtvaart
Government Service for Aeronautical Studies RSL
5 April 1919 - 14 June 1937

The Government Service RSL was converted into the Foundation NLL in 1937.

NLL = Nationaal Luchtvaart-Laboratorium
National Aeronautical Laboratory NLL
14 June 1937 - 13 April 1961

On 13 April 1961 the name of the Foundation NLL was changed to include Space Flight.

NLR = Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Preface

On 5 April 1919 the laboratory of the RSL - the predecessor of NLR - was officially opened. This book was published on the occasion of the 75th Anniversary of that event.

The book was written for those who are interested in the development of the laboratory over this seventy-five year period:

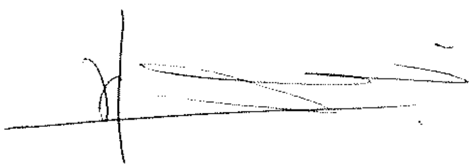
- *present and former employees,*
- *users of the services of the laboratory,*
- *government and industry,*
- *colleagues in aerospace and other institutes*

and all who are interested in this part of engineering history.

Many men and women at all levels played important roles in the history of the laboratory and, although the author had to make a selection of the subjects and the individuals who contributed significantly to the evolution of NLR, we would like to dedicate this volume to all those who enthusiastically contributed to the success of the laboratory.

Amsterdam/Noordoostpolder, 5 April 1994

B.M. Spee
General Director



J. van Houwelingen
Chairman of the Board

Acknowledgements

I am indebted to Ir. D.J. van den Hoek for reviewing the contents in great detail. We had many discussions on the book and he was extremely helpful in the selection of the illustrations. To both of us this was an exciting endeavor: an attempt to record what we think the laboratory community stands for.

At an early stage Ing. J.H.A. te Boekhorst supplied historical information.
Dr. B.J. Meijer read the manuscript and many of his suggestions were incorporated.

Parts of the manuscript were reviewed by Ir. A.J. Marx, Ir. W.J. Wolff, Prof. Dr. Ir. H. Tijdeman, Prof. Ir. J.W. Slooff and Ir. W. Loeve.

Dr. S. Dharmavasan of the NDE Centre, University College, London, UK, kindly read the manuscript and suggested numerous improvements.

Personally I am indebted to Ing. P. Kluit for installing my computer. Without that the book would not have been completed till the 80th Anniversary of NLR.

The greatest gratitude I owe to my wife Corry, with whom I shared 40 exciting years in the aerospace community. In spite of her many and diverse activities, she listened endlessly to my stories and always contributed constructively in overcoming the daily problems.

Jan A. van der Bliek

Colophon

Production Coordination
HOEK MARKETING, Zoetermeer (*Peter van den Hoek*)

Design and Lay-out
SkipDesign, Zoetermeer (*Winny Koenn*)

Lithography
DUO LITHO, Zoetermeer

Printed by
Joh. Enschedé, Amsterdam

1. Introduction

Aeronautics and astronautics are very special among human endeavors. From the early beginning the possibility of flight intrigued not only inventors, visionaries, dreamers, dare-devils, entrepreneurs and mechanical tinkerers, but also serious scientists and engineers who were attracted by the problems of flight. This mixture of adventurers, entrepreneurs, engineers and scientists still forms the fabric on which aerospace is embroidered.

After men such as Lanchester in the UK, the brothers Lilienthal in Germany and many others laid the engineering foundation for flight with heavier-than-air machines, the Wright brothers in the USA made their first flight on 17 December 1903. They set the standards for many years to come by studying all the available literature, carrying out many tests in their own wind tunnel and even building their own engine before attempting the first powered flight with the Wright Flyer.

This review of the history of the National Aerospace Laboratory NLR is in part a reflection on the history of the aeronautical engineering sciences in The Netherlands, and it is of course closely associated with the history in other countries. There is no generally accepted 'standard' history of the aeronautical engineering sciences. The views emanating from various publications differ widely, each concentrating on the history of a particular group, laboratory or industry. The present volume is no exception to this and the views resulting from this book are likely to differ from those expressed in other publications covering the same period.

Some of the larger research organizations employ professional historians, particularly in the USA, and there are now several volumes describing the history of the NACA/NASA activities and the history of the aerospace research centers of the US Air Force. These are based on detailed studies of the archives, interviews of individuals who played a key role, and studies of the literature of the period concerned. Such an approach is necessary for a balanced view of the history of the institutes. The achievements can then be viewed in a proper context and successes and failures can be judged in the light of the prevailing circumstances. In writing this book the author began to appreciate the special skills of historians capable of writing the history of an organization.

On the occasion of the 50th Anniversary of NLR in 1969, an interesting series of articles was published in a special issue of 'De Ingenieur', the periodical of the Royal Institute of Engineers, (Koninklijk Instituut van Ingenieurs - KIvI), [Ref. 1]. It gave a review of the current activities and capabilities with some historical background. It was the result of contributions of some twenty people actively working at NLR at that time, some of them having been employed at NLR for nearly 40 years.

For the 75th Anniversary a different approach was chosen. This book is a sketch of NLR, giving the essential features in a historical context with examples to illustrate the development of the laboratory during that period. The sources of information were the Annual Reports, Technical Publications, personal knowledge and experience, and personal memoirs of some former employees made available to the author.

This sketch of the development of aeronautical and space technology research at NLR during the seventy-five year period of 1919 to 1994 is not a classical landscape painting with all the details filled in, nor is it a modern painting in which at least the whole area is colored. It is a sketch of the development of the laboratory showing its main characteristics and its achievements.

Review of Aeronautical Activities in The Netherlands till 1919

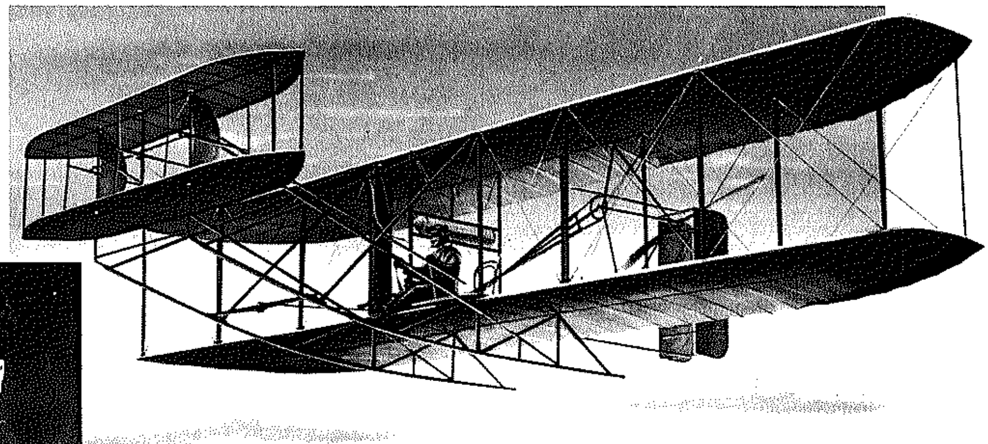
The RSL, the predecessor of NLR, was officially founded on **5 April 1919**, shortly after the First World War. The Netherlands remained neutral during that war. Although air power did not play a decisive role during the First World War, aeronautics had nevertheless progressed very rapidly during that period. Up to 1919 there were no real civil applications although in many quarters plans for civil operations were being made.

What were the events that led to the establishment of the RSL?

Aeronautics developed slowly in The Netherlands - compared to the neighboring countries - during the first two decades of this century. There was however a growing interest in aeronautics in general and also in the underlying engineering sciences, [Ref. 2, 3, 4, 5 and 6]. Before 1900 a few individuals were active with lighter-than-air vehicles – balloons – but apparently no spectacular flights, as for instance in France, were made. The Army used cable balloons at the end of the 19th Century, but nothing special was reported.

A significant event was the foundation of a society for the advancement of aerial navigation, on **19 October 1907**, at the initiative of the Navy Lieutenant A.E. Rambaldo[1].

Count de Lambert and his Wright Flyer, 27 June 1909



General (then Colonel) C.J. Snijders was the first Chairman (1907-1910) of this Netherlands Aeronautical Society.
This Society became the Royal Netherlands Aeronautical Society (Koninklijke Nederlandse Vereniging voor Luchtvaart, KNVvL). The title 'Royal' was granted in 1914. The Society, still very active, became the focal point for all aspects of aeronautics ranging from building and flying model airplanes to aeronautical engineering and, especially gliding.

Lt. Rambaldo and Col. Snijders were among the first to fly balloons in The Netherlands. Gen. Snijders played a very important role in charting the course of military and civil aviation in The Netherlands as will become clear in the following Chapters. From 1 August 1914 to 1 November 1918, during the period of the First World War, he was Commander of the Armed Forces of The Netherlands.

[1] Alfred Emile Rambaldo was born 16 November 1879 at Rembang, Indonesia. In 1897 he enrolled at the Royal Naval Academy (KIM = Koninklijk Instituut voor de Marine) at Den Helder from which he graduated on 21 September 1901. He died in a crash with the balloon 'Batavia' near Blora (Java) on 5 August 1911. A bust, mounted on a pedestal, was placed in a park in Surabaya (Java) to commemorate this aviation pioneer. This statue was recovered later and was placed at the Navy Air Base Valkenburg. [Ref. 7].

In 1909 Mr. A.P. Kapteyn, a promotor of aviation and member of the KNVvL, gave a lecture before the Royal Institute of Engineers, KIvI, on the state of the art of aeronautics and proposed to start aerodynamic investigations in a wind tunnel.
With the limited means of the KNVvL a small aerodynamic laboratory was started at the Technical University Delft. On 27 September 1918 Mr. Kapteyn gave another extensive lecture before the KIvI on aeronautics, [Ref. 8], and he complained that the laboratory in Delft had found little support from the University and from the Government, but he stated that he was happy to have learned that Dr. Wolff had been appointed recently to organize an aeronautical laboratory on a sufficiently large scale. Later the KNVvL instrumentation was transferred to the RSL, (Chapter 2).

The first issue of Jane's 'All the World's Airships', 1909, [Ref. 9], lists several Wright biplanes in The Netherlands. A general note in Jane's read:

> -*"Little or no interest is yet taken in flying. Two Dutch inventors are rumored to have aeroplanes in hand or projected, but no details or confirmation are procurable."*

Compared to other European countries, particularly France, the aeronautical activities in The Netherlands were certainly limited at that time.

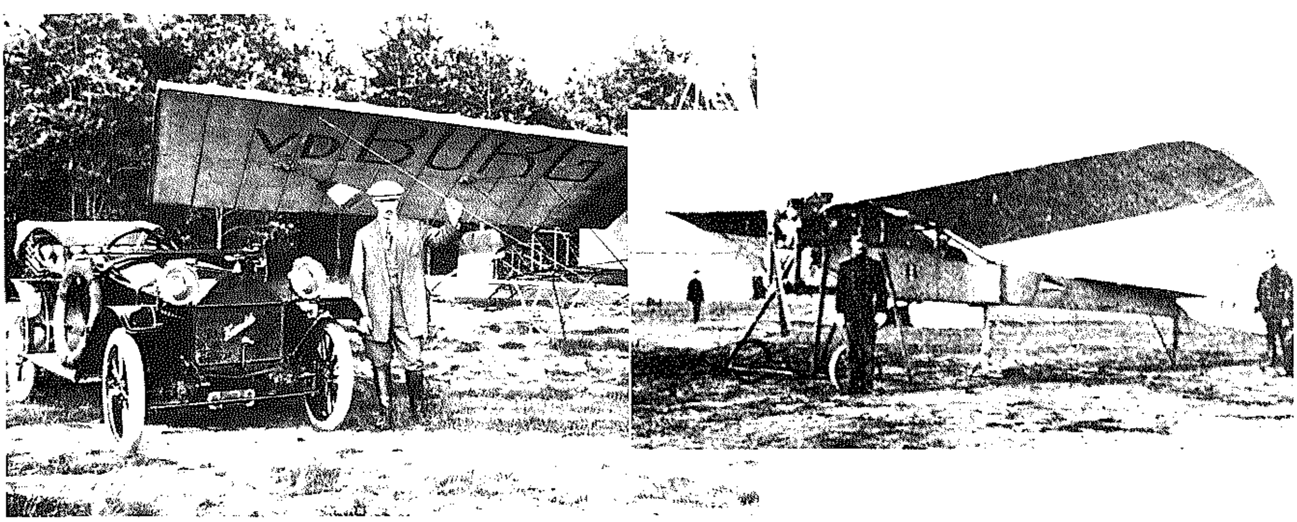
The first public flight demonstration in The Netherlands took place on **27 June 1909** at Etten-Leur, near the Belgian border. The flight was performed by Count Charles de Lambert of Liège, Belgium, in a Wright airplane built in France. It was an improved version of the original Wright Flyer, using a drop weight and sled for take-off. The event was sponsored by Mr. Heerma van Voss, a sugar manufacturer, to celebrate the 40th anniversary of his plant.

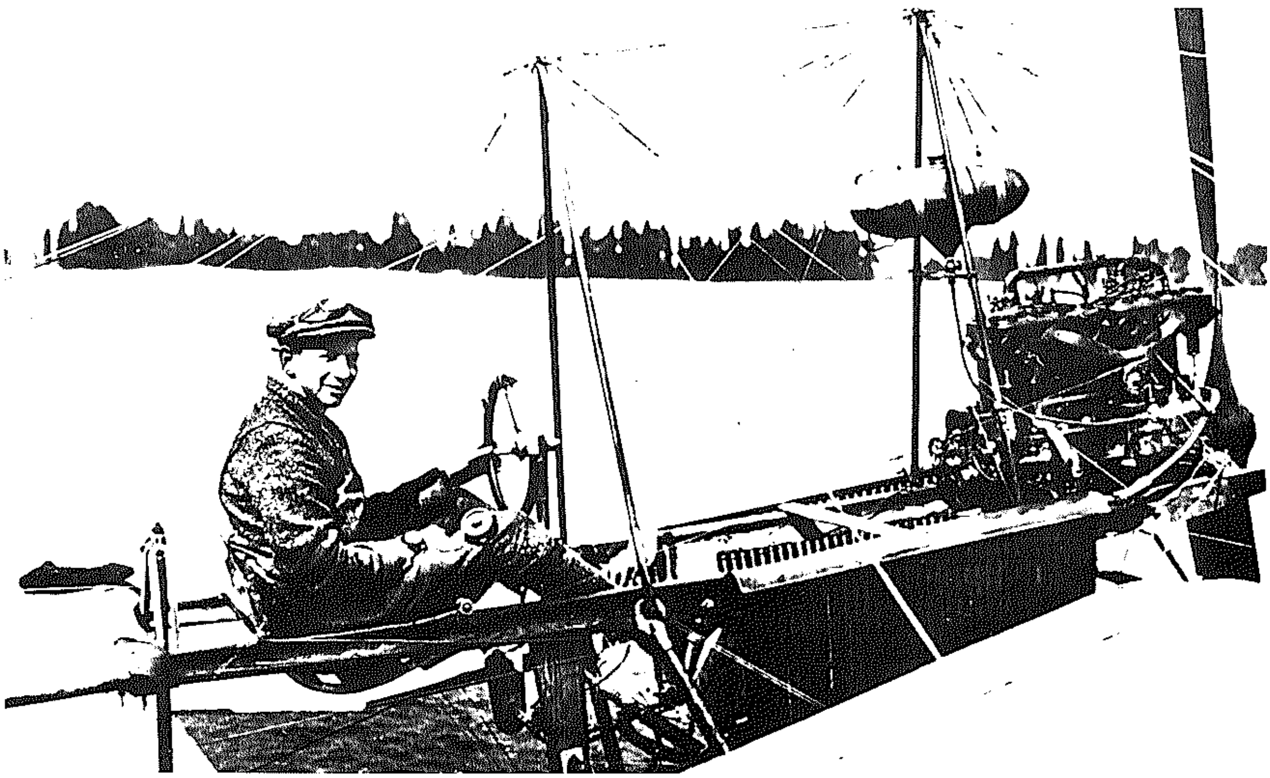
Interestingly enough, the first powered flight in Indonesia (then the colony Netherlands East Indies) which took place on **7 March 1911**, was also sponsored by sugar manufacturers. The flight in Indonesia took place at Surabaya, East Java, and was carried out by Ir. Gijs Küller. He had learned to fly in France and had acquired two French 'Antoinette' aircraft which he took to Indonesia.

After the first flight in The Netherlands many flight demonstrations were organized in rapid succession and the number of aviators and aircraft grew accordingly. In the period 1909-1914, before the First World War, several enthusiasts started to build their own airplanes, often after having initially bought an airplane in France.

Mr. Hein J.C.W. van der Burg was the first person in The Netherlands who designed and built his own airplane, which he flew on **8 February 1911**, [Ref. 2 and 4].

The first airplane designed and built in The Netherlands by Van der Burg, flew for the first time on 8 February 1911





Fokker with his 'Spin'

A major historical event was the flight of Anthony H.G. Fokker over the city of Haarlem, circling the Saint Bavo Church, on **31 August 1911**, the Queen's birthday. The aircraft, The Spider (Spin), was a monoplane which he had designed and built. With due respect to all the others who pondered seriously the engineering aspects and the possible applications of flying, this single event demonstrated very convincingly to the public and the politicians that aviation had arrived.

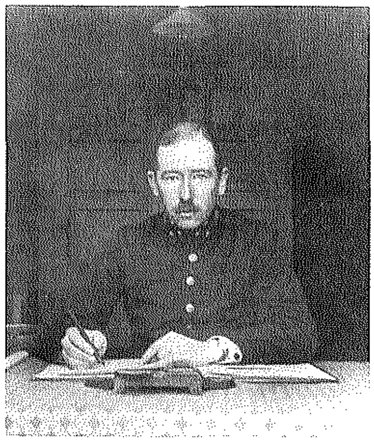
Fokker, born 6 April 1890, went to Germany in 1910 to attend an auto-mechanics school and ended up by taking flying lessons. In Baden-Baden, Germany, he built his first airplane in 1910 and he obtained his pilot license in May 1911. In 1912 he returned to Germany and started an aircraft factory at Berlin (Johannisthal).

As in many countries, the military, always interested in the latest technical advances, soon became seriously interested in aviation. In 1909 Capt. Hendrik Walaardt Sacré (1873-1949), who was then a Captain in the Corps of Engineers of the Army, was sent to the German Airship Battalion ('Luftschiffer-Bataillon') to observe the military applications of balloons. He spent two months in Germany and gathered much useful information on the application of balloons, including powered airships. He also visited Johannisthal, Berlin, where he observed the state of the art of flying machines. In his report to the General Staff he made recommendations about establishing a balloon department for the Army; he stated that flying machines did not yet have military significance and he recommended not to purchase aircraft.
However the airplane developed rapidly and after he made a second trip to Germany in July 1910, his report about the possible use of airplanes was more positive, [Ref. 10].

Gen. C.J. Snijders, Army Chief of Staff, who initiated the Army Air Force

On **26 March 1910** the Minister of War installed a Committee to study the possibility of forming an Air Division of the Army. Capt. H. Walaardt Sacré was appointed Secretary of this Committee. Initially this committee was mostly interested in the employment of cable balloons and lighter-than-air vehicles. However this changed within one year, when the Army Chief of Staff Lt-Gen. C.J. Snijders rented six airplanes and two balloons to participate in a great Army exercise, held in **September 1911**. These maneuvers demonstrated the usefulness of aircraft to the Army. Capt. Walaardt Sacré wrote a report on this exercise which included notes of many shortcomings and several suggestions but he concluded that there was a great future for practical applications of the airplane. General Snijders, who himself flew for the first time as an observer during these maneuvers, decided that an experimental department was necessary, with two aircraft to train pilots, to study the applications of aircraft in military operations and to follow the developments abroad.

Capt. H. Walaardt Sacré, the first Commander of the Army Air Force at Soesterberg Air Base



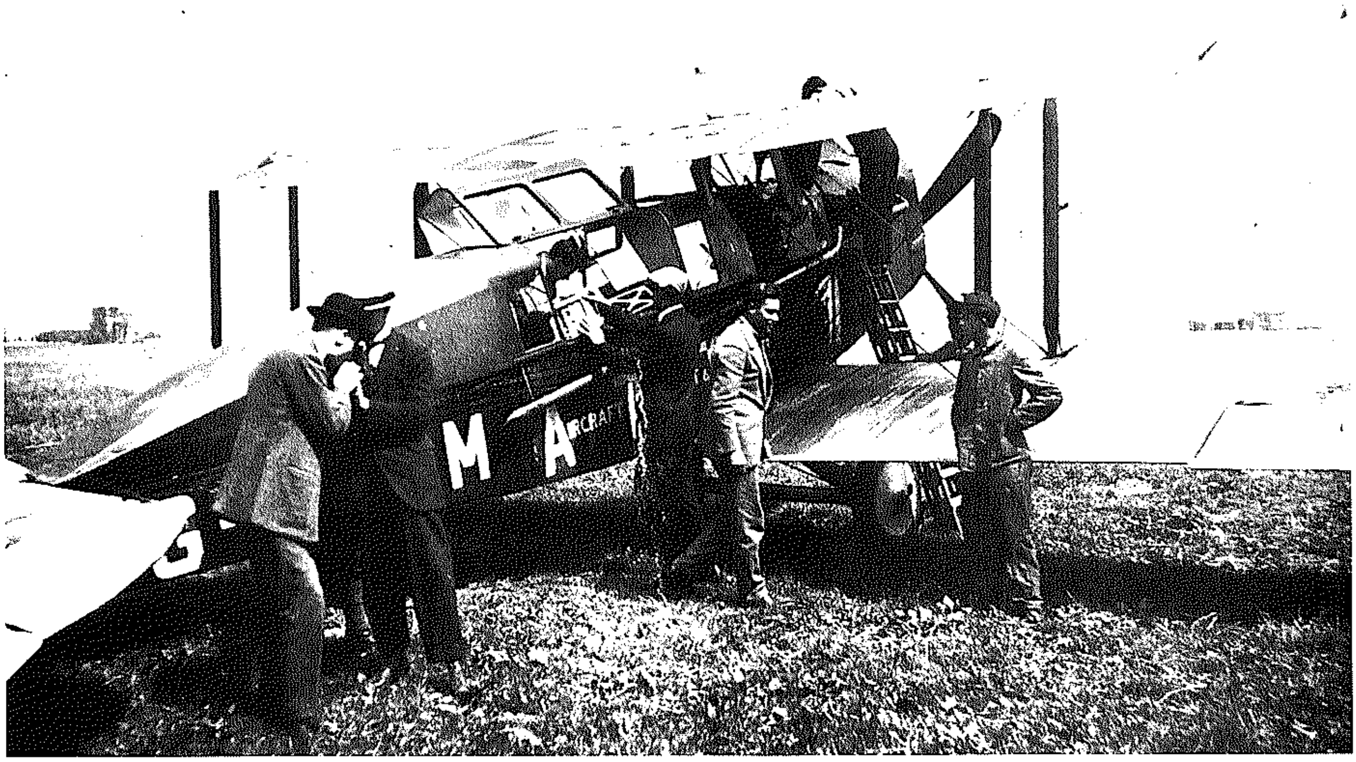
The result was that on **1 July 1913** the Aeronautical Department of the Army, the **LVA** (Luchtvaart-Afdeling) was formed. Capt. Walaardt Sacré was appointed Commander of the Aeronautical Department, a position he held till his resignation from the Army in October 1919. Initially the personnel totaled 33, including three pilots.
The LVA was based at Soesterberg. In 1910 the automobile firm Verwey and Lugard had leased a 300 HA field near Soesterberg where a flying school was established by the 'Aeronautical Company', (Maatschappij voor Luchtvaart), a private enterprise to promote aeronautics. It was not very successful and on **28 March 1913** the Government purchased the airfield and the buildings for the LVA.
The first Army pilots had to bring their own airplanes. Gradually the LVA started to buy its own airplanes, initially from France. The airfield at Soesterberg, centrally located in The Netherlands, became the breeding ground for many aeronautical activities in The Netherlands.

The Royal Netherlands Navy started its Naval Air Service, **MLD** (Marine Luchtvaartdienst) officially on **18 August 1917**, first on the island Texel and later the MLD acquired an airfield, 'De Kooy', near Den Helder, the main Naval Base. The Navy started with Swedish and German seaplanes and later bought airplanes with floats from Van Berkels Patent, a company in The Netherlands manufacturing food cutting machines, (see also Chapter 9 under 'Flutter').

When on **1 August 1914** a general mobilization of the armed forces was ordered by the Government, Gen. Snijders was appointed Chief of the Armed Forces. The Netherlands managed to stay neutral during the First World War (1914-1918) but there was of course a greatly increased emphasis on defense. Only the military aspect of aviation received attention. The economic conditions deteriorated very rapidly and there were no possibilities to develop civil aviation applications.

The flying material of the LVA was expanded continuously during the war period. A welcome supplement were the foreign aircraft making emergency landings in The Netherlands. Of the 107 aircraft so acquired 69 were repaired and flown by the LVA for some time. By the end of the war there were some 200 aircraft registered with the LVA, although perhaps only 100 were on flight status.

H.R.H. Queen Wilhelmina with Lt. Plesman (left) and Gen. Snijders (right) after the official opening of the ELTA Exhibition, August 1919



A converted reconnaissance-bomber aircraft DH-16 used as a passenger plane hired by KLM for the service Amsterdam-London in 1920

At the end of 1918 the LVA had expanded to a complement of 646, including 62 officers.

During the period of 1913 to 1919 several new military airfields were constructed. In 1914 the airfields at Gilze-Rijen, Arnhem and Vlissingen, all near the borders of Germany and Belgium, were opened. Two years later military airfields were established at Oldenbroek, for artillery training and near Amsterdam within the fortification of that city. The latter was **Schiphol** which became operational in **1917**. The main aeronautical activities were still concentrated at Soesterberg. Several of the young officers, all enthusiastic aviators, played an important role in post-war aviation in The Netherlands. One of the young officers at Soesterberg was Lieutenant Albert Plesman, the founder of KLM.

After the Armistice, **11 November 1918**, the aeronautical community started to concentrate on the application of the newly obtained skills and experience. The Government appointed a committee to review the possibilities of aerial applications. The year 1919 saw many new initiatives. A real mile-stone was the organization of the First Aviation Exhibition in Amsterdam: the **ELTA**, Eerste Luchtverkeer Tentoonstelling Amsterdam, held in **August 1919**. The chief organizers were the Lieutenants Plesman and Hofstee of the LVA with the strong support of Gen. Snijders and the KNVvL. That exhibition was visited by 500,000 people; probably an absolute record for an exhibition ever held in The Netherlands till that date. Many countries participated. There were daily flight demonstrations and 4000 people flew for the first time as passengers. Even to-day that is considered as an unbelievable number. The ELTA convinced many people that aviation was here to stay and that it had a real economic potential.

The KLM, Royal Dutch Airlines (Koninklijke Luchtvaart Maatschappij), was founded on **7 October 1919** and the first daily service from Amsterdam to London was inaugurated on **17 May 1920** in cooperation with the UK company 'Aircraft Transport & Travel, Ltd'[2]. The first aircraft used was a converted military plane, a De Havilland DH-9, soon replaced by Fokker F.II's, in passenger plane versions.

[2] The following story gives an impression of one of these 'regular' daily flights from Amsterdam to London. Dr. Wolff, the first Director of the RSL, recalled:
-*"We established contacts abroad and on 15 July 1920 I flew for the first time to London with KLM. KLM then still used converted military machines. Pigeaud (his first employee) and I travelled in a converted De Havilland machine with a Siddeley engine. There were four seats with a transparent canopy over the cockpit. It was an ATT machine (Aircraft Transport & Travel) and we had a British pilot. The aircraft did not appear very attractive and safe. We flew along the coast of Belgium till Cape Gris Nes and then crossed the Channel. About halfway across the Channel the engine began to run irregularly. Fortunately the pilot managed to gain altitude and then he continued along a glide path to land at Lympne near the coast. After the landing it appeared that the engine could not be turned, it was stuck. We continued the voyage by train, which was made to make an unscheduled stop at an intermediate station. In London I wondered if I should return by plane, but Pigeaud advised me to take the ferry boat because of inclement weather and so I returned to Vlissingen (Flushing) on 23 July 1920."*

KLM had great ambitions as was expressed by its full name: Royal Airline for The Netherlands and Colonies. The 'Colonies' meant the Netherlands East Indies (Indonesia) and the Netherlands West Indies (Netherlands islands in the Caribbean and Suriname). The long-term goal of the company to start regular services to those far away places must have been seen as unrealistic by some at the time. However the British aviators John Alcock and Arthur Whitten Brown had just completed the first trans-Atlantic flight from New Foundland, Canada, to Ireland in June 1919. Their aircraft was a twin-engined Vickers Vimy. The Vimy, originally a bomber plane, was shown in a civil version at the ELTA Exhibition at Amsterdam in August-September 1919. KLM's founding fathers must have been impressed!

On **21 July 1919** Fokker established the 'Nederlandsche Vliegtuigenfabriek', later known as the Fokker Aircraft Company. The factory was housed at the site where the ELTA Exhibition had been held, Amsterdam-North. Fokker managed to transport much of his flying material and equipment from Germany to Amsterdam. After a war-time contract, which the Government had granted to the Dutch Company 'Trompenburg Automobile and Aircraft Company', was transferred to Fokker, Fokker became well established in The Netherlands. Fokker was also quick to enter the market with the Fokker F.II passenger plane and sell it to KLM.

All these events around 1920 pointed towards a great future for civil aviation. However many technical, financial and organizational problems had to be solved before a significant part of passenger transportation could take place by air.
In this connection it is interesting to quote from Orville Wright, the first man to fly a powered airplane, [Ref. 11]. In 1919 he wrote in the first issue of Aviation Magazine (the fore-runner of the weekly magazine 'Aviation Week & Space Technology'):

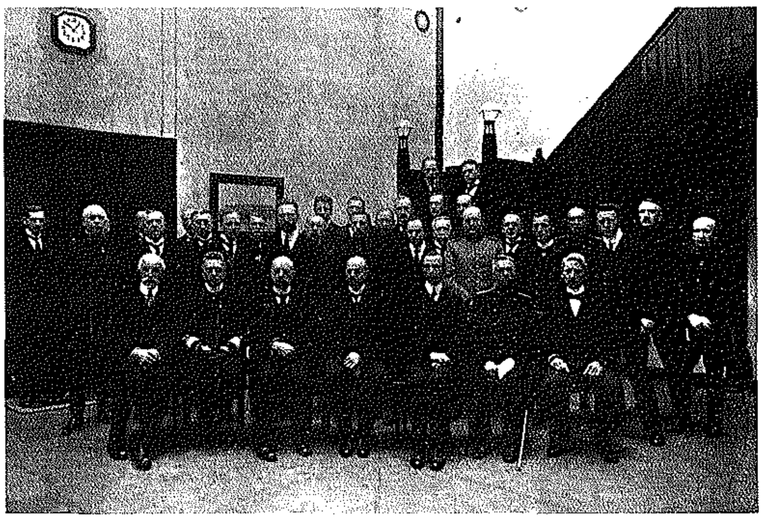
> -*"Although it is now fifteen years since the first flight was made with a heavier-than-air machine, the use of the airplane for commerce and sport has developed but little."*

He, the inventor of the airplane, went on to explain the reasons. He felt - and one must assume that most of the aeronautical engineers at that time agreed - that a reduction of the landing distance was urgently needed and that the lack of a sufficient number of suitable airfields was a limiting factor. He also stated that the application of brakes and reversible propellers had been suggested, but that these techniques had not been developed sufficiently.
Looking back from the vantage point of 75 years of aeronautical development, the more dominating problems seem to have been related to reliability, capacity and cost and it was not until those factors could be controlled sufficiently that civil aviation really became an important factor in transportation.

Alexander Klemin, the first technical editor of Aviation Magazine, noted that at the beginning of the 1920's the European plans for commercial application of the airplane were far more advanced than America's. The Americans seemed to be more occupied with developing the automobile system (cars and roads) than the Europeans. In the following decade the position of American aviation changed, especially with the introduction of the all-metal airplanes such as the Douglas DC-2 and the DC-3. In fact, one publication, [Ref. 12], states that in 1939, 90 percent of the world's airline traffic was carried out with Douglas DC-3's. However that was not till after the 1920's and 1930's when Fokker aircraft had covered a large segment of the world transport aircraft market. KLM, initially the most important civil customer of Fokker, had greatly contributed to that success.

2. The Early Days

On Saturday 5 April 1919, (Saturday was a normal working day), the new laboratory of the 'Rijksstudiedienst voor de Luchtvaart', RSL (Government Service for Aeronautical Studies) was officially opened in the presence of representatives of the Government, including three Ministers, the Military Services, the Industry and the Royal Netherlands Aeronautical Society (KNVvL). That date is now regarded as the official founding date of the RSL, the predecessor of NLR.



The official opening of the RSL, 5 April 1919

The Creation of the RSL, the Initial Conditions, the Motivation

The guests were welcomed by Prof. L.A. van Royen[1]. In a comprehensive speech, [Ref. 13], he reviewed the events leading towards the foundation of the Service and the establishment of the laboratory.

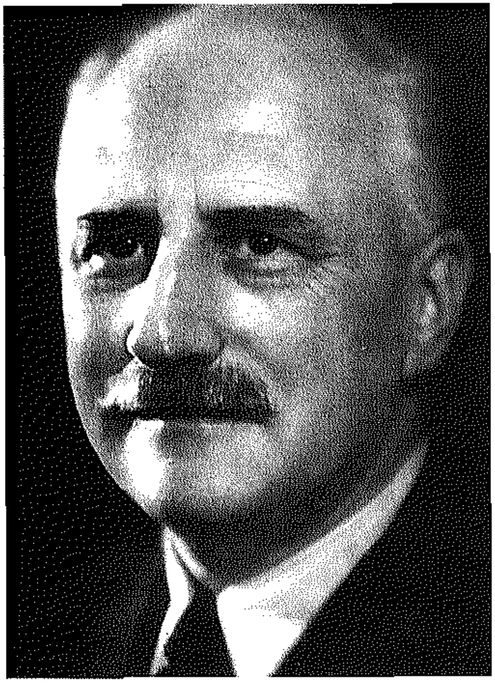
At this official opening there was already a laboratory in operation. What had actually taken place during the last few years of the War period?

Prof. Van Royen, Chairman of the Bureau of Ammunition (1915-1920) of the Ministry of War, had proposed on **17 November 1917** to the three Ministers of War (Army), the Navy and the Colonies, to form an institute for aeronautical studies and to ask the Bureau of Ammunition to prepare a proposal for such an institute. Prof. Van Royen was strongly supported by the Commanders of the Army and Navy Air Services, Lt-Col. H. Walaardt Sacré and Capt. D. Vreede.

The Minister of War and the Minister of the Interior (Domestic Affairs) agreed to this proposal. The Defense budget for the calendar year **1918** listed an amount of DGL. 40,000 for the new institute; DGL. 5,000 for personnel cost and DGL. 35,000 for material expenses.

Dr. Ir. E.B. Wolff, employed at Werkspoor, a machine industry at Amsterdam, was appointed Director of the Aeronautical Studies Department of the Bureau of Ammunition. His official appointment was on **15 April 1918**, but he had already started with the design of the laboratory, (see also the story of Wolff, Chapter 29). It was agreed that, at least initially, this activity, later named RSL, would operate under the Bureau of Ammunition since at that time the government interests in

[1] Prof. Louis Anne van Royen (1865-1946) was Professor of Mechanical Technology at the Technical University Delft during the period of 1906-1934 and he was also Rector (President) during the academic year 1922-1923. He had a considerable impact on engineering education and the industry. At the University he promoted the introduction of material sciences, related to metals, at the Department of Mechanical Engineering. After a separate chair had been created for Production Techniques (Prof. P. Landberg), his successor (Prof. W.F. Brandsma) was the first full-time Professor of Metallography in that Department.
He was a member of the Board of 'Hoogovens' (Dutch Iron and Steelworks) during the period 1929-1946, representing the Dutch Government. He also served as Chairman of the Government Metal Committee, advising Government and Industry on the long-term policy.
After his retirement from the University he kept an active interest in engineering and he served from 1935 to 1938 as President of the Royal Institute of Engineers, KIvI.
He was Minister of War and the Navy during the year 1926.
His contributions to aeronautics are clear from his role during the formative period of the RSL when he was Chairman of the Bureau of Ammunition. For four years he was also Chairman of the RSL Advisory Committee which was formed in 1920.



Dr. Ir. E.B. Wolff

aeronautics were predominantly defense oriented. In fact it is almost certain that in 1917 when a definite proposal was submitted, there was little support, if any, for civil aeronautics in government circles.

The Navy made available a building, located at the Navy Yard in Amsterdam, and locally known as 'the Old Saw Mill' (de Oude Zaagmolen). It was basically an empty shell but it seemed suitable for the purpose. It was intended as a temporary building but 'temporary' turned out to be close to 22 years.

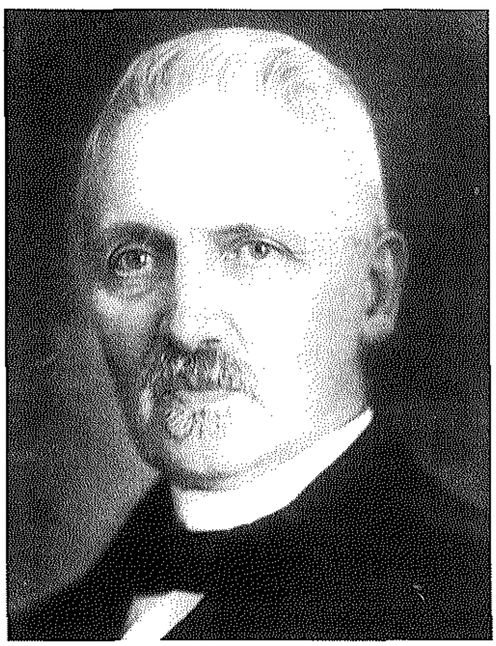
In **July 1918** the refurbishment of the building was started. Dr. Wolff began ordering equipment. The KNVvL had collected various instruments for aerodynamic experimentation at the Technical University Delft. This Society transferred the instrumentation to the RSL. At the official opening of the RSL on 5 April 1919 the visitors saw a laboratory in operation, be it on a limited scale.

In his opening speech Prof. Van Royen emphasized that there should be ample room for ideas and initiatives of interested parties. As 'interested parties' he listed: the Ministries of War, the Navy, the Colonies, the Interior, Education, Agriculture, Trade and Commerce, Public Works (Waterstaat), industry, airlines and the KNVvL.
The RSL should develop free and open communications with the aeronautical world and in turn the RSL should be assisted to come into contact with those who are interested in the activities of the RSL. The interested parties should also be able to influence the activities of RSL, taking into account final guidance from the Minister concerned. He saw an excellent opportunity for RSL to become the focal point for aeronautics and he warned against tendencies to drift in separate directions.

Dr. Wolff recognized the importance of this basic philosophy in developing the laboratory with a very small staff. He realized that The Netherlands had been isolated from many new technical developments during the war period. Dr. Wolff said on **5 April 1919**:

> *-"At present we live here in The Netherlands, in many aspects, in pre-war times as far as our knowledge is concerned. Even though we have heard about the lessons learned during the war and had the opportunity to study some aircraft which landed here, many subjects remained unknown to us."*

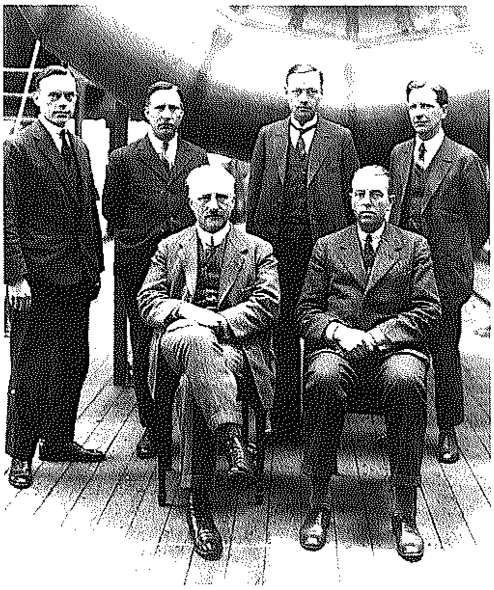
He was given the task of building up technical-scientific aeronautical knowledge and experience to a level comparable to that of institutes in neighboring countries. That could only be done with the assistance of all concerned.
The laboratory RSL was given an excellent start, although the human and material resources were limited.



Prof. L.A. van Royen

Clearly, RSL originated at offices belonging to the Ministry of Defense mainly as a result of aviation activities of the Army (since 1913) and the Navy (since 1917). The groundwork for the foundation of RSL started in 1917, in the middle of the First World War, when civil aviation in The Netherlands was non-existent, and for that matter almost anywhere else.

However shortly after the war, when defense spending was cut drastically and civil aviation appeared at the horizon, a discussion started to evolve in government circles as to under which Minister the RSL should operate.



The leading personnel of the RSL, 1929

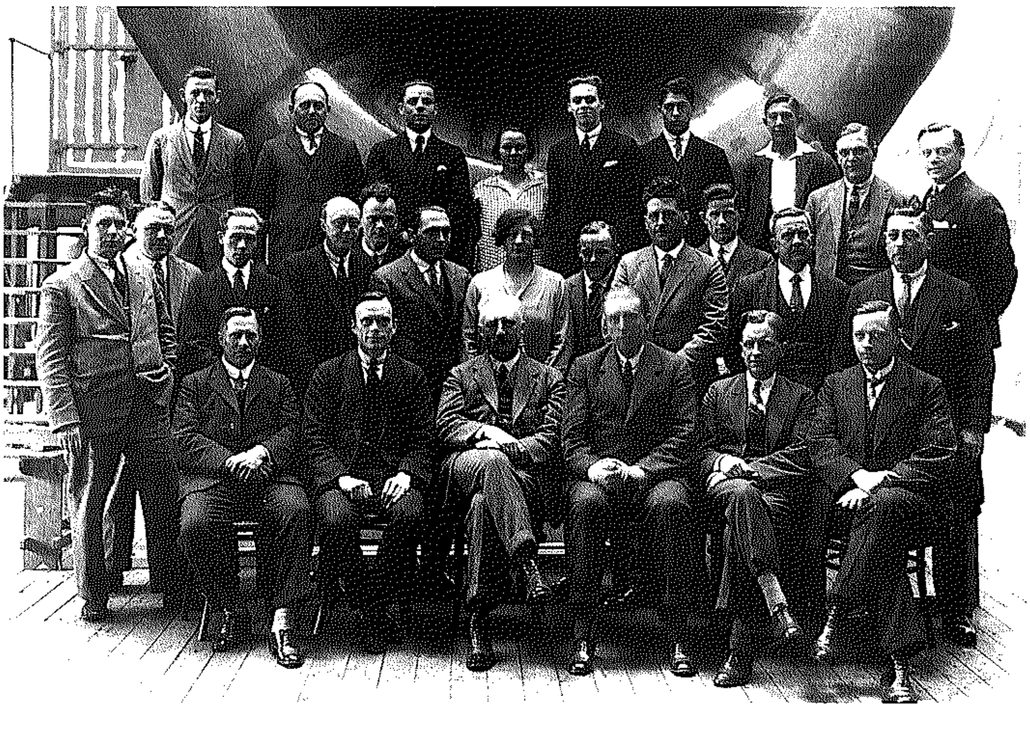
Prof. Van Royen suggested therefore in **January 1919** that the Ministers of Defense (War), the Navy, the Colonies, the Interior, Education, and Public Works (Waterstaat) form a 'Curatorium', a kind of supervising committee, for RSL. The Curatorium would meet every two months and the Director would report monthly to one of the - yet to be determined - Ministers, through this Curatorium. By this mechanism civil and military aeronautical interests would be safeguarded, independent of which Ministry would finally fund the budget of the RSL. The Minister of Public Works was not in favor of such an arrangement because his Ministry would, certainly in the future, carry the major share of the responsibility and the government finances associated with aviation. The dispute was finally settled and, as suggested by Prof. Van Royen, a 'Curatorium'- an Advisory Committee - was established. This Committee also included representatives of the Minister of Agriculture, the Minister of Trade and Commerce and of the KNVvL.
The actual transfer of the RSL from the Ministry of Defense to the Ministry of Public Works (Waterstaat) took place on **1 January 1920**.

The Uncertainties after World War I

During the post-war period drastic economic and political changes took place. On the one hand civil aviation began to flourish - the aircraft manufacturers, particularly Fokker but also smaller companies in The Netherlands were successful and the airline KLM developed spectacularly -, but on the other hand, the Government went through a financial crisis in the 1920's.

As early as 1922, only two years after the Ministry of Public Works took over RSL, the Minister proposed to terminate RSL. The main argument was that the annual funding of DGL. 200,000 was considered extravagant. Fortunately nothing happened immediately and the dispute was continued for many years.

The complete staff of the RSL, 1929



However in 1925 the situation became very critical and in **January 1926** it was decided in principle to abolish RSL.[2] This decision in principle (apparently this meant that details had to be worked out and that no date had been set yet) was based in part on the recommendation of a Central Committee on the Reorganization and Budget Reduction. A Special State Committee on Aeronautics also was set up to consider the case of the RSL. In 1927 that Committee recommended that RSL should be maintained but that the supervision of airworthiness should be transferred to the Civil Service within the Government. Later this became the Department of Civil Aviation, the Rijksluchtvaartdienst, (**RLD**). Presumably this also included air traffic control, maintenance of airfields, etc, although these functions were not so prominent as they are at present.

It is also interesting to note here that earlier, in 1925, a government proposal had been advanced to divide the technical-scientific task (and the equipment) of the RSL between the Technical University Delft and the Army Air Force, LVA, at Soesterberg. The idea of finally moving RSL to Delft had already been mentioned by Prof. Van Royen in his first discussions with Dr. Wolff in 1917, (see Chapter 29). However the University was not interested.
In retrospect it was extremely fortunate that Prof. Van Royen and Gen. Snijders (the originator of the Army Air Force, the LVA) were still very active. Prof. Van Royen, Gen. Snijders and Dr. Wolff formed the core of the team that finally rescued RSL in that difficult budgetary period. They were the '**Men of Vision**' who managed to convince the outside world of the value of RSL.

GROEP DER AANWEZIGEN BIJ DE HERDENKINGSPLECHTIGHEID.

The 10th Anniversary of the RSL, 5 April 1929

Front row (from left to right): Vice-Adm. (ret.) G.F. Tydeman, Prof. L.A. van Royen, Gen. (ret.) C.J. Snijders, Mr. H. van der Vegte - Minister of Public Works, Col. J.H. Hardenberg - Commander LVA and Representative of the Minister of Defense and of the Chief General Staff, Ir. R.A. van Sandick - Gen. Secretary KIVI, Dr. Ir. E.B. Wolff - Director RSL, Lt-Col. (ret.) H. Walaardt Sacré - Gen. Secretary KNVvL, Capt. J.P. Remeynse - Commander Naval Airbase 'de Kooy', Ir. A.G. von Baumhauer - Deputy Director RSL and Dr. Ir. H.J. van der Maas - Engineer-pilot RSL

[2]A consolation was, although Dr. Wolff was probably not aware of it, that even NACA's laboratory at Langley Field, Virginia, USA, which was not very much larger than RSL in the early 1920's, was also involved in a struggle to survive, [Ref. 15].

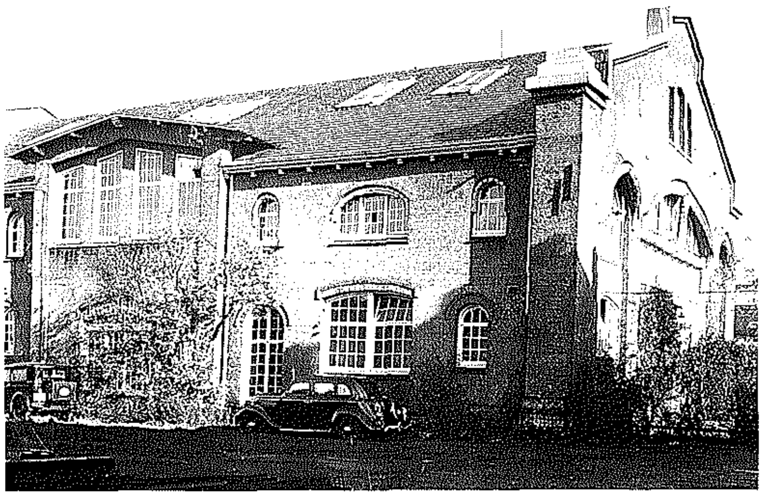
On the occasion of the **10th Anniversary of RSL, 5 April 1929**, Dr. Wolff reviewed the events that had taken place during the 1920's, [Ref. 14]. This celebration must have been an emotional event for the personnel and the main players. The positive remarks of Mr. Van der Vegte, then Minister of Public Works (Waterstaat), Gen. Snijders and Prof. Van Royen about the achievements of the RSL were very much appreciated by Dr. Wolff and his team. After all, they were the originators and they had guided the RSL through this difficult stage of formation. The RSL now was firmly established and the responsibilities between the Government and the RSL were clarified.

Although some form of stability had been achieved for RSL, this did not mean that an easy period had arrived. Dr. Wolff referred to the difficulty of carrying out high quality research with a minimum of staff, while at the same time having to carry out many ad-hoc investigations which had a high priority. He stated that this ad-hoc research was often of little interest to outsiders who are interested in the results of aeronautical research and one often heard the complaint: *"what is the use of the RSL, we never hear anything about it"*.

Similar comments have been heard over the years since much of the work is carried out on contract and not published widely. But in spite of the uncertain conditions under which the personnel had to work and in spite of the fact that their work did not appear glamorous to outsiders, a small group of exceptionally talented and enthusiastic engineers and technicians gained valuable experience and laid the foundation for the laboratory of to-day.

3. The Government Aeronautical Service- The RSL

The 1919 the Government Aeronautical Service RSL essentially developed along the lines as planned during 1918-1919, till it was converted into the Foundation NLL in 1937. The only major change in its formal task took place when a separate Department of Civil Aviation (Rijksluchtvaartdienst, RLD) was created to supervise airworthiness and aircraft operations in The Netherlands. However this did not have much effect on the technical content of the work of the RSL; it was a separation of responsibilities.

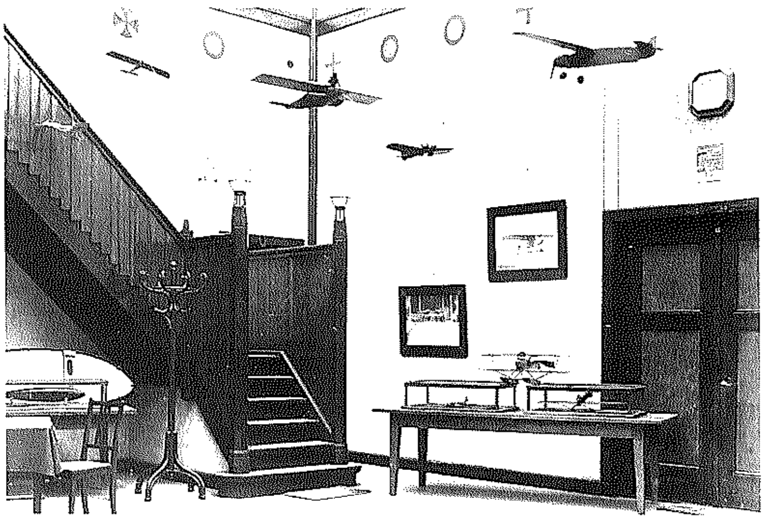


The RSL Main Building at the Navy Yard in Amsterdam

Ir. A.J. Marx[1] recalled that this shift of responsibilities was related to the wishes of the aircraft industry in the 1930's. Their desire was to have a national laboratory to which all interested parties would have access on an equal basis. It is very likely that this wish was based in part on the unique position of e.g. Van der Maas and Von Baumhauer who were responsible for carrying out the final flight tests for certification and at the same time advised the aircraft industry about flying qualities. This was probably the main reason why the industry insisted on converting the RSL, a Government Service, into the independent Foundation NLL.

[1] Ir. A.J. Marx joined the RSL in 1934 after having obtained his Ingenieur's Diploma in Naval Architectural Engineering at the Technical University Delft. In 1947 he became Chief Engineer of the whole laboratory and in 1956 he was appointed Director. During the period 1 November 1956 till his retirement on 1 March 1976 he was General Director of NLR. During this twenty year period of considerable economic growth in The Netherlands and in Europe, the personnel increased from 280 to 650 and a completely new generation moved in. Under the able guidance of Ir. Marx the increase in quality of the services rendered by NLR was disproportionally more than the increase in personnel. Ir. Marx was Ridder in de Orde van de Nederlandse Leeuw (Knight of the Order of the Netherlands' Lion) and Officier in de Orde van Oranje-Nassau (Officer of the Order of Orange-Nassau).

Ir. A.J. Marx, 1911-1993



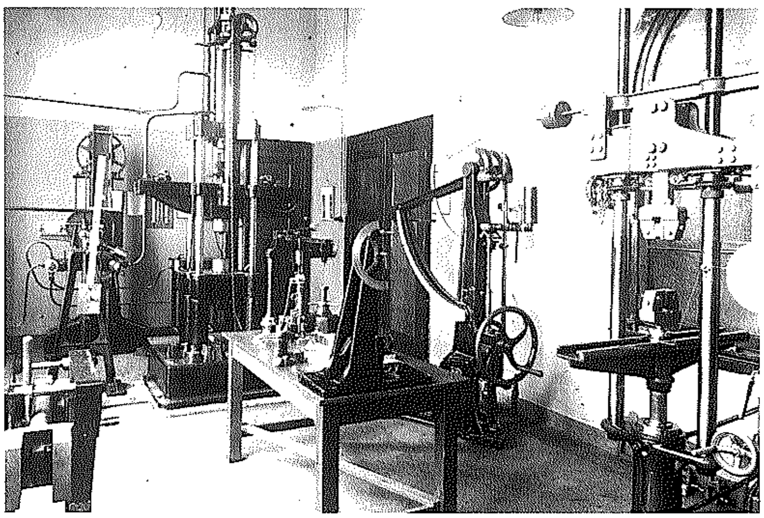
The Entrance Hall of the RSL

The Laboratory

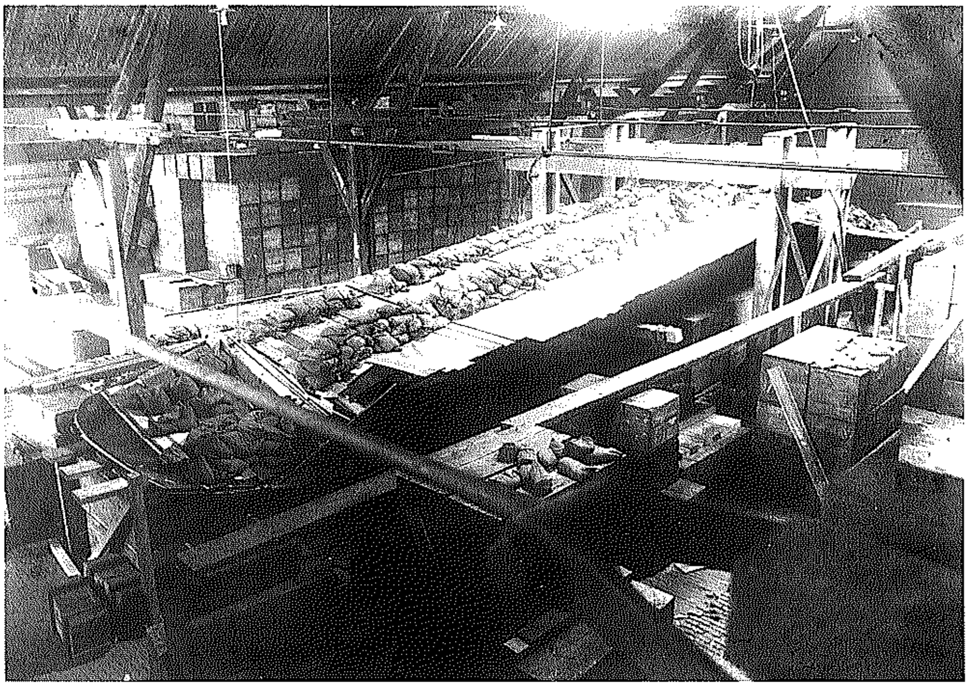
As mentioned in the preceding Chapter, the RSL was located in a building at the Navy Yard in Amsterdam. The building had two floors and in it were housed the Aerodynamics Department, the Materials Department and later also the Engine Department. The center piece was an Eiffel type wind tunnel.
Across the road there was another building with a workshop of the Materials Department, an Instruments Shop, part of the Engine Department, and a large hall for carrying out load tests on full-scale aircraft wings.

The Material Testing Laboratory
It must have been relatively easy for Dr. Wolff to plan the Materials Department with his background, (Chapter 29). He was aware of the methods of testing structures and materials. During the following years he managed to build up the laboratory with mechanical testing equipment that was available on the market.

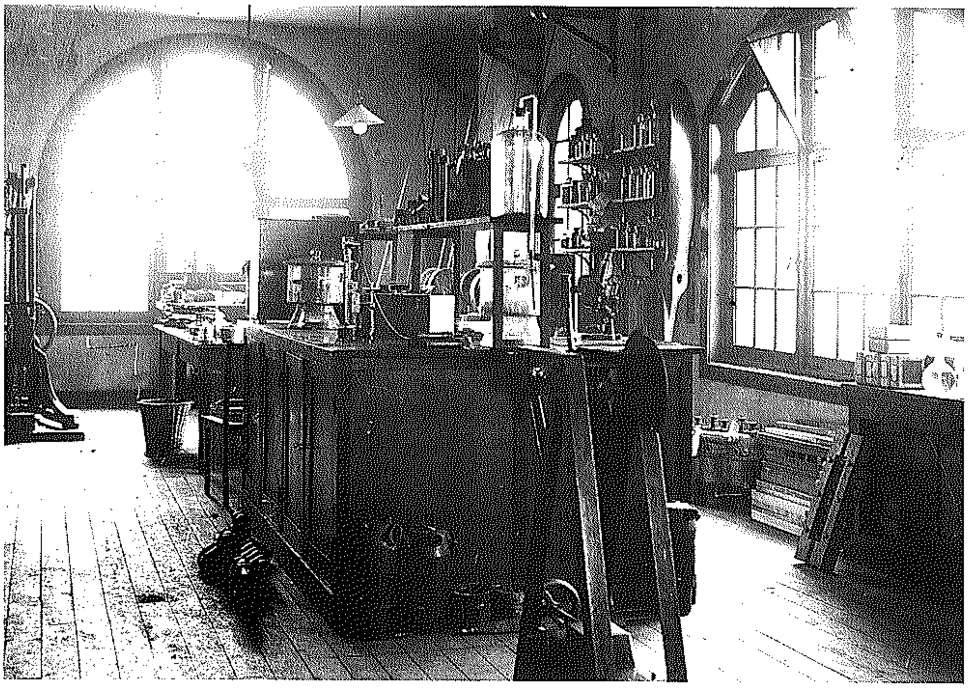
Full-scale structural static tests were carried out on e.g. wings by loading them with sand bags or lead weights.



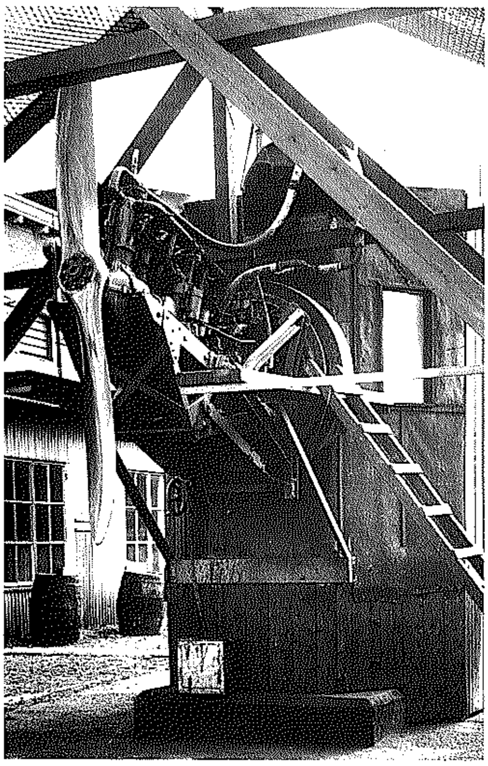
The Materials Laboratory of the RSL



Test on a wooden wing of a Fokker F.III aircraft



The Chemical Laboratory of the RSL



Aircraft engine and propeller mounted in the Engine Test Stand of the RSL

The Chemical Laboratory

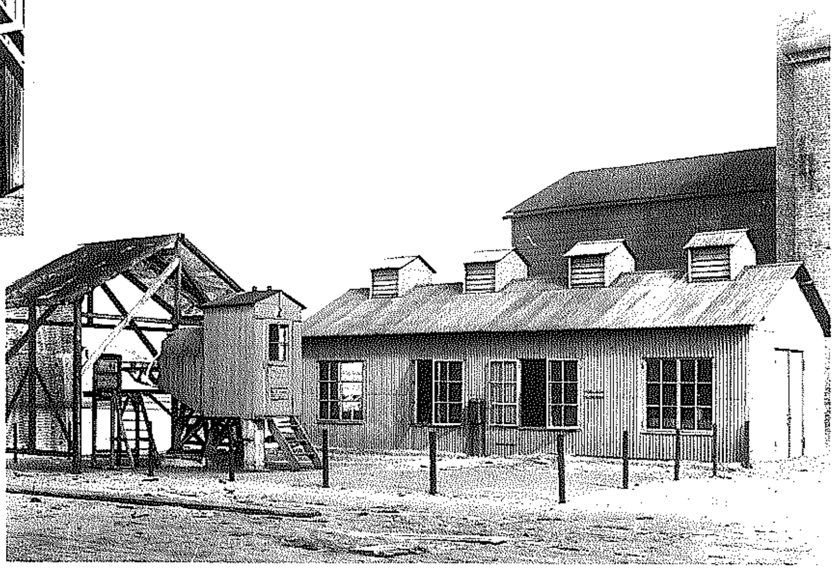
A laboratory for chemical analyses of materials was installed on the second floor.

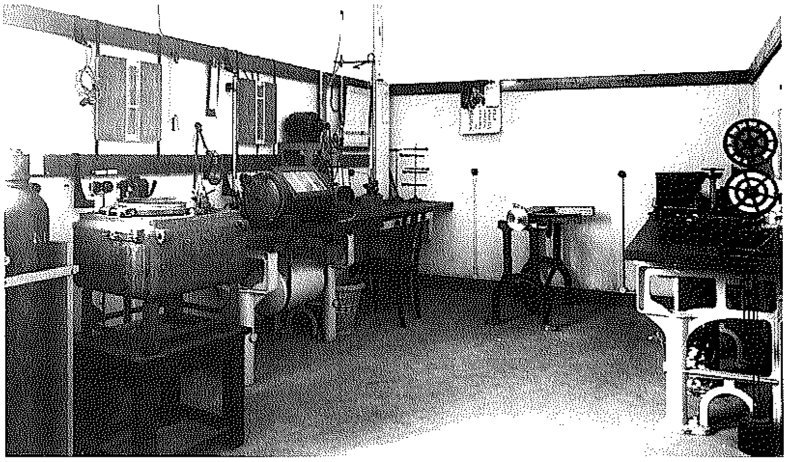
The Engine Test Stand

The engine test stand was located outside the main building. It was erected shortly after the official opening of the RSL. In Chapter 7, dealing with Propulsion, some of the engine test activities at the RSL are mentioned. By the time the laboratory was moved to the new building in 1940, these activities had been terminated for two reasons - lack of funds and reduced demand.

The Instrumentation Calibration Laboratory

In order to carry out the calibration of the special flight test and engine instruments, a calibration laboratory was started at an early stage.





Although now the aircraft operators and the aircraft industry have their own capability to calibrate most aircraft instruments, this activity has remained important to this day and in fact the laboratory is now officially accredited as a calibration laboratory for certain types of measurements.

The Flight Instrumentation Calibration Laboratory of the RSL

The Wind Tunnel

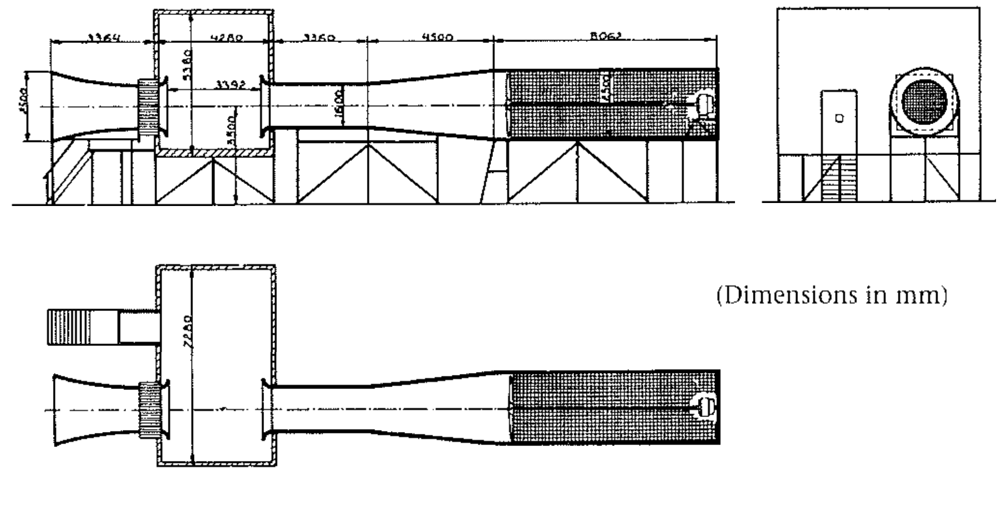
The construction of a wind tunnel was more complicated. Dr. Wolff had started the design in 1918 when he was still with Werkspoor. With the limited information available, he managed to produce an operational tunnel by March 1919 and it was shown at the official opening of the RSL on that famous Saturday 5 April 1919, the official birthday of the RSL, (Chapter 2).

The tunnel had an open test section and with a maximum power of 30 HP the mean velocity at the 1.6 meter diameter test section was 25 m/sec. However the uniformity of the flow across the test section was quite unsatisfactory and large fluctuations in time, 10 to 20%, occurred.

It was a wind tunnel of the Eiffel type - essentially a pipe with two open ends - that is the air was drawn from the room in which the tunnel was placed and it was exhausted into that same room at the other end. This contrasted with the so-called Göttingen type whereby the air is pumped around in a closed circuit. The latter type is more energy efficient and it offers better possibilities to produce a high quality uniform flow in the test section. The first closed circuit wind tunnel had been in operation at Göttingen, Germany, since 1908 (Prandtl's first wind tunnel), and presumably Dr. Wolff had some information on that facility, although he could not visit Germany in 1918. It must be assumed that he decided on an Eiffel type tunnel because of the size and limitations of the building and on the results published by Eiffel. Through this arrangement he achieved at least a facility of reasonable size and Reynolds Number.[2]

After detailed investigations of the flow in the wind tunnel were carried out, several modifications were introduced. A closed cylindrical test section was installed, the flow in the room around the tunnel was examined carefully and the room was modified and also the motor was replaced by a 50 HP unit. Apparently in 1919 there was no shortage of material anymore which had limited the size of the motor in 1918 as mentioned in Dr. Wolff's personal memoirs (see Chapter 29).

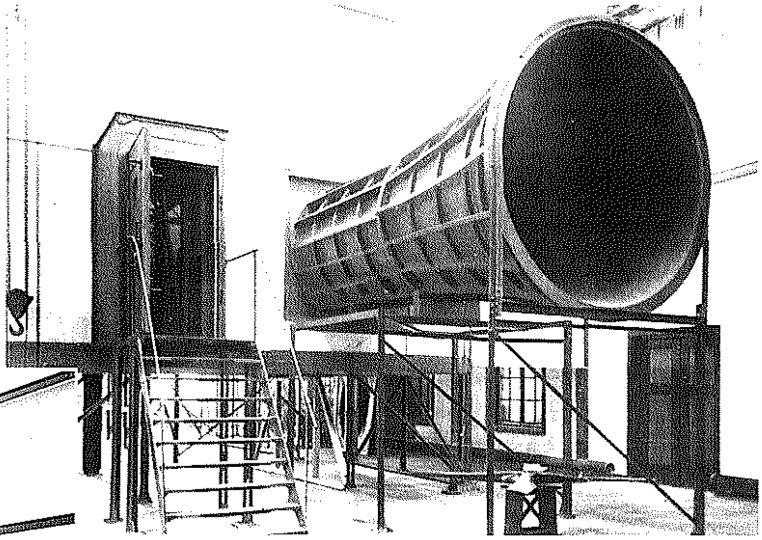
The original lay-out of the Wind Tunnel of the RSL



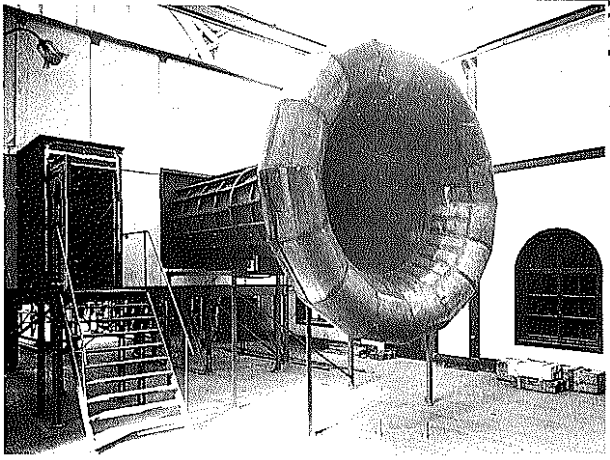
(Dimensions in mm)

[2] The Reynolds Number (air density x speed x a typical length of the model, divided by the viscosity of the air) is a measure for the similarity of the flow pattern around a model as compared to the full-scale aircraft. Wind tunnel data obtained at a Reynolds Number lower than in actual flight of an aircraft have to be extrapolated to the full-scale situation

The tunnel entrance of the RSL Wind Tunnel, around 1920

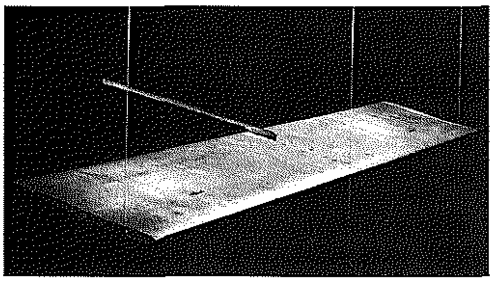


The modified tunnel entrance



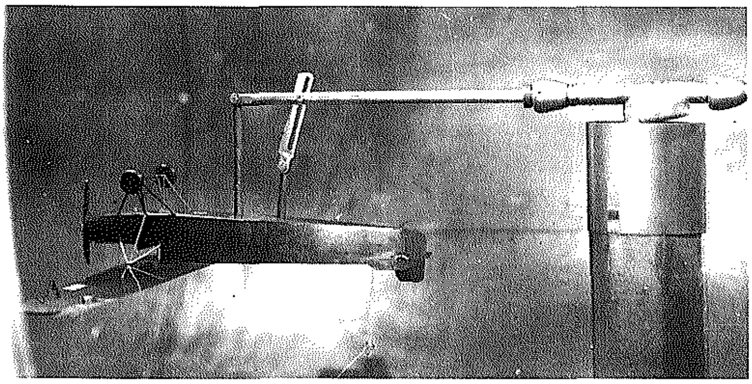
The result was that by July 1920 a fairly uniform and steady air flow of about 35 m/sec in the test section was obtained, [Ref. 16].
This tunnel was used extensively for a period of 20 years and apart from smaller research facilities which were built at the Technical University Delft, it was the only wind tunnel available for aeronautical development in The Netherlands till 1940.

The **validation of the measurements** carried out in wind tunnels was of great concern to the wind tunnel operators all over the world and in the early 1920's the Aeronautical Research Committee (ARC) in the UK initiated tests on a 'standard model' in different wind tunnels. The RSL participated in this exercise and carried out a test on a simple rectangular wing (an RAF 15 model) on loan from the ARC.
The model was, as all models at that time, suspended upside down with thin steel wires from the top of the test section and the forces were measured with external weight balances. It was concluded that the agreement with the British results was satisfactory, [Ref. 17].
This may well have been the first international cooperation in wind tunnel testing. It was the first exercise to compare the performance of test installations in aeronautics. Much later, under the auspices of the Advisory Group for Aerospace Research and Development of NATO, **AGARD**, standard wind tunnel models were developed in the 1950's which were used by the major wind tunnel operators in the world and in the 1980's complete jet engines were tested in various engine test stands, (see Chapter 7).
The AGARD Panels carried out similar comparative exercises with computational methods and structural (coupon) testing methods.



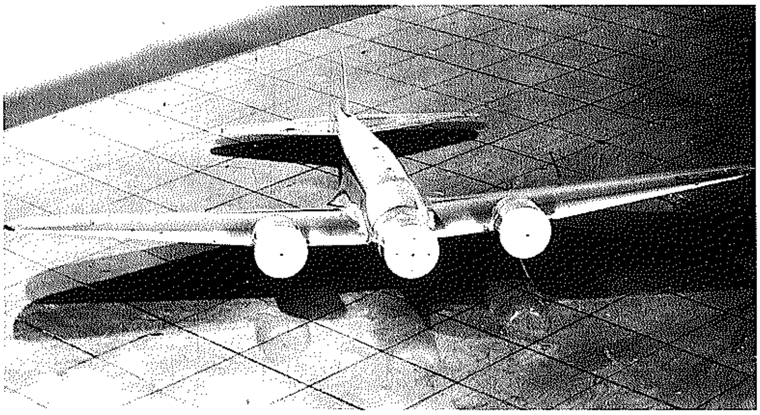
Test on an RAF 15 'Standard Wind Tunnel Model' in the RSL Wind Tunnel

During 20 years the wind tunnel was used for a **variety of aeronautical tests**. Some were related to actual aircraft design, some to project studies of Fokker and KLM, ideas of individuals, etc. Often the tests were

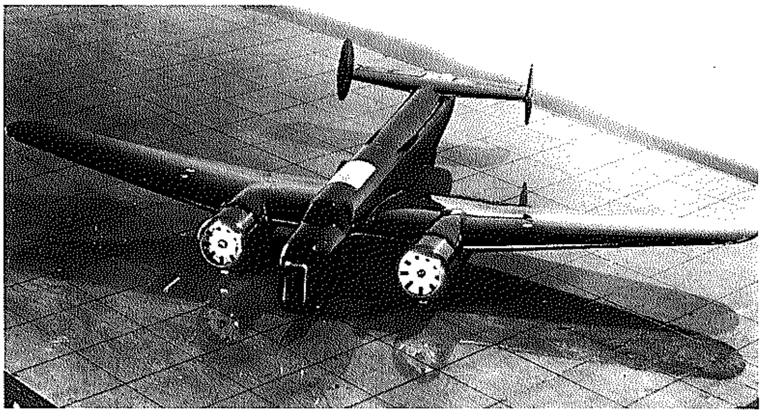


Model of a Fokker F.II mounted in the RSL Wind Tunnel

A wind tunnel model of the Pander 'Postjager', designed by Ir. Th. Slot for fast mail services to the Netherlands East Indies. In 1934 the 'Postjager' participated in the London-Melbourne race but met with an accident in Allahabad



A wind tunnel model of the Fokker T.5 bomber aircraft; first flight 1937

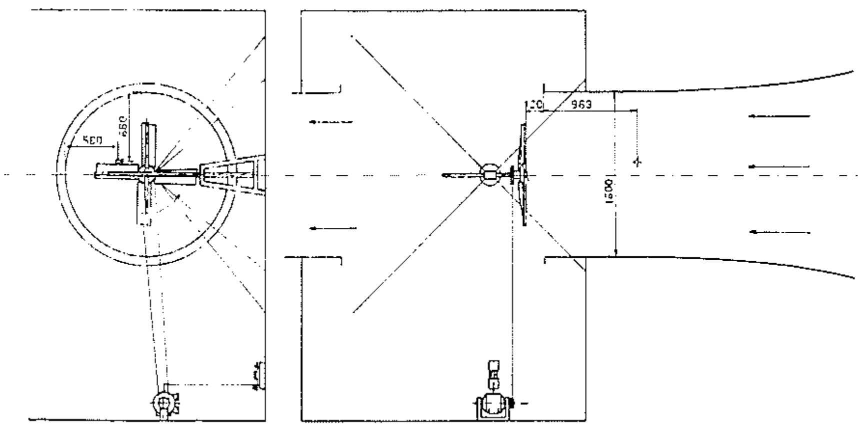


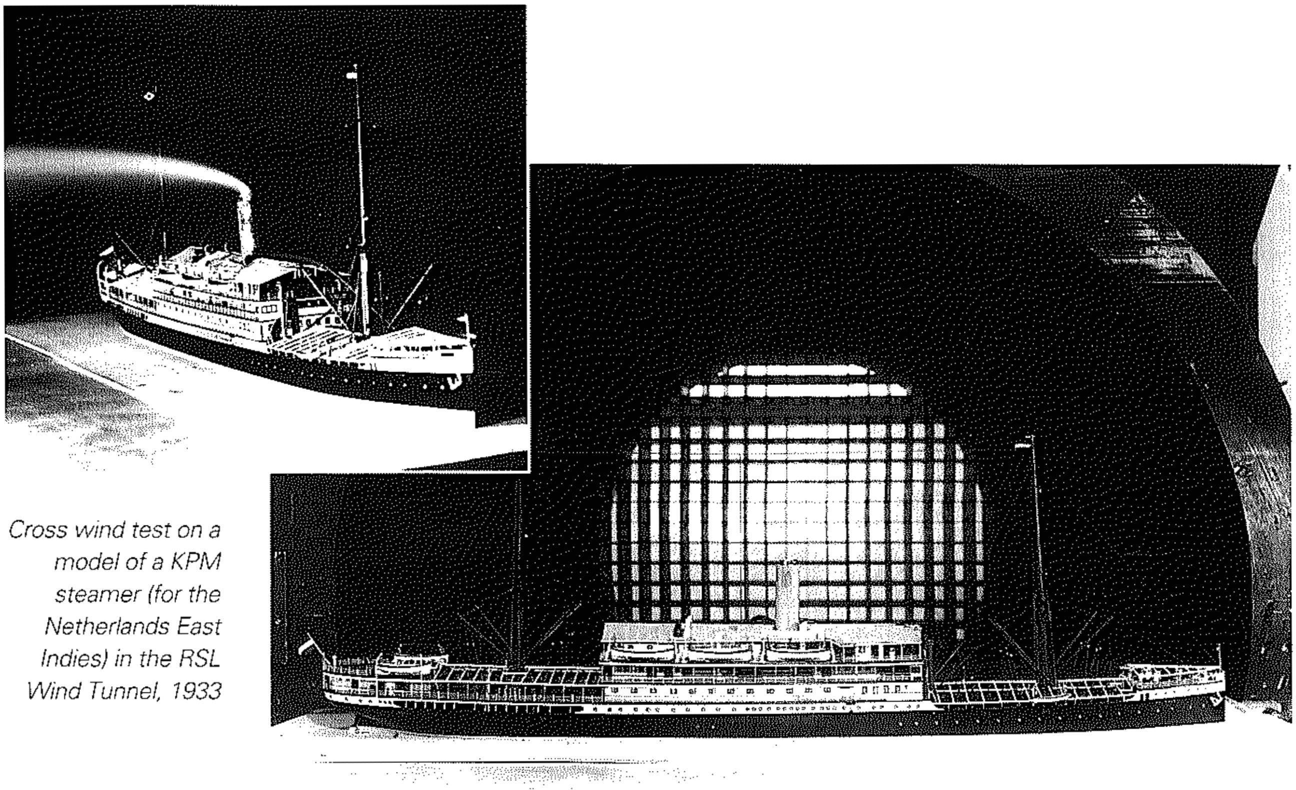
related to proposals for improvements of parts of aircraft such as cockpit wind screens, engine cowlings, radiators of liquid cooled engines, undercarriage drag, aerodynamic control surfaces (flaps, ailerons, elevator surfaces).

The tunnel was also used for **non-aeronautical tests**. As can be expected in The Netherlands there were many people interested in wind mills. In the 1920's and in the 1930's several wind tunnel tests were carried out on wind mills, at the initiative of both RSL personnel and others. The object was to study the aerodynamics of the wings of wind mills and to try to improve the efficiency. Without basically disturbing the original design of the 'Dutch Wind Mill' it was possible to increase the efficiency markedly by modifying the leading edge and the trailing edge as would be expected by aeronautical engineers.

One of the first tests, if not the first, dealing with the **wind climate around buildings** was concerned with improving the wind climate in a cattle market at Zwolle in The Netherlands; it was a covered building with open ends. The question posed in 1931 was: what is the effect of placing a fence near the open side of the building and what is the required height? A wind tunnel test gave the answer. Since that time many tests have been carried out on models of buildings, particularly high rise complexes, and urban city plans.

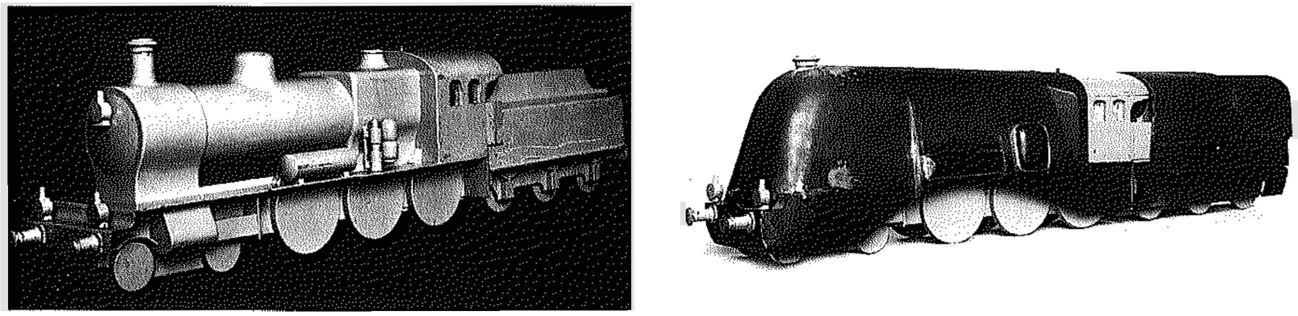
Sketch of a model of a Wind Mill, driving a dynamometer, mounted in the RSL Wind Tunnel, Period 1926-1929





Cross wind test on a model of a KPM steamer (for the Netherlands East Indies) in the RSL Wind Tunnel, 1933

In 1932 an engineer of the Sanitation Department of the City of Amsterdam asked for advice on reducing the nuisance of dust experienced by the operators of the city's garbage trucks during high winds. Such tests did not take much time but the results were rewarding to the personnel involved. The wind tunnel was also used for tests on models of ships, road and rail vehicles. Some examples are shown in the photographs.



Tests on a railroad engine, without and with streamline covers, 1935.
A reduction of 90 HP could be achieved at a speed of 100 KM/hr.

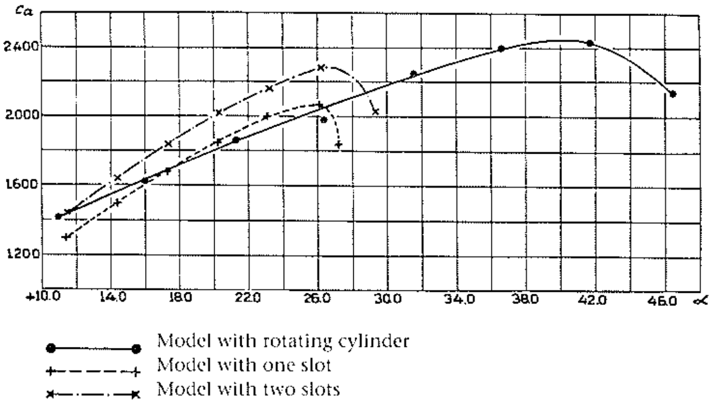
Examples of the Research Activities

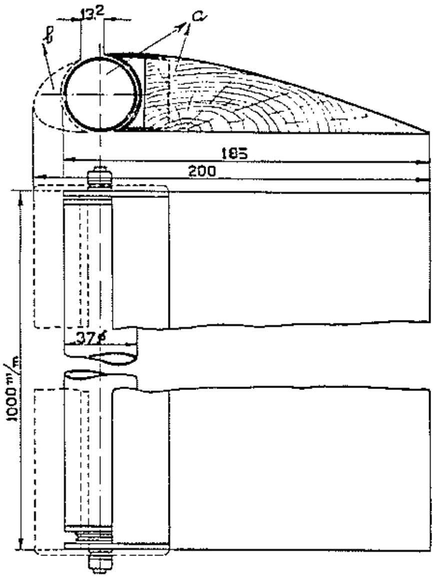
In 1929 Dr. Van der Maas read a paper before the British Royal Aeronautical Society, RAeS, [Ref. 18], in which he reviewed examples of the research activities of the RSL during its first ten years of operation. Some of these are:

Experiments on the effects of the wires employed to suspend models in the wind tunnel
The flow around the model in a wind tunnel is influenced by the presence of the test section walls and the suspension system of the model. This has been a subject of investigation almost continuously - and still is. Shortly after the RSL tunnel was put into operation it was discovered that the wires by which the models were suspended in the tunnel could have a great influence on the flow pattern around the model. Particularly the wires attached to the upper surface of a wing model appeared to affect the drag and lift forces. In one case the drag was as much as 40% too high and the lift between 12 and 40% too low. Considering the fact that the steel wires were very thin, this was very surprising but it alerted the staff to flow separation - triggered by the wires - at the upper surface of the model at relatively small angles of attack. Once this was recognized appropriate measures could be taken.

Airfoil model with a rotating cylinder at the nose; with and without a streamlining nose piece

Comparison of lift coefficients obtained with a rotating cylinder at the nose and with slotted wings





a. Model without nosepiece.
b. Model with nosepiece.

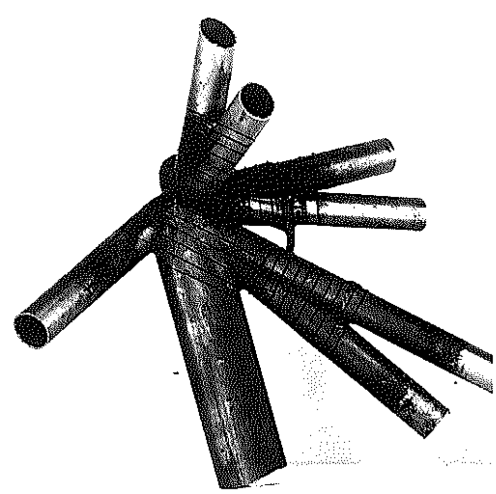
Unstable oscillations of a wing-aileron system

The unstable oscillations observed on a wing-aileron system led to the flutter investigations of Von Baumhauer and Koning, (see Chapter 9), explaining this phenomenon theoretically and experimentally and advancing the cure: mass balancing of the control surface. The results had been reported at the Air Congress, London, 1923.

Study of the influence of a rotating cylinder at the nose of an airfoil

Wolff and Koning investigated the effect of a rotating cylinder mounted at the nose of an airfoil, [Ref. 19 and 20].
It had been known for some time that by rotating a cylinder, placed in an air stream, cross forces are generated. However, the drag of such a cylinder is quite high. Wolff's idea was to improve the situation by placing a streamline body behind the cylinder and thus reduce the drag. The initial results were remarkable.
This first results were obtained with a model without a nose piece. More sophisticated tests, also supported by detailed boundary layer measurements carried out in Delft by Van der Hegge Zijnen, [Ref. 21], pointed towards the possibility to increase the lift substantially, be it then that the maximum lift occurred at rather high angles of attack (some 40°). It must be remembered that there were very few results available on airfoils with slots on the nose by which an acceleration of the flow close to the upper surface can also be achieved.
The rotating cylinder did not make it into practical applications but it stimulated detailed investigation of high lift devices. The results are still intriguing: with an (unswept) airfoil a lift coefficient of 2.4 was obtained at an angle of attack of 40°, comparable to the characteristics of modern delta wings. Airfoils with one or two slots reached maximum lift at 26°.

Example of a complicated joint of welded seamless steel tubing of the fuselage of a Fokker aircraft



Testing and validation of steel tubing

A specialty of Fokker was the use of seamless steel tubing in the construction of the fuselage. The testing of steel tubing for safety and reliability became an important activity at the RSL. Most airplane fuselage structures were made of wood and the authorities in the various countries had to be convinced that welded steel tube structures were reliable and safe.

Tests on the tensile and compression strength of various kind of steel tubing were carried out. A most important part was the investigation of the welding of steel tubing and the structural behavior of the often complicated joints.

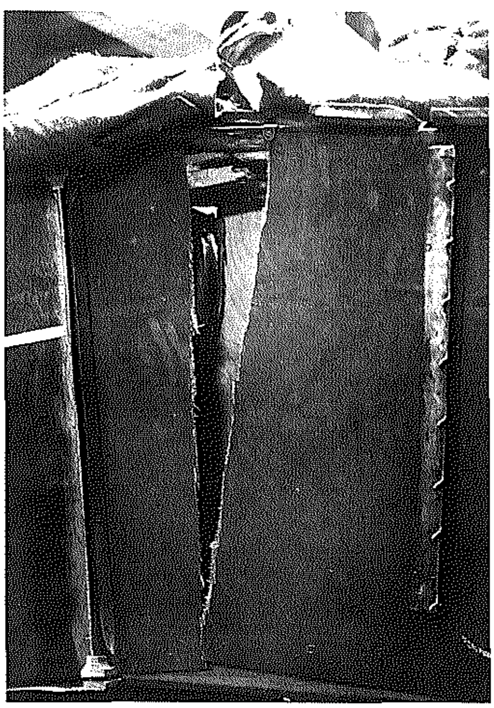
In this connection an investigation was carried out to check the airworthiness of Fokker C.I aircraft. This airplane had been in use with the Army Air Force for a long time. The fuselage of one of the aircraft was completely dissected; tensile and compression tests were carried out on all tubes and the welded joints were X-rayed, sliced and microscopically examined. No flaws were detected.

The structural strength of wings - effects of ribs and skin

Over a period of roughly ten years (1925-1935) a series of papers was written by Biezeno and Koch (Technical University Delft) and by Koning and Van der Neut (RSL) on the subject of the strength calculations of aircraft wings. The wooden aircraft wings consisted of two cantilever or semi-cantilever spars (beams) connected by ribs and covered with plywood sheets. Biezeno and Koch had, in cooperation with Koning, first developed a method to carry out stress calculations for such a wing without taking into account the effect of the skin. Then Koning developed the method further to include the effect of the plywood skin. Biezeno engaged Van der Neut, still a student, to carry out numerical calculations. But the RSL did not have the funds and so Fokker paid Van der Neut DGL. 150,- per month to carry out this task. That was a very high salary for a student!

After Van der Neut had graduated with Biezeno, he went to the RSL where he became the sole member of the Structures Group, directly responsible to Dr. Wolff, the Director of the RSL.

Suitable numerical methods were adapted and developed. The actual numerical calculations were very laborious and a group of young ladies, the Calculation Bureau, carried out the calculations mostly in tabular form using mechanical hand calculators.

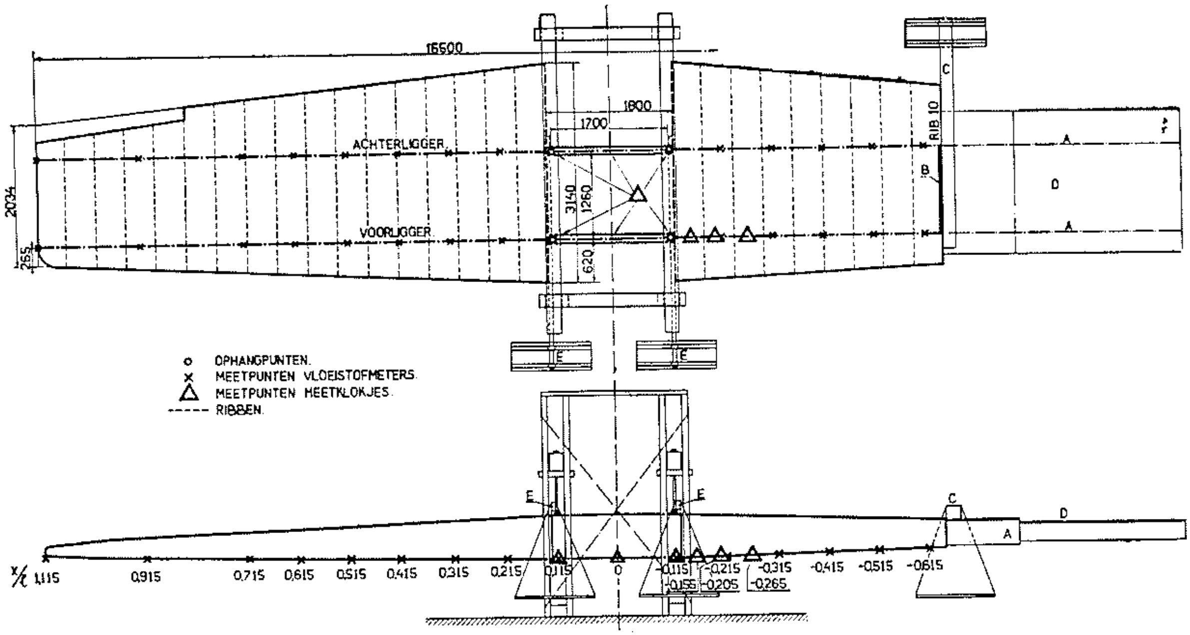


Structural failure of the front spar of the Fokker F.III wing

The analytical and numerical methods developed were meant in the first place for application in the industry, but the RSL also received many requests to carry out numerical strength calculations for the Airworthiness Authorities, the Armed Forces and KLM. During this period there were never more than two to four engineers available who could carry out such calculations[3].

This multi-year program also included experimental verifications of the calculation methods. Tests were carried out on three wings which were obtained from KLM and Fokker. A not unimportant detail was that is was not easy to obtain wings for structural testing. When an aircraft crashed, the wing was often not too badly damaged and it was repaired and mounted on another aircraft.

[3]Prof. Van der Neut later said that he was constantly asked to carry out ad-hoc calculations and that he never had enough time to carry out more basic research, but he did also remark that it kept him on the right path: he learned to look for practical applications. This experience served him very well when he became Professor of Aeronautical Engineering, specializing in structures, at Delft in 1945.
During the Second World War, when there was more time for research, he had together with Plantema, Koiter, Legger and Potma, contributed to the first post-war Technical Handbook (Technische Vraagbaak), [Ref. 22]. This was an important publication for the engineering community in The Netherlands at that time.



Test rig for the HN-ABU Fokker F.III wing with dummy structure on the right

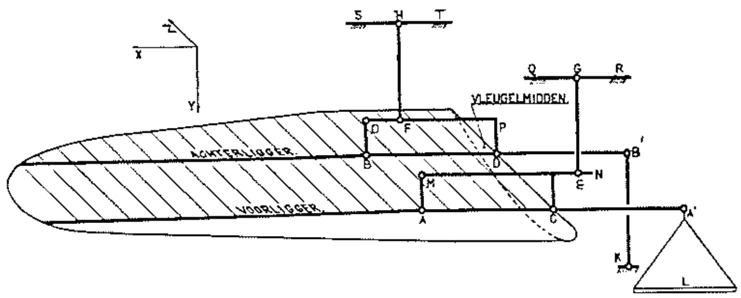
A summary of this extensive series of structural tests is given in [Ref. 23]:

1928 The first full-scale test was carried out on a wing of the Fokker aircraft HN-ABI (type F.III, Siddeley Puma engine). The aircraft had been built in 1921 and was written off after a crash at Hamburg in 1925. The total number of flight hours accumulated was 2015. The undercarriage was destroyed and the cabin heavily damaged but the wing was only slightly damaged on the outside. The load on this wing, mounted upside down, was gradually increased till the ultimate load was reached and it broke at 7.5 times the design load.

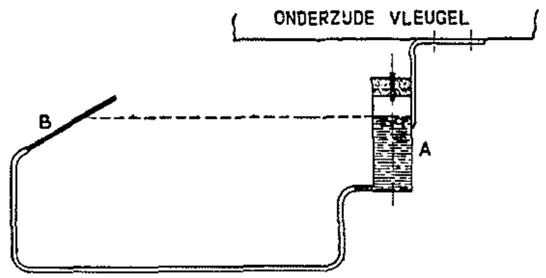
1932 The second test took place on a similar wing of the Fokker aircraft HN-ABU (type F.III, Rolls Royce engine). This aircraft was built in 1922 and had crashed at Schiphol in 1928. Since part of the wing had broken off, a dummy structure was added with which the bending moment and the torsion loads were applied at the station where it broke, so that a symmetrical load condition of the wing was achieved.

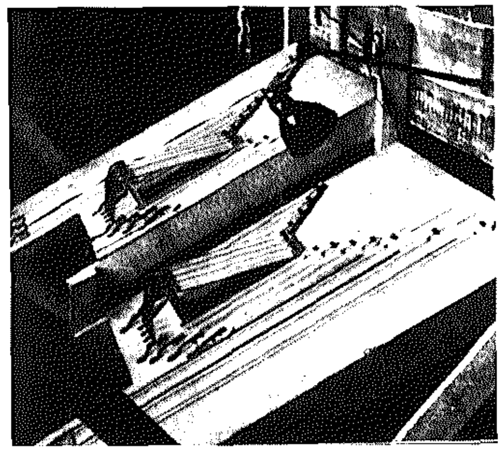
1933/1934 The third test of this program was on a wing of a Koolhoven airplane PH-AIL (type FK-43). This was a smaller wing (11 meter span against 16.50 meter span for the Fokker wings) and the

The loading system for the wing of the PH-AIL Koolhoven FK-43 aircraft



System for measuring accurately the local deflection of a wing

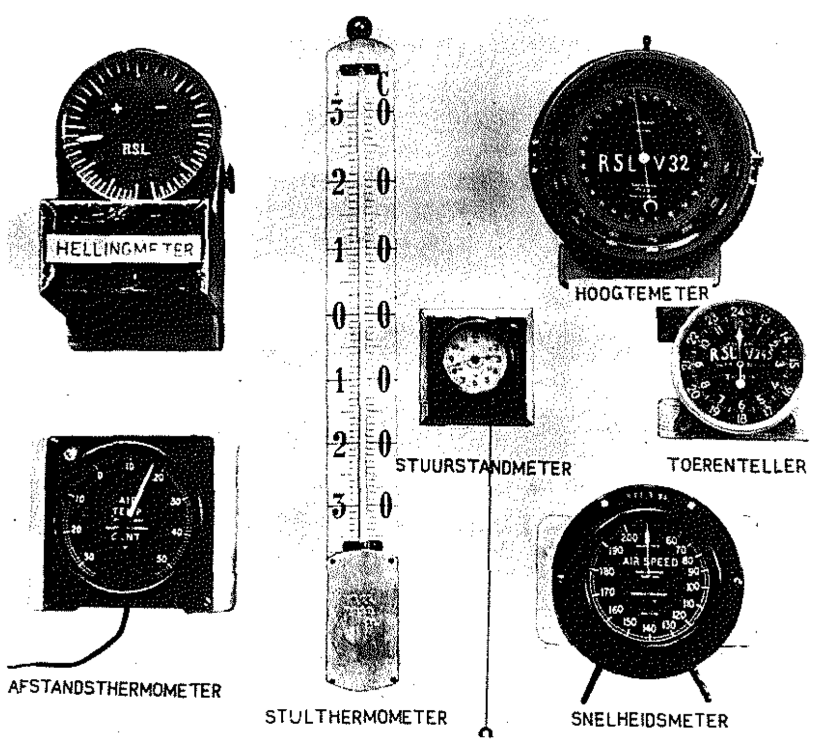


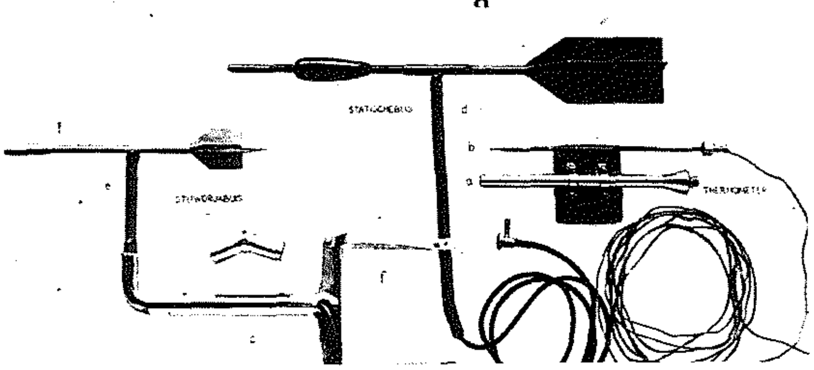


test was more complicated in that it was a semi-cantilever wing, requiring a special loading system to simulate the effects introduced by the supports.

During the last two tests in particular, accurate displacement measurements were made along the wing span to determine the deflection of the wings. The calculated bending and torsion of the wings agreed very well with the measurements.

A variety of instruments used in flight testing





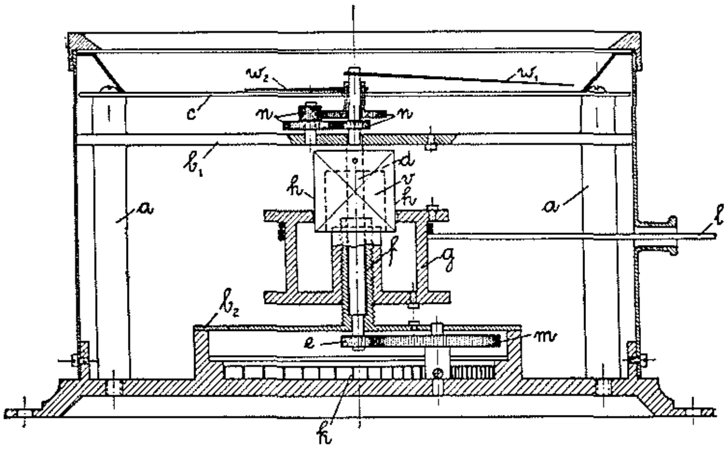
Measurement Techniques

Since there were relatively few instruments on the market to carry out the various measurements and since the funds available were very limited, the instrumentation was often developed in-house.

An interesting example is the **method of measuring the displacement** of the wings during the load tests described above. This was done by attaching small reservoirs with water to the wing at various stations along the span. These formed legs of U-tubes (communicating vessels), the other ends of the tubes were grouped together on a board. By adjusting the inclination of this board the sensitivity was adjusted.

The **flight test instrumentation** - and of course the calibration of the instruments - required much attention. A collection of flight test instruments used during the stability tests series, mentioned in Chapter 6, is shown.

These were instruments used in the 1920's. The picture shows a Pitot tube for measuring the total pressure, a static pressure tube towed by the aircraft and a thermometer for measuring the outside air temperature. The drawing on the next page shows an instrument developed by Von Baumhauer to measure the stick position and through this the elevator

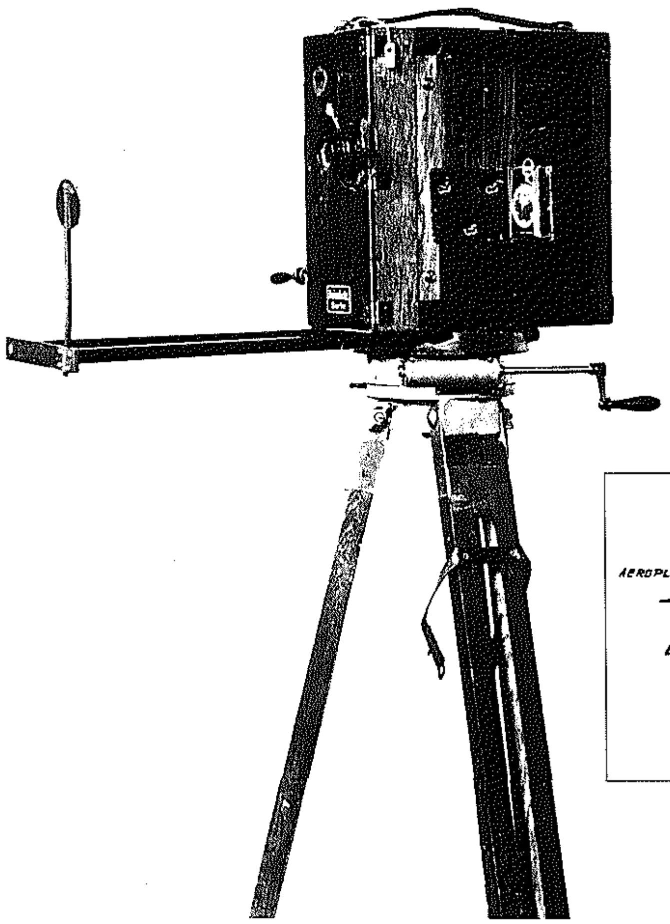


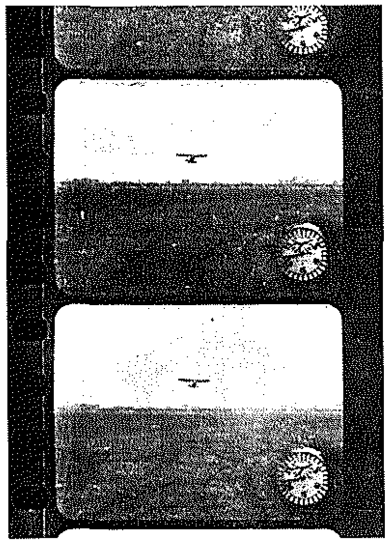
A dial instrument developed by Von Baumhauer to measure the aircraft control stick position

angle. With normal elevator linkage an accuracy of better than 0.2° in elevator angle could be achieved. Von Baumhauer also developed a (manually driven) movie camera for recording the flight path during take-off and landing trials, [Ref. 24].
By photographing a watch (reading seconds), mounted externally on the camera, and using the known wing span as a reference, the distance from the camera to the aircraft and the altitude were determined from each of the pictures.

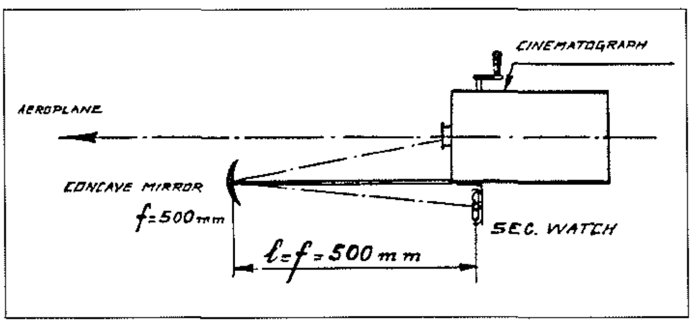
This same basic method, later refined and with modern film readers and data handling equipment, was successfully used till about 1960.

A movie camera developed by Von Baumhauer to record the flight path from the ground





Movie pictures



Schematic of the movie camera

Propeller Slipstream Wing Interference

With the advent of multi-engine aircraft the influence of the propeller slipstream on the characteristics of the wing became important. Koning published several papers on the aerodynamic properties of propellers operating in the close vicinity of a wing. His approach to this problem drew international attention and in 1934 he was asked to summarize the state of the art of this important subject and contribute to the six volume standard work 'Aerodynamic Theory', edited by W.F. Durand,[4] [Ref. 25]. This is still a classic reference on this subject. It was not till the Fokker 50 was designed (1985-1987) that more sophisticated methods were available. By then meaningful aerodynamic data on the interference of propellers and wings could be obtained by CFD (Computational Fluid Dynamics) methods. An example was presented at an AGARD meeting in 1991, [Ref. 26].

Preparations for the New Laboratory (NLL at the Sloterweg in Amsterdam)

As mentioned earlier, when in 1918 the RSL was planned, the location at the Navy Yard in Amsterdam was meant as a temporary site only. Prof. Van Royen intended to establish a permanent laboratory in Delft, in close association with the Technical University. However the University was apparently not too eager to accommodate the RSL. This may have been caused by the problems encountered in the 1920's after the transfer of the RSL from the Ministry of Defense to the Ministry of Public Works. Also, flight testing had become an important part of the activities and several people felt that a location close to Schiphol and Fokker (the factory was still located at Amsterdam-North) was more important than being close to the University of Delft.

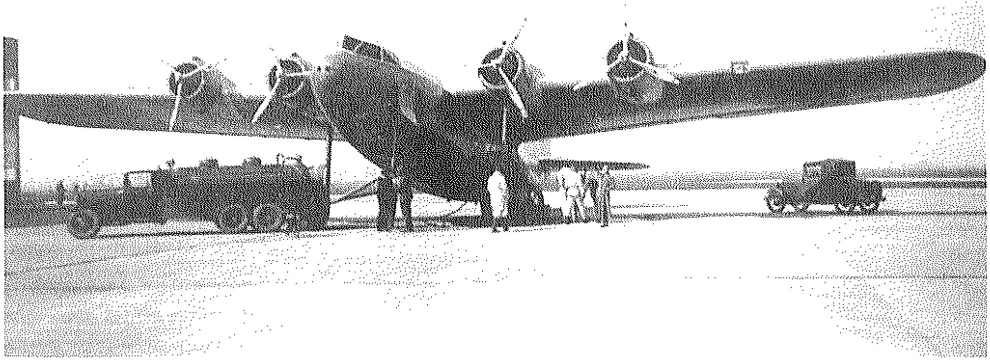
In the meantime Wolff and Koning carried out studies for new wind tunnel facilities. There were several reasons why the old RSL wind tunnel with a 1.6 meter diameter test section and maximum speed of 35 m/sec was not adequate anymore to meet the requirements of that time. In a paper published in 1935, [Ref. 27], they stated that the main shortcomings were:

- in a number of cases the details of the models were too small;
- the force differences due to configuration changes could often not be measured accurately enough;
- the available model motors to drive the propellers were too large and could not be used for multi-engined aircraft models; a model engine could only be accommodated in the fuselage where enough space was available for model motors with the required power;
- tests on many full-scale aircraft parts could not be conducted due to the size of the tunnel.

They realized of course that Reynolds Numbers close to 25 million would be required to obtain results directly comparable to full-scale. That was the Reynolds Number for the Fokker F36 at maximum speed, an aircraft which had been defined in 1932: 32 passengers, 4 crew, span 33 meter and indeed a very large aircraft for that period.
The largest wind tunnels were the American 'full-scale' tunnel at NACA with a 30x60 ft^2 (9.1x18.3 M^2) test section and the French tunnel at Chalais-Meudon with a test section of 8x6 M^2 which was under construction. However even for those tunnels the Reynolds Number was only 7 to 9 million.

For a given size tunnel the Reynolds Number could also be increased by operating with compressed air in the closed tunnel circuit. There were two pressurized tunnels in operation, one at NACA in the USA and one at the National Physical Laboratory, NPL, in the UK. These tunnels were providing much basic information on Reynolds Number effects and the whole aeronautical community profited from their publications (the maximum Reynolds Number of the NPL tunnel was 11.2 million).

[4]Another author from The Netherlands contributing to this series was Prof. J.M. Burgers of the Technical University Delft who wrote with Prof. Th. von Kármán the second volume: 'General Aerodynamic Theory: Perfect Fluids'. The Durand series was sponsored by the Guggenheim Foundation, USA. Interestingly enough the books were first published in Germany; there was little interest in the USA for the subject. That situation changed drastically during the following ten years!



The F36 was conceived after KLM had been very successful in operating the Amsterdam-Batavia (Jakarta) route during the early 1930's - in spite of the world-wide economic crisis.
Anthony Fokker and Albert Plesman had a meeting on 6 June 1932 from which this design finally emerged. The aircraft flew for the first time on 22 June 1934. Although a very impressive aircraft, it was never adopted by KLM for the Far East route. The aircraft was designed along the well proven lines of Fokker, i.e. wooden wings, a fuselage of steel tubing, covered with linen and a fixed undercarriage with very large wheels (1.78 meter diameter) for operating from soggy, unprepared airfields along the route to Batavia. The range was however shorter than that of the DC-2 and the DC-3 and KLM switched to the all-metal aircraft of Douglas.

Based on their studies and keeping in mind the financial limitations with which they would be faced, Wolff and Koning decided on a 3x2 M^2 facility which was large enough to test models with a fair possibility to scale properly the geometric features and to accommodate electric model engines capable of producing enough power to simulate powered aircraft flight in the wind tunnel and a smaller, 1.5x1.5 M^2 tunnel for research purposes and non-aeronautical wind tunnel testing. As a result two closed circuit type wind tunnels were built in the new laboratory:

	The LST 3x2 M^2	The LST 1.5x1.5 M^2
Power	600 HP	60 HP
Maximum speed	80 m/sec	40 m/sec
Reynolds Number/meter	5.2 million	2.6 million

These facilities became operational in 1940. They were the main low speed aerodynamics facilities for over 40 years till the German-Dutch Wind Tunnel, the DNW (the joint venture with the German sister organization DLR, (Chapter 18), became operational in 1980, followed by the LST 3x2.25 M^2 of NLR, both in the Noordoostpolder.

There were several other activities in connection with the new laboratory such as the preparation of an extended Structures and Materials laboratory, a laboratory for the Flight Department for calibration and instrumentation of flight test equipment, and a modern Instrument and Machine shop.

Evaluation

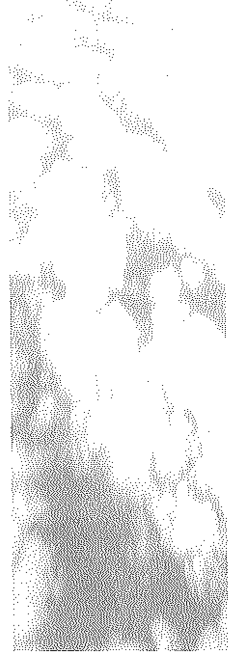
How to evaluate this period of the RSL - 1918-1937? It was essentially the period (1919-1939) between the two World Wars.

It was certainly a small effort compared to the current activity of NLR. Roughly 500 man-years were spent at the RSL during this twenty year period, that is about half the capacity that is now

available at NLR per year. It was however the period in which aeronautics became of age. The activities in other countries were comparable, taking into account the size of the countries. An exception was Germany, where during the 1930's an enormous growth in aeronautical research took place. But for instance the total number of NACA employees was 500 in 1939 while NLL had 84 employees, which was a good ratio considering the relative size of the countries.
NACA produced much basic aeronautical design data of significant scope. The RSL never was in a position to carry out elaborate systematic tests on e.g. airfoil shapes; it had to confine itself mainly to direct support of aeronautics in The Netherlands. Fortunately, most of the (few) RSL research engineers produced papers of a more fundamental engineering importance which were well received by the international community.

Based on the foundations laid by this small group it was possible to build up a significant aeronautical research activity after the Second World War, in spite of the fact that NLL had missed the impetus gained by the war activities. With confidence it can be stated that without the ground work and the tradition established during the RSL period, it would have been almost impossible for NLR to achieve the present status in the aeronautical engineering sciences.

4. The Second World War Period



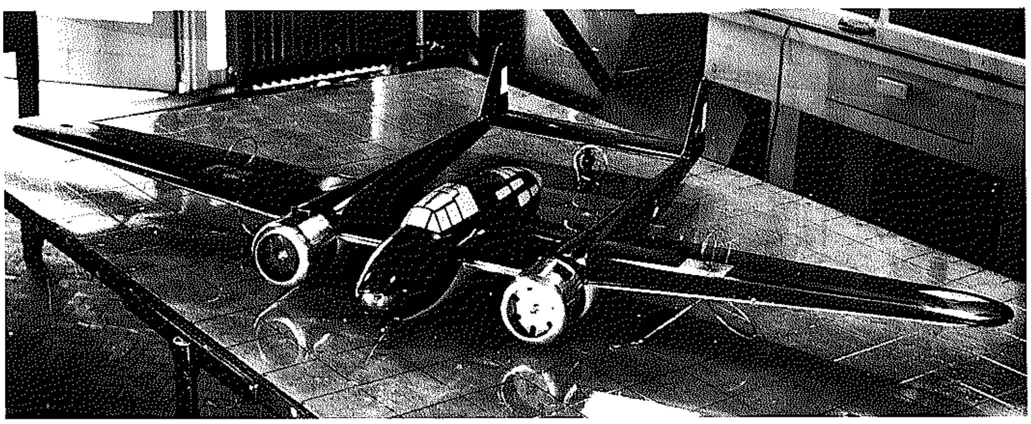
Before tracing some of the events at the NLL during World War II a few general remarks should be made.
This is the most difficult period of the 75 years of history of the laboratory to report. The Annual Reports are 'cryptic' and do not give much detail. A complete and balanced account of this period would have to be produced by a professional historian and that is certainly outside the scope of this book. Only some of the events and achievements are related in this Chapter and it does not do justice to those who carried the laboratory through this trying period.

On Friday 10 May 1940, before daybreak, Nazi-Germany moved its war machine Westward. The war in The Netherlands lasted only a few days and subsequently the country was occupied by Nazi-Germany.
Commencing September 1944 parts of The Netherlands were liberated. The occupation of the Western part, including Amsterdam, ended with the capitulation of the German forces on 5 May 1945.
The history of the Second World War has been described extensively in the literature. Although The Netherlands was in a state of mobilization since August 1939 at the beginning of that war, it was not very well prepared. During the First World War The Netherlands had managed to stay neutral and the government policy was again to stay neutral. There were of course several politicians who predicted that this war was different and that The Netherlands would be involved.

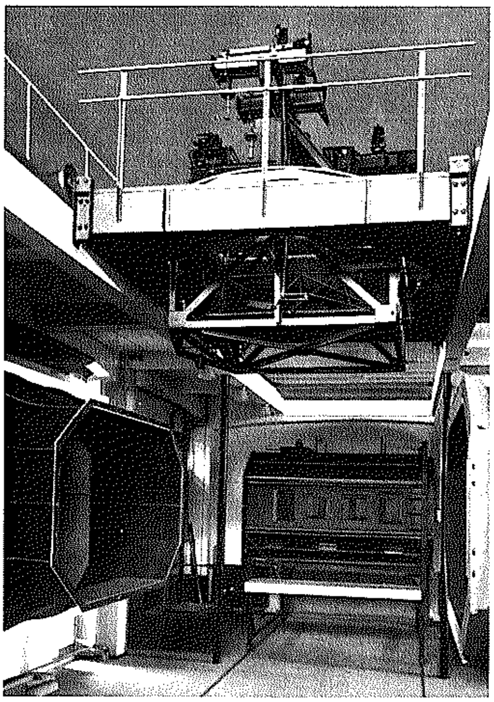
The Army Air Force

Although not part of the history of NLR it is noted here that on 10 May 1940 the Army Air Force had 194 aircraft in flying condition of which 144 were suitable for aerial combat. During the surprise attack of the German Air Force 44 aircraft were lost on the first day, including a large fraction of the 23 Fokker G-1's, the advanced twin-engined, twin-tail fighter-bomber.

The Netherlands armed forces were no match for the well-trained massive German forces. Nevertheless Germany lost 350 aircraft during this five-day battle including 224 Junkers Ju-52 transport planes. This was a factor in reducing the chances to carry out a successful 'Blitzkrieg' invasion of the UK as seemed to be the original idea, [Ref. 5].



Wind tunnel model of the Fokker G-1 fighter aircraft. The Fokker G-1 was first exhibited at the Paris Airshow in 1936



The Move to the New Laboratory

The NLL laboratory was located at a Navy Yard in Amsterdam. The new laboratory was under construction on the outskirts of Amsterdam-South, on the road to The Hague. The building was far from complete; the construction had been interrupted from 15 December 1939 till 26 February 1940 due to adverse weather conditions. The Navy Yard was a potential military target and it was decided on 10 May to move valuable documents and instruments immediately to the basement of the new laboratory building.

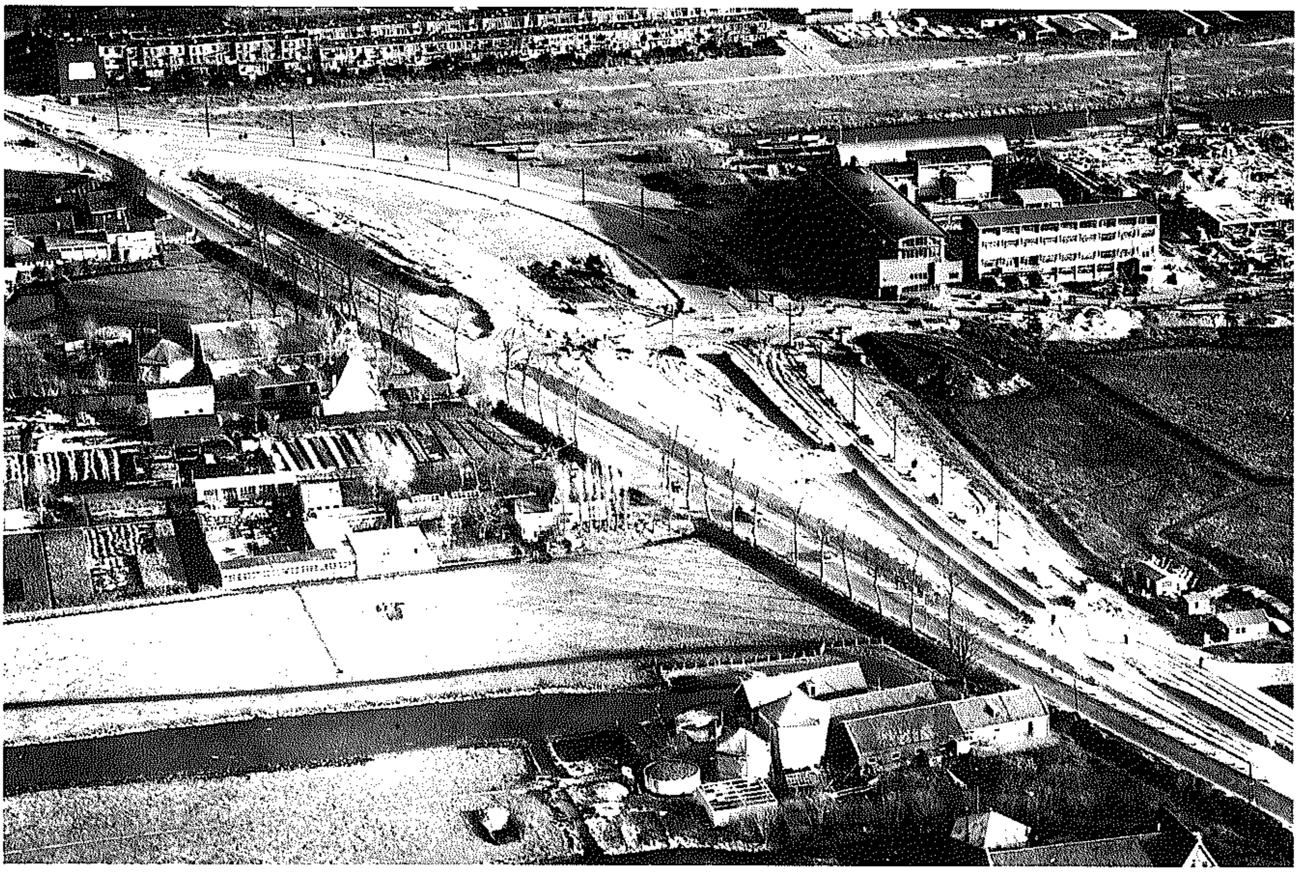
The construction of the building was completed shortly after the move. The building included the low speed wind tunnel with a test section of a 3x2 M² and the smaller tunnel with a 1.5x1.5 M² test section. These were both constructed out of reinforced concrete and were integral parts of the building. The commissioning of the first tunnel started on 17 June 1940 and the operation of the second tunnel began on 29 November of that year. By the end of 1940 the new laboratory was in full operation.

The NLL Low Speed Wind Tunnel 3x2M² in open test section configuration

The immediate effects

From the records and the accounts it appears that in mid-May 1940 it was the intention to continue with the activities as planned as much as was practicable. There were however several important changes: all investigations related to military projects stopped and the development of civil aircraft in The Netherlands was suspended. Nevertheless, activities related to civil aeronautics, the development of equipment and measuring techniques and studies related to future civil aircraft were continued as far as possible. Flight testing with the laboratory aircraft, a Fokker F.VIIa, had to be discontinued. The aircraft was hidden, (see Chapter 6).

Aerial view of the NLL at the Sloterweg in Amsterdam



On 18 May 1940 Mr. Käufl of the Aerodynamische Versuchsanstalt, AVA (Aeronautical Research Laboratory) Göttingen and Mr. Wernitz of the Reichs Luftfahrtministerium, RLM (Ministry of Aviation) visited the new laboratory. They expressed their wish to maintain the laboratory. Mr. Käufl was appointed liaison officer ('Beauftragte') for the German authorities. During the summer of 1940 Prof. Betz and Dr. Engelbrecht of the AVA visited NLL and initiated discussions on future work. It was their intention to involve NLL in their long-term scientific research efforts. NLL was to be excluded from research directly connected with the war effort. Their interest was focused on experimental aerodynamics and basic research in structures. The NLL equipment was well advanced and particularly the investigations related to flutter problems and the possibility of developing equipment for unsteady aerodynamic measurements drew the attention of the Göttingen group.

The advantage (if 'advantage' is a proper word in this connection) of the arrangement with AVA was that NLL was declared a 'protected' organization which meant that the employees were given permits excluding them from being drafted for work in the German industry. This protection was also extended to some of the personnel from other institutions who could either be formally employed by NLL or incorporated in a list of indispensable personnel.

A personal account

Prof. Van der Neut, who was employed at NLL till 1945, when he became Professor of Aeronautical Engineering at the Technical University Delft, later recalled some of his experiences, [Ref. 28]:

> *-"We spent most of our time on our own research and the majority of our reports were related to that. From that point of view the occupation period was a fine time for the researcher, without the less interesting ad-hoc type projects associated with the airworthiness of airplanes. In fact as I write this I am feeling guilty at having enjoyed that period as far as my scientific work is concerned, while many others lived in a state of great despair (...) The work on German contracts implied the risk that the results would benefit the enemy, in spite of the original intention expressed by AVA. When it seemed that an investigation would clearly benefit the German war effort (wind tunnel tests on a specific aircraft model), Koning, the Director, contacted Prof. Betz of AVA. Koning and Betz had known each other for a long time and had had friendly scientific contacts for many years before the war. Prof. Betz understood the problem. He canceled the contract and issued the following guidelines for contracts with NLL:*
> *- If the subject was of eminent importance for the war effort it should not be let to NLL since the Dutch were not to be trusted,*
> *- If the contract had no direct bearing on the war or if it was of a more general nature, it could be granted to NLL and it should be labeled 'Kriegswichtig' (important for the war).*
> *This agreement was not recorded but the important factor was that the AVA adhered to it."*

Prof. Van der Neut recalled that one rather large contract with AVA was concerned with the experimental determination of the torsion stiffness under fluctuating torsion loads of a mono-spar Me-109 wing with reduced skin reinforcements. He concluded that the major result was that two Me-109 wings could not be used during the war.

One of Prof. Van der Neut's own research projects was concerned with theoretical investigation of the stability of cylindrical shells, with longitudinal and circular stiffeners, under axial loads. He found this very interesting and he thought this was one of his best pieces of research. When he obtained this contract he believed that the only aeronautical application would be for the fuselage of very large transport airplanes. One of the conclusions of this work was that external stiffeners were far more effective than internal ones but this did not seem practical for aircraft. Later he understood that his work would have been very applicable to the V-2 missile. During an AGARD meeting in the US (probably in 1956) he paid a visit to Huntsville, Allabama, USA, where he met the designer who had worked at Peenemünde in Germany, the site where the V-2 was designed, and asked if his

Ir. C. Koning
1893 - 1952

reports had been consulted. To his relief Prof. Van der Neut learned that the design had been frozen in 1942, before his work was completed.

The personnel

Although the total contract work-load of the laboratory decreased dramatically during the five years of the war, the personnel increased by 40%! Obviously the laboratory served as a 'legalized' hiding place. Another factor contributing to that effect was also that the efficiency of the operation dropped very much as it did in the country as a whole.

The combined Annual Reports of NLL over the years 1944 and 1945, published in 1946, give a summary of the events during the period of 1940-1945.
Unfortunately the information is very limited. In retrospect this is perhaps not very surprising. Immediately after the war the emphasis was on the future - the re-construction of the country.

The laboratory, being a technical institute, carried out many jobs for resistance groups, mostly related to the maintenance and repair of weapons. Initially this was done at the workshops after regular working hours. Later, when road checks became more frequent, the activities were moved to a factory in the Haarlemmermeer and instrument technicians and machines of NLL were made available.

Dr. Wolff had been seriously ill since December 1939 and on 1 August 1940, when it had become clear that he would not be able to resume his work at the laboratory, the Board appointed Ir. C. Koning as Scientific Director and Mr. J.L. Chaillet as Commercial Director.

Several employees became actively involved in the underground resistance. One of those was Mr. Chaillet. He became a member of a national resistance committee, [Ref. 29]. This committee generated ideas and distributed pamphlets to civil servants and managers in industry, including the Railways, on how to avoid effective work for the German occupational forces. He was arrested on 12 April 1944 and jailed in Amsterdam, moved to Vught and later deported to the concentration camp Sachsenhausen in Germany. Fortunately he returned after the war.

Several employees were arrested and jailed for some time. Dr. Wolff, who was Jewish, died on 7 February 1941, just before the massive persecution of the Jewish populations began. The young engineer A. Spits and the designer H. Groen who were also Jewish, were imprisoned and transported to Germany. They did not survive.

At the end of August 1944 the AVA liaison officer was called back to Göttingen. In the combined Annual Reports over the years 1944 and 1945 it is stated:

> *-"At the end of August the 'Beauftragte', Mr. Käufl, was called back to Göttingen. He left on 4 September 1944, but he came back on 18 September for a day to arrange some business. On behalf of the RLM (Ministry of Aviation) he took with him some equipment that had been ordered by the AVA Göttingen and manufactured, partially by NLL and partially by the industry. This departure was seen as a sign of the changing circumstances and it was welcomed with joy. It must be admitted that, during the period this man was charged with the liaison of NLL and the German authorities, he did his best to maintain the laboratory and prevented foreign intervention as much as possible."*

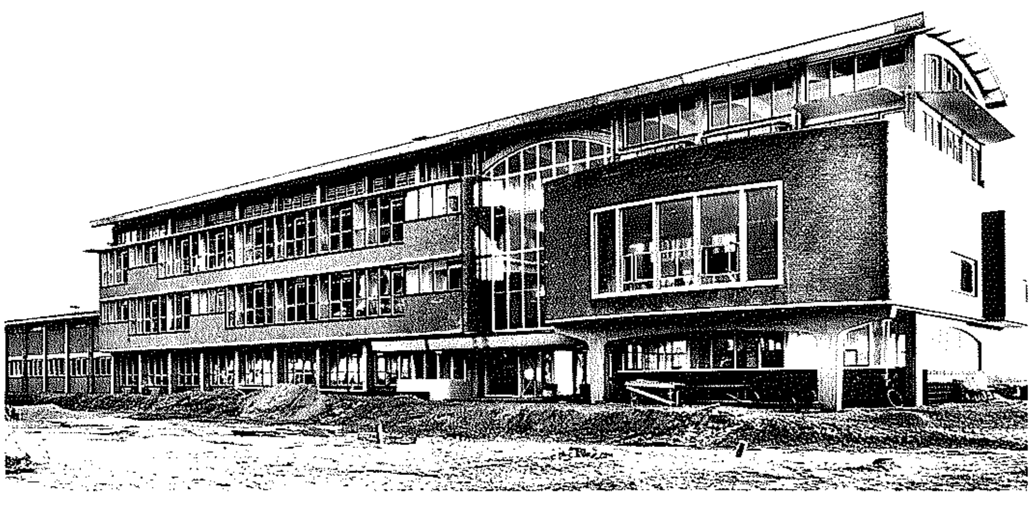
In September 1944, three months after D-Day (6 June 1944), the situation in The Netherlands changed very dramatically when the Allied Forces entered The Netherlands, near Breda on Tuesday 5 September, (Dolle Dinsdag - Mad Tuesday) and Sunday 17 September, when Allied Forces landed with paratroopers and gliders near Arnhem (Operation Market Garden). The Western part of

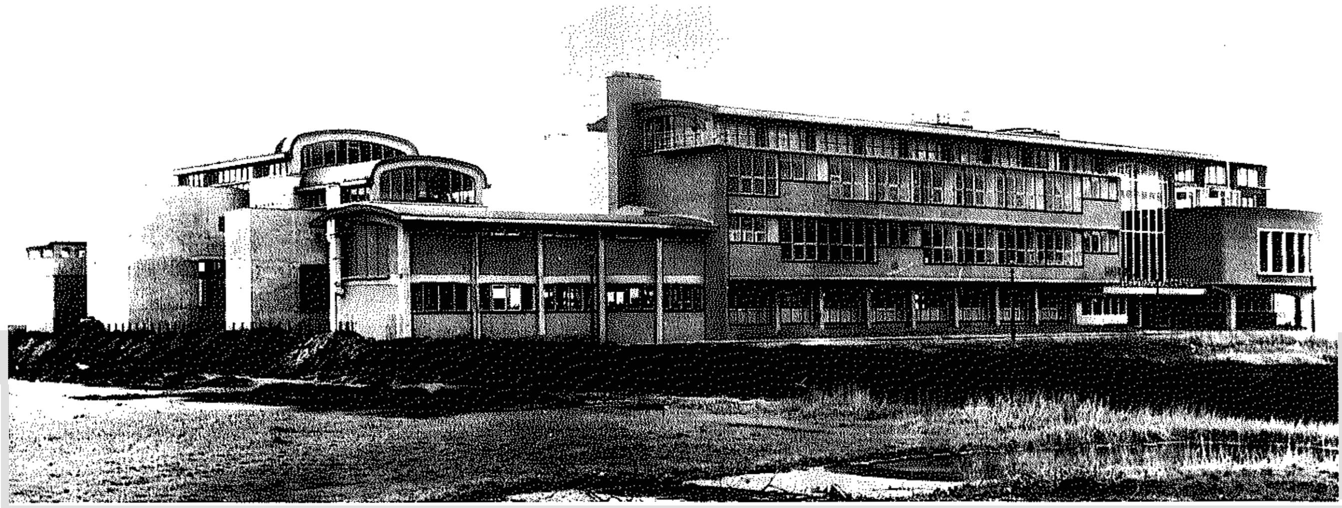
The Netherlands was completely cut off from the rest of the country. The food and fuel supply, already at a bare minimum, practically stopped.
It was expected that the operation of the laboratory could not be continued for long. There was the danger of war damage and plundering and so on 8 September a start was made to store machines, tools, instruments and documents in safe places. Larger pieces were taken to vegetable storage sheds of nearby gardeners and other items stored at the homes of the personnel. A substantial part was stored in the basement of NLL which was then closed with a brick wall. Later the ground water became abnormally high - presumably due to electric power shortage - and the contents had to be transferred to the large wind tunnel circuit.
Due to problems of transportation, electricity supply (lighting), food supply and other problems, the working hours were reduced to the minimum of 27 hours per week in December 1944.
Experimental work came to a stop. Office work continued to some extent but everybody was mentally occupied with the problems of war, survival, food and fuel. Only manual labor could be carried out in the workshops. To a large extent this consisted of the manufacture of small stoves, lamps and other utensils for the personnel. With (aeronautical) productivity rapidly falling it would have been possible to decide to close the laboratory but it was considered prudent to continue the operation as long as possible since it would provide some protection for the personnel and the laboratory in a very uncertain situation. Also, it was still possible to organize collectively food expeditions to the rural areas, even as far as Friesland in the North of The Netherlands. The transports, 'legalized' by German papers, took place with rented trucks. It is reported that 40 tons of food was collected and distributed among the personnel.

Technical-scientific Activities during World War II

Now, some 50 years after World War II, it can be concluded that the laboratory was fortunate - scientifically speaking - that during this war it had a number of excellent engineers and scientists who were active, albeit under most unfavorable conditions, and that they spent their time very productively.
It is difficult to single out individual activities. The research on structural stability of cylindrical shells by Dr. Van der Neut was already mentioned in this Chapter. Of great importance were the contributions of Ir. W.T. Koiter (who was detached to NLL during the war from the RLD, the Netherlands Department of Civil Aviation), on the buckling of plates (effective width of plates) and the buckling behavior of plates under shear forces. Interestingly enough Koiter later recalled, [Ref. 30], that the five years of isolation from the immense research effort in the free world and his intense occupation with the urgent practical business at the RLD in the immediate post-war period, had effectively prevented him from studying seriously the enormous stream of literature after the war. That was also true of course for all of the NLL staff, but at least in Koiter's case, he had contributed to the advancement of the technical sciences during this period of isolation.

The NLL Main Building with the Entrance Hall at the right





The NLL Main Building with the two Wind Tunnels integrated in the building at the left

A few examples of the work of the NLL staff during this period are:

Ir. A. Boelen, Head of the Aerodynamics Department, had initiated an extensive series of lift distribution calculations for a variety of wing planforms.

Ir. A.J. Marx, Head of the Flight Department, (with Van der Maas and Van Oosterom) had completed the lateral stability analyses and that Department did then have time to analyze the gust loads, recorded over a number of years on KLM aircraft on the route to Indonesia.

Ir. T. van Oosterom, later Head of the Flight Department and Professor at the Technical University Delft, had analyzed many flight tests and further developed the measurement techniques.

Dr. J.H. Greidanus, who later became Director of Fokker, and Ir. A.I. van de Vooren, who later became Professor of Mathematics at the University of Groningen and served as Chairman of the Scientific Committee (Chapter 24) studied unsteady aerodynamics and developed methods to calculate the response of an aircraft to gust loads.

During this war period several investigations took place in connection with possible new aircraft and their operation for airlines to North America and the Netherlands East Indies (Indonesia). These studies were mainly concerned with the possibility of designing and operating larger aircraft. Some of these studies were inspired by KLM's President Albert Plesman, (see also Chapter 5). Although these studies took place in isolation from developments abroad, they were nevertheless important for the post-war development of civil aviation in The Netherlands.

After the War a report was written summarizing the technical-scientific activities at NLL during the War, at the request of the Allied Armed Forces. From this it appears that a large number of subjects was studied in depth, including:

- methods of calculating the strength and stiffness of cantilever wings with non-parallel spars;
- the calculation of the 'effective width' of plates under compression, with various edge conditions;
- buckling of sandwich constructions;
- the calculation of lift distribution for an extensive series of wing planforms;
- experimental and theoretical research on flutter and vibrations in general;
- the dynamics of tailless (all-wing) aircraft;
- studies of the performance of rotorcraft.

Much of this work was published after the war but the most important aspect of it was that at least the basic activities were kept alive so that immediately after the war there was enough of a basis to absorb the new developments and apply the knowledge to the problems at hand during the post-war reconstruction period.

The two new wind tunnels were used extensively. Curiously enough, it was reported that in 1941 a two-shift operation was started to increase the productivity. Not all did go well: On 10 September 1941 a propeller blade of the 3 x 2 M^2 tunnel broke. Van der Neut recalled, [Ref. 28], that the natural frequency of the bending mode of the blades for the rotating propeller had not been calculated and compared to the flow irregularities ahead of the propeller. The blade was repaired but in 1942 a similar accident happened. Finally a properly designed propeller was installed in March 1943.

After the Liberation

After the Liberation on 5 May 1945 the laboratory was closed for 10 days, but soon after that the personnel started to collect the hidden equipment and documents and to resume normal operation. The electricity supply was restored on 13 June 1945. Most people were physically and mentally exhausted and it took several months till the performance became 'normal'.

The contacts with the outside world, nationally and internationally, were resumed.

During the second half of 1945 several changes in personnel took place. It was not surprising that immediately after the Liberation, 5 May 1945, many employees left NLL, either to return to their former employers or to take up jobs elsewhere, their first allegiance not being aeronautics and because there was an enormous shortage of technically trained people to reconstruct the country.
Mr. Chaillet returned to his former job at the Royal Dutch/Shell Company and on 1 September 1945 the position of Commercial Director was filled by Mr. F.C. Beelaerts van Blokland.
New personnel was hired and by the end of 1945 the total personnel was again at 129 - the level before the end of the war - and expanding rapidly.

5. Post World War II Expansion

Immediately after the war the activities of the laboratory were resumed. Although the laboratory did not incur physical damage during the war, it was not in the best condition, due to lack of funds and materials, the underground activities and the pre-occupation of the personnel with survival during the war period.

The facilities of the aircraft companies, Fokker, Aviolanda, De Schelde, Avio-Diepen and a few smaller organizations had been dismantled or destroyed and much of the machinery had been taken away. The original staff was scattered over the country and abroad.

KLM had carried out transport missions for the Allied Forces during the war and so there was an organization in operating condition. Many of the pilots had escaped to the UK at the beginning of the war. The President of KLM, Mr. Albert Plesman, (1889-1953), [Ref. 31], remained in The Netherlands, initially in The Hague. After having been taken prisoner as one of a group of hostages on 9 May 1941, he was exiled to the East of The Netherlands in April 1942. He stayed at Driene, near Enschede, where the campus of the University Twente is now located. The long time in jail and at Driene gave Plesman ample time to think about the future of 'his' KLM.
Plesman used that time very productively to develop plans for the operation of the airline, managerial and technical concepts and also to contemplate various forms of international cooperation.
After the war he was a founder member of the International Air Transport Association, IATA, a world wide association representing the major regular airlines, promoting air transportation and dealing with a variety of subjects, including standardization and compatibility of equipment.[1] He remained at Driene till the liberation by the Canadian Army in April 1945. As soon as the Canadian Army moved in he made his way to London to take charge of the part of KLM that had been operating for the Allied Forces and started the re-construction of the airline.

Units of the Army Air Force and the Navy Air Service had been actively engaged in the war, mostly as part of, or closely associated with, the (British) Royal Air Force, RAF. These groups formed the core of the new Air Force of the Army (Luchtstrijdkrachten, LSK), which was finally transformed into the Royal Netherlands Air Force, RNLAF (Koninklijke Luchtmacht, KLu) on 11 March 1953.

In the period 1945-1946 there was no doubt about the future of the KLM and the Air Force but it was less clear that the aircraft industry would recover, at least as far as the development of civil transport and military aircraft was concerned. In the light of the enormous progress that had been made in North America and the United Kingdom many felt that the only possible activity for the aircraft industry would be maintenance, repair and possible participation in production or production of complete aircraft under license of other, foreign, manufacturers. The latter did take place and - besides the development and production of a small business plane - soon after the war fighter aircraft were produced under license.

In September 1945 the Government appointed Dr. Ir. Th.P. Tromp (formerly a Director of the Philips Company and Minister of Public Works and Reconstruction during the period in 1944-1945 when

[1]Indicative of Plesman's activities is the recollection of Prof. Van der Neut, [Ref. 28], that Koning, Director of NLL, and he were invited by Plesman to visit him at Driene during the war to discuss the relative weight savings which could be achieved by using larger transport aircraft. During the war period NLL carried out studies for KLM on this and similar subjects in preparation for the post-war period.

the Southern part of The Netherlands had been liberated) as a special advisor to consider the reconstruction of the aircraft industry. Dr. Ir. W.T. Koiter served as his Secretary. Early in 1946 Dr. Tromp invited a few hundred representatives of government, industry, university, etc. for what would now be called a 'hearing'. This helped to convince him that there were interesting opportunities for an aircraft industry with a full design and development capability.

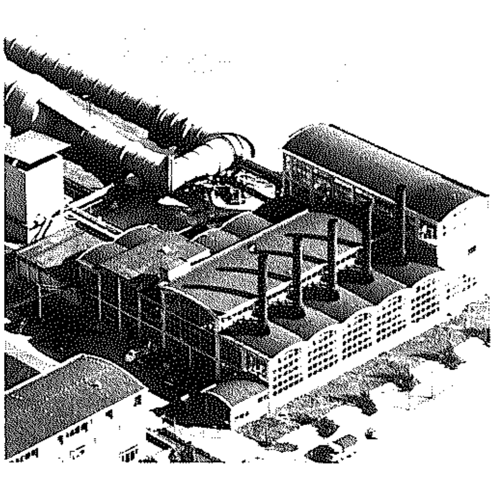
On 14 May 1946 the Government agreed in principle to support the reconstruction of such an industry. A condition of the Government was that closer cooperation should be established between Fokker and some smaller aircraft companies in The Netherlands.
The Government was not well equipped to handle the complicated matter of support to the reconstruction and the development of the aircraft industry and there were also different views within the Ministries concerned as to the form this support should take. Dr. Tromp then proposed to form an intermediate body, a kind of 'trustee' between the Government and the aircraft industry. This body would advise the Government and manage the expenditures of government funds for aircraft development. Thus the Netherlands Institute for Aircraft Development, NIV (Nederlands Instituut voor Vliegtuigontwikkeling) was founded on 19 June 1946. The signatory members were Koiter, Geudeker, Witholt, Jongsma, Gaastra and De Wolff. The Board of this Foundation consisted of representatives of the Government (Ministries, the Air Force and the Navy), the industry, the airline (KLM) and the research sector (universities and laboratories). Dr. Tromp proposed Prof. Van der Maas as the first Chairman and Head of a small executive office. Soon Ir. L.L.Th. Huls (Prof. Van der Maas' second aeronautical engineering graduate) and Mr. G.C. Klapwijk, a lawyer, joined his office, respectively as Technical Assistant and Secretary-Treasurer.

This was a positive development for the NLL.

Encouraged by the Government's intention to promote the design and development of aircraft in The Netherlands, NLL prepared plans to design and construct:

- a high speed (transonic) wind tunnel;
- a scale model of that tunnel (scale 1:5);
- a supersonic blow-down wind tunnel;
- a low turbulence, low speed wind tunnel;
- an extension of general laboratory equipment;
- an extension of the office building;
- a hall for full-scale structural and vibrational testing.

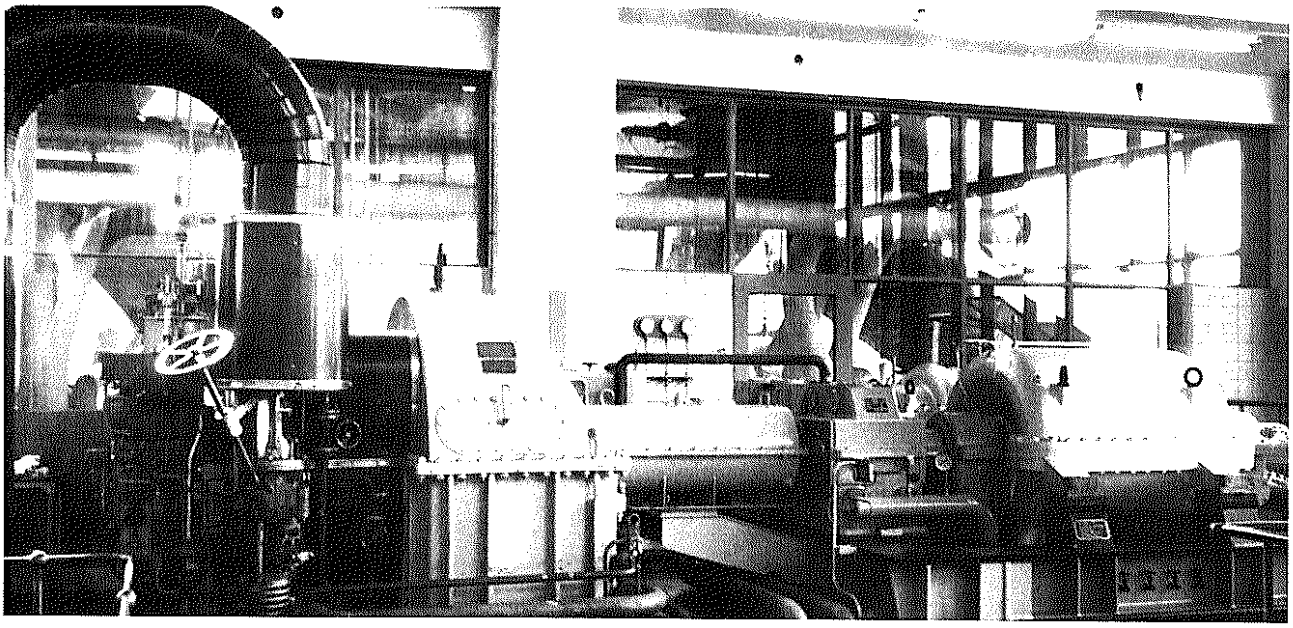
These were ambitious plans. The general positive attitude towards industrialization and the foundation of NIV encouraged NLL to carry on with this expansion plan. The management was strengthened: Ir. A.J. Marx, till then Head of the Flight Department, was appointed in 1947 as Chief Engineer for the whole laboratory to support the Directorate.



Aerial view of the Power Plant at the NLL in Amsterdam, around 1960

When the plans were further detailed during the period 1946-1947 it appeared that the local power company (GEB Amsterdam) was not in a position to supply the electric power of around 20 MW required for the transonic tunnel. The power company would have to extend its plant and special cables would have to be laid. Also, due to the intermittent character of the envisaged wind tunnel operations, this would result in a very high price per KWH. A new power plant at the NLL site, only for the laboratory was also very expensive. The solution was found when, oil-fired, steam turbine power plants of American war surplus escort vessels (destroyers) became available. Six of these units plus spares were bought for the sum of DGL. 300,000. Initially five steam boilers were installed and in 1966 a sixth was added when more power was needed for additional compressors. In 1948 additional spare parts of the H.M.S. Hotham were bought from the UK Ministry of Supply which had had in operation destroyers of the same class. At the end of 1947 a contract

The extension of the Power Plant with a sixth steam boiler and chimney and with a new compressor in 1967



was let to design and construct a turbo-electric power plant utilizing this equipment. At that time Government approval had been obtained for the laboratory expansion and the design of the various facilities was started.

The Crisis

During the course of 1949, when the design had progressed quite far and the construction of the foundations of the facilities had started, the Government re-considered the plans for the reconstruction of the aircraft industry.
It must be recalled that, although the economy was recovering at a satisfactory rate, the Government expenditures had risen to unprecedented levels, not in the least due to the military expenditures in connection with Indonesia, the former Netherlands East Indies.
Immediately after the surrender of the Japanese forces in what was then the Netherlands East Indies, a group of Indonesian leaders, headed by Sukarno and Hatta, declared the independence of

Indonesia on 17 August 1945. Although the policy of the Netherlands Government was, at least in principle, to grant Indonesia gradually more independence and to move into a direction of a union of states, The Netherlands assembled expeditionary forces and ship them to Indonesia to restore law and order. This led to a political and military struggle which ended in 1949 with the recognition of the independent state Indonesia. The financial strain of these actions on the Government budget, still very much burdened by the recovery from the effects of the war in Europe, was enormous.

The result was that on 31 October 1949 NLL was informed that it had to stop all work associated with the expansion plans. After many discussions, the Ministerial Council for Economic Affairs decided on 30 November 1949 that, in principle, it would continue to support the development of aircraft in The Netherlands. However no decision was taken about the NLL expansion plans.

NLL had done its utmost to build up the staff and several important financial commitments had been made in connection with the expansion plans. The laboratory was now in a very difficult financial position.

Apparently the Government saw no direct link between the decision to support aircraft development in The Netherlands and the expansion and modernization plans of NLL. It is possible that the ministers and officials dealing with this matter felt that financial aid to the industry in the form of loans through NIV was a sufficient condition to give the industry a fair chance. It is also possible that it was felt that sufficient laboratory support could be given with the existing facilities. However the Minister of Traffic and Public Works did appoint a Committee to advise him on the organization, the management, the extent of the activities and equipment of the NLL required in the coming years. This Committee was also asked to advise on the need and desirability of the expansion program which had been halted. This Committee, formally charged by letter dated 7 January 1950, consisted of Ir. J. Blackstone attached to the Ministry and Chairman of the Board of the Foundation NLL, Dr. Ir. M.H. Damme, Director General of the PTT and Prof. Dr. Ir. H.J. van der Maas, Professor of Aeronautical Engineering at the Technical University Delft. The Committee went to work immediately and completed its report by the end of March 1950. Many of the thoughts incorporated in the report were the result of debates during the months before the Committee was formed.

This Blackstone-Damme-Van der Maas Report, which became internally known as the **BDM Report**, had a great impact on the operation of the laboratory. The importance of the report was perhaps not that it introduced completely new ideas about the management of the laboratory, but that it analyzed in detail the possibilities and limitations for carrying out aeronautical research in The Netherlands. (The system of financial management proposed in the BDM Report had basically been in operation since the very beginning of the RSL, albeit on a less formal basis when the scale of the operation was smaller.)
The BDM Report recommended in particular:

- *That the annual government subsidy should be abandoned and that the interested parties (NIV, Industry, Defense, RLD, KLM, etc) should supply an equivalent amount on a contractual basis. This sum should be guaranteed and the contractors should indicate their priorities.*
- *That amortization (including interest) should not be included in the rates applied for the usage of equipment and installations (including buildings, small equipment, etc. for which no separate rates existed) and that a special Government annual subsidy should be given to NLL to cover these costs. These subsidies could be used to create an investment fund.*
- *That a government subsidy should be made available for basic research (not earmarked for a particular application) amounting to 10% of the income received from contracts.*
- *That the original expansion plans should be executed with some adjustments and reductions.*

At the beginning of 1950 the Board of NLL had approved the budget for that year, which was submitted to the Government, assuming that the recommendations of the BDM Report would be accepted. However by mid-1950 the Minister informed the Board that no decisions had been taken yet concerning the expansion of the laboratory and that in any case measures should be taken to reduce the personnel cost substantially in view of the expected financial shortfall in the budget. The Board then had to decide to reduce the number of personnel drastically. This led to a crisis in the Board and the vast majority of the members proposed in a meeting on 30 August 1950 that the Board should resign and that the members hand in their resignation to the Ministries and organizations which had appointed them, in order to create the possibility to form a new Board. The Board then resigned.

It should be noted here that there was no direct representation of the aircraft industry on the Board. In fact there was no aircraft industry representation on the Board during the period 1942-1954. The airline (KLM) was continuously represented.

During the last quarter of 1950 a new Board was formed which held its first meeting on 5 December 1950. The Board proposed Prof. Van der Maas as its new Chairman and on 27 December 1950 he was appointed as such by the Minister of Traffic and Public Works. Prof. Van der Maas now came into the unique position of heading the Aeronautical Engineering Department (then still a Sub-Department of the Department of Mechanical Engineering but soon to become a separate Department) of the Technical University Delft, the NIV (the Netherlands Institute for Aircraft Development) and the laboratory NLL. It was the beginning of a period of more than 25 years of very fruitful aerospace development in The Netherlands to which Prof. Van der Maas contributed enormously through these key positions.

It still took more than two years before the political climate became more favorable for NLL. The laboratory was faced with a great problem. For an engineering research laboratory such as NLL, where preparations extend over many years before actual project support can be given, such a long delay was disappointing.

Severe measures had to be taken. In 1949 the number of personnel was reduced by 15 through natural attrition but in the middle of 1950 the Board had to decide that a further 59 employees had to be released before the end of 1950. Such measures had a disastrous effect on the morale of the personnel, particularly in a time frame when there was a general shortage of technical personnel in the country. In fact by the end of 1950 there were 204 employees, compared to 304 early in 1949. A reduction of the personnel by one third in about one year is very serious indeed. The reduction was equally divided among the various personnel categories. For many years, even to this date, this shock effect led to a very cautious hiring policy for permanent personnel. Another effect was that when it was again possible to hire new personnel, it was difficult to attract suitable personnel, so badly needed for the expansion plans and the growing number of contracts.[2]

The recommendations of the BDM Report were finally approved by the Government on 3 March 1952. The interruption had lasted 28 months. This delay was caused to a large extent by the financial problems of the Government but there was also another important factor involved. The foundation of NIV in 1946 was a positive step but it did not guarantee the viability of the aircraft industry. Many leading politicians wanted to be assured that an aircraft industry with its own design and development capability could survive. It was not till early in 1952 that this appeared to be a reasonable gamble.

A major change was that, as a result of the critical years, the Board of NLL, through the office of the Chairman took a far more active part in the planning and decision making process. In 1953 it was decided to establish a small office at Delft to assist the Chairman. The staff included

[2]After the Government approval had been given, Prof. Van der Maas, through his unique position, urged promising students in the 1950's to take up employment at NLL before they had completed their studies. They graduated while working at NLL and several of those later made up the backbone of the engineering and research staff of NLL.

Mr. G.C. Klapwijk (who was also Secretary-Treasurer of NIV and who later became Chairman of the Board of Fokker and also of the Holding Company VFW-Fokker) who served as Secretary-Treasurer of the Board, Ir. J. Boel (who later moved to the laboratory and became Deputy Director during the period 1967-1971) for technical matters and Mrs. M.J.M. Janson-van Wijk (till that time Head of the Administration at the laboratory in Amsterdam) for administrative matters.
With the approval of the BDM Report, NLL was given a new lease on life. The cost of carrying out the modified expansion plans was estimated at DGL. 26.1 million. The completion date given in the report of early 1950, was optimistically estimated as sometime in 1953. Obviously that date had to be adjusted. At the time of the interruption a total of DGL. 9.7 million had been committed of which DGL. 8.45 million had been paid at the resumption of the activities in 1952. The Power Plant was in an advanced state of construction and the foundations of the new wind tunnels had been constructed.

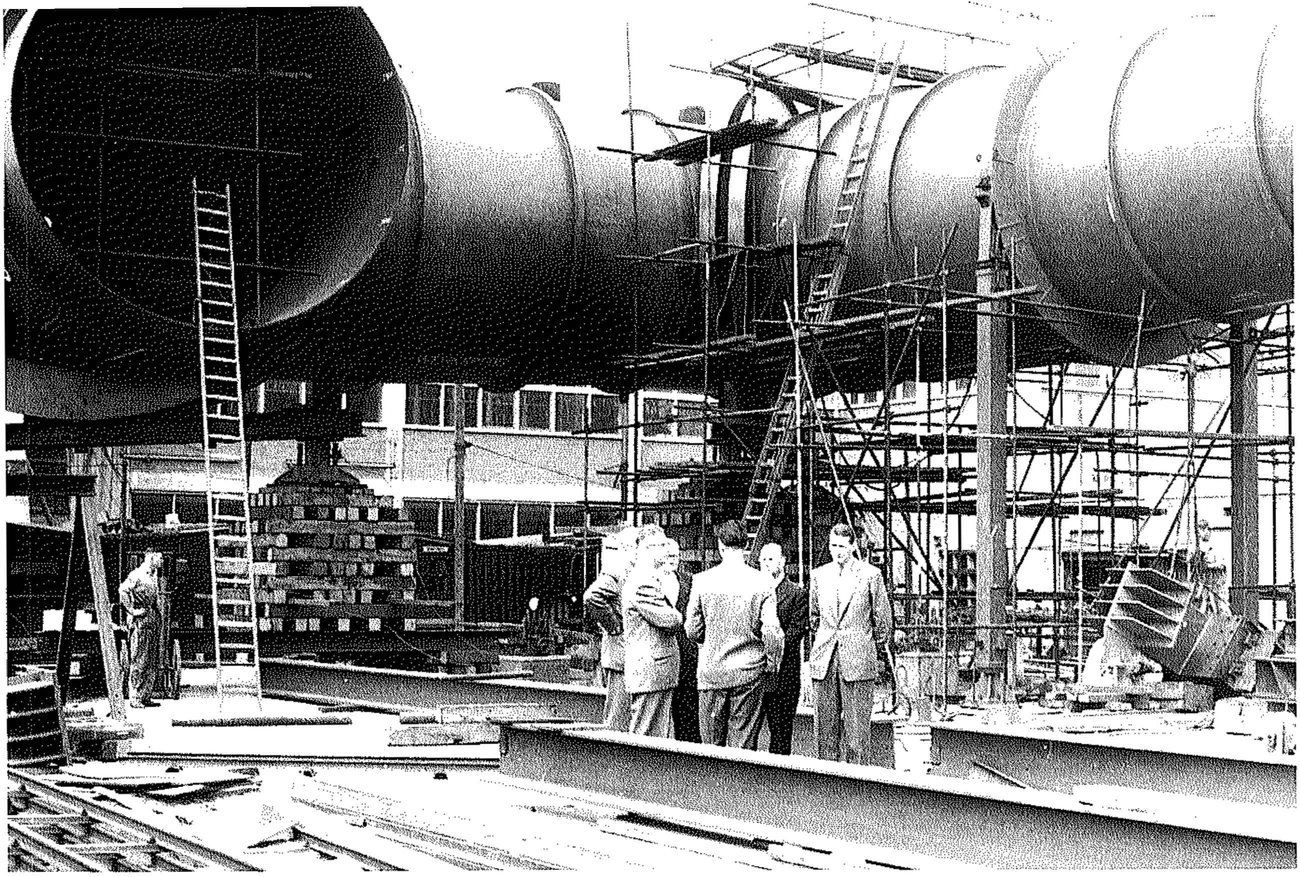
The changes in the plans were that the construction of the low speed low turbulence tunnel[3] and the construction of the hall for vibrational and structural testing at Schiphol were canceled. One reason for the latter was probably that it was realized that for the real long term the site at Amsterdam would not suffice and that a second laboratory site had to be found. Facilities for structural testing could then be located at this new site.
There were also many detailed technical changes particularly for the high speed tunnel (HST). In the original plan of the HST (1947-1949) the aim was to achieve a maximum Mach Number in the test section between 0.85 and 0.90, which was the highest Mach Number attainable with a conventional, solid wall, test section.
When in 1952 the construction plans were taken up again it was known to NLL engineers that it was possible to build a test section which would accommodate a flow with Mach Number larger than one, a true transonic test section. Although few details of the new transonic testing techniques, developed elsewhere, particularly in the USA, were known, a re-design of the test section of that wind tunnel was undertaken with the assistance of a Swiss firm. It became a test section with longitudinal slots in the top and bottom walls of the test section and a plenum chamber around the test section - a 'ventilated' test section.

Dr. Th. von Kármán, Chairman of AGARD, wrote the following story about the HST transonic test section, [Ref. 32]:

> -*"They (NLL) planned a large wind tunnel going up to the speed of sound. Transonic speeds were unattainable with design methods available in the open literature because of a phenomenon called 'choking'. During the war, however, John Stack and his group working for the National Advisory Committee for Aeronautics in the United States had developed a transonic 'throat' which made possible wind tunnel operation in the important region just above the speed of sound. Unfortunately, this information was still classified and unavailable to The Netherlands. The Dutch scientists spoke to me about it, and I agreed that it would be a waste for them to build an expensive obsolete wind tunnel when there was an urgent need on the Continent for data in the new speed region. I urged NACA to declassify the material, but I was told the process would take quite a while.*
> *I couldn't help but believe that there was a way around this silly red tape, and it occurred to me that some Swiss engineers knew the principle of the transonic throat because they had been working in the United States on it before the method was classified.[4] Since the Swiss were unhampered by*

[3]The large concrete foundation of the low speed low turbulence tunnel in the middle of the NLL laboratory site became known among the personnel as the King's Tomb (Koningsgraf, perhaps referring to the Director Koning). It resembled the coffin of a giant king. During the late 1960's an office building was constructed on this foundation.

[4]Note by the author: Actually the idea of a 'slotted' test section could be traced to early theoretical work of Prandtl and Glauert in Germany during the 1920's and a very specific configuration suggested by Wieselsberger in Germany in 1942, [Ref. 15].

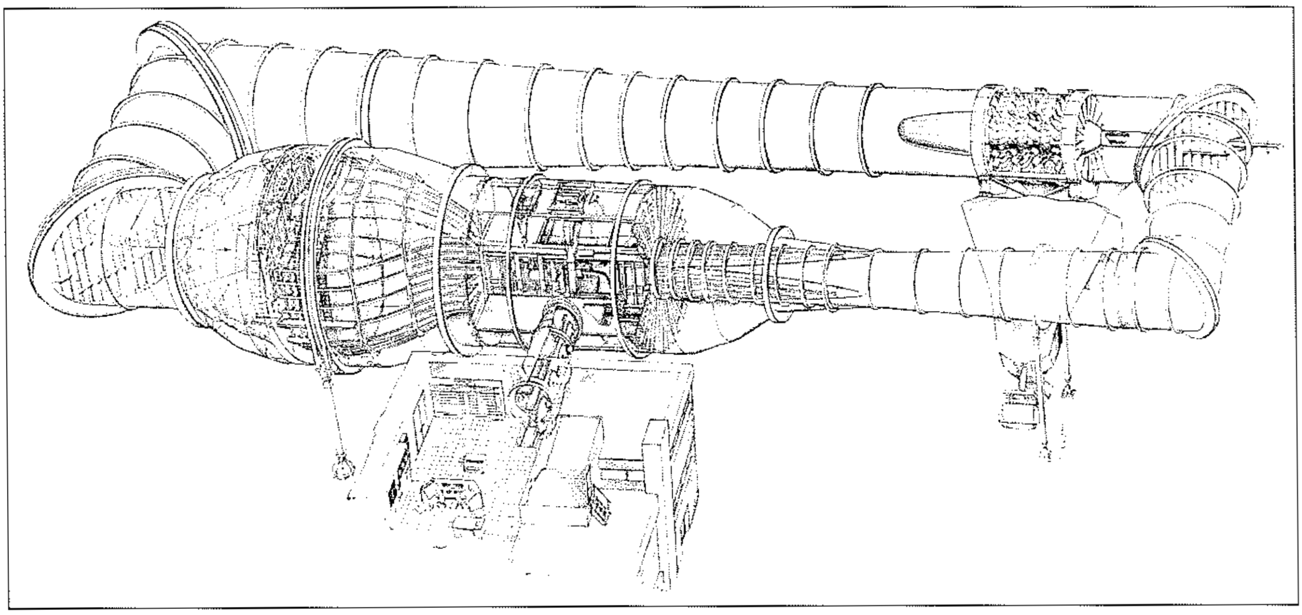


The High Speed Wind Tunnel HST under construction around 1956

NATO agreements, however, they were free to help The Netherlands. The drawback was that the U.S. research had progressed considerably since the Swiss left the United States. To overcome this gap I inquired in the United States whether it was possible for American engineers to criticize the designs of our NATO partners, even if they were not allowed to pass out information on U.S. designs. The authorities said this was possible, so I arranged for U.S. experts to visit The Netherlands and constructively criticize Dutch drawings of designs based on Swiss information.
This worked. Instead of a 'lemon' The Netherlands has one of the best facilities on the Continent and has made outstanding contributions to the design of European aircraft."

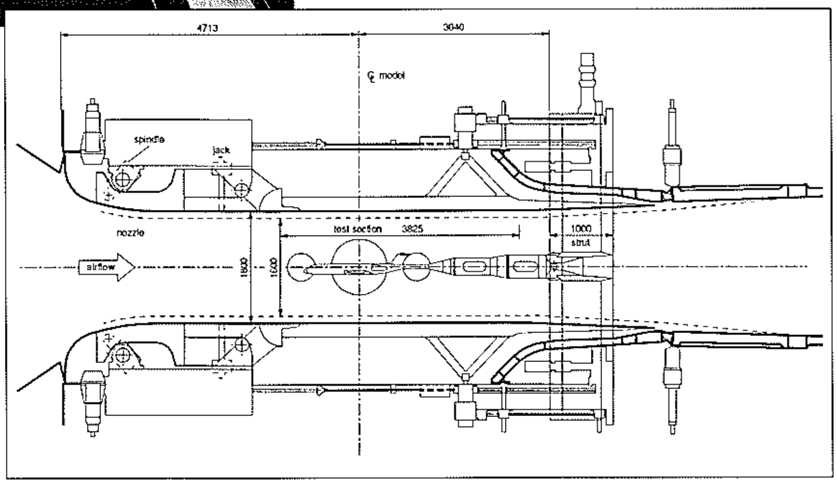
Sketch of the High Speed Wind Tunnel HST, as it was built

Starting from this 'Swiss design' the adjustable throat ahead of the test section, the test section itself and the second throat after the test section were further developed and the HST is now indeed a superb transonic wind tunnel.



The High Speed Wind Tunnel HST completed

The latest modifications, completed in 1992, include adjustable top and bottom test section walls - from 2.00 x 1.60 M² to 2.00 x 1.80 M² -, a new model support system, modification of the control system and data handling system.



The new test section, with increased length and variable height, of the High Speed Wind Tunnel HST, 1992

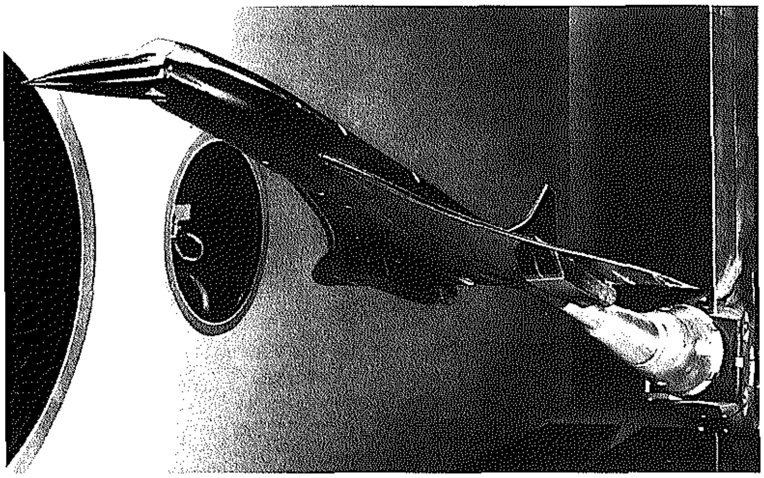
An International Encounter

One of the annexes of the BDM Report was a letter (dated 10 February 1950) of Prof. Maurice Roy, the Director of ONERA, the Office National d'Études et de Recherches Aéronautiques (the French Aeronautical Research Organization), to Ir. C. Koning, the Director of NLL, indicating ONERA's interest in some form of cooperation with respect to the variable density transonic tunnel under consideration at NLL. The French interest in the project was used in the BDM Report as supporting evidence for the NLL plans. In retrospect it is difficult to determine how much influence this had on the final decision of the Government to approve the plans. It may not have been important for the direct decision, but it was the beginning of international cooperation and 'cross utilization' of facilities.

In January 1950 Mr. R.A. Willaume[5] of ONERA visited NLL and discussed the wind tunnel plans of NLL. In France ONERA was involved in a large construction activity at Modane-Avrieux in the French Alps. The major wind tunnel under construction was a high speed wind tunnel with a test section diameter of 8 M. This facility originated in Germany during the Second World War and was under construction at Ötzal, Austria, at the end of the war.[6] The plans of ONERA also included a transonic tunnel with a test section of approximately 2 M². However France was also faced with financial limitations and ONERA realized that the plans to construct a transonic facility might be retarded. That must have been Prof. Roy's motivation to explore some form of cooperation with NLL. In return he could offer the use of the large 8-Meter high speed wind tunnel at Modane.

[5]Mr. Willaume's trip report of January 1950 was made available to the author by IGA M. Benichou, President of ONERA.
Mr. Willaume was External Relations Officer at ONERA. Later he joined Dr. Th. von Kármán when AGARD was established in Paris. He served as AGARD's Director of Plans and Programmes during the period 1952-1980 and assisted Von Kármán and Wattendorf, respectively Chairman and Director of AGARD, in the liaison with the French authorities. Through his position at AGARD he was also instrumental in assisting in the cooperation between several other countries.

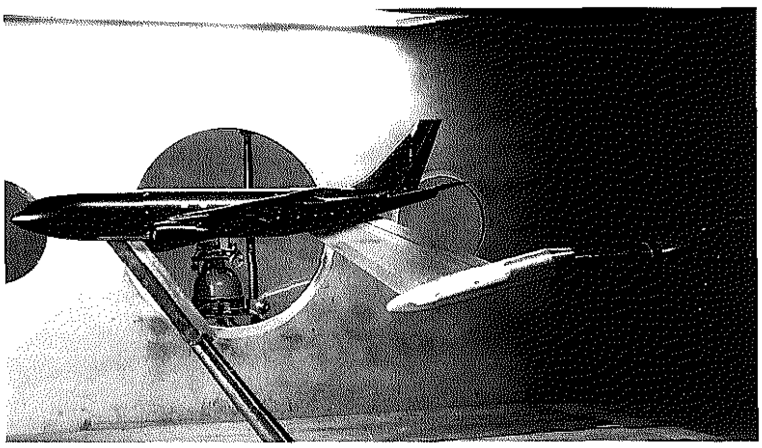
[6]The highly interesting story of the transfer to France of this facility and the subsequent construction of the facilities at Modane was described by Marcel Pierre who was the engineer in charge of the development at Modane, [Ref. 33].



A model of the French-British Concorde in the High Speed Wind Tunnel HST

At that point in time (1950) no further progress in international cooperation could be made since NLL had not received government approval to proceed with its expansion plans. However some time later, at the end of 1953, the Association Internationale des Constructeurs de Matérial Aéronautique, AICMA, (European Association of Aircraft Manufacturers), established the Commité Internationale Permanent des Souffleries, CIPS (Permanent Committee on Wind Tunnels). This Committee made an inventory of the need for development facilities in Europe and on 26 March 1954 a meeting was held at the Paris' office of AICMA. The CIPS representatives discussed with Prof. Van der Maas and Prof. Zwikker (who then was the Director of NLL) a proposal for the utilization of the HST which was then under construction and also for the supersonic tunnel, the SST which was in the design stage. On 9 and 10 April 1954, during a meeting in The Netherlands, various modes of cooperation were further discussed with representatives of some aircraft manufacturers. Finally these discussions led to the signing of a contract between AICMA-CIPS and NLL, which stipulated that NLL would make available the HST to members of AICMA for up to 50% of the available testing time. This contract, signed on 23 February 1955, included details about the minimum occupancy by AICMA members, AICMA fees, the principles of the wind tunnel charges and details on the reservation of testing times.

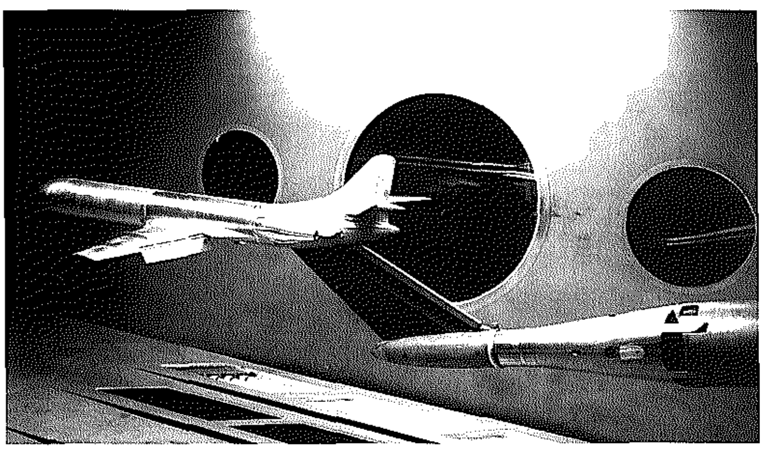
A model of an Airbus in the High Speed Wind Tunnel HST



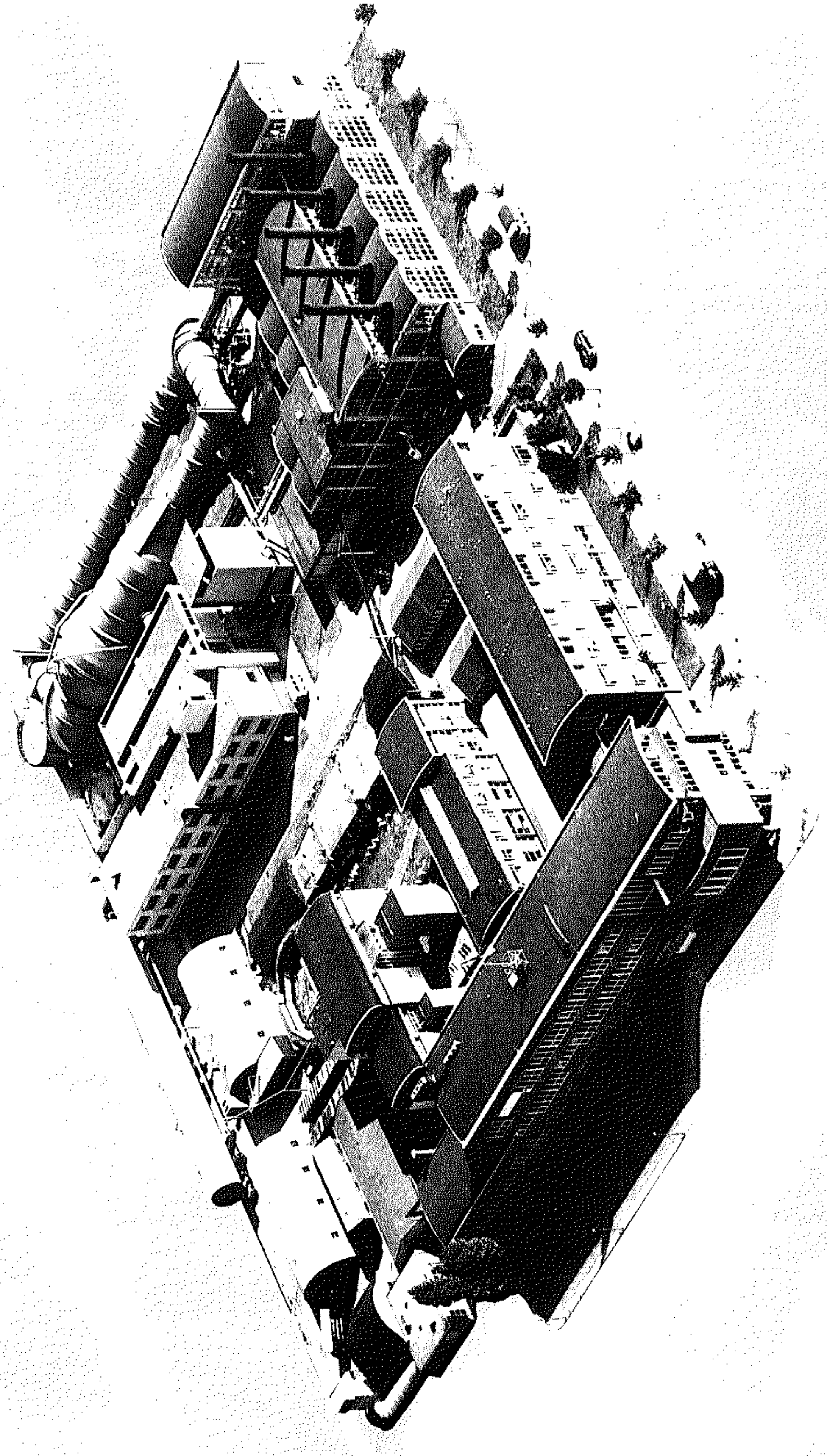
During the following decades this agreement resulted in a very fruitful utilization by various AICMA members of the HST and later also of the SST. It also served as a stimulant to further cooperation across the borders although this was a rather slow process.

The participants in the CIPS planned to go much farther and their plans included a large blow-down facility, with a 3x3 M^2 test section, for up to Mach Number 3 and suitable for engine tests at supersonic speeds. In the period 1956-1958 the French company SESSIA built an 0.85x0.85 M^2 pilot facility, with a high pressure (65 atm.) hot water (270°C) injector after the second throat.

A model of the Caravelle in the High Speed Wind Tunnel HST



Aerial view of NLL in Amsterdam around 1960 with the uncovered High Speed Wind Tunnel HST in the rear



Members of the Board, Directorate and Staff of the NLL, 1959

It was hoped that at least five countries would participate in the full-scale facility. It was apparently too early.

Since the 1950's many cooperative aerospace projects were carried out in Europe whereby companies of different countries worked together closely during the design, development and manufacturing stages. However it was not till 1976 when a two-nation (Germany and The Netherlands) aeronautical test facility, the DNW, (Chapter 18), became a reality, and it took till 1988 when finally a four-nation (France, Germany, the UK and The Netherlands) aeronautical test facility, the ETW, (Chapter 19), was started.
The best that could be achieved in the 1950's in the area of cooperation in planning and operation of facilities was the AICMA/NLL-contract.

6. Flight Testing

With some notable exceptions most of the early aeronautical research laboratories concentrated on aerodynamics, structures, materials and propulsion. Flight testing was often carried out by separate organizations. Dr. Wolff, Director of the RSL, had from the very beginning the firm conviction that a major task of the laboratory was to investigate all aspects of flying with real airplanes. That was not easy to realize. A first requirement was to recruit someone who was not only an excellent pilot but who was also a keen scientist interested in all aspects of flight.

Even before the RSL was officially founded on 5 April 1919, Dr. Wolff managed to hire Ir. J.C.G. Grasé[1], an engineer who had graduated from the Technical University Delft. Ir. Grasé wanted to go to England to join the Army and learn to fly but he was persuaded to join RSL instead. Dr. Wolff made arrangements with the LVA of the Army at Soesterberg for Ir. Grasé to receive a pilot's training. It was the only place in The Netherlands where one could learn to fly properly. Later Dr. Wolff managed a similar arrangement for Ir. Van der Maas, who joined the RSL in 1923 and who succeeded Ir. Grasé. For Ir. Wynia, who worked at the RSL/NLL from 1932-1952, and also for Ir. Marx, who joined RSL in 1934, similar arrangements were made.

The RSL engineers were very dependent on the instructors and of course on the weather. The pilots at Soesterberg thought, at least initially, that it was perhaps useful that research engineers knew something about flying, but it seemed to them research ought to be carried out in a laboratory on the ground and they (the LVA) would do the flying.

Dr. Wolff recalled later that Ir. Grasé became one of the best pilots. Anthony Fokker, who himself was an excellent pilot, appreciated Ir. Grasé's opinion and he often took him along on trips and so Ir. Grasé had the opportunity to fly many planes which never became available at Soesterberg or anywhere else in The Netherlands.

The engineer-pilot Ir. J.C.G. Grasé in the cockpit

[1] How Ir. Grasé came to work at RSL was later recalled, [Ref. 34], by Dr. Wolff:

-*"For flight testing and the study of the airplane in general I had engaged Ir. Bertus Grasé. He was the son of my former English teacher and he had been a good student at Delft. I received a letter from his father with an urgent request to employ him. Grasé wanted to go to the UK and join the Army and become a pilot. He was at home with the flu and his father tried to convince him not to go abroad and participate in the war. I employed him since his references from the Technical University Delft were excellent and I was convinced that we needed an engineer-pilot. This was of crucial importance to me. Most laboratories were not much concerned with flying and specialized in aerodynamics. I had the conviction that our mission was flying and the study of phenomena associated with it. Aerodynamics, propulsion and materials were secondary subjects. The problem was that it is much more difficult - and more dangerous - to carry out flight tests than laboratory tests. One needs excellent pilots with a scientific mind who are able to recognize the phenomena occurring during flight, to analyze them and then to carry out flight tests with a limited number of parameters. I was lucky in that it was easy to convince Prof. Van Royen of this point of view and that I found Grasé and later Van der Maas who fully understood their task."*

Ir. Grasé (1891-1929) stayed with the RSL till June 1923, when he went to Fokker. It was rumored that Fokker found him too difficult as the certifying government official at the RSL and offered him a higher salary. There may be some truth in that but Dr. Wolff recalled that Fokker appreciated very much the technical knowledge and flying skills of Grasé and they had cooperated several times in flight demonstrations. Grasé and Roosenschoon (who was the first lecturer in Aeronautical Engineering in Delft), designed the wing for the so successful Fokker F.VIIa, working under Platz, Fokker's chief design engineer.

During the 1920's and the 1930's RSL personnel participated as pilots and observers in **many hundreds - perhaps thousands - of flight tests** for KLM, the Army, the Navy and the Dutch aircraft manufacturers Fokker, Van Berkel, Koolhoven, Pander, De Schelde, Spijker and several foreign aircraft manufacturers who wanted to demonstrate their aircraft.
Many of the flight tests dealt with the take-off and landing characteristics, the climb performance, the performance at altitude, stability and control, spin characteristics, stall performance, maneuverability and very often with undesirable vibrations. Different aircraft of the same type often exhibited different vibration characteristics.
The flight tests were often carried out for the aircraft manufacturers and for the users in combination with tests for airworthiness certification.
There was also a constant demand to measure the performance (speed, fuel consumption, range, etc) of aircraft, often based on the desire to increase the range and the payload. The handbooks supplied by manufacturers were in general not very complete.
The RSL was requested frequently to advise on a possible cure of an undesirable characteristic of an aircraft or on the effect of changing to another engine or propeller.

A major activity in support of flight testing was **the calibration of instruments and the positioning of sensors on aircraft**. Much attention was paid to the positioning of Venturi tubes, used in the early days, Pitot tubes, static pressure measurements and the measurement of fuel consumption.
The RSL and later NLL carried out aircraft instrument calibrations for many aircraft users. The laboratory built up and maintained a complete calibration laboratory for this purpose. After World War II when the major users acquired their own facilities, this activity was more and more limited to the calibration of the instruments used by the laboratory itself.

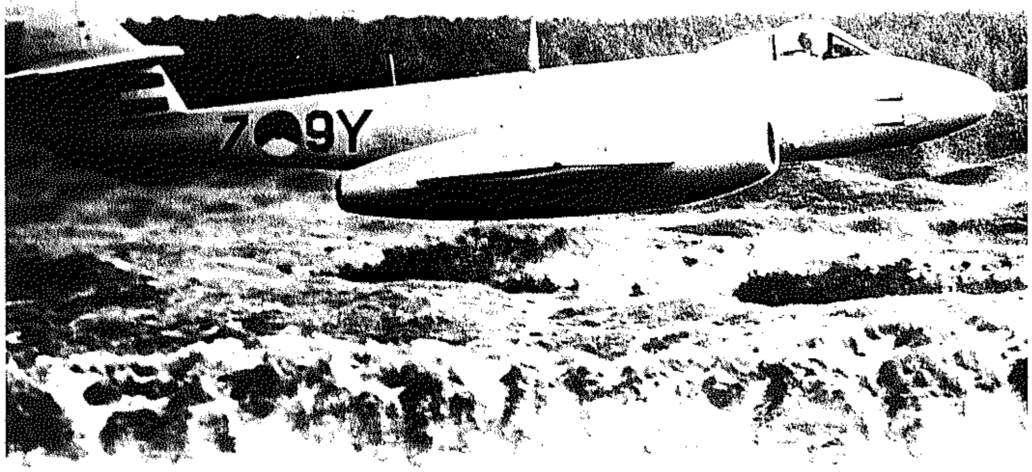
The reports were short and clear, mainly reporting the results and the conclusions, often only on one page. This conciseness must have been due - in part - to the fact that there were only a few engineers involved in the flight testing at the RSL. They were the only authoritative persons around and little further explanation was needed. There was only one layer of approval: the Director of the RSL!
It must also be remarked that many of these flight tests reports did not have a long lasting effect. During the 1920's and the 1930's the aircraft types and the various versions of each type succeeded each other very rapidly.
Modifications were often made overnight and it was very hard to stay current with the characteristics of a particular type of aircraft.

RSL was also occupied with **aircraft accident and incident investigations**. Many emergency landings - relatively easily carried out in the early days - had to do with engine failures; some accidents were related to structural problems and often the cause could be traced. An example of an aircraft accident investigation in 1934 is mentioned in Chapter 29. Other accidents gave rise to a more thorough investigation with a long lasting effect, for example the flutter investigation described in Chapter 9.

A speed and altitude record

During 1949, when NLL had only the Siebel aircraft available for flight testing, the opportunity arose to carry out measurements with a high performance aircraft. The Air Force[2] decided to carry out a series of flights to establish a Netherlands' speed and altitude record with one of its Gloster Meteor Mk.IV fighter aircraft. The Air Force had received its first Meteors in 1948. The Air Force received a total of 266 Meteors in various versions. The Royal Netherlands Air Force operated the Meteors till 1959. Fokker built till 1953 a total of 330 Meteors - under license - for the Air Forces of Belgium and The Netherlands.

[2]Actually the Air Force was still part of the Royal Netherlands Army and did not become a separate Force till 11 March 1953 when the Royal Netherlands Air Force was formed. It was almost 35 years after the Royal Air Force of the UK was formed. A consolation was that the United States Air Force was also formed rather late, on 26 July 1947.



The Gloster Meteor Mk.IV with which the Netherlands' speed and altitude record was established in 1949

The flights were carried out in August 1949 by Maj. J.L. Flinterman[3] over the island of Ameland in the North of The Netherlands. NLL carried out the measurements and adapted the instrumentation in the aircraft and on the ground. Apart from the fact that this was a welcome and stimulating exercise for the NLL personnel, it also was an exercise in which the technical staff of the Air Force and NLL became acquainted with each other's capabilities. This first major post-War joint activity laid the foundation for a much broader cooperation between the Air Force and NLL.

Stability and Control

Now again going back to the pre-World War II period. The extensive experience gained in flight testing and the many observations of the aircraft characteristics, particularly the aircraft stability, led Ir. Van der Maas to an investigation of the longitudinal static stability of aircraft. For this he carried out many measurements on a Fokker F.VII with one, two and three engines and with a Pander type EC aircraft. He analyzed the longitudinal stability using the concept of constant stick position lines (lines of constant elevator angle) for various angles of attack and throttle positions. From this he developed criteria to judge the longitudinal stability of aircraft. This work led to his dissertation for which he was awarded the degree of Doctor at the Technical University Delft in 1929. This was one of the first attempts to formulate a scientific basis for aircraft flight testing, [Ref. 35].
The stability criterion based on stick position was later superseded by the criterion of stick force stability as it was developed particularly in the USA during the 1940's, [Ref. 36]. Without going into details, it seems that with the current development of 'fly-by-wire' and computer controlled flight systems - whereby unstable aircraft are made to fly -, stick position stability becomes again a relevant criterion. These investigations were later extended to the lateral static stability characteristics. Again using the concept of constant stick position lines, criteria were developed to judge the lateral stability and control of aircraft. Although this work, authored by Van der Maas, Marx and Van Oosterom, [Ref. 37], was essentially completed several years before, due to the pressure of contract work it was not published till 1940.

The study of stability and control of aircraft remained one of the most essential parts of aeronautics. The problem always was: how to determine quantitatively the desirable and acceptable flying properties and how to determine these properties in flight.
With the advent of large computers and flight simulators many studies on the behavior of aircraft are carried out in the laboratory. In addition, with the introduction of flight control systems the emphasis is often on developing the proper control laws long before the aircraft flies.

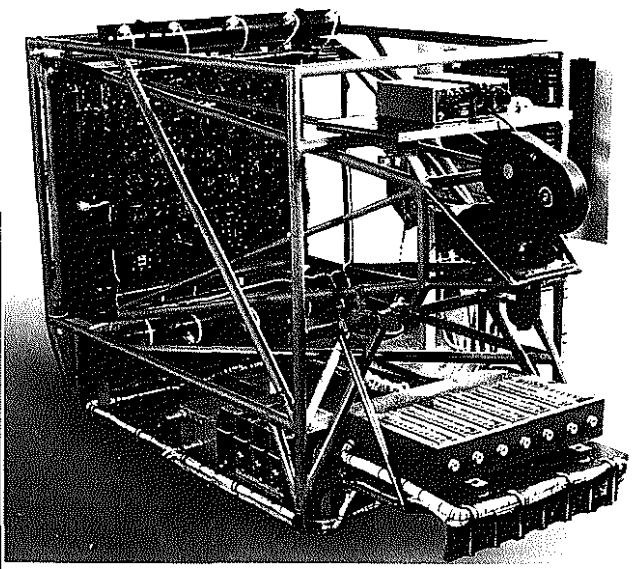
[3]Maj. Jan L. Flinterman had escaped to the UK during the Second World War. From there he had flown over 400 missions with Spitfires. After the war he served with the Royal Netherlands Air Force and after his retirement from the Air Force he served for some time with the NIVR, managing space programs. With the Gloster Meteor he established in 1949 the Netherlands' speed record of 953 KM/HR and the altitude record of 14,821 M.

An associated problem is that accurate flight data are needed to be able to model the aircraft properly on a computer or flight simulator. The information needed for an accurate mathematical model is often not available from wind tunnel tests and calculations and so once the aircraft is built, flight tests are carried out to complete the mathematical model to be used in a flight simulator and of course also to prepare the final aircraft manual.

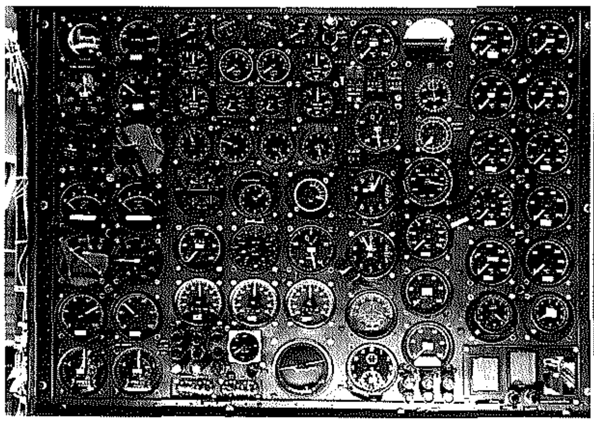
Measurement Techniques

New measurement techniques and instrumentation for carrying out its flight tests were continuously developed at RSL.
During the first years after the Second World War, when the need arose to measure more parameters simultaneously during one flight, a so-called automatic observer was developed. It consisted of a panel on which many dial gauge instruments were mounted. During flight tests this panel was photographed by a movie camera.

The instrument panel photographed by the 'automatic observer'

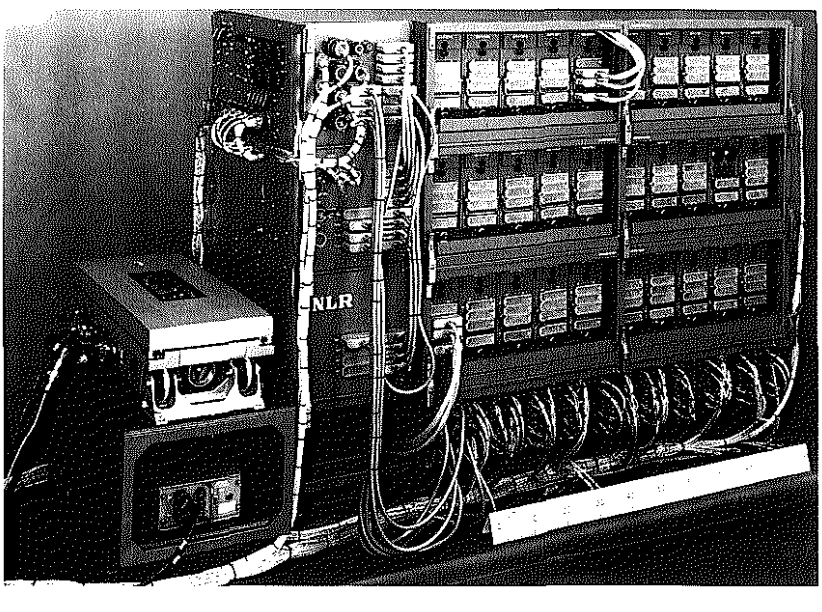


Photograph of the instrument panel taken by the 'automatic observer'



When digital recording equipment became available, special magnetic tape flight recorders were developed and the measurements were increasingly carried out with sensors with digital outputs. The first complete digital recording installation, the DR28, was used during the flight tests of the Fokker F28.

The first digital flight data recorder developed at NLR, the DR28



During the 1970's and the 1980's the demand for flight testing increased considerably and a new, modular system was built up which could handle flight tests for a variety of aircraft. This system called MRVS - the Dutch acronym for System for Measuring, Recording and Processing Flight Test Data (Meet, Registratie- en Verwerkingssysteem voor Vliegproeven) - included an autoland camera, telemetry equipment and also a quick-look system for use on board and many other practical features.

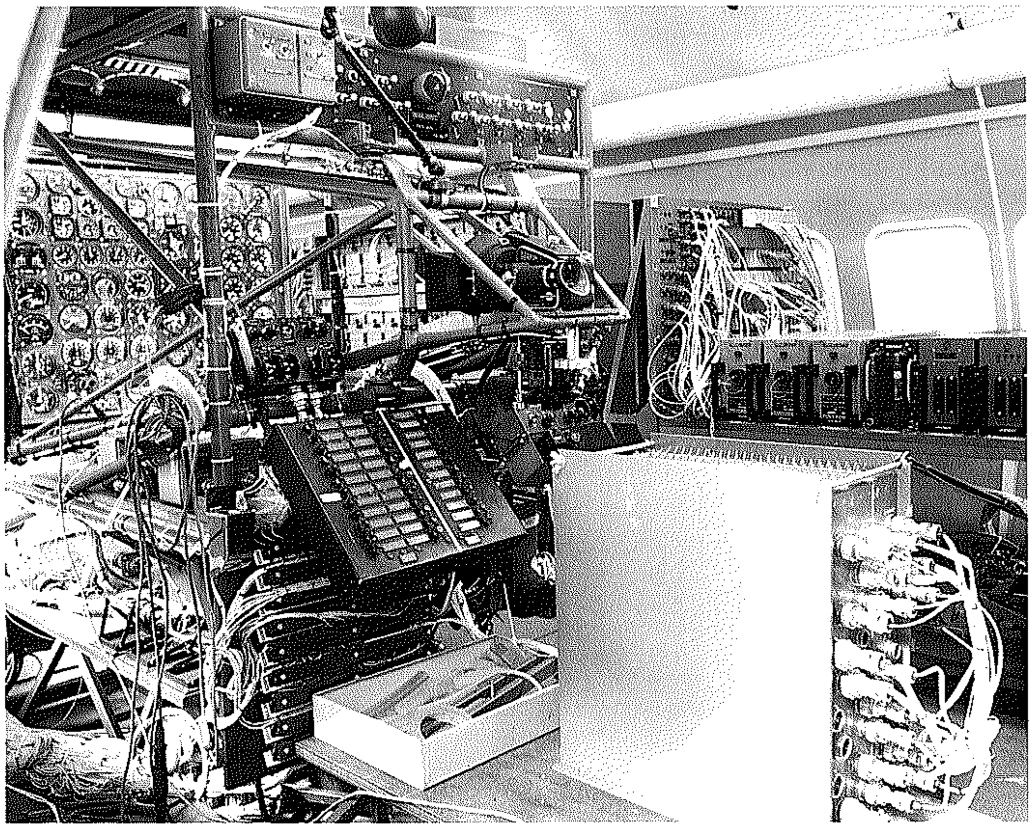
The system was developed in close cooperation with Fokker, the prime user, and Fokker developed a specific part of it. Agreement was reached on a division of tasks between Fokker and NLR. This created a unique situation in aircraft flight testing whereby both partners were fully dependent on each other. The NIVR, the organization providing a substantial part of the funding, played a crucial role in this arrangement.
During the 1990's a new version of the MRVS is being developed, again in close cooperation with the Fokker Aircraft Company.

Schedule of flight tests using an MRVS in various configurations, with an indication of the relative size of the tests

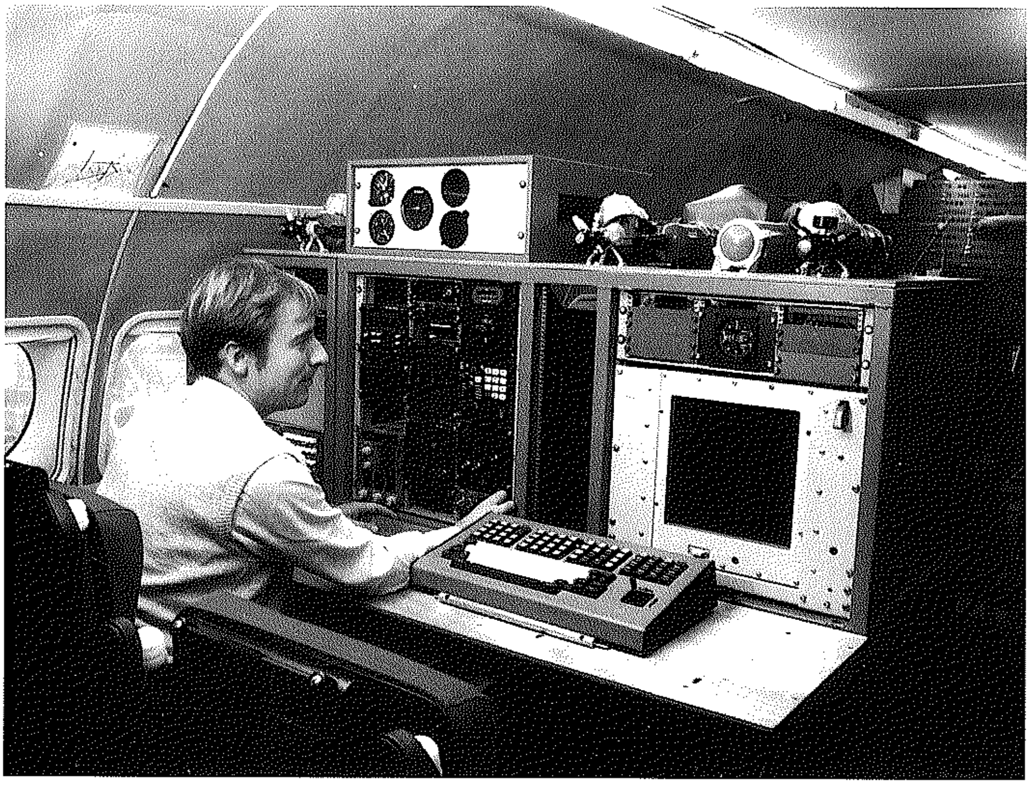
AIRCRAFT	CLASS	'79	'80	'81	'82	'83	'84	'85	'86	'87	Number of parameters from aircraft systems	Number of parameters from MRVS transducers	Total number of measured values per second
METRO II	○										0	30	1250
F27 - F83	○										40	35	3000
LOCKHEED ORION	○										20	20	2000
F27 - F555	○○										25	125	6000
QUEEN AIR	○										5	20	550
F16	○										40	40	6500
METRO II	○										15	60	3500
F28 - A1 - ATB	○○										4000	300	22000
FOKKER 50/1	○○○										350	450	10000
FOKKER 50/2	○○○										350	450	10000
FOKKER 100/1	○○○○										7500	700	30000
FOKKER 100/2	○○○○										7500	900	30000

○ = SMALL
○○ = MEDIUM-SIZED
○○○ = LARGE
○○○○ = VERY LARGE

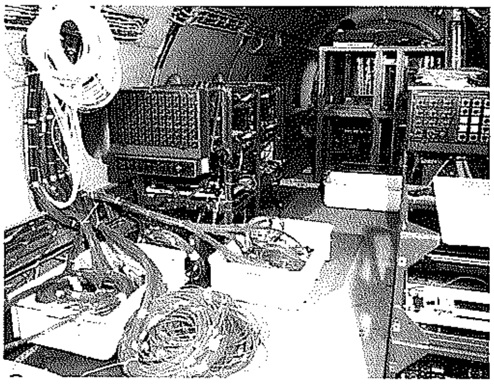
▬▬ = (PLANNED) OPERATIONAL PERIOD
······ = EXPECTED EXTENSION OF THE OPERATIONAL PERIOD



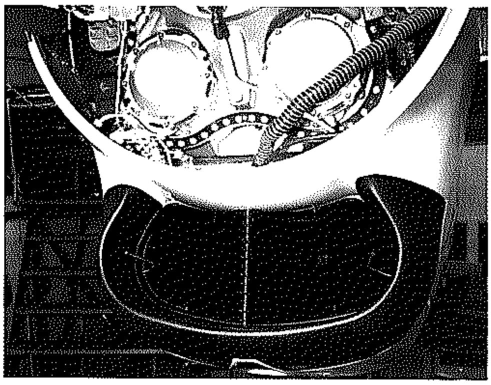
MRVS equipment mounted in a Fokker F28 Fellowship



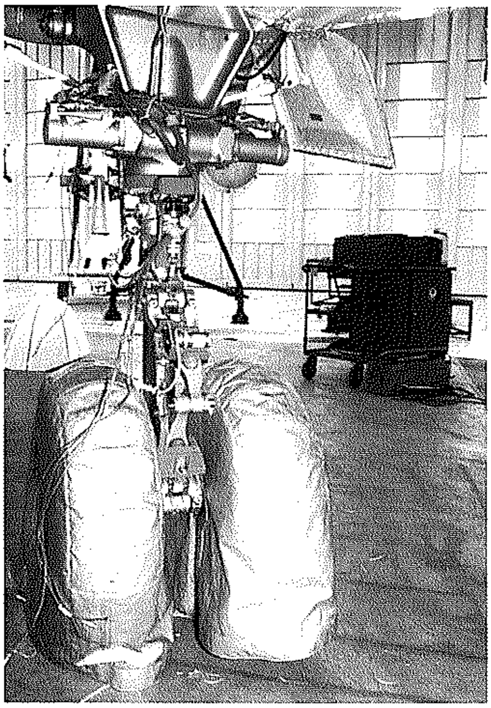
Operator's console of the flight test instruments in the Fokker 100 Avionics Test Bed



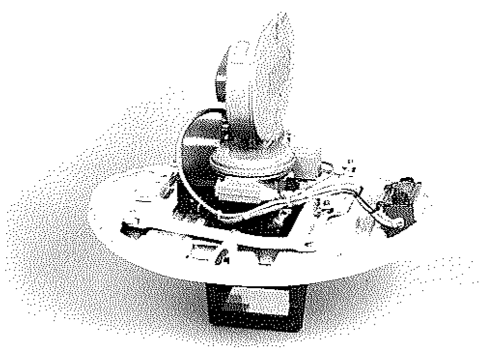
NLR flight test equipment installed in the Fokker 50 prototype

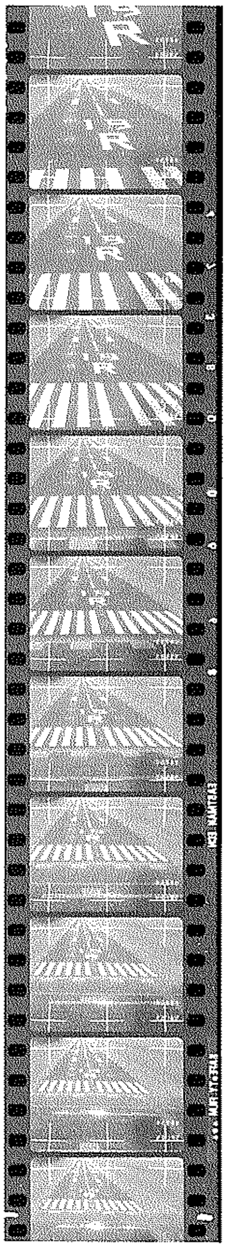


Airflow measuring probes in the intake of a P&W 124 engine of the Fokker 50 prototype



NLR flight test instruments on the main landing gear of the Fokker 50 prototype





NLR Autoland camera hatch and images of the runway taken during landing with the camera

Laboratory Aircraft

Although from the start flight testing was a major element of the RSL/NLL/NLR activities, the laboratory was never abundantly equipped with airplanes.

It was not until 1931 that the laboratory obtained for the first time its own aircraft, in spite of the fact that Ir. Grasé and Ir. Van der Maas had carried out hundreds of flight tests with aircraft of other organizations. This first laboratory aircraft was a **Fokker F.II**.

This specific aircraft was originally built in Germany in 1918 as a prototype for Fokker's first passenger plane. It was smuggled out of Germany in the Spring of 1920 because Fokker wanted to demonstrate it on the day Plesman's KLM made its first flight to London with a converted De Havilland military plane, 17 May 1920, and so attract the attention of the authorities and KLM. A few months later KLM did place an order for two Fokker F.II aircraft and the aircraft which later became the first laboratory aircraft of the RSL was one of those two. Besides with KLM it had also served with the Belgian Airline SABENA before it was registered as PH-RSL. During a period of 5 years it was used for the development of flight test instrumentation and for various flight tests, particularly in the area of stability and control. Interestingly enough this aircraft did not have a vertical stabilizer and the rudder was directly mounted at the tail end of the fuselage. Presumably the square fuselage provided enough directional stability. Another peculiarity was that the ailerons extended beyond the wing tips. In 1936 the aircraft was returned to Fokker for incorporation into a museum collection, but in 1940 it was destroyed during the bombardment of Schiphol Airport.

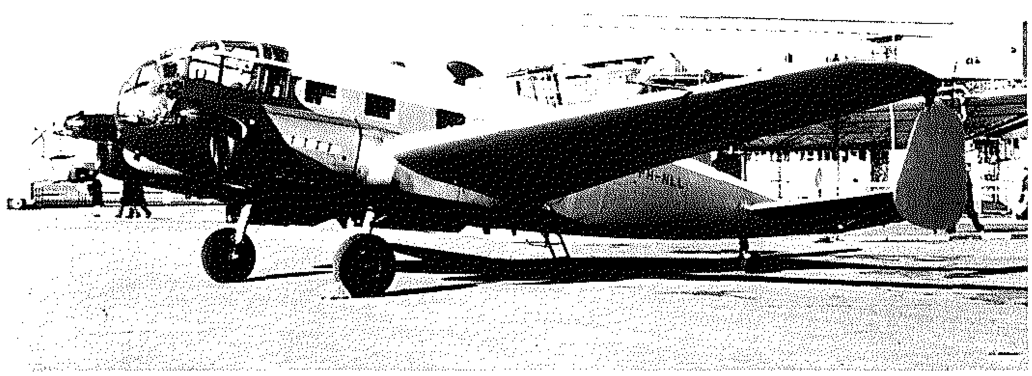
The Fokker F.II Laboratory Aircraft

In 1936 the RSL acquired a **Fokker F.VIIa** through the cooperation of Fokker and KLM. Fokker built 36 aircraft of this type. Oddly enough KLM also built four Fokker F.VIIa's from spare parts and parts retrieved from crashed airplanes. The RSL aircraft was one of those aircraft built or assembled by KLM. When the RSL acquired it, it had flown more than 7 years with KLM. The main usage of this airplane was also in the context of stability and control research. During the war it was hidden at the yacht harbor of Van Dam, Oude Wetering. It had been damaged by gun fire during the war. For quite some time there were plans to restore it, but finally in 1960 it was sold to a scrap dealer.

The Fokker F.VIIa Laboratory Aircraft

Immediately after the Second World War, May 1945, it was extremely difficult for the laboratory to obtain an aircraft suitable for flight testing. In retrospect this seems strange since there was an enormous surplus of military aircraft. This may have been due to the lack of funds and the shortage of fuel. It must be remembered that in 1945 many essential items were still in short supply even though the economic conditions improved very rapidly.
The laboratory did have a glider, the **Tromp Gövier**, for flight testing but that was a very limited flight testing capability.
Then in 1946, H.R.H. Bernhard Prince of The Netherlands offered the use of his aircraft, a **Siebel 204-D-1.** This aircraft, a military version, had been built in 1942. In 1955 the ownership was transferred to NLL. It was extensively used for comparison of wind tunnel data with flight test data, including the effects of propeller wakes.

The Siebel 204-D-1 Laboratory Aircraft



Also with this aircraft the first performance measurements in non-stationary (accelerated) flight were carried out, [Ref. 38]. The tests were inspired by a report of the Centre d'Essais on Vol (CEV), France, 1947, whereby flight data were taken during a symmetrical dive or climb. In principle such a mode of flight testing would result in an important saving in flight test time. Various flight paths were flown with the Siebel aircraft.
The results were encouraging but with the type of instrumentation available then, the accuracy of the test results was far less than those obtained in stationary flight. The development of this flight test technique was to become an important activity at the Technical University Delft, when under the guidance and inspiration of Professor Dr. Ir. O.H. Gerlach[4] suitable instrumentation and data reduction methods were developed.
The Siebel was also used for flight test exercises of students of the Aeronautical Engineering Department of the Technical University Delft.
An interesting detail is that during the first days of February 1953 the aircraft was used to transport sand bags to plug the holes in the dikes in the disaster area during the floods in Zeeland.
The Siebel had to be scrapped finally in 1964 due to lack of spare parts.

There were fortunately other opportunities to become involved in flight testing. For example a group of organizations in The Netherlands had banded together in 1947 to purchase a Sikorsky S51 helicopter to investigate the applications of helicopters in The Netherlands. NLL staff had the opportunity to carry out performance measurements on this helicopter. It was at that time that Ir. Meyer Drees, who later designed the Kolibrie helicopter (see Chapter 12) became interested in

[4]Prof. Gerlach, an aeronautical engineer and pilot, the successor of Prof. Van der Maas, became Lector (Associate Professor) in 1958 and full Professor of Aeronautical Engineering in 1965 at the Technical University Delft. He had written his Doctoral dissertation on the measurement of performance, stability and control characteristics in non-steady flight, [Ref. 39]. He introduced several new and important ideas in this emerging technique which became known as Aircraft Parameter Identification.

the flow through rotors. Although the helicopter had been purchased mainly to investigate the possible applications for military operations, postal services, rescue operations, city-center to city-center passenger transportation, etc, it provided NLL the opportunity to obtain first hand experience with helicopters. It is to be noted that futurologists at that time expected that helicopters would soon be used extensively for short haul transportation.

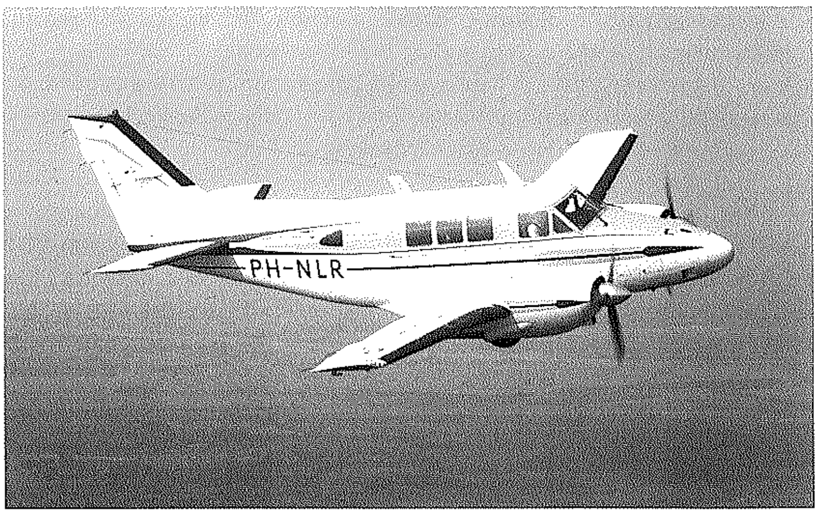
The Sikorsky S51 helicopter used for various experiments in The Netherlands

In the late 1940's Fokker designed its first jet aircraft, the **Fokker S14**, a side-by-side jet trainer. It made its first flight on 19 May 1951 and it was probably the first jet aircraft designed from the start as a trainer. Finally only 20 aircraft of this type were sold to the Royal Netherlands Air Force, because at that time many countries were provided with Lockheed T.33's, a two-seat version of the F.80 jet fighter, under the Mutual Defence Assistance Program, MDAP.
In 1961 NLL obtained an S14 - the first one built - from the NIV, the Netherlands Institute for Aircraft Development. Till 1966 it was often used as a calibration aircraft (pacer) for other aircraft. It was the laboratory's first direct experience with the operation of a jet aircraft. In 1971 it was handed over tc the National Aeronautical Museum AVIODOME at Schiphol Airport.

The Fokker S14 Laboratory Aircraft

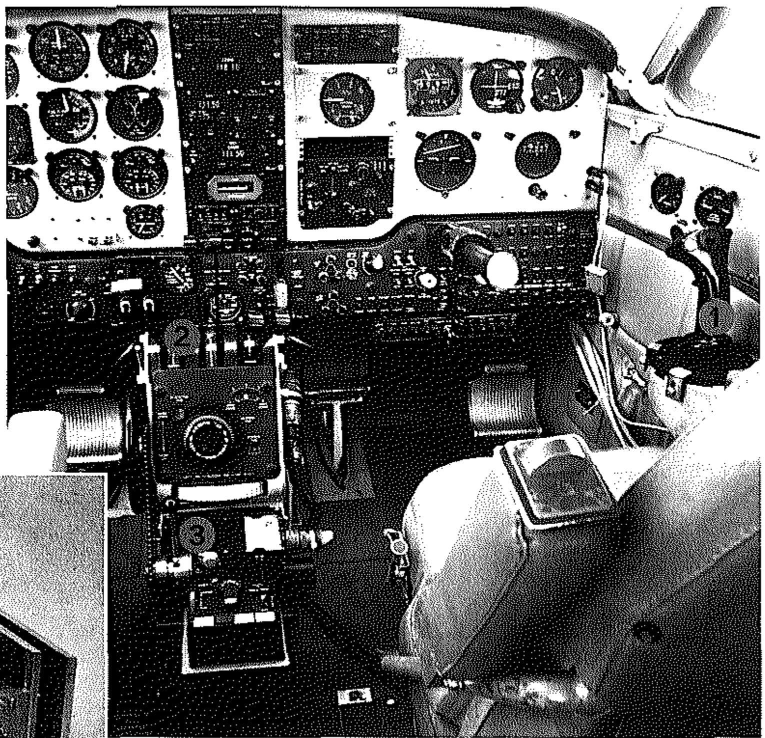
In 1963 the NLL was in a position for the first time to buy a new aircraft. It was a **Beechcraft Queen Air model 80.**
On 7 November 1963 it arrived at Schiphol Airport, after a flight of 8000 km in 5 stages, from Kansas, Wich. USA. Ir. F.E. Douwes Dekker, the NLL engineer-pilot and a pilot from Beechcraft made the trans-Atlantic crossing. For this flight an extra fuel tank with 1200 liter of gasoline had been installed in the cabin.

The Beechcraft Queen Air 80 Laboratory Aircraft

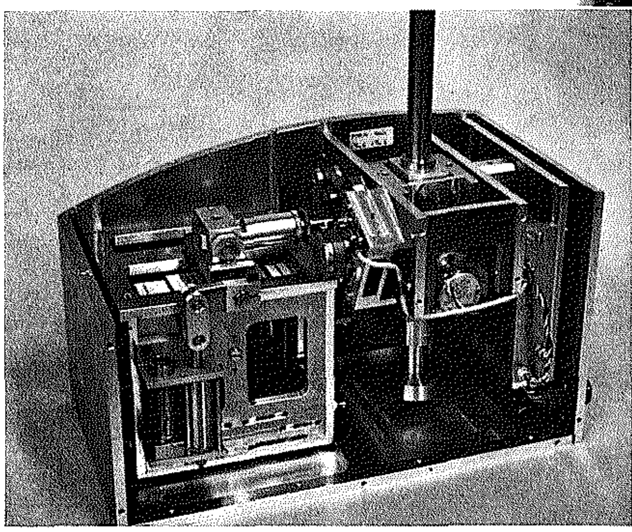


This aircraft was used for a variety of tasks. It was used for both developing new measurement techniques and testing of flight test instrumentation. This included the flight testing of individual instruments such as radio altitude gauges, airborne computers, and complete flight test instrumentation systems as developed for flight testing of the Fokker aircraft and aircraft of the Air Force. Over the years this aircraft was used as a real laboratory aircraft, a flying laboratory.

The Side-Stick Controller mounted in the Queen Air Laboratory Aircraft



The Side-Stick Controller developed at NLR



A very interesting development was the **side-stick controller**. In 1971 the first flight tests were carried out in the Queen Air with a side-stick controller similar to that used for the first time in the Airbus 310. After a laboratory test three pilots carried out flight tests with a side-stick controller installed in the Queen Air laboratory aircraft.

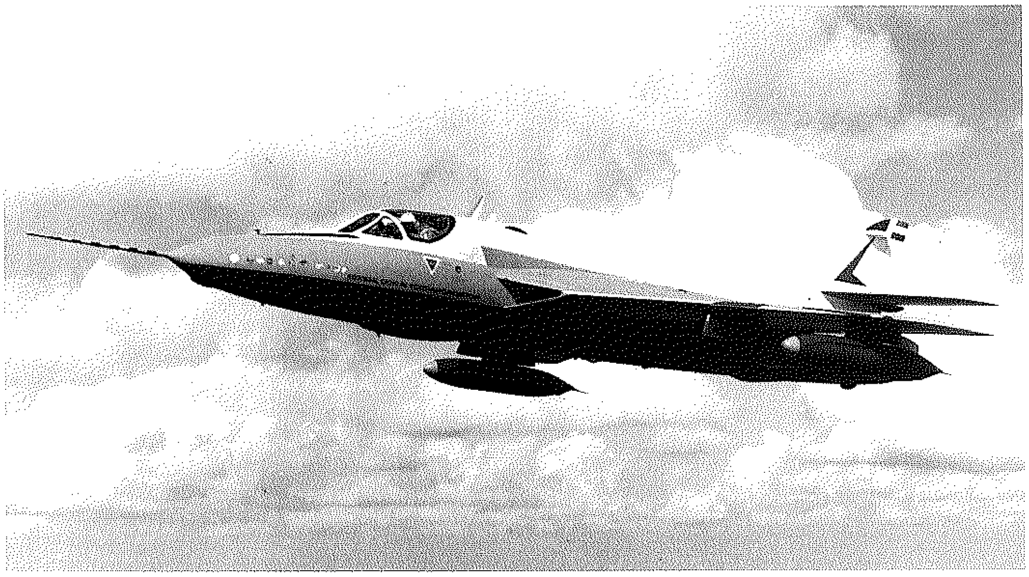
These tests were continued several years. At the time there was no immediate application in sight for an aircraft developed in The Netherlands, but the knowledge and experience gained was useful for the evaluation of applications in e.g. the General Dynamics F16 and later the Airbus family of aircraft.

The NLR side-stick controller was also tested in 1976 in a series of flight tests with the Fokker F28-A1 (the first prototype of the Fokker Fellowship that was used for a variety of development flight tests). It was used in a program to investigate the positive stick force stability in attitude stabilized aircraft.
The results of this advanced research were communicated to the international community through specialist meetings such as organized by AGARD.

In the 1960's the laboratory aircraft were increasingly used for applications which were not strictly aeronautical, particularly remote sensing. This included infrared and radar measurements of the sea state, measurements of pollution, particularly oil at sea, agricultural growth monitoring, ship movements, infrared measurements for military and civil purposes, e.g. the dispersion of cooling water from power plants, etc. Many of these flights were carried out under the auspices of a national interdepartmental program for the application of remote sensing (Nederlandse Interdepartementale Werkgemeenschap voor het Applicatie-onderzoek van Remote Sensing technieken, **NIWARS**), (see also Chapter 17). In most cases the flights involved very accurate navigation, recording and analyses, and the upgrading of existing equipment to acceptable airworthiness standards. The development of the instrumentation was carried out in cooperation with other, national and international, organizations.

In 1966 the Royal Netherlands Air Force transferred to NLR two **Hawker Hunter T Mk-7** dual seat jet fighter aircraft, one in flying condition and one for spare parts. The last Hunters were phased out by the Air Force in 1968. During more than 13 year this aircraft was also used for a variety of investigations.
It was one of the aircraft with which extensive test flights were made for the development of the Non-Stationary Method (NSM) for measuring performance characteristics of aircraft.

The Hawker T Mk-7 Hunter Laboratory Aircraft

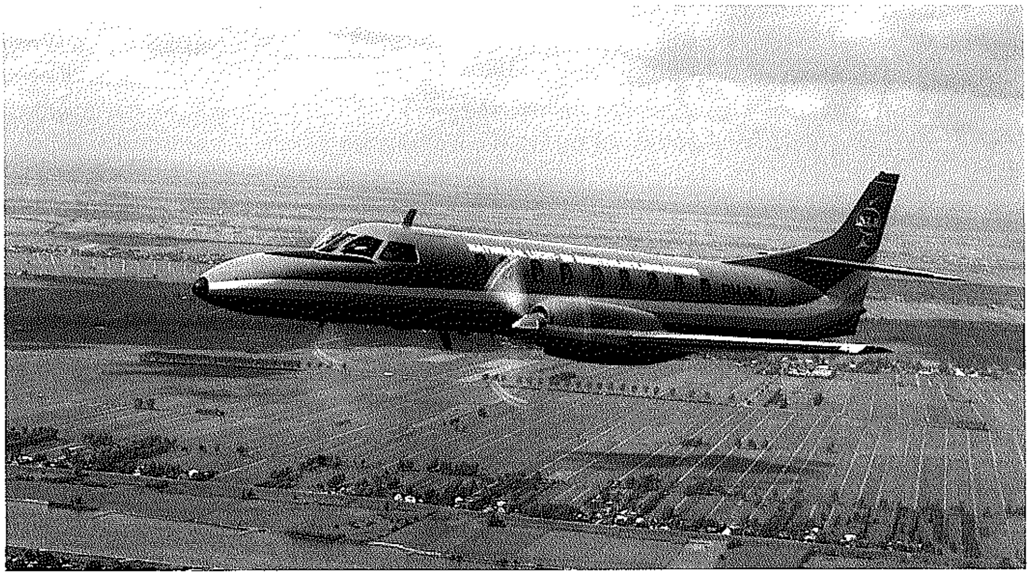


With this aircraft many flights were made in the 1960's with the ORPHEUS day and night reconnaissance system. This system was developed by Delft Instruments in cooperation with Fokker and NLR and later used by the Netherlands and Italian Air Forces. In fact for NLR it was the stimulant for the activities in the area of remote sensing, (Chapter 17).

The Hunter aircraft was employed in the validation of the moving base research flight simulator, which was then under development at NLR. It was an aircraft for which the mathematical model (the characteristics or coefficients of the equations of motions) was known and also the NLR engineer-pilots could judge the motion fidelity as incorporated in the flight simulator.

This aircraft was flown by NLR till 1980 when it was sold to an aircraft dealer.

The Swearingen Metro II Laboratory Aircraft

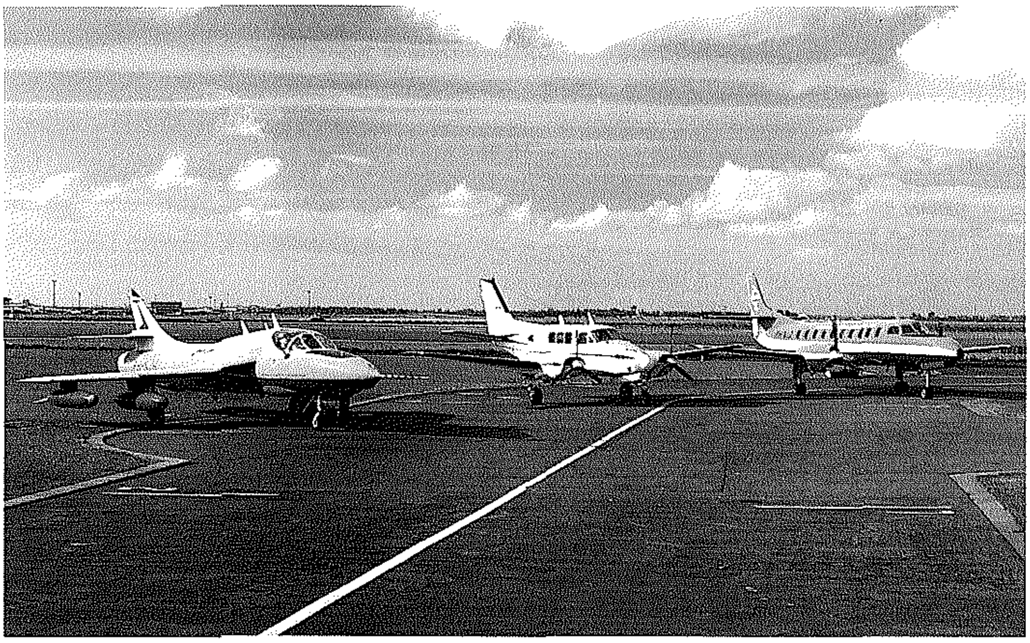


The arrival of the Swearingen Metro II Laboratory Aircraft at Schiphol Airport, 29 April 1979

Flight testing of complete systems became more and more important in the 1970's and after careful considerations it was decided to purchase a somewhat larger aircraft than the Queen Air. On 29 April 1979 a new laboratory aircraft arrived at Schiphol Airport with an all NLR crew. It was the **Swearingen Metro II**, which they had flown from San Antonio, Texas, USA, via Goosebay and Iceland to Amsterdam. This aircraft had been specially modified to accommodate laboratory equipment, including a camera dome in the cabin floor, extra electrical power supplies and 'hard-points' for carrying external instrumentation pods. In the 1980's this aircraft was used extensively both for testing of the flight test instrumentation of the Fokker 50, the Fokker 100 and military aircraft and for remote sensing experiments.

For a short period NLR had three laboratory aircraft in operation.

The three Laboratory Aircraft in 1979



The operation of laboratory aircraft is a relatively costly affair. The number of actual flying hours is seldom more than 100 per year. That is very low compared to the number of flying hours in commercial operations and even compared to military or general aviation operations. Very little routine flying is carried out with laboratory aircraft; practically every flight is a test flight. It is not surprising then that the number of occupancy hours, that is the number of hours required for preparation of the test flights, is 10 to 20 times the number of flight hours. Over the years attempts have been made to realize more flight hours so as to reduce the cost per effective flying hour. It was thus not surprising that the laboratory, with never more than three fully qualified engineer-pilots, had to dispose of the Hawker Hunter. An agreement was made with the Royal Netherlands Air Force whereby NLR could make use of high speed aircraft of the Air Force for occasional flight tests if these were thought to be of national interest, thus obviating the need for NLR to maintain and operate a fighter type aircraft.

In order to maintain the flight proficiency of the NLR pilots and - what proved to be even more important - to have available at the laboratory first hand experience with the operation of current airliners, arrangements were made for the engineer-pilots to fly with commercial airlines on a part-time basis. During the last few decades such arrangements have been made for the pilots of NLR and the Technical University Delft, mostly with charter airline companies. The advantages are obvious: the engineers stay current on airline practices which is important when dealing with air traffic problems and when teaching students. The airlines concerned have the part-time service of highly motivated and capable pilots.

For many years the Siebel and later the Queen Air were used for flight test exercises with students of the Department of Aerospace Engineering of the Technical University Delft. Also in other aspects the cooperation with that Department was pursued over the years through the execution of joint research projects.
When it became clear at the end of the 1980's, that the University had to replace its more than 30 year old laboratory aircraft, a De Havilland DHC-2 Beaver, and the Queen Air of NLR would have to be phased out within a few years, the Department of Aerospace Engineering and NLR decided to purchase and operate jointly a new laboratory aircraft, a Cessna Citation II. The aircraft was flown across the Atlantic Ocean by Ir. Kleingeld and Mr. Groeneveld of NLR and Ir. Hosman of the Technical University Delft and landed at Schiphol on 19 March 1993.

The Cessna Citation II Laboratory Aircraft jointly owned and operated by NLR and the Aerospace Engineering Department of the Technical University Delft

With the joint ownership and operation of a new laboratory aircraft in 1993 this cooperation between the Department of Aerospace Engineering and NLR will be further intensified.

The Hangars at Schiphol

During the 1980's it became more difficult to maintain hangar space at Schiphol Airport - the airport closest to the laboratory. NLR had been very fortunate to have had access to an airport only a few kilometers distance from Amsterdam and adjacent to the Fokker Flight Test Center. Due to the increased pressure from the ever growing commercial aircraft operations it became almost impossible to lease a secure hangar space at Schiphol and NLR lost its rented hangar space when a major re-construction program was carried out. Fortunately the Dutch Dakota Association (DDA) took the initiative to construct a hangar at Schiphol in 1989 and this Association was interested in leasing part of the hangar to NLR since obviously it would strengthen its case to maintain a hangar space at Schiphol Airport.

The DDA was founded in 1982 under the energetic leadership of Capt. A.C. Groeneveld. The Association is a private organization and it operates a Dakota (the PH-DDA) and plans to have a second Dakota (the PH-DDZ) operational in 1994. Groeneveld managed in 1988-1989 to build a hangar at Schiphol from where the DDA aircraft are maintained and operated by professional volunteers. The DDA, run by volunteers, organizes tourist flights over The Netherlands. It is a great pleasure to watch a DC-3/Dakota 'touring' over The Netherlands, often during week-ends. There is a growing, nostalgic, interest of the public in those remarkable planes which contributed so much to the development of civil aviation and of course also to the transport needs during the Second World War and even later. It is nice that through this arrangement the connection of this historical Douglas aircraft and NLR is continued.

NLR instrument pod (left) installed on the NF-5A Test Aircraft K-3001 of the Royal Netherlands Air Force

Participation of NLR in the Operation, Training and Adaptation of RNLAF aircraft

During the 1960's the technical cooperation with the Royal Netherlands Air Force was again intensified. One reason was the purchase of the Northrop F-5. The particular version was produced by Canadair, Montreal, Canada. It became known as the NF-5. The NF-5 aircraft - 105 in all - were flown from Canada to The Netherlands (Air Force Base Twente, near Enschede) during 1969-1972. This aircraft had been modified to accommodate the requirements of the Royal Netherlands Air Force. The first aircraft of this series, the K-3001, was assigned to the Air Force Test Group at the Twente Air Force Base. This Test Group consisted of an Air Force test pilot, a ground crew and a permanent support group of NLR engineers and technicians. This aircraft was used as a test aircraft for a variety of experiments such as flutter testing with various external loads (bombs, fuel tanks, dispensers, etc.), fatigue monitoring and various electronic installations. The flight tests were carried out by the Air Force and NLR prepared and installed the instrumentation and carried out the analyses of the flight test data. This joint Air Force-NLR team operated during the period when the NF-5 was operational with the Air Force.

When the Royal Netherlands Air Force purchased the General Dynamics F-16 (deliveries began in 1979) the aim was to achieve a high degree of commonality with the USAF and the other three European Air Forces (Belgium, Denmark and Norway). A separate Netherlands test aircraft would then not be necessary for the investigations of such matters as new external store configurations, new mission patterns, etc. This goal was largely achieved during the first few years of operation of the F-16. The task of NLR shifted towards the participation in **field trials, mission preparation** and **evaluation of the effectiveness** of the aircraft in a changing environment.

After some years there arose the need for further special instrumentation and NLR became more involved with the Air Force operations of the F-16 aircraft. An extensive task was the development of a mission planning system - **CAMPAL** - Computer Aided Mission Planning at Air Base Level, in close cooperation with the RNLAF, (Chapter 16).

Preparing a flight plan with the CAMPAL System (Computer Aided Mission Planning at Air Base Level)

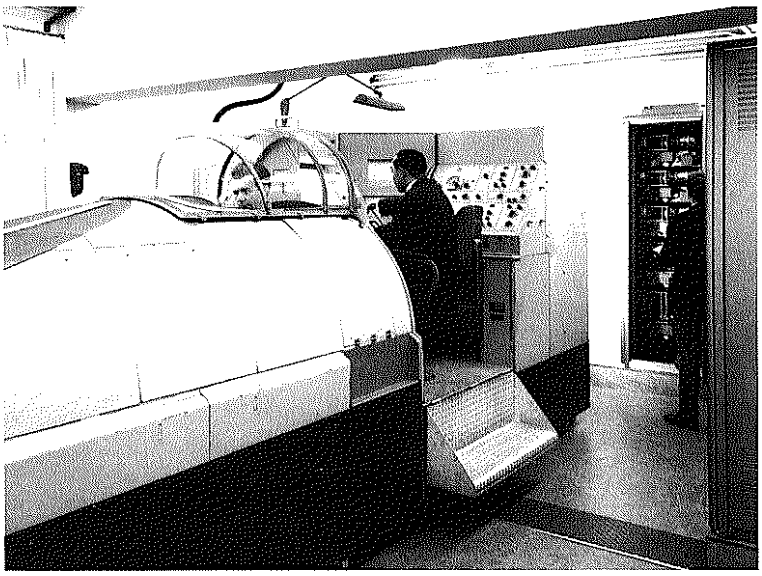
Around 1990 the Royal Netherlands Air Force decided to maintain the F-16 for several more years and to carry out a Mid-Life Update (MLU). In this undertaking the Air Forces of the USA, The Netherlands, Belgium, Norway and Denmark participated. Here NLR is carrying out several tasks in close cooperation with the U.S. Companies and the RNLAF. The Mid-Life Update may eventually include:

- a modernized cockpit;
- digital terrain following equipment;
- an upgraded radar;
- an advanced IFF (Identification Friend or Foe) system;
- provisions for night vision.

Flight Simulation

Chapter 15 mentions that at NLR the first complete analog computer was installed in 1955. With this computer it became possible to 'fly' an aircraft in the laboratory in real time in a simplified form. Gradually more functions were added and with the so-called V/STOL simulator it was possible to study take-off and landing characteristics of aircraft.

The fixed base V/STOL Flight Simulator

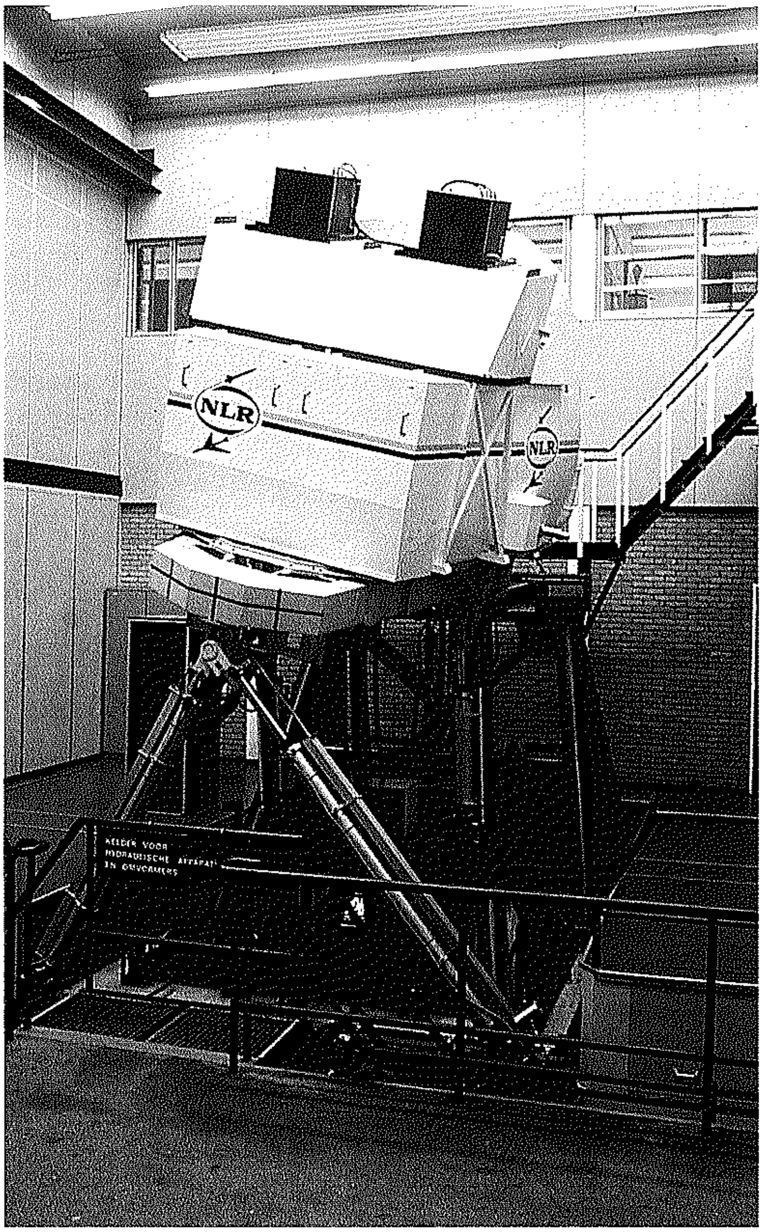


In 1972 the construction of a flight simulator with a moving base was started in a separate building at the laboratory in Amsterdam. The moving base of this simulator was driven by special 'frictionless' hydraulic cylinders.
These cylinders were developed by Prof. Dr. Ir. T.J. Viersma and his associates of the Department of Mechanical Engineering of the Technical University Delft in close cooperation with the Department of Aerospace Engineering of that University. The cylinders are made 'frictionless' by means of hydrostatic bearings - an oil film leaks constantly between the piston and the cylinder and the piston does not make contact with the cylinder. This means that 'sticking' and 'jitter' are down to a level that cannot be felt by the pilot in the cockpit mounted on the moving platform.[5]

The flight simulator was provided with two, interchangeable, cockpits: a single seat F-104 cockpit obtained from the Air Force and a dual seat DC-5 cockpit obtained from KLM.
The visual system consists of mirrors projecting an image on the cockpit windscreen obtained by a small camera moving above a vertically placed board with a landscape which includes an airfield. Around 1970, when the system design was frozen and the major components were ordered, the capability to generate 'landscapes' with computers was still in its infancy and certainly not suitable for application in a comprehensive research simulator system as envisaged by the NLR simulation group.

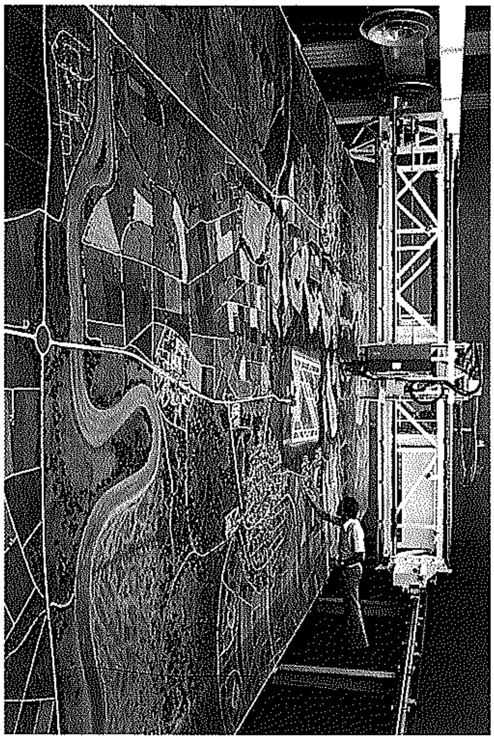
The visual system was very useful in research concerned with such widely different subjects as take-off and landing procedures and the development of low altitude high speed flight control characteristics for fighter aircraft.

[5]Around 1970 it was felt that such a refinement was not necessary for ordinary flight simulators as used by the airlines for pilot training. But as the importance of training simulators and the demands for better quality increased, this type of motion system became also common for pilot training simulators.
For the second - six degrees of freedom - motion system of NLR, the firm Hydraudyne Systems & Engineering produced the motion system and platform, with technical advise from the Technical University Delft. Since that time a substantial number of motion systems was produced for simulator manufacturers.

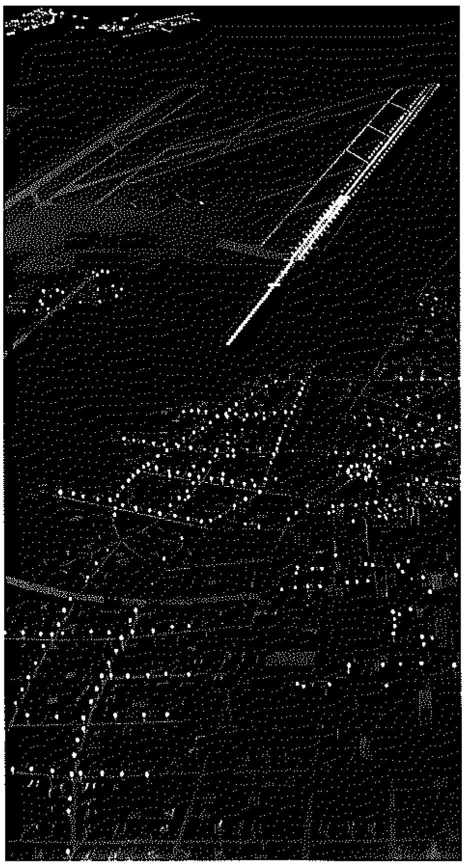


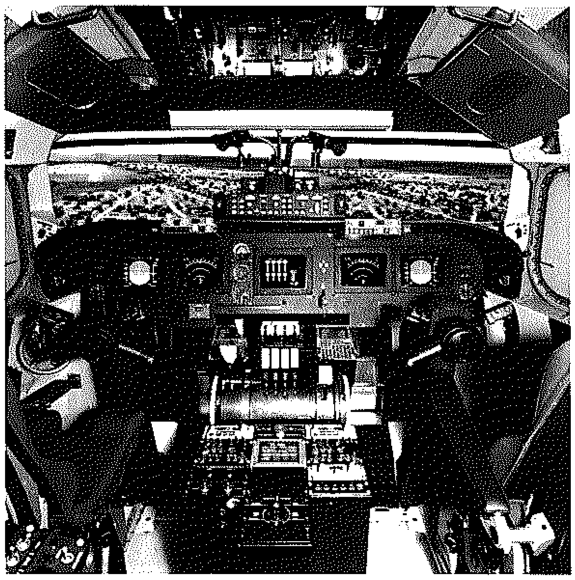
The moving base Flight Simulator with four degrees of freedom (Research Flight Simulator RFS)

The model landscape board with moving camera of the RFS



The outside view presented to the pilots of the landscape board illuminated for simulation of the night situation



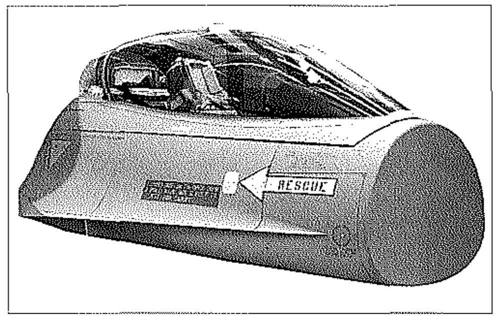


Dual seat cockpit (transport aircraft configuration) of the RFS

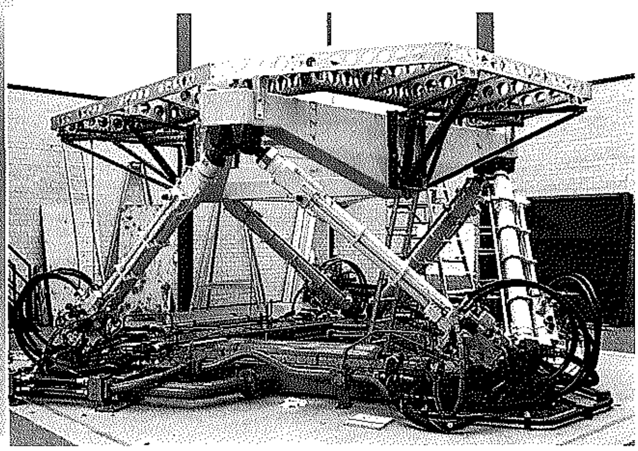
The development of a research flight simulator proved to be a very challenging task. Although many components were obtained from vendors, there still was an enormous amount of work to be carried out in-house, particularly since the simulator incorporated many new features. For the validation of the simulator mathematical models of the DC-9 and the Hawker Hunter laboratory aircraft were installed. Pilots of NLR and external pilots carried out the validation.

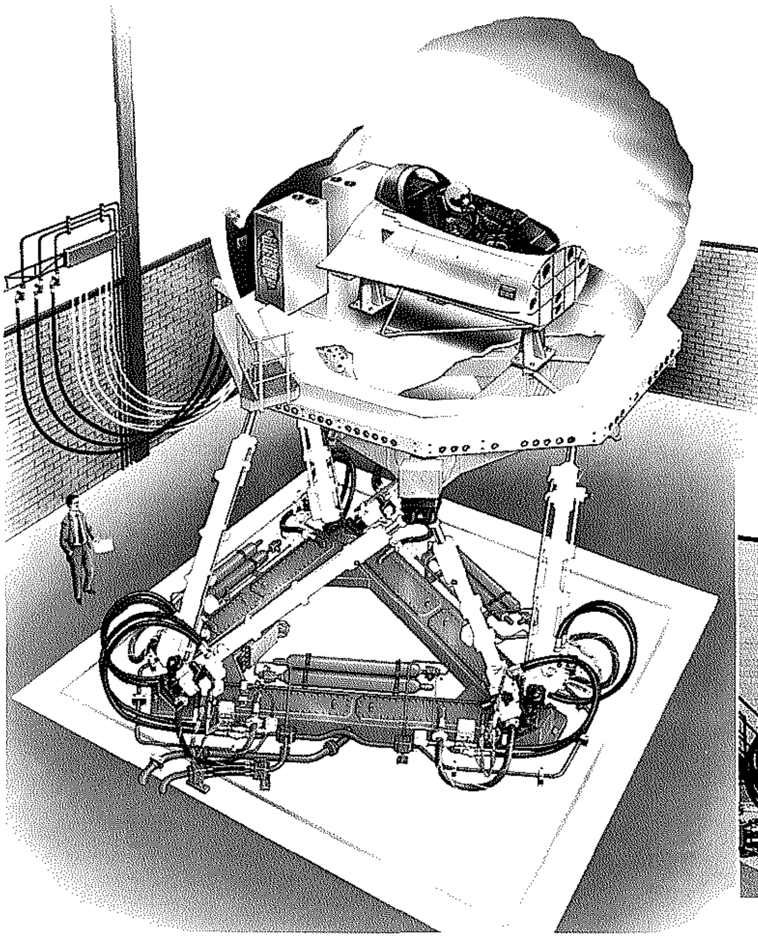
During more than 20 years of operation the facility has been used for several different research and development projects. NLR was also very fortunate to find a large number of civil airline and military pilots prepared and interested to participate in these programs.

F-16 cockpit of the NSF



Moving base of the NSF





Artist view of the moving base Flight Simulator with six degrees of freedom (National Simulation Facility, NSF)

Examples of projects in which the flight simulator was engaged are:

- Simulations of **MLS** (Microwave Landing Systems) and related Air Traffic Control problems sponsored by the RLD of The Netherlands, Eurocontrol (the European organization concerned with air traffic control), the FAA (the US Federal Aviation Administration responsible for air traffic control) and research projects within the cooperation framework with DLR. A mathematical model of the Boeing-747 was used for many of those simulations.

- Simulations in connection with the development of the **Fokker 100** civil aircraft. Those simulations were obviously of a different nature. They were concerned with the flying characteristics and the development of the flight control systems of this aircraft and the development of symbology on the display screen ('the full glass cockpit').

- During the selection of a new fighter aircraft for the Royal Netherlands Air Force in the first half of the 1970's, the 'riding qualities' of the four competing aircraft types were investigated and particularly the **F-16** riding qualities were investigated with the NLR flight simulator.
  Later a complete mathematical model of the **F-16** was implemented which was used in connection with the Air Force operations and also for accident investigations.

- Following this the simulator was engaged in an extensive research and development program of the **Lavi** aircraft of the Israel Aircraft Industry - IAI - and particularly the flight control laws for the flight control system, under development with the US company Kearfoot. This program was very demanding for the, very few, members of the NLR flight simulator staff, charged with several other tasks during this period. The final result and the experience gained proved to be extremely useful in the further development of the 'art' of flight simulation at NLR.

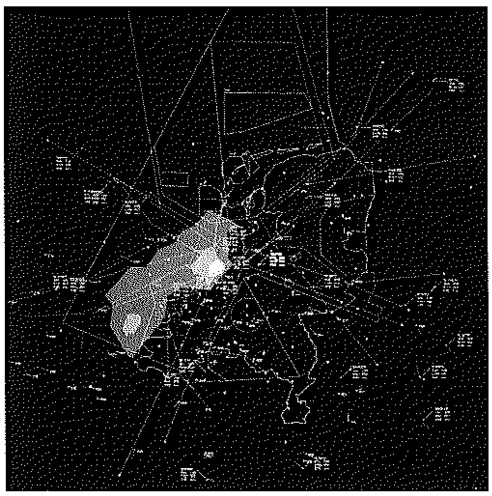
Following these experiences it became possible to define the next generation of research flight simulators: a new simulator with six degrees of freedom. This facility was developed into a 'National Simulation Facility', NSF.

The installation has a fully computer-generated visual system and several cockpits, including an F-16 cockpit. At the time of writing this book the plans were to employ the installation for the further development of the F-16 and to develop programs for low altitude high speed flight training, which became an important subject in the late 1980's when the aircraft noise associated with low altitude flight training became an important environmental problem in certain areas of Europe.
The simulator will also be employed in research of Air Traffic Control and air routing around airports. The studies carried out during the last several years in connection with helicopter operations will also be continued with this simulator.
Obviously the art of simulation has now progressed so far that for any new civil and military aircraft development the installation will be of great use.

The NLR Air Traffic Control Research Simulator NARSIM

Air traffic simulation.

As explained above the moving base flight simulator was used to carry out research in connection with the possible use of different approach and take-off procedures, mostly motivated by the increasing air traffic at several airports. A closely associated technical problem is



Detailed view of The Netherlands' en-route airspace structure

that of the air traffic control; the control of many aircraft approaching an airport in a given period of time and the control of many, civil and military, aircraft overflying a certain area simultaneously.
NLR assisted the RLD and the industry (Signaal) in this field over a period of many years. This led to the development of the NLR Air Traffic Control Research Simulator (**NARSIM**) with which various ATC-scenarios can be studied.

Currently developments have progressed to the point that the combination of an aircraft in the air (the Metro II laboratory aircraft), a laboratory air traffic simulator (NARSIM) and possibly the flight simulator will be coupled to create a 'laboratory environment' in which future Air Traffic Control scenarios can be studied.

Flight Testing, Flight Mechanics, Flight Operations, Flight Systems

That could have been the title of this Chapter. Finally all that counts is the contribution to **safe and effective flight**. The process is complicated but there was never any doubt about the goals of NLR.

For this book the choice was made not to describe systematically the activities of all the Departments but to select certain topics. This Chapter is therefore not an account of all the achievements of the Flight Division. Some laboratories in other countries are organized differently in that often a **Systems Division** is incorporated dealing with the aircraft as a total system. At NLR this need did not arise since the laboratory seldom was involved directly in the development of a total aircraft system. That was and is the responsibility of the aircraft industry.
Nevertheless in research related to civil and military aircraft operations all aspects of the system are often important. It is remarkable to note here that in the context of AGARD - basically an organization for exchange of information and cooperation in the area of aeronautical research - the total system aspects are usually assigned to only one of the nine AGARD Panels, namely the Flight Mechanics Panel. That is a reflection of the opinion of most people involved in aircraft research and development. The most successful aircraft designers do involve their test pilots in the design process.
This does not mean the aerodynamicists, propulsion engineers, structural engineers, avionics engineers, etc., are less important in this process. The ideal chief designer combines all these aspects with those of economics, manufacturing and a multitude of other elements which together make a successful aircraft design.

7. Propulsion

Propulsion is obviously the key to powered flight. It was not until an engine of sufficient reliability and with a specific mass (mass per horse power delivered) much lower than for other - earth bound - purposes was developed, that flying became a reality.

During the early aeronautical days a few types of aircraft engines were developed and built on a limited scale in The Netherlands (by Artillerie Inrichtingen and Hollandse Machine Fabriek) but this activity was abandoned in the 1930's. Assembly of aircraft engines took place from time to time, the latest under license of Pratt & Whitney Canada for the Fokker 50 aircraft. Aircraft engine maintenance and repair did become a substantial activity at KLM and the Royal Netherlands Air Force.
During the last few decades also the manufacturing of components under sub-contract with foreign engine manufacturers gained in importance.
Also some companies specialized in the interesting activity of repairing and coating of compressor and turbine blades of jet engines. Turbine blades often cost several thousands of guilders each and repairing and coating has become an economically viable activity in The Netherlands as elsewhere. Anti-corrosion coating is of particular importance in The Netherlands and in Western Europe where the degree of acidity at lower altitude is rather high compared to other parts of the world. For the aircraft of the Royal Netherlands Air Force, which are employed very much in low altitude training, coating is necessary to reduce the operating cost.
The propulsion activities at the RSL/NLL/NLR reflected the situation sketched above.

Engine Testing

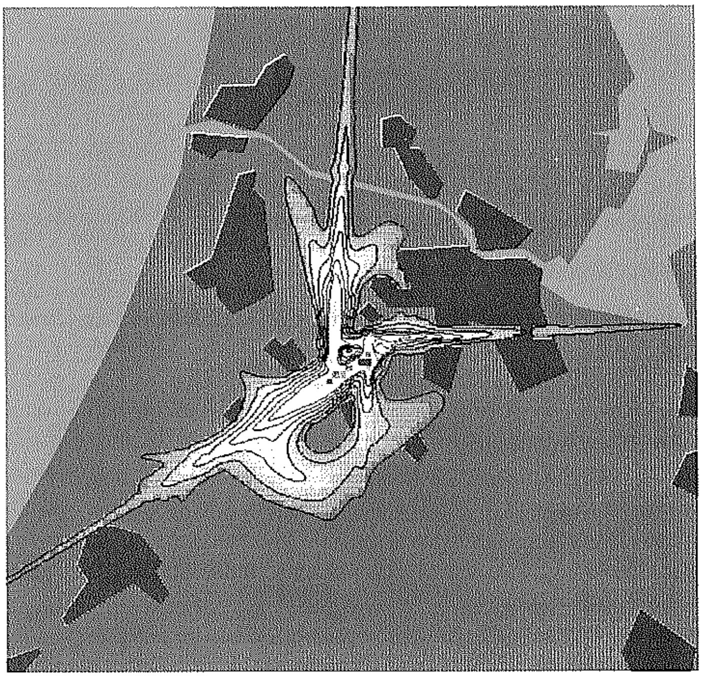
When the RSL was still in the planning stage the need to test aircraft engines was identified. In 1919, shortly after the RSL was founded Ing. C. Kuipers was appointed to start an Engine Department. A simple engine test stand was erected at the laboratory site at the Navy Yard in Amsterdam.

At the beginning these activities were built up rather rapidly. Typical for the work load was that during one month, in 1924, a series of 20 Napier-Lion engines was tested for the Ministry of the Colonies. These were engines with a power rating of 450 HP. The tests consisted mainly of measuring the power and the fuel consumption. (The fuel consumption was 237-248 gram/HP/hour which was not particularly low for that time period.)

Other tests were concerned with the comparison of engine performance with different kinds of fuel such as mixtures of gasoline and benzol and tests in which the effects of changing various parameters, valve settings, carburetor adjustments, etc., were measured. The tests were carried out mainly for the Armed Forces and KLM.

As the main users of aircraft engines gradually acquired their own facilities to test engines in their maintenance shops and as the data supplied by the (foreign) engine manufacturers became more reliable it was logical to terminate this activity at the RSL in the 1930's.

In 1932 the RSL received Government orders to reduce its personnel by 12% and it was decided to release Ing. Kuipers and five other personnel members of the Engine Department by 1 January 1933. The activity was continued for some time under Ir. Von Baumhauer and finally terminated in 1937 on the occasion of the change from the Governmental Service RSL to the Foundation National Aeronautical Laboratory (NLL). From then on matters concerning the performance of aircraft engines were handled by the Flight Department of NLL.



There remained a keen interest at NLL in the performance of aircraft engines and often aircraft operators were advised on the performance of aircraft engines, e.g. operating under various circumstances such as in tropical climates and at high altitudes.

Engine Noise Measurements

In 1929 the Engine Department of the RSL started to develop methods for measuring noise. Although the external aircraft noise measured on the ground (fly-over noise) was not yet a problem, the internal cabin noise certainly was. The measurement techniques developed were reported and several comparative measurements were carried out, but it seems that around 1930 there were few attempts to reduce the internal noise level drastically.

Much later, during the 1960's, engine noise became a major problem area in aeronautics and various activities were started at NLR to tackle this problem as is summarized in Chapter 11.

Example of calculated contours of constant noise nuisance levels around Schiphol Airport

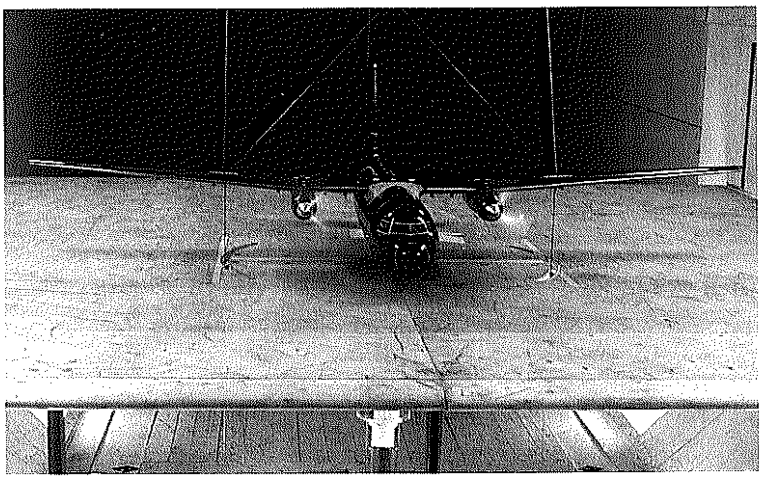
Models were developed to calculate the 'noise loading' around airports. Contours of constant noise loading - a measure of the degree of nuisance experienced on the ground - were calculated for all airports, civil and military, in The Netherlands. Here the sound level, the duration and the time of the day are taken into account to arrive at a number which characterizes the integrated noise nuisance level.

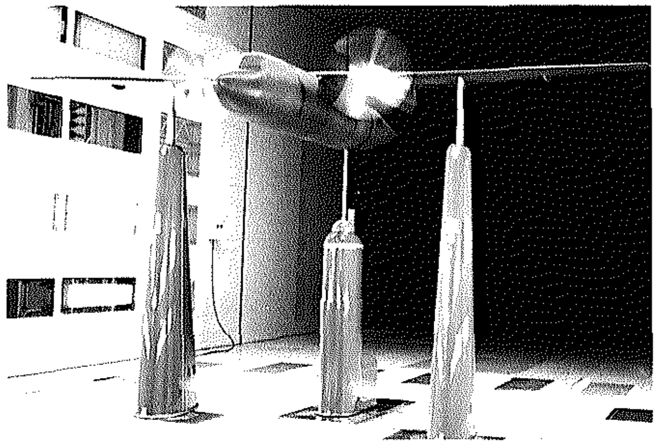
Such contours are important for urban planning. With the computer programs developed for this purpose, predictions are made of the effects of different runway usage, projected new runways, the changing composition of aircraft types making use of a particular airport, etc. Over a period of years this model has been refined to such an extent that it can be reliably applied in city and airport planning. Models such as these can also be used to assess the effect of aircraft noise rulings which prohibit older, more noisy, aircraft from using a particular airport.

Testing of Propeller Powered Aircraft Models

At NLL/NLR - as at other aeronautical laboratories - techniques were developed for wind tunnel testing of aircraft models with powered propellers. Small direct current electric motors were installed in the aircraft model and driven by a Ward-Leonard electric generator - located outside the wind tunnel - converting alternating current to direct current.

Wind tunnel test with electrically powered Model Engines of the Fokker F27, 1955





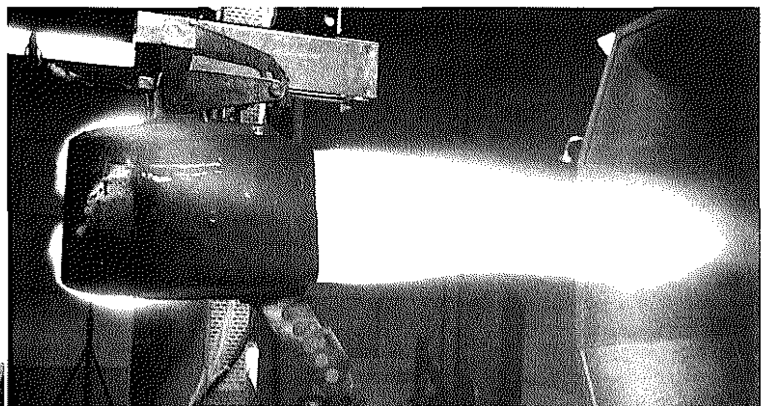
Wind tunnel test with compressed air-driven Model Engines of the Fokker 50, 1983

More recently, as turbo-powered model engines became available - see below under Turbofan Engine Simulation - propeller driven aircraft models have also been supplied with turbo-powered model engines, driven by compressed air. The advantage is that they can deliver more power to the propellers for a given size of the model than electric motors.

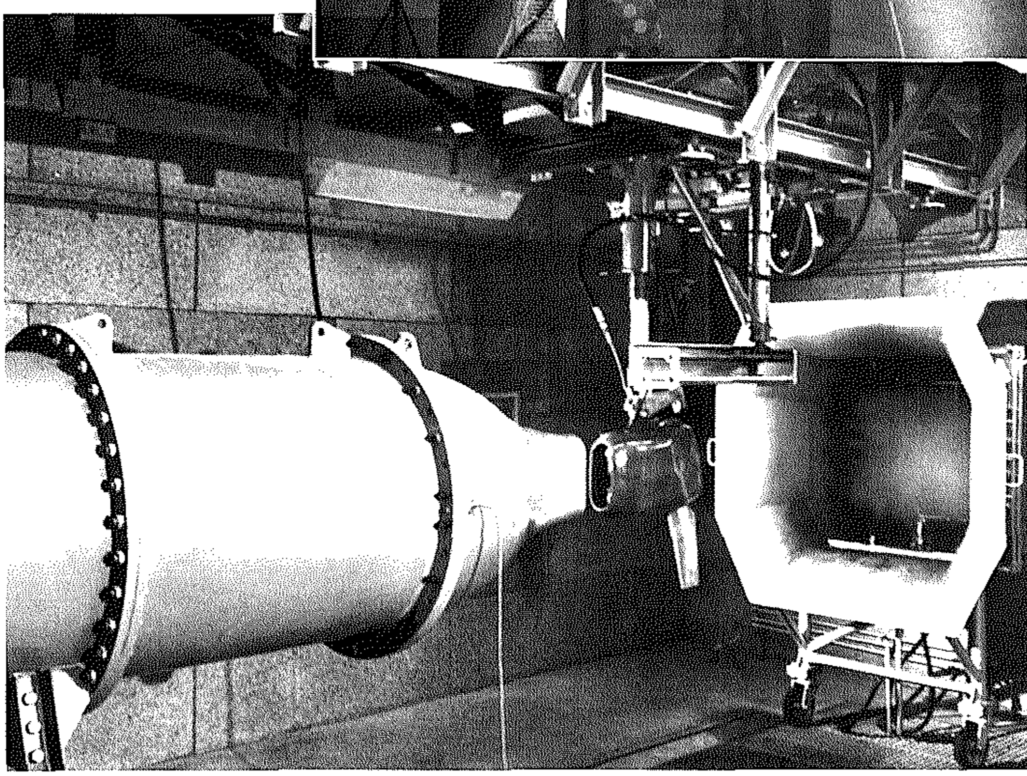
Ramjet Engine Testing

During the development in The Netherlands of the Kolibrie helicopter, (see Chapter 12), which was provided with ramjet engines at the rotor tips, various tests were carried out in a static test stand constructed at the Noordoostpolder laboratory. The development of this helicopter was terminated at the end of the 1950's and the facility was used later for testing small model jet engines, including testing of exhaust noise suppressors.

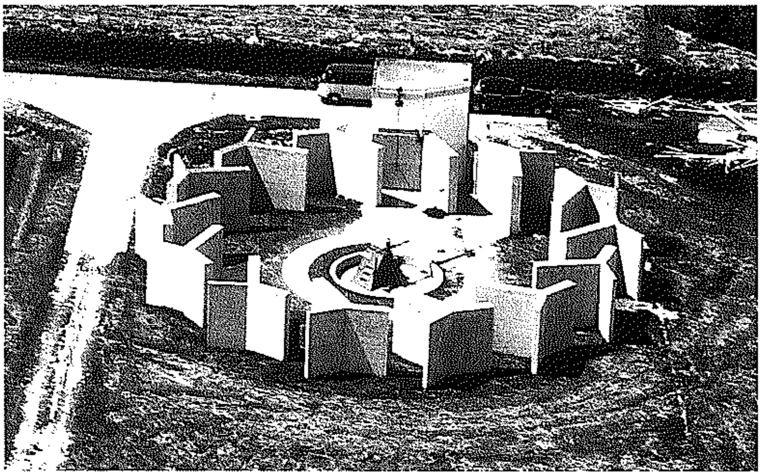
The ramjet engines at the tip of the rotor blades did introduce special problems such as the operation of the fuel system under the load of very high centrifugal forces and the problem of ingestion of the exhaust gases of one engine into the engine of the opposite blade. This called for an experi-



Test of the Ramjet Engine of the 'Kolibrie' helicopter in the Static Engine Test Stand at the Noordoostpolder, around 1958



mental investigation and a rotary test stand was built at the laboratory in Amsterdam. The noise was not acceptable to the surrounding community and the test stand was moved to the newly acquired laboratory site in the Noordoostpolder. There it was placed in the middle of the 200 HA site and it was surrounded by a wall for safety reasons and to reduce the noise.



The Rotary Test Stand at the Noordoostpolder in the mid-1950's

Jet Engine Exhaust Simulation

The exhaust flow of jet engines and rockets interacts with the external flow and greatly affects the performance. The mixing of the jet with the surrounding flow is characterized mainly by the ratio of the exhaust flow velocity to the surrounding flow velocity and the density ratio (and temperatures) of these two flow streams. The after-body drag of an aircraft with the exhaust at the tail (e.g. a single engine fighter plane) can amount to as much as 20 to 50 percent of the total drag. In order to simulate the proper conditions in wind tunnel testing it is therefore necessary to duplicate not only the proper velocity ratio but also the proper density ratio. The latter can be achieved by heating the exhaust gas of the model engine. Another factor that plays a role in this is the ratio of the specific heat of the two gas streams.

At NLR a jet simulation system was developed whereby the ratio of the temperatures and the ratio of specific heat are simulated by means of an H_2O_2-gas (hydrogen peroxide) generator. The liquid hydrogen peroxide is pumped to the engine model installed in the aircraft or rocket model to be tested. It flows through a small-mesh silver wire netting which acts as a catalyst and the hydrogen peroxide decomposes into water and oxygen while releasing heat. The gas, a mixture of superheated steam and oxygen simulates the hot exhaust gas of the engine. By varying the ratio of hydrogen peroxide and air flowing through the engine model exhaust gas temperatures between 225°C to 1000°C can be achieved.

For obtaining higher temperatures, such as may be required for the simulation of rocket exhaust gases, NLR used hollow polyethylene cartridges through which hydrogen peroxide was fed. Temperatures up to 3000°C can then be achieved with ratios of specific heat close to those of that of rocket exhaust gases.

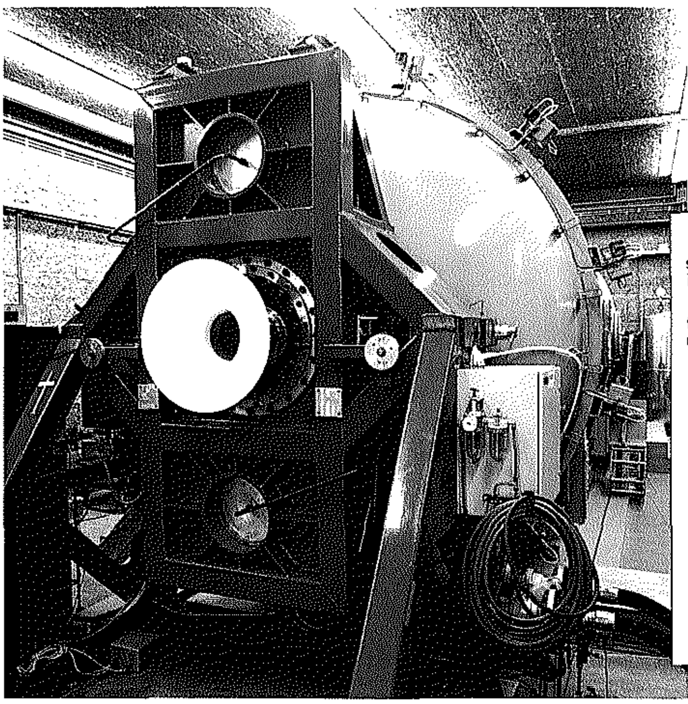
The hydrogen peroxide installation was mounted on a trailer so that it could be used at various wind tunnels in Amsterdam and in the Noordoostpolder.

The mobile Hydrogen Peroxide H_2O_2 installation

Turbofan Engine Simulation

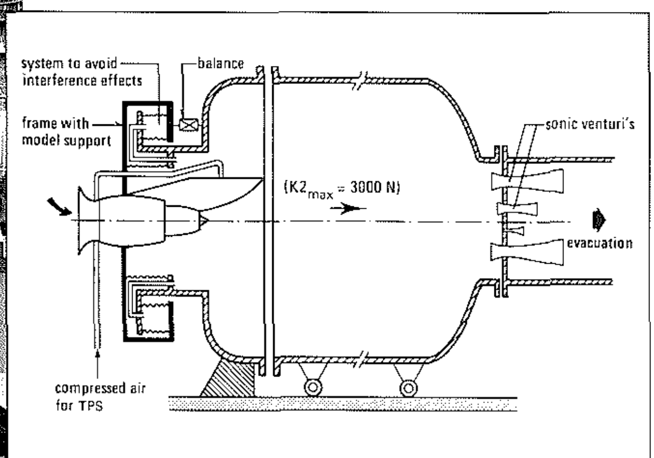
In the 1970's high bypass engines were introduced for application in civil aircraft. These engines have a lower fuel consumption and the engine noise is greatly reduced compared to the previous generation of low bypass engines. The simulation of the flow around the larger diameter engines and the aircraft-engine combinations required new wind tunnel simulation techniques. In the USA small Turbine Powered Simulators - **TPS** - were developed. NLR and DNW purchased several of these model engines of different size and power. They are small turbofan model engines where the fan is driven by a turbine, mounted inside the model engine. This turbine is in turn driven by high pressure air from a pressure vessel outside the wind tunnel and piped through the aircraft model to the model turbine. The emphasis in measurements on aircraft models with high bypass engines is often on the interference drag of the relatively large engines and the flow around the aircraft model, particularly the wing.

In order to determine the thrust of these model engines under the correct operating conditions, a special calibration facility is required. This installation consists of a tank which is evacuated and in which the model engine exhausts. The front of the engine is open to the ambient air and the pressure difference corresponds to the stagnation pressure of the air stream in the wind tunnel. The engine operates in the same way as when it is installed in the wind tunnel model, that is the turbine inside the engine is driven by compressed air. By carefully mounting the model engine on a balance and compensating for extraneous force effects, it is possible to calibrate the model engine thrust to within a small fraction of a percent. This TPS calibration installation was put into operation in 1982, and is used for calibration of model engines for the NLR wind tunnels and for the DNW.



The Calibration installation for Turbo-Powered Engine Simulators (TPS)

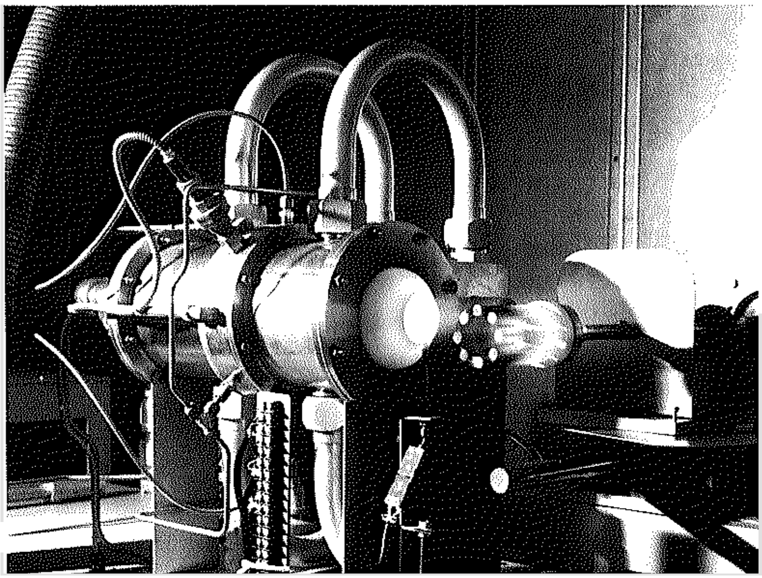
Schematic of the TPS Calibration installation



There are only a limited number of similar calibration installations in the world. Accurate calibration of TPS engines proved to be quite complicated due to the difficulty of carrying out accurate force measurements while high pressure air has to be ducted into the engine, the difficulty of simulating accurately the inlet flow conditions, etc.

Compressor and Turbine Blade Testing

The atmosphere in Western Europe and in The Netherlands in particular is rather corrosive. This is caused by a relatively high atmospheric humidity, moderate air temperatures, frequent rain, salt from the sea in the atmosphere (chloride-ions) and industrial air pollution, especially sulfur-dioxide. Through these factors the life-time of some engine components may be reduced by a factor of two

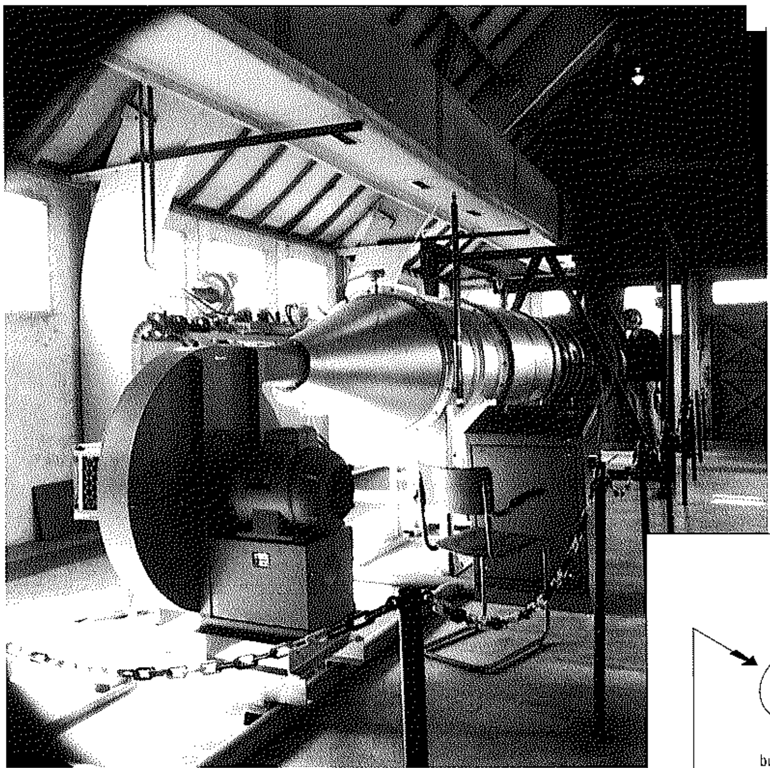


as compared with operating in an environment where these effects are of no importance. These effects, combined with the corrosive effects of the jet combustion products on the turbine rotor and stator blades have led to the development of various coatings to protect the expensive blades.

The 'Burner Rig' for testing Jet Engine Turbine Blades

In order to provide a realistic test environment a 'Burner Rig' was developed and put in operation by the Structures and Materials Division at NLR-NOP in 1975, in which turbine blades are exposed to hot exhaust gases produced by a jet engine combustion can. Controlled quantities of contaminants are introduced in the hot gas stream. This installation was later replaced by a commercially available, more economical, combustion chamber especially designed for this type of testing.

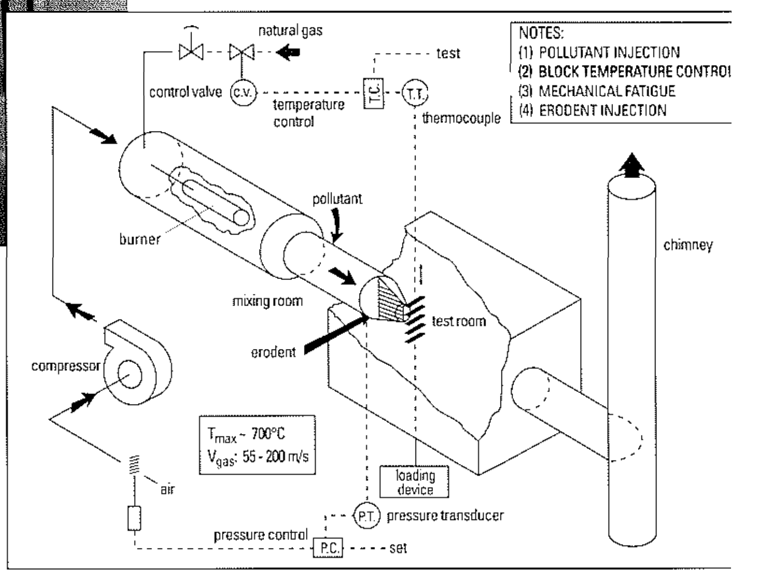
By moving the turbine blades in and out of the hot and cold gas stream - in a pre-programmed manner - thermal cycling as occurs in reality can be simulated. The gas temperature is typically 1000°C.



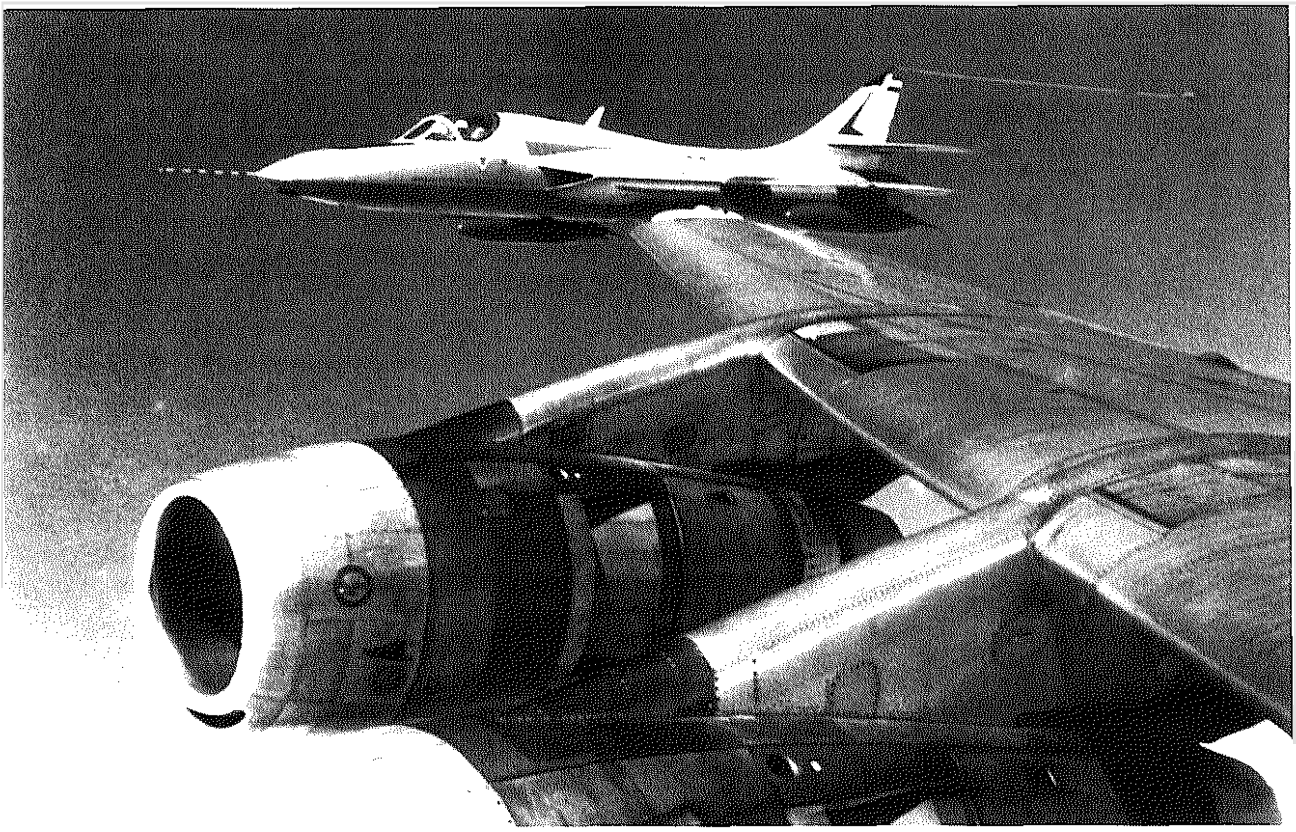
The 'Compressor Rig' for testing Jet Engine Compressor Blades

A similar installation for testing compressor blades with temperatures up to 600°C was also built at the Structures and Materials Division. Here the gas is supplied by a centrifugal compressor and heated by a natural gas burner. With an electro-magnetic excitation device the blades can be subjected to fatigue tests at their natural frequency.

Several test programs were carried out in these facilities in close international cooperation under the auspices of the Structures and Materials Panel of AGARD and of other international groups.



Schematic of the 'Compressor Rig



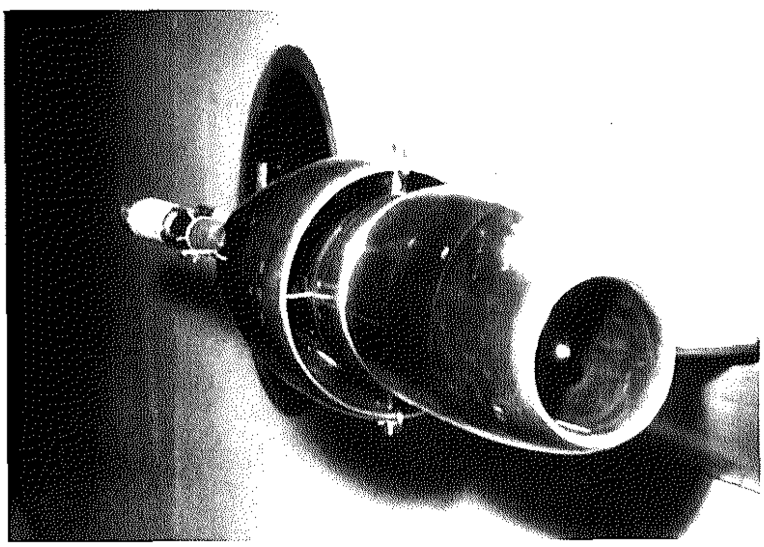
The Hunter T Mk-7 Laboratory Aircraft, pacing a KLM DC-8 aircraft, 1974. The cone trailing the tail of the Hunter was used to measure the static pressure.

Other Activities

During the last several decades NLR carried our many ad-hoc investigations associated with engine performance and operational problems, particularly for the Royal Netherlands Air Force and the Royal Netherlands Navy.

An interesting problem was to determine why some of the DC-8's of the KLM had a higher fuel consumption (up to 5%) than others. The major cause was finally traced to modifications which had been executed at the rear end of the engine, causing flow separation. Ir. J.P.K. Vleghert of the Flight Division of NLR came to that conclusion after photographing the behavior of wool-tufts attached to the rear part of the engine during an uncomfortable airfreight flight from Amsterdam to Teheran. Such experimentation during a passenger flight might have been discomforting to the passengers! The DC-8 was also photographed from the NLR Hawker Hunter laboratory aircraft which was used as a pacer for speed calibration.

Tests on an early By-pass Engine Model in the High Speed Wind Tunnel HST, 1960



During the period 1980-1987 specially prepared and instrumented turbine engines (Pratt & Whitney J57-P-19W) were tested in eight different test bed and ground test facilities in five different countries. This very extensive program, under the auspices of AGARD's Propulsion and Energetics Panel, resulted in an in-depth assessment of the quality of the engine test facilities and it formed the basis for improving the accuracy of turbine engine testing.

Ir. Vleghert contributed to this program by heading an international group to assess the measurement uncertainties, [Ref. 40].

8. Structures and Materials

When the RSL was founded in 1919 one of the departments was the Mechanical Testing Department, later called the Materials Department. It was initially equipped in a manner similar to the testing departments of the Technical University Delft and of some of the larger industries: equipment for testing material specimens and small structural components and a chemical laboratory for analyzing the composition of materials. Soon series of mechanical tests were carried out on large structures such as wooden wing structures.

The Materials Department was headed by Dr. Ir. L.J.G. van Ewijk from the start in 1919 till he retired from NLL in 1945. He was succeeded by Ir. J.H. Palm and when Palm left NLL in 1950 the Materials Department was merged with the **Structures Department**.

From 1919 structural analyses were carried out by Ir. C. Koning, who was also responsible for Aerodynamics, till Ir. A. van der Neut came to work at the RSL in November 1928. Among the others who later joined him were Ir. F.J. Plantema, Ir. W.T. Koiter and Ing. J.H. Rondeel.[1]
The group was called: the **Aircraft Department B** with the task to provide the data of the structural part of aircraft for airworthiness certification. The Department also carried out many investigations related to aircraft accidents and incidents.

When the Government Service RSL was converted into the Foundation NLL in 1937 the Aircraft Department B became the **Structures Department**, with Dr. Ir. A. van der Neut[2] as the Chief till he became a full-time Professor at the Technical University Delft in 1945. His successor was Ir. F.J. Plantema, who had joined the RSL in 1934.
Ir. Plantema advanced the state of knowledge of constructions made out of sandwich materials (two thin sheets of a high strength material with a thick layer of a low density material, of relatively low strength, sandwiched between the two sheets), particularly for aircraft structures. Theoretical studies of sandwich constructions at NLL had started in 1943 and some of the results had been presented at the VIIth Congress for Applied Mechanics, London, 1949. He wrote his Doctoral dissertation in 1952 on the theory and experiments on the overall elastic stability of flat sandwich plates. Dr. Plantema summarized his work in 1966 in a book on sandwich construction, [Ref. 41]. Dr. Plantema passed away untimely on 13 November 1966.

To complete the story of the organization:
The Structures and Materials Division was moved from Amsterdam to the Noordoostpolder in 1966. Around this time the laboratory was re-organized into the Divisions **Fluid Dynamics, Flight, Structures and Materials**, and **Space** - with effect from 1967.

[1] Ing. Rondeel started at the RSL in 1931. When the Structures and Materials Division moved to the NOP in 1966 he stayed in Amsterdam and was responsible for the liaison with Fokker in connection with the structural testing of the Fokker F28 Fellowship. In 1969 he retired after more than 38 years of service. When the RSL became the NLL in 1937, he was one of the few employees who elected to remain a civil servant and so for 32 years he was employed by the Netherlands Department of Civil Aviation (RLD) but worked at NLL/NLR.

[2] Dr. Van der Neut received his Doctor's degree in 1932. His dissertation was on the problem of buckling of spherical shells. Prof. C.B. Biezeno was his promotor.

Prof. Dr. Ir. J. Schijve[3] became Head of the Structures and Materials Division. In 1971 he divided the Division into four Departments:

- Loads;
- Structures;
- Materials;
- Testing Facilities

This is on the one hand an expression of the distinctive disciplines with which the Division is occupied and on the other hand it expresses the close relations of these activities in aircraft research and development and also in aircraft operations.

When Prof. Schijve became a full-time Professor at the Technical University Delft on 15 November 1973, he was succeeded by Ir. H.P. van Leeuwen as Head of the Structures and Materials Division. Dr. Van Leeuwen obtained his Doctor's degree in 1976 with a thesis on 'A Quantitative Analysis of Hydrogen-induced Cracking'. This work pertains particularly to the phenomenon of hydrogen embrittlement of high strength steels. His contributions, clarifying and quantifying these effects, had also applications outside aeronautics, e.g. for pressure vessels and piping.
Dr. Van Leeuwen retired on 1 August 1989 and Dr. Ir. G. Bartelds became his successor.

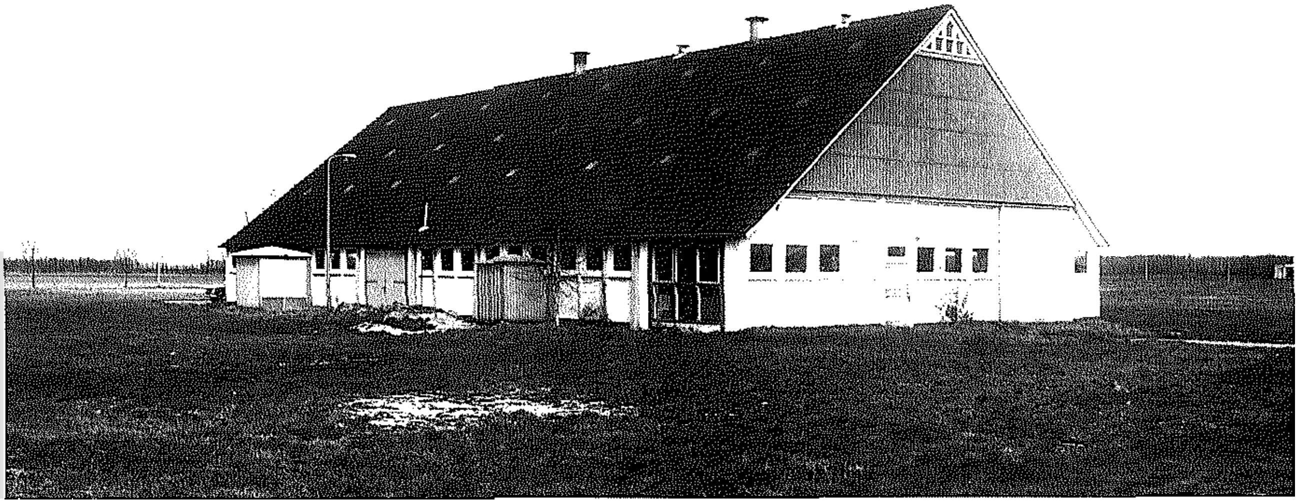
At foreign - larger - aerospace laboratories the research on structures (including loads) and on materials is organized in separate Divisions or Departments. At NLR the combination of Structures and Materials has been maintained since 1950. A major reason was that the number of people in the Division was - and still is - relatively small. It is about 10 percent of the total personnel of the Divisions of Fluid Dynamics, Flight, Structures and Materials, Space, and Informatics together. This does not include the support activities of the Services, but as a first approximation that support is equally divided over the Divisions. As time progressed much of the research requested by the customers required inputs from all four Departments of the Division and with this combination it was possible to serve a variety of customers[4] with a relatively small group. This became even more important with the advent of research on composite structures - e.g. carbon fiber re-inforced plastics - where the properties of the material and the shape of the structure are closely linked and the optimization of the structure is dependent on inputs of all the Departments. So perhaps NLR is fortunate to have these (sub)disciplines represented in one Division of Structures and Materials.

The Facilities

The facilities and accommodations of the Structures and Materials laboratory at the RSL site at the Navy Yard in Amsterdam - 1919-1940 - are shown in Chapter 3. After moving to the laboratory site Sloterweg (now Anthony Fokkerweg) in Amsterdam and when planning the post-war expansions for the 1950's the intention was to construct a hall for full-scale testing at Schiphol, jointly with the new Fokker aircraft plant. After the work stoppage of the expansions, 1949-1952, this plan was not realized. Finally, after the laboratory site at the Noordoostpolder (the NOP) had been acquired, a structural testing hall was built at the NOP. It was completed in 1960. The construction was similar to the local agricultural storage buildings.

[3]Prof. Schijve had been employed at NLL since 1953 and had already made many valuable contributions related to materials research, research of structures, non-destructive testing and accident investigations. In 1964 he wrote his Doctoral thesis on the fatigue phenomenon in aluminum alloys, [Ref. 42]. Prof. Ir. P. Jongenburger was his promotor. In 1964 he was appointed part-time Professor of Aeronautical Engineering (Aircraft Materials) at the Technical University Delft.

[4]The effectiveness of the relatively small Structures and Materials Division was not always clear to outsiders. During the 1970's and the 1980's the Director of NLR regularly asked representatives of the 'Rolling Budget' contractors (Chapter 23) about the effectiveness of the support rendered by NLR. The response was very positive and for example the Head of Scientific Research of the Royal Netherlands Air Force stated invariably that the Structures and Materials Division was the most effective part of NLR as far as the support of the operations of the Air Force was concerned.

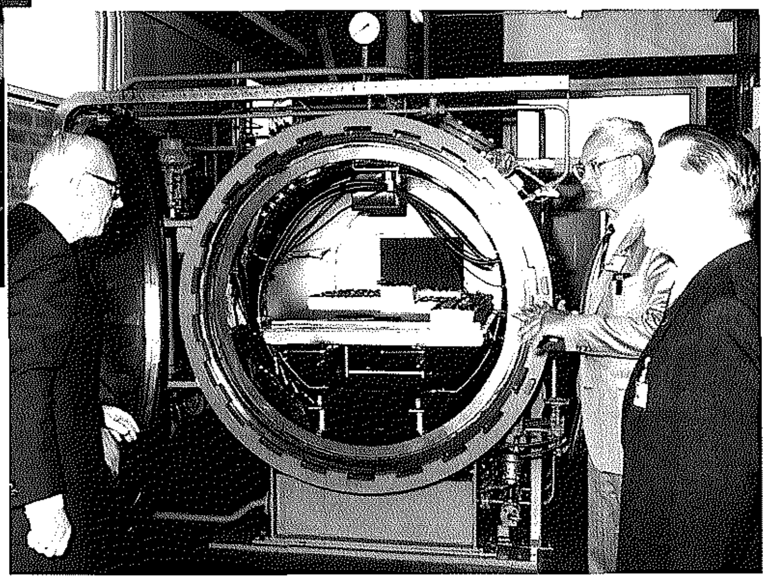


The Structural Testing Building at the Noord-oostpolder, 1960

Several years later, in 1966, a new combined laboratory and office building was completed and the whole Structures and Materials Division moved to the NOP. During the following years the offices and laboratory space were expanded. The last major expansion included the addition of a composites laboratory which included an autoclave for the manufacture of test articles made of composite materials (Carbon Fiber Re-inforced Plastics) and an ultrasonic installation (C-Scan) for inspecting test articles for irregularities or flaws.

Dr. Van Leeuwen (Head of the Structures and Materials Division) and Prof. Gerlach (Chairman of the Board) watch the Mayor of the Noord-oostpolder, Mr. R.S. Hofstee Holtrop, push the button to officially open the new Composite Materials Laboratory, 18 June 1986

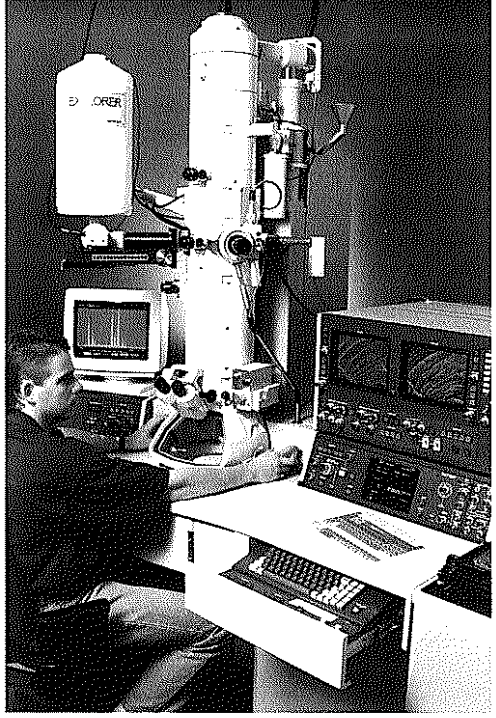
First product of the autoclave in the Composite Materials Laboratory: a huge cake for the guests at the opening ceremony



The laboratory was equipped with a variety of mechanical test installations including machines for servo-controlled fatigue testing whereby the varying loads, as they occur during the service life of an aircraft, are applied.

Microscopic investigations are important to study the fracture surfaces. From such studies the cause of a fracture can often be determined and the propagation of cracks under varying loads can

An Electron Microscope for scanning the micro-structure of surfaces of metal-alloys (magnification up to 1 million)



Fracture Surface photographed by an Electron Microscope, showing the growth of a fatigue crack under periodic loading

be studied. This is done with the aid of optical microscopes, transmission electronic microscopes, surface scanning reflection microscopes and X-ray diffraction and fluorescence machines.

From Wooden to Metal Structures

In Chapter 3 an impression is given of the research on the wooden structures of wings and how this problem area was approached theoretically and with experiments. This included the contribution of the wooden (plywood) skin to the strength of the wings. With the introduction of all-metal wings in the 1930's the idea of stressed skins became important. The wing structure was no longer composed of two spars (beams) with heavy flanges. The function of the flanges were partially replaced by many stiffeners relatively closely spaced, to stabilize the thin skin. This re-inforced skin largely took over the function of the flanges of the spars. The Douglas DC-2 was the first aircraft operating in The Netherlands in which these principles were applied.

The Netherlands' certification authorities were faced with a new type of aircraft construction and Dr. Van der Neut was the only person who could be consulted for this certification. He had often critically examined stress calculations submitted by the aircraft industry for certification. It was therefore not surprising that Plesman, the President of KLM, when the first DC-2 was unloaded in 1934 at the harbor of Rotterdam, snapped at Van der Neut: *"Don't you dare touch it!"* [Ref. 28]. This did not mean that Plesman did not appreciate Van der Neut's technical-scientific capability, but he did not want any delays in getting this aircraft in operation for KLM.

The RSL did contribute soon afterwards to this Douglas aircraft by locating the most critically stressed parts, some of which were thought to be prone to fatigue due to stress concentrations. In January-February 1935 Dr. Wolff and Dr. Van der Neut went to Inglewood, Calif., USA, and discussed their findings with representatives of the Western Office of the Department of Commerce, the Douglas Company, KLM and Fokker (Presumably the Fokker representative, Ir. Van Meerten, participated since Fokker was European sales representative of Douglas). This visit resulted in an agreement 'Structural changes in the DC-2 airplane made in order to satisfy the requirements of the RSL of The Netherlands', [Ref. 43].
Undoubtedly this exercise introduced the RSL very rapidly into aluminum aircraft structures and from then on much of the research was concerned with all-metal aircraft.

Dr. Van der Neut, who was then 27 years old, later recalled that the confrontation with the Douglas engineers was of great importance to his further work. For him it was the first time he was confronted with the 'New World' and although he was impressed, he was also critical and stayed in

The Netherlands in spite of the fact that there were many opportunities to move to the USA. For The Netherlands this was fortunate: In 1945 he became the second Professor of Aeronautical Engineering at the Technical University Delft and his influence on the (post Second World War) generation of aeronautical engineering students till his retirement in 1973, was profound. After moving to Delft he kept contributing to NLR as an advisor, through specific projects such as the stress calculations for the High Speed Wind Tunnel, HST, and through his participation in the Scientific Committee NLR/NIVR.

Fatigue

The problem of metal fatigue can be defined as the failure of metal components subjected to many cyclic forces which are much smaller than the forces that would be required for a failure under a static loading. As early as 1839 Poncelet appears to have recognized the problem of metal fatigue, [Ref. 44]. The phenomenon was studied extensively by those involved in railroad engineering and for a long time the criteria developed by the railroad engineer A. Wöhler (1819-1914) were used to design parts subjected to cyclic loadings.
In aeronautics the introduction of aluminum as a construction material gave a new dimension to metal fatigue research. Around 1950 NLL carried out many fatigue investigations - i.a. various aluminum alloys and bonded aluminum structures - in close cooperation with the aircraft industry and material manufacturers. This research drew international attention.

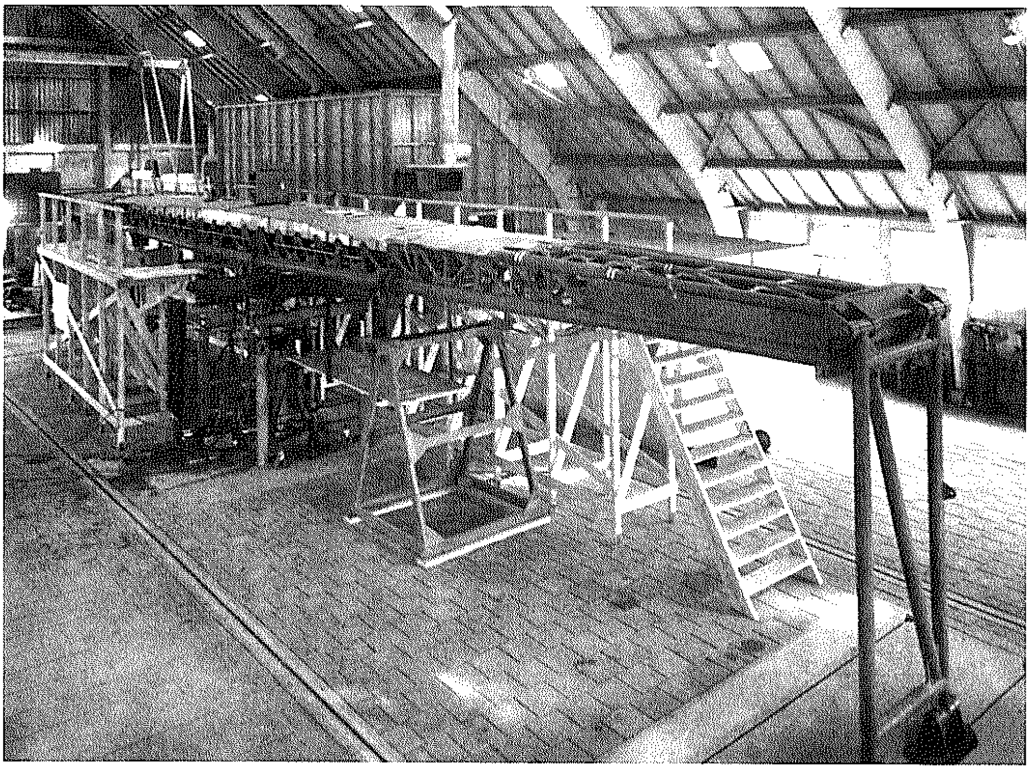
In **May 1951** NLL (Plantema) and Fokker (Van Beek) proposed to the RAE (UK) and to the FFA (Sweden) to cooperate in the area of fatigue research and a first meeting was held at Cranfield (UK). Plantema was appointed Coordinator. The cooperation was extended to include laboratories in Belgium and Switzerland and on 25-26 September 1952 a conference was held at NLL in which representatives of these five countries participated. It constituted the foundation of the International Committee on Aeronautical Fatigue, **ICAF**. Later institutes of other countries joined the Committee.
Dr. Ir. F.J. Plantema was the General Secretary till his untimely death at the age of 55 in 1966. To honor his contribution to ICAF, the Committee instituted the **F.J. Plantema Memorial Lecture** to be given by a distinguished engineering scientist at the bi-annual ICAF Congresses.
Prof. Schijve, Plantema's successor as Head of the Structures and Materials Division at NLR, became the National Delegate to ICAF in 1967 and since 1979 he serves as General Secretary.

Aeronautical fatigue really came to the fore-ground after the accidents with the De Havilland Comet. This first operational[5], four-engined, jet transport aircraft received its Airworthiness Certificate on 22 January 1952 and on 2 May 1952 the Comet left London for its first operational flight to Johannesburg, South Africa. The following quotation, [Ref. 46], summarized the events:

> -*"The subsequent story of the Comet is well-known. The rapid spread of jet airliner routes was halted in the Spring of 1954, when following unexplained accidents over the Mediterranean the Comets were grounded. The subsequent investigation by the Royal Aircraft Establishment, Farnborough, discovered the cause of the disasters - metal fatigue - and as a result changed the entire nature of large jet airliner manufacture for the rest of the world to follow. The Comet design was revised .... and entered on 4 October 1958 - the first regular trans-Atlantic jet airliner service .... Britain's overall lead in jet airliner development had been overtaken by the US with the development of the Boeing 707 and Douglas DC-8...."*

[5]The De Havilland Comet made its first flight on 27 July 1949 but according to [Ref. 45] it rose only a few feet above the runway to become the first commercial jet to fly. Only two weeks later, on 10 August 1949, Canada's Jetliner, the AVRO C-102, flew over an hour up to an altitude of 13,000 feet. On 18 April 1950 the Jetliner delivered the first jet mail between Toronto and New York. Like the De Havilland Comet it also did not - but for different reasons - become a commercial success.

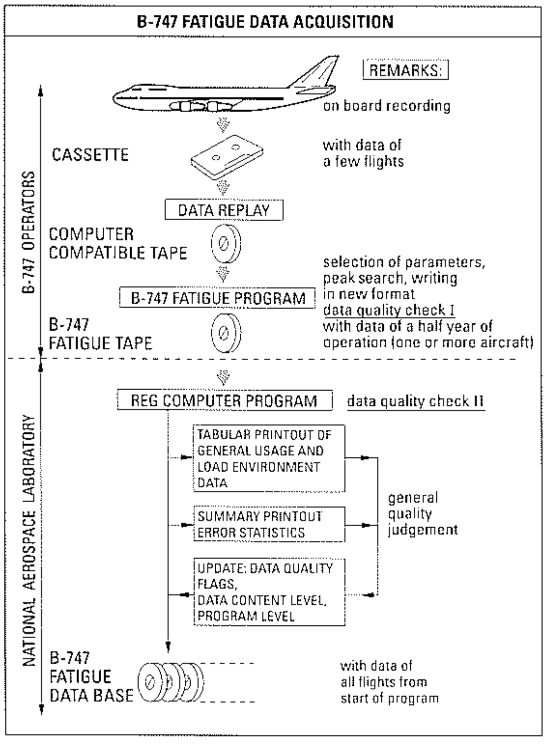
Following the tragic events with the Comet, NLR gained considerable experience by fatigue testing of 13 full-scale wing center section panels of the Fokker F27.



Fatigue tests on Fokker F27 Wing Panels around 1960, partially sponsored by the USAF

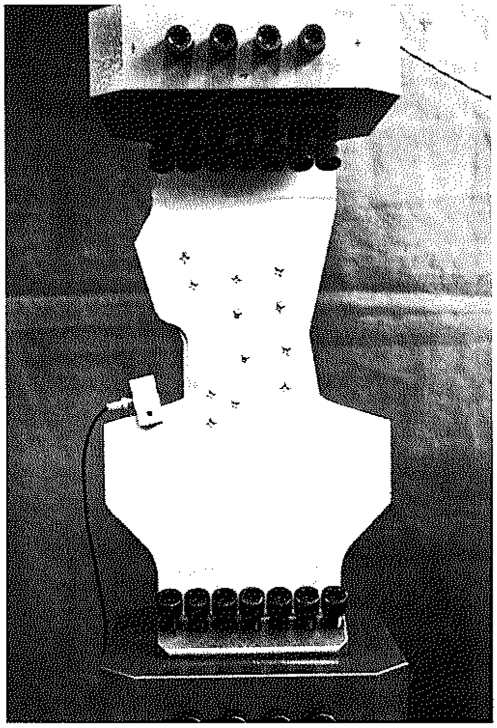
The system for acquisition data of Aircraft Loads during actual flight operations

Clearly, fatigue of aircraft structures is of great importance to flight safety and the subject transcends personal, company and national interests. Therefore the participants in ICAF regularly exchanged reports among each other and at the Congresses national reviews of the results of research were presented.

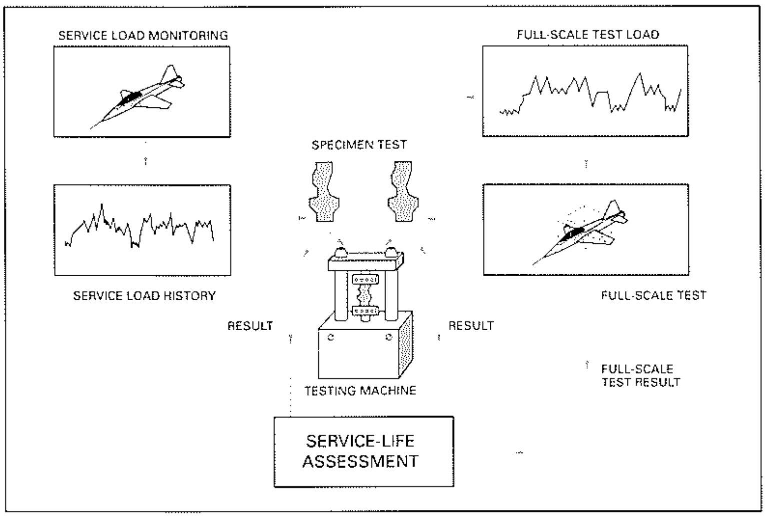


The recording and the analysis of loads on aircraft structures during actual operations provides the input for research on fatigue of metals and structures. At NLR activities in this area can be traced back to the time of the pioneering flights of KLM's DC-2 and DC-3's from Amsterdam to Batavia (Jakarta,Indonesia) during the 1930's, when gust loads were recorded and finally analyzed during the Second World War period.
The measurements were refined and the statistical analysis of the data resulted in standard load spectra for designing aircraft and testing components and full-scale aircraft structures. The load spectra contain the different loads and the frequency of occurrence of the loads that can be expected during the operational life of an aircraft. It was found that the sequence of the loads of different magnitudes is important for the fatigue life of aircraft structures. Much of this work during the last decades took place in international groups in which the Structures and Materials Panel of AGARD plays an important role.

Several programs were initiated to develop standard load spectra for civil aircraft, fighters and helicopters. The load spectra were used for many detail tests of components, joints, notched parts and for complete structures.



Computer-generated model of a critically stressed part - a lug connecting the wing to the fuselage of the NF-5 Fighter Aircraft - used in the laboratory for service-life assessment of the NF-5



An example, developed at NLR during the 1970's, is shown in the Figure above. A structural component was subjected to the loads as experienced during flight operations of an NF-5 fighter. The test specimen was designed and shaped such that it experienced at the critical points the same stresses as occurred in the actual component of the aircraft.
In turn, when the fatigue properties of critical parts of an aircraft are known, it is possible to determine the remaining life of a particular aircraft. For the Royal Netherlands Air Force extensive programs were run to determine the remaining life-time of fighter aircraft - using recorded data from operational aircraft - as time progressed and the mission profile changed. Often aircraft experience loads of a magnitude and frequency different from the design loads used during the design of the aircraft. This is particularly true for military aircraft which are in service for a long-time period when often the standard maneuvers change, while also the external loads carried by the aircraft change during its life-time.

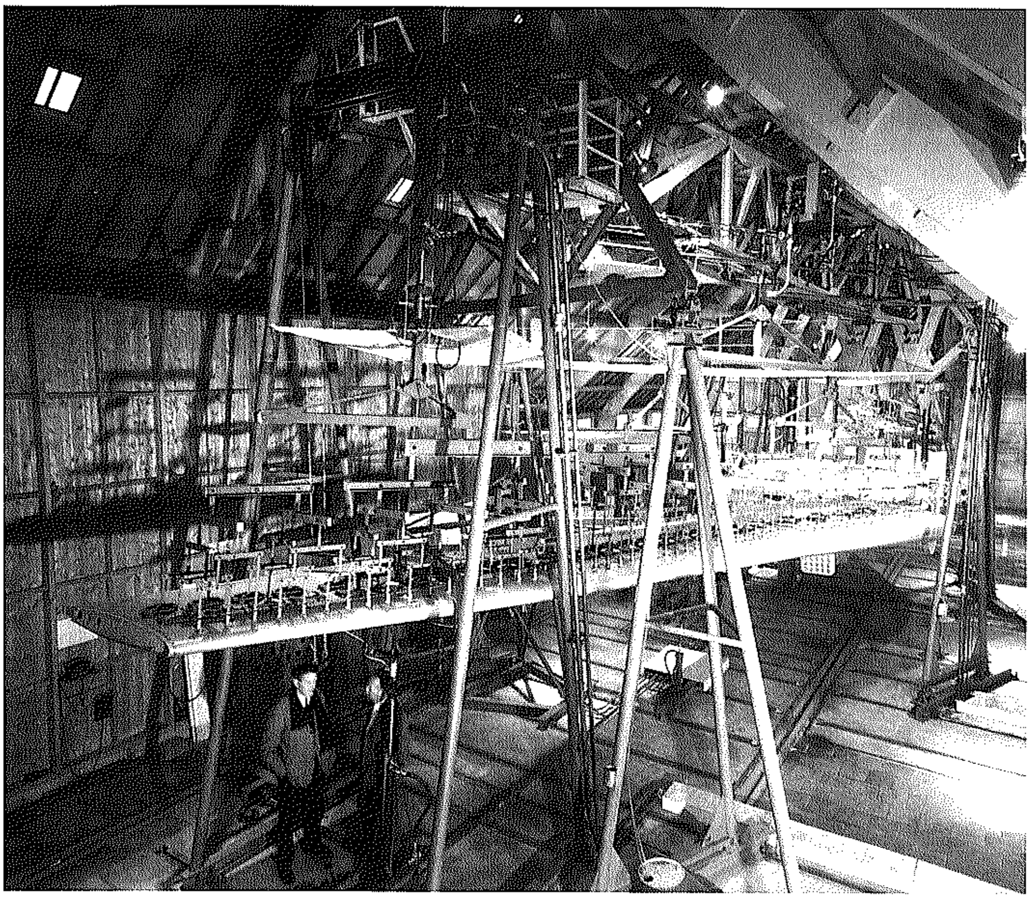
Similarly the service-life of civil aircraft was extended far beyond the design-life as it was originally conceived. The airlines were then confronted with the problem of 'aging aircraft'. This called for detailed analysis of the flight history of aircraft and during the 1980's a world wide activity developed to determine standards for safe life and to develop reliable inspection methods and also acceptable repair methods.

Full-scale Structural Testing

The full-scale testing of aircraft structures is basically the task of the aircraft industry developing the aircraft. The designer has to prove the validity of the structural design. Although numerical stress calculations are now very elaborate and are of great assistance in designing efficient structures, final full-scale testing is still carried out by the aircraft industry except perhaps when it concerns derivatives of proven structures.

Since the Second World War NLR has obtained contracts from NIVR to carry out a part of the structural testing of Fokker aircraft. This participation in full-scale structural test programs is important for the laboratory since NLR is then directly confronted with the problems of testing full-scale structures. The benefits for the laboratory are that it offers an opportunity to obtain first hand experience with the possibilities and limitations of current test techniques and from it ideas for further research result. NLR also cooperated with Fokker in specifying the load spectra and the loading, recording and data handling equipment for the full-scale tests at Fokker.

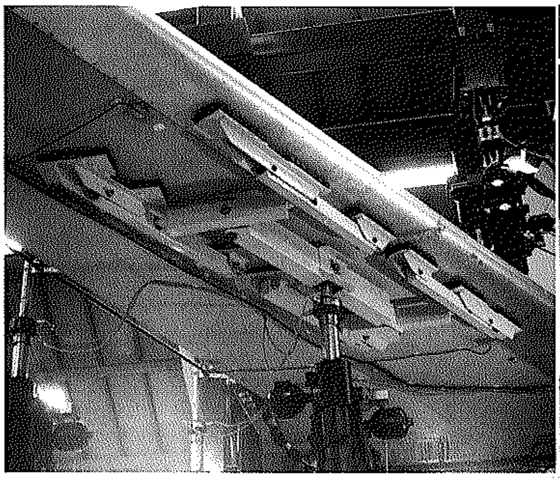
Structural strength and fatigue tests of the Fokker F28 Wing

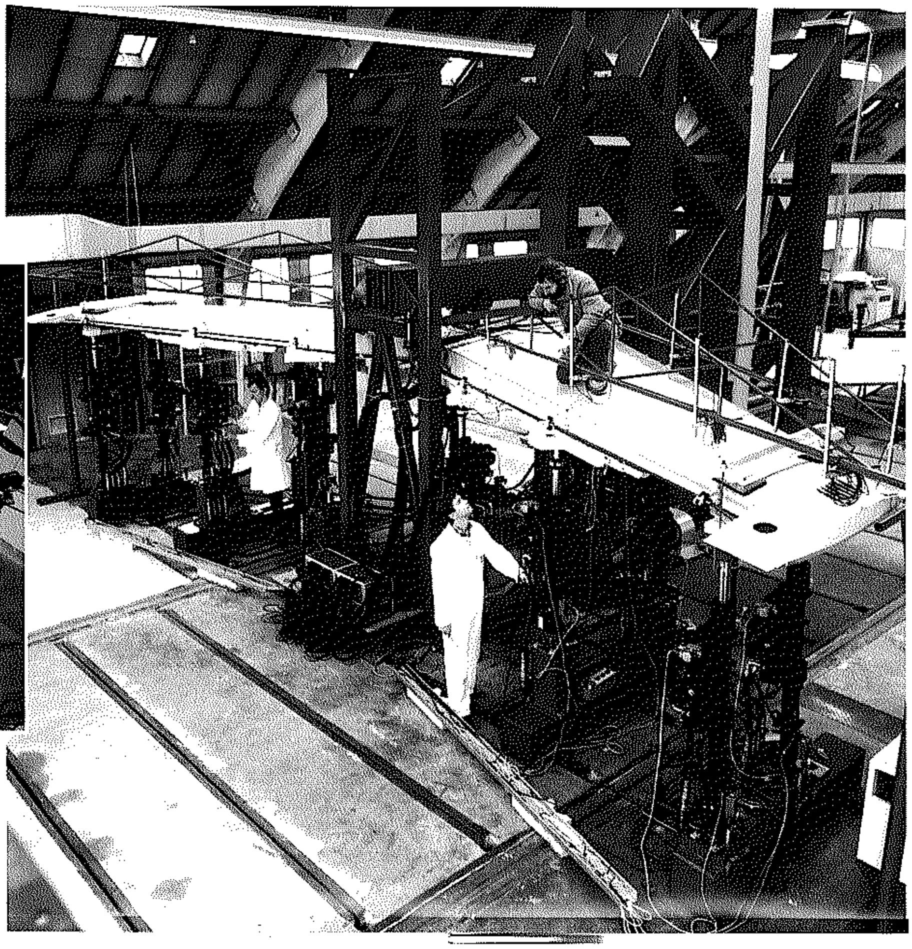


A static and an extensive fatigue test was carried out at the NOP on the wing of the Fokker F28 during the period of 1966-1971. A total of 180,000 flights were simulated.
A similar test series was carried out on the T-tail surfaces of the Fokker 100 during the period of 1987-1992. There is a considerable difference in the loading equipment between those two test series, as is clear from the pictures.
The test consisted of static and residual strength testing of the horizontal stabilizer and a fatigue test series on the combined horizontal and vertical stabilizer surfaces. The fatigue test consisted of a series of 180,000 simulated flights (twice the 'economic repair life') with loads as can be expected during the life-time of the aircraft. After the simulation of 90,000 flights the crack growth of artificially induced cracks was studied, requiring frequent inspections.

Structural strength and fatigue tests of the Fokker 100 Tail Surfaces

Detail showing the attachment of the hydraulic loading system of the test on the Fokker 100 Tail Surfaces



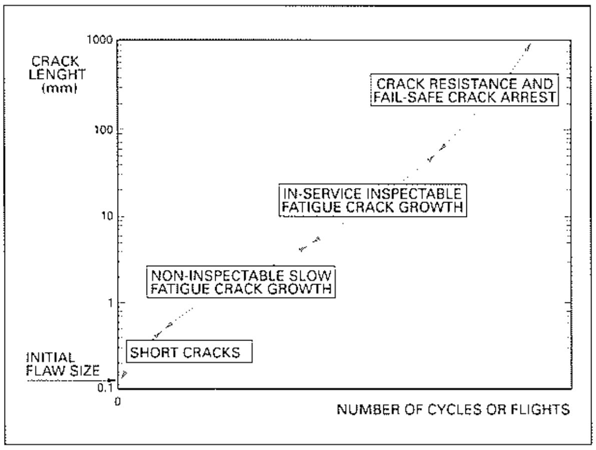


Finally a series of tests (flights 180,000 to 360,000) was carried out with reduced loads and reduced inspection periods to study the fatigue properties of specific parts of the structure such as the hinge fittings and the effect of the use of thrust reversers.

Crack Growth - Damage Tolerance

Research on crack growth is concerned with defects or cracks ranging from a micron (a thousandth of a millimeter) or less to a length of 10 cm or more. Microscopic studies reveal the details of the surface of the cracks. Airworthiness Authorities require proof that the aircraft structure is sufficiently robust - damage tolerant - to survive the development of a crack in a primary load bearing part of the structure between inspection periods. This proof is usually given in a form combining the results of calculations and experiments. Knowledge of crack growth - the speed at which a crack becomes larger under a load - is thus of paramount importance.

Schematic crack growth curve in terms of Damage Tolerance approach



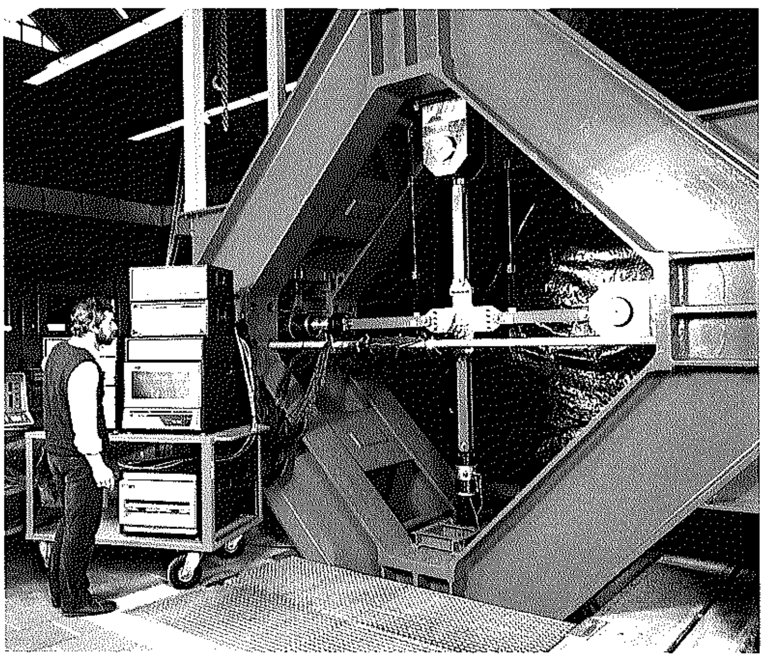
The Structures and Materials Division of NLR has, in cooperation with aerospace laboratories of other countries, accumulated a wealth of experience on crack growth. The analyses of the experiments has also resulted in theoretical models with which it is possible to predict the crack growth for various materials. From this, the safe life-time of a structure can be predicted and - for a given load spectrum - specific inspection periods can be recommended.

The process of crack propagation is complicated. There is for instance the phenomenon of crack closure, that is a crack closes and may not be visible after it has developed under a loading condition. Reliable inspection methods and of course qualified inspectors are therefore of great importance for the safe operation of civil and military aircraft.

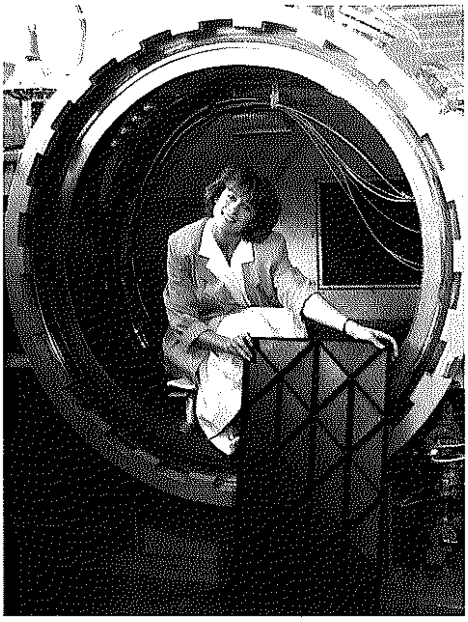
New Materials

Before a new material can be introduced in a primary load carrying aircraft structure the state of knowledge of the characteristics of that material must be brought to a level equal to that of materials which have been used for a long time. Besides that, the aircraft designer and the aircraft manufacturer must be fully familiar with the material properties and its possibilities. Since the Second World War several new materials and alloys have been introduced, such as Aluminum-Copper-Magnesium (AlCuMg), Aluminum-Zinc-Magnesium-Copper Alloys (AlZnMgCu), the Aluminum Alloys 2024 and 7075 and also several Titanium and Aluminum-Lithium alloys. In all cases very extensive test programs were carried out by the material manufacturers, the aeronautical research laboratories and the aircraft industry. Of course the application of new materials is not only determined by acceptable mechanical properties but also by such factors as costs, availability, machinability, cost of adapting the manufacturing process, etc.

Test of an ARALL specimen for the simulation of fuselage panels under bi-axial loading



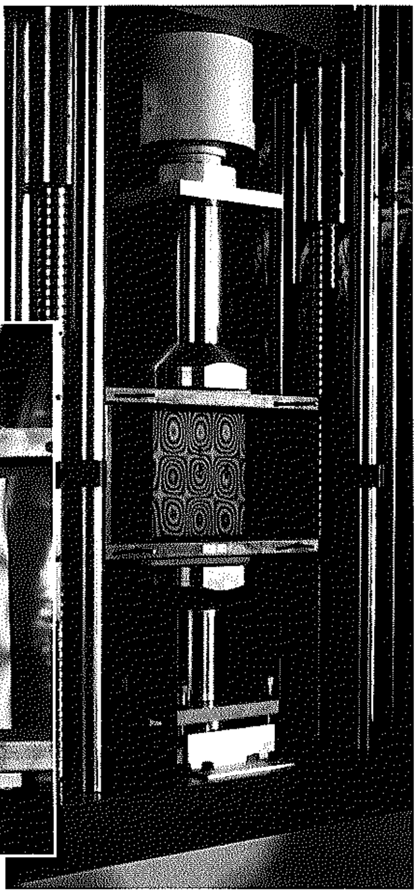
NLR contributed extensively to this accumulation of knowledge - investigation of the mechanical, fatigue and corrosive properties - often in the context of Working Groups of the Structures and Materials Panel of AGARD and later also in the framework of GARTEUR Action Groups. Through this theoretical and experimental work - often financed by NIVR - NLR was in a position to advise the industry,



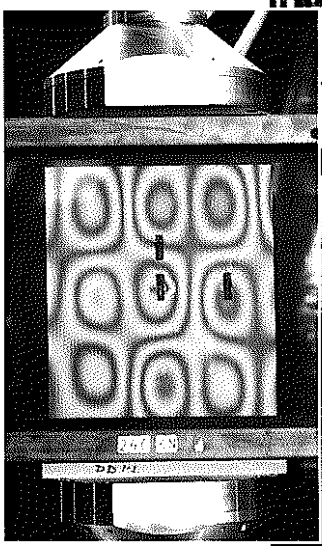
the RLD (the Airworthiness Authority) and the aircraft operators on the applicability of new types of aircraft material.

During the 1980's a new class of aircraft materials with greatly improved fatigue resistance was developed by Prof. Schijve and his associates at the Technical University Delft. From his research on crack propagation in aluminum sheets he concluded that thin aluminum sheets, laminated with aramide fibers embedded in adhesive layers, would produce a material with an extremely high crack propagation resistance. This material was called ARALL (Aramide Aluminum Laminate). Later a similar composite with glass fibers (GLARE) was also developed by the group in Delft. In this damage tolerant composite an optimum combination was achieved of the mechanical properties of the metal sheets, fibers and adhesive. These fatigue resistant materials (ARALL and GLARE) are now coming into production with ALCOA (USA) and AKZO (The Netherlands) and the first applications in aircraft structures have been announced.[6]

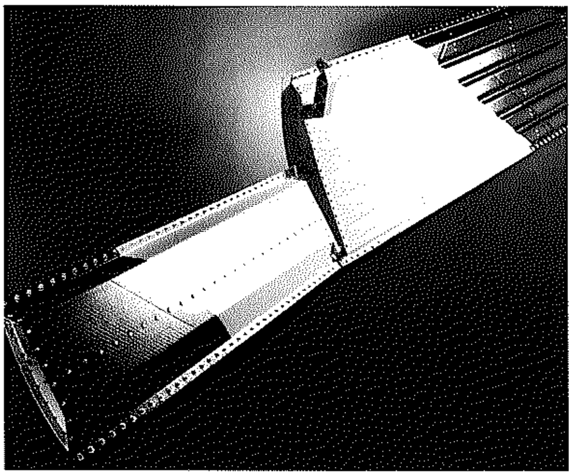
Fokker investigated the aircraft application of these composites by producing panels and curved surfaces from laminated sheet material. At an early stage NLR became involved in evaluation of this material, including a study of the feasibility of a wing torsion box (Prof. Schijve has been Advisor to NLR since he moved to the Technical University Delft in 1973). As indicated above, it takes a long time before a new aircraft material is fully accepted for load carrying structural parts by the industry and the certifying authorities - and rightly so - but it may well be so that future aircraft will be constructed of laminated materials, taking advantage of the combination of the properties of the elements of which they are composed.



Example of a stiffened composite panel developed in cooperation with Fokker Aircraft



Stiffened composite panel showing a Moiré pattern during a compression test



Prototype of a Fokker 50 Main Undercarriage Door made of thermoplastic material in cooperation with Fokker Aircraft

[6]In May 1992 Prof. Schijve retired, after 30 years, from his post of Professor of Aeronautical Engineering at the Department of Aerospace Engineering of the Technical University Delft. The Proceedings of a Specialists' Conference on the occasion of his retirement, [Ref. 47], summarize the state-of-the-art of fatigue of aircraft materials and show that enormous progress has been made. Nevertheless accidents due to fatigue of aircraft materials still take place and much work remains to be done, not only in the development of crack resistant materials but also in the area of monitoring the state of the aircraft structure and inspection methods.