90 YEARS OF HELICOPTER DESIGN, DEVELOPMENT AND TESTING IN THE NETHERLANDS

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1. Abstract

Apart from a brief period during the 1950’s the Netherlands never possessed an indigenous helicopter industry. Yet the helicopter has been on the Dutch agenda for almost 90 years. At three different points in time in the last century helicopter projects started, two purely national, and one in which the Netherlands is a participant in an international project. The paper focuses on the two national projects, the Von Baumhauer helicopter and the Kolibrie project. Both emanate from the personal interest in helicopters of young people.

Albert Gilles von Baumhauer, who from 1910 onwards, even before he became a mechanical engineer, is thinking of technical solutions for helicopters. He concludes that a single rotor helicopter with cyclic blade pitch control offers better stability and control than a multi rotor helicopter. This concept as well as that of a separate tail rotor to counteract rotor torque is patented. He has the skill to work out his ideas into models and prototypes based on detailed calculations, sketches and drawings. He also is able to make others enthusiastic for his ideas. In 1924 the Dutch Helicopter Association is founded. The task is to study the scientific and operational aspects of helicopters. An excellent opportunity to bring this task into practice is the building and testing of the so called Von Baumhauer helicopter, which contains the above mentioned design novelties. In the period 1924 -1930 the helicopter is built and tested. Von Baumhauer in 1921 becomes deputy director of the Government Service for Aeronautical Studies (RSL), at that time a government body. In view of his position he formally has to stay at a distance from the association. In practice he is the driving force behind the project and there is a continuous involvement of the RSL with the project. Some 40 RSL test reports are available in the NLR museum, covering the whole test period from 1925 to 1930. A number of those is referred to in detail to give an impression how the very complex problem of helicopter vibrations is dealt with, some 85 years ago.

Twenty years later two other young men, like Von Baumhauer graduated from Delft University of Technology, meet each other. One is Gerard Verhage, who is thinking of a helicopter rotor type, which automatically reduces the blade pitch angle to make a safe autorotation possible. The other is Jan Meijer Drees, working for the National Aeronautical Laboratory (NLL), which since 1937 is the name of the former RSL. He is an expert on helicopter rotor flow. A growing interest for the helicopter is emerging in the Netherlands. The Helicopter Foundation is established and a Sikorsky S-51 helicopter is acquired to assess the operational capabilities. NLL is assigned to set up and execute the test program. The outcome is promising and a new foundation with the name SOBEH is created to build and develop an experimental helicopter. Verhage and Meijer Drees later join SOBEH. This project is financed with the remaining funds from the S-51 test program. The first SOBEH helicopter uses the soft-in-plane rotor of Verhage and is fitted with tip jets.

The paper describes the development steps made by the very enthusiastic and almost autonomously operating design team, their success and setbacks. Sometimes the latter are a result of inherent characteristics of the new rotor type or the ram jet engines that so far are not known or not taken into account in the design phase. In 1955 the development work leads to the H-3 helicopter configuration, which is successfully demonstrated to government officials. The decision is made to start the production of this helicopter with the name Kolibrie. However the original development funds are depleted. In that year the Netherlands Helicopter Industry is founded with the aim to finance the trajectory leading to certification and production. The Netherlands Institute for Aircraft Development (NIV) from that moment on has a more prominent role, as it provides the funds for further research of the helicopter. NLL is assigned by Professor Van der Maas, the chairman of NIV, to do much more fundamental work on the helicopter which is already common practice for the Fokker aircraft development programs. The certification process is successfully completed in 1958. Some 100 NLL reports cover the Kolibrie project. This does not become a commercial success, primarily because of the high fuel consumption, which leads to a short range and endurance.

1. The earliest research on helicopters in the Netherlands

In 1910, as a 19 year old student at the Delft University of Technology, Albert Gilles von Baumhauer is already highly interested in helicopters and builds a helicopter model[1]. Around 1912 he is experimenting with multi rotor helicopters as this concept seems to be the only possible solution for adequate stability and control. However the counter rotating helicopter model, which he builds in 1912 is not stable enough. This is the moment when the idea comes to Von Baumhauer to use only one rotor for pitch and roll control of the helicopter. In his concept he uses the principle of a swash plate to produce differential lift between the blades through the cyclic change of the blade pitch angle. This solution was patented in 1912/1913 in France and England and in the Netherlands in 1920. He foresees two different solutions to counteract the rotor torque, which is inherent to most single rotor helicopters. The first solution is a propeller in the helicopter nose that blows air through vertical vanes at the tail. The air is deflected and produces a horizontal force. The other is an engine driven tail rotor, which produces a horizontal force and is patented in 1920 in England and the Netherlands[2].

Figure 1 Albert Gilles von Baumhauer

Von Baumhauers early experiments with helicopter concepts are described in his numerous personal notes, sketches and calculations, most of which are preserved. Because of their scientific character on the one hand, but also in view of his efforts made to create practical solutions it is justified that Von Baumhauer around 1910 made the start of the design, development and testing of helicopters in the Netherlands.

In 1916 Von Baumhauer graduates from Delft University of Technology as a mechanical engineer. This is followed by a study on aerodynamics in Zürich (Switzerland) and in Göttingen (Germany), where he meets Professor Von Kármán, respectively Professor Prandtl. The latter is already involved in building a helicopter. During several occasions Von Baumhauer presents lectures on helicopters in the Netherlands[3] and abroad. In 1921 he joins the Government Service for Aeronautical Studies (RSL), His interest in helicopters remains until his untimely death in 1939 during a test flight with a Boeing Stratoliner.

2. The Von Baumhauer helicopter project

2.1. A fully developed helicopter design

Around 1920 the conceptual work of Von Baumhauer has culminated in a full scale helicopter design, which contains the innovations mentioned before. A two bladed helicopter with cyclic and collective blade pitch control. The rotor is driven via a long shaft by an engine mounted in the nose. At the tail a separate engine is installed, driving a vertical propeller which accelerates air through a set of horizontal and vertical guide vanes to support lateral, respectively longitudinal control. The structure supporting the blades with tubes and cables is mounted to a transmission body. The pilot is seated just aft of the rotor mast and for longitudinal balance the fuel tank is fitted at the nose of the helicopter. The estimated weight of this concept is 600 kg.

2.2. The Dutch Helicopter Association

In 1924 there is an opportunity for Von Baumhauer to really build this helicopter. The British Air Ministry announces a contest for building a helicopter which has to meet very demanding performance requirements. One of the most severe is to make an engine-off autorotation, from a height of 500ft, followed by a safe landing. The price is £ 50,000 and the dead line for showing that the helicopter meets the requirements is 1 May 1925. It is decided that the Netherlands will take part in this contest. To that end the Dutch Helicopter Association is established, in which a number of organizations in the Netherlands participate and together take design responsibility. Von Baumhauer, although the initiator of the project, is not a member of the board of the association. He officially keeps the position of advisor, but in practice he is the driving power of the project. It is decided that all legal and financial rights with respect to helicopter innovations will be transferred from the State of the Netherland, to which the RSL belongs, to the Dutch Helicopter Association[4]. This of course has to do with the position of Von Baumhauer at the RSL. Building the helicopter starts in August 1924 and is completed in June 1925.

2.3. The helicopter structure

To better understand the problems encountered during the test program some attention will be given to the detailed structure and components of this unique vehicle (fig.2). The tapered blades are composed of four wooden spars with wooden ribs and are covered with ply wood. Each rotor blade has a length of 7 m with a rotor diameter of 15.4 m. This is relatively large as it is efficient to give a large air mass an as low as possible downward acceleration. The low rotor disc load is favorable for hover conditions and hence helps to meet the autorotation requirements of the British Air Ministry contest. The rotor has a nominal speed of

Figure 2 The Von Baumhauer helicopter

105 revolutions per minute (RPM) which gives a tip speed of around 100 m/sec. This is exceptionally low compared to the tip speed of about 200 m/sec used in later helicopter generations. The large taper with a chord of 1,20 m at the blade root and 0,28 m at the blade tip still gives a for helicopters nowadays normal solidity factor of 4.5%. The blade mass is 54 kg and the blade twist is 10˚. The blade upper side is curved, the lower side is flat.

A model of this rotor has been tested in the RSL wind tunnel in 1924 to determine lift and drag. Later a rotor is tested provided with a mechanism that, during a rotor rotation, allows changes of the pitch angle of plus or minus 3˚ around an average of 13˚. One of the interesting conclusions is that strong vibrations are experienced in the suspension ropes of the model. In 1925 the static stability behavior of this scale 1:10 rotor (fig.3) has been tested in ground proximity conditions[5].

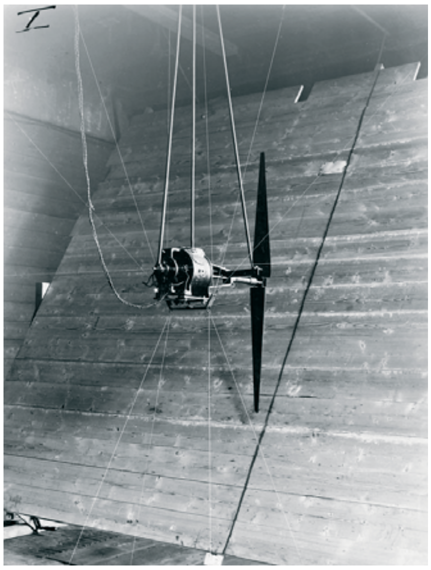

Figure 3 Rotor static stability test in simulated ground effect

The fuselage is made of welded steel tubes. In the helicopter nose a 160 HP Oberursel radial rotary engine is installed, controlled by a handle/throttle in the cockpit. A relatively long and thin horizontal shaft drives a rotating inner, conical shaped drum, the rotor shaft and the rotor hub to which the blades are connected with blade arms. To engage and disengage the heavy rotor an automobile type clutch is used, operated by a handle in the cockpit. The reduction mechanism, providing an 11:1 reduction, is an oil cooled worm wheel connected to the rotating drum. With bearings, also carrying the thrust of the rotor, this drum is supported in a fixed outer drum. Behind the reduction mechanism is the pilot's seat. At the back of the fuselage is an air cooled Anzani 40 HP radial engine, driving a two-bladed vertical fixed propeller. The propeller slipstream is directed towards a system of five vertical and three horizontal tail planes. The vertical planes are controlled by the pilot foot pedals, the horizontal planes by a separate wheel. They are used to provide a vertical force to control the tail attitude. A handle/throttle controls tail rotor power. Each engine has a separate tank. The undercarriage is of a wheel type on either side and a wheel support at the back with a skid at the front.

The rotor shaft is relatively thin. A system of tubes and wires is used to support the heavy rotor blades and to transfer the engine power to the rotor. The blades are driven by steel wires, on the upper side connected to a bar at the rotor hub, perpendicular to the longitudinal axis of the blades, on the lower side to the inner drum. Below the rotor two concentric rings are mounted connected to each other by bearings. The non-rotating inner ring is mounted on gimbals which allow it to tilt and to move along the shaft. It is connected to the longitudinal and lateral cyclic and collective controls in the cockpit. The outer ring rotates with the rotor and allows a collective and cyclic blade pitch change through a rod connected to each blade.

Half spherical type supports give the blades limited freedom of flapping relative to the blade arms. Each blade is attached to the rotor mast with a cable and a spring. The other cable end is fixed to the blade upper side at a distance of 5 m from the mast. Blades have the freedom of flapping, however limited by cable stops. A system of lower cables passing along segments, that can tumble, is mounted on the inner drum. This transfers the lift from the rotor blades to the fuselage. One such cable runs from one blade via the segment to the other blade.

Cyclic control is made with a control column on top of which is a horizontal wheel for pitch changes.

2.4. The available test reports

In the spirit of the historical session of this 35th ERF from now on the focus will be on technical problems encountered during the test programs and the way they are addressed. The archives of the NLR museum (fig.4) contain more than 40 test reports with a RSL number, which are dealing with the Von Baumhauer helicopter. They indicate that the RSL played an important role in the development of the Von Baumhauer helicopter[6]. This can to some extent also be concluded from the many monthly RSL reports, which refer to these helicopter tests. Unfortunately the test reports in general do not mention the persons attending a test except, on some occasions, the pilot. Almost all test reports are available as a hard copy or as a micro-fiche document. Normally the first part of a test report describes the changes or modifications to the helicopter made since the previous test.

Figure 4 Von Baumhauer test reports in NLR museum

This is followed by details about the conditions and results of the test of the particular day. They together give a pretty good insight in the whole period 1925-1930 from the first test run on 5 June 1925 to the catastrophic last run. This was on 29 August 1930 when one of the blades broke-off as a result of a fatigue failure.

2.5. Problem area's in the development

In the following sub paragraphs the areas, which required most attention will be addressed. Although the test reports are written in the Dutch language they will be referred to. They give a very detailed insight in the way problems in the field of mechanical engineering or aerodynamics of helicopters are dealt with some 85 years ago.

2.5.1. Vibrations of the drive shaft to the gear box

RSL-report V-0102/18 June 1925:

On 5 June 1925 the test program on the Von Baumhauer helicopter starts. As a result of this test some modifications are made to the rotor support. But also the behavior of the drive shaft between the engine and the gear box causes some concern. A look at the torsional and bending characteristics of this shaft is required. With a diameter of 60 mm, a wall thickness of 1.5 mm and a length of some meters the shaft is not very stiff (fig.5). During the first test run with the rotor running the shaft showed unacceptable deflections at 700 RPM. To reduce these deflections a damper bearing is installed, mounted on a tubular fuselage bulkhead. The new damper bearing is made of two parallel metal plates covered with felt material cooked in oil to avoid overheating of the bearing.

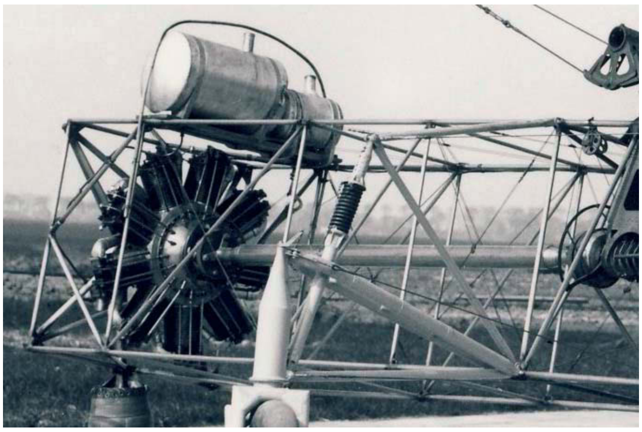

Figure 5 Horizontal drive shaft

A so called torsiograph (vibrometer) is used to measure torsional vibrations. A fabric string around the shaft provides the input to the vibrograph. The damper bearing indeed has a positive effect on the vibration levels with the rotor stopped. It is however recognized that local fixes to reduce the vibration levels of the drive shaft may introduce different vibration levels once the heavy rotor is driven. Therefore it is decided that the torsiograph will be used during all further tests. Another concern is the considerable bending deflections of the drive shaft. They do not show a consistent deflection pattern under various test conditions. On one occasion there is a maximum in a specific RPM range. In another case the deflections continued to increase with RPM. The cause of this inconsistency cannot be explained. Therefore the next step is to determine the natural frequency of the shaft. This frequency happens to be very close to the normal engine operating RPM, which is regarded a great risk. As a consequence the shaft has to be modified in one or the other way. The easiest solution is not to change the shaft itself as this may also have implications for the shape and characteristics of the elastic flanges on both sides.

Two extra bearings are installed, provided with so called white metal parts, which will melt at too high temperatures, when the bearings are overloaded by excessive fuselage deformation. The additional bearings will increase the natural frequency of the shaft. At this point in time the possible effect of the 14 engine cylinders is taken into account. They introduce seven excitations per revolution of the drive shaft and may be the cause or one of the causes of the above mentioned and so far unexplained increase of the shaft deflection. It is also recognized that a proper alignment of the engine drive shaft with the long shaft to the gearbox is essential. However also other effects like the elastic deformation of the fuselage under various load conditions of the rotor may contribute. Anyhow the two extra bearings will increase the own frequency of the shaft well above the engine frequency. A second advantage is that they will avoid the heavy deflections of the shaft, which is seen as a great risk. As a firm condition for the continuation of the tests it is decided that in the future the shaft deviation on either side and in the middle has to be less than 1 mm.

RSL report V-102A/3 July 1925:

The test is resumed after checks have been made on bearing alignment and whether the shaft is perfectly straight. To that end two separate methods are used, a micrometer with an accuracy of 1/100 mm and an indicator dial with depth indication with an amplification factor of 100. A complicating factor is that the new bearings and also the engine nose bearing, are suspended and kept in position with cables fixed to the tubular fuselage structure. Adjustments of the bearing position only can be made by adjusting the cable tension. A check run is made with the engine driving the shaft. Although the amplitude of the vibration in the newly installed bearings is less than two mm their temperature is in the order of 90˚ C, which causes some concern. Therefore additional bearing lubrication is necessary. After the run the condition is checked and it appears that the bearing metal has worked properly. It is still needed to readjust the bearing position to prevent that they are the cause of shaft bending. It is finally decided to replace the existing shaft with a steel shaft with a diameter of 100 mm and a wall thickness of 2 mm. Before resuming the tests it is also decided that, in view of the risk of resonance and low stiffness, the natural frequencies will be determined of all major rotary components of the helicopter.

2.5.2. What causes the helicopter oscillations?

RSL report V-160/5 May 1926:

The drive system development for the moment is completed and the natural frequency of major rotary components is determined. The focus will be again on running rotor tests. The helicopter which is now weighing around 1200 kg, is lashed with cables to the ground. The cyclic stick is kept as much as possible in the neutral position and blade pitch is low. After the first runs a subject of concern is the oscillation of the helicopter with the rotor running. The frequency seems to be equal to the rotor RPM. There is also a considerable difference in height of the tip path of the two blades. Pitch control rod adjustments are made, as well as adjustments to the upper cables and the position of the stop in these cables. They are fitted to the rotor mast and allow a certain degree of flapping (fig.6).

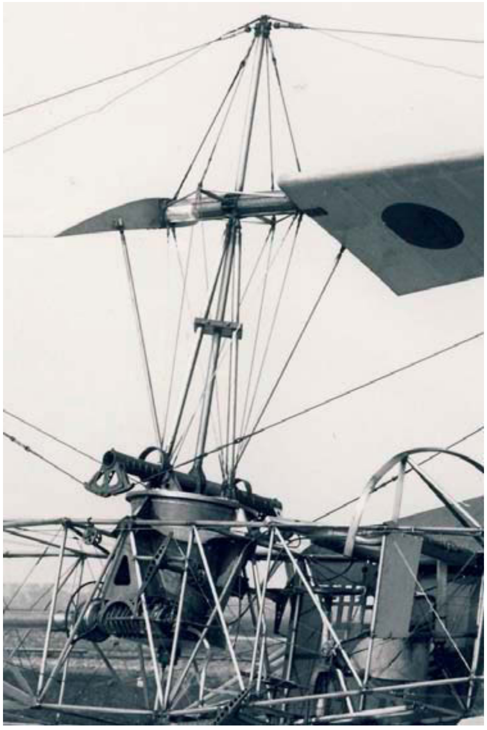

Figure 6 Support and control of rotor blades

A camera mounted on the rotating rotor support is used to record the behavior of the cable stops after each adjustment. In this stage also the effectiveness of the rotor control system is checked. The effect of small lateral control deflections is determined from the change in the length of the springs in the undercarriage of the helicopter. The effect of the actual wind speed and relative direction to the longitudinal axis of the helicopter is carefully recorded. It is noted that the blade moving upwind quickly moves upward and after 180˚ quickly moved down.

RSL report V-161/10 May 1926:

Rubber strands are fitted between the upper cable tension devices and the rotor shaft. During a test run at moderate engine speed with a wind velocity between 3 and 5 m/sec at an angle of 60˚ relative to the fuselage the blades produced heavy shakes, presumably caused by the cable stops touching the mast. Again the upwind blade moved upward rapidly and after 180˚ swiftly went down.

RSL report V-164/14 May 1926:

The effectiveness of the control system in this stage is marginal. This is concluded from the small changes of the length of the spring in the undercarriage after sideways control inputs.

RSL report V-202/17 February 1927:

The tail wheel and nose support strut are replaced by leather footballs with a sac type leather cover. The reason is to facilitate movements of nose and tail in all directions when the helicopter lifts off for short hops. The helicopter controls are tested and the helicopter leaves the ground although secured to the ground with four cables. The control column experiences strong shocks in particular after control inputs to the left or forward. After lift off the nose is much higher than the tail. The longitudinal and lateral oscillations of the fuselage are recorded by a vertical pencil fixed to the fuselage. A piece of paper is held against the pencil during one rotor rotation (fig.7). The numbers in the graph refer to the particular test run. The result helps to make a decision on a next adjustment to the cables or even a modification.

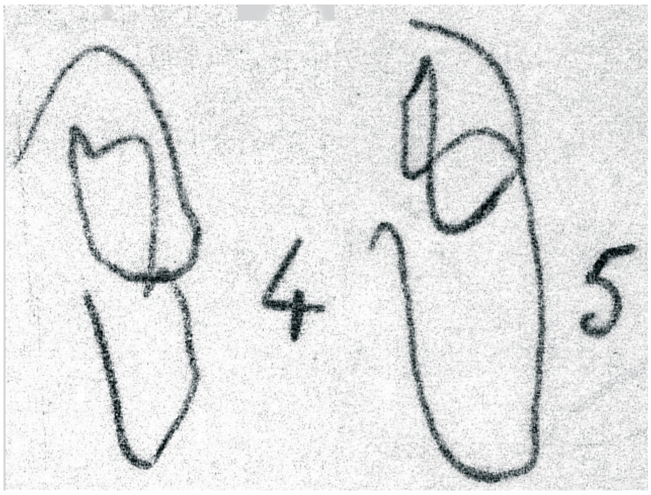

Figure 7 Vibrogram made with pencil and paper

RSL report V-254/1 May 1928:

Since the last test additional cables are fitted from a newly installed cross bar at the rotor head perpendicular to the longitudinal axes of the rotor blades to keep the blades and the rotor shaft in one plane. This also helps to neutralize the possible elongation of the drive cables between the gearbox and the blades. A new test is made with the cyclic blade pitch control system inoperative and with a fixed pitch setting. In spite of all measures taken the helicopter still shows the fuselage oscillations. The point is reached to make a drastic investigation into the cause of these oscillations and their relation with modifications to the helicopter, which each time are carefully recorded. It is noticed that the frequency of the fuselage oscillations is around two per rotor revolution. The RSL is asked to provide the equipment for the systematic registration of the oscillations. Attached to the above mentioned test report is an overview about the oscillations of the helicopter. The conclusion therein is that, after nearly three years, further testing of the rotor system and the controllability at full power is not possible in view of the oscillations and the risk of a serious failure. It is urgently needed to first investigate their cause and characteristics.

The summary below points at six possible causes of the vibrations:

1. the center of gravity of the rotor does not coincide with the rotor axis of rotation

2. one blade produces more lift than the other

3. the headwind blade induces an asymmetry, whereby a periodic force to the fuselage is transferred

4. the blade closest to the ground, due to the rotor shaft inclination, produces more lift than the other

5. the pitch control mechanism causes a periodic force

6. the stiffness of the upper cables, carrying the blades is inadequate so that the headwind blade lags behind the average position.

For a number of reasons mentioned in the summary the numbers 4, 5 and 6 are excluded as possible causes of the oscillations. However 1 seems to be important and will have particular attention, which is described in the following lines. The numbers 2 and 3 are possibly related and inherent with the design concept of the rotor, which only allows blade flapping to a limited extent, because of the upper cable stops. To address cause 1 a new weighing procedure is introduced to determine the offset of the common center of gravity of the rotor system to the rotor shaft. The offset produces a centrifugal force acting on the mast, depending on the rotor RPM.

Example: when the mass of the blades and the blade support together is 110 kg and with the engine running at 1300 RPM an offset of 1 cm will cause a centrifugal force of 15 kg. From now on a strong focus is on avoiding any offset. Until then the check of the rotor centre of gravity position is made with a viewer, while the blades are slowly rotated into different positions. It is assumed that blade mass and center of gravity is adequately checked during the production of the blades at the Pander factory. In 1925 a separate pendulum test has indicated that the mass distribution is correct. From now on the fuselage, before each test, is placed on a sort of knife-edge type support located as close as possible to the helicopter center of gravity. Then the helicopter is balanced fore and aft precisely, with small weights, around the landing gear wheel supports. After this step sensitive balances under nose and tail with a maximum of 25 kg. are used, during a rotation of the rotor, to measure and calculate the offset of the rotor centre of gravity. If needed adjustments are made to the tubes of the rotor support system or to the cable tension.

2.5.3. Tethered and controlled flights

RSL report V-263/covering the period 12 February 1926-11 March 1927:

This report contains data and results in the form of graphs and tables collected from movie pictures taken during tests in the above mentioned period. The purpose is to investigate and analyze the oscillations during different conditions in further attempts to find the cause of the oscillation. An important conclusion is that the oscillation of the rotor has the same frequency as the rotor RPM. The fuselage oscillates with a frequency two times the rotor RPM.

RSL report V-265/11 June 1928:

The vibrograms show a horizontal fore and aft oscillation equal to the rotor RPM only above 900 rotor RPM. A vertical oscillation exists with a frequency two times the rotor RPM. During the second part of the test, without wind, there is hardly any vibration, in particular at high RPM. The helicopter partly lifts off, only one wheel still touches the ground.

From now on the test reports describe a series of tests when the helicopter partly or totally leaves the ground, although tethered with cables. On occasions the helicopter is airborne and is very stable. As a result of the new weighing method the rotor offset from the rotor mast can be kept small. Helicopter control sometimes is erroneous and in this respect the tethering cables must have had a negative influence on controllability by the pilot.

RSL report V-298/19 September 1928:

The pilot, after the test run, is convinced that the helicopter can be controlled adequately.

RSL report V-313/January 1929:

The report contains a series of reports on separate tests with the tail rotor engine at the RSL premises.

RSL report V-409/28 August 1930:

Von Baumhauer decides to replace the four ropes by four outriggers. At the end of each outrigger a rather heavy chain of about three to four meters long is attached. Their purpose is to add extra weight to whatever side of the helicopter which is most elevated but also to avoid by the total weight of these four chains that the aircraft would rise too high in the air. Von Baumhauer is the pilot when four different tests of longer duration are made with the tail engine also operating. He is satisfied with the test results.

RSL report V-410/29 August 1930:

During a demonstration of the helicopter, when Von Baumhauer again is at the controls, the helicopter crashes. A fatigue crack in the attachment bolt of one of the blades caused this blade to detach. The helicopter becomes totally destroyed. The test run is precisely described and logged, partly by Von Baumhauer. There is hardly any wind. After the start of both engines the rotor is engaged. The power of each engine is increased and the horizontal guide vanes at the tail are deflected downward to help them carry the tail (fig.8).

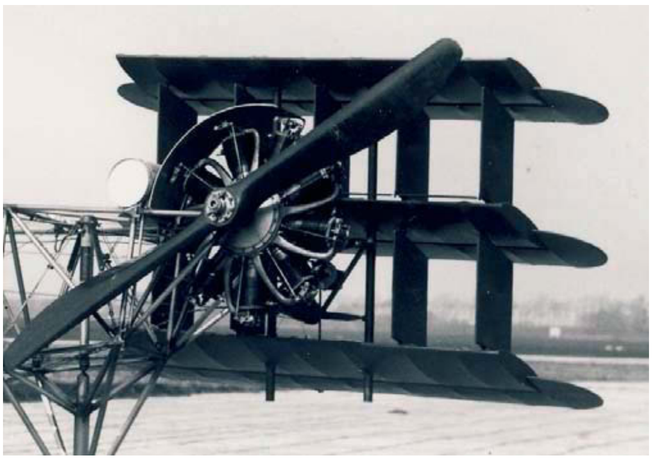

Figure 8 Tail guide vanes

The fuselage oscillates twice per rotor revolution, the rotor rotates steadily. The helicopter lifts off and the pilot makes small cyclic control adjustments. Lateral control is more direct than longitudinal control, which responds with a delay. Directional control is a combination of manual tail rotor thrust setting and foot pedal movements. With the help of an outside reference mark the heading can be easily maintained.

With the horizontal control wheel mounted on the cyclic control stick the blade pitch is changed twice, which as can be expected, leads to a small heading change. After 10 min. the flight suddenly ends, as mentioned above, leaving Von Baumhauer unhurt. The test is filmed with a camera[7].

2.6. Spin off

As no funds are available the program is terminated. The helicopter has flown, in the beginning tethered, later freely dragging heavy chains. The two innovations Von Baumhauer has used in his helicopter have proven to be very important. Until today most helicopter types still have a single main rotor, with cyclic blade pitch control and have a tail rotor. The numerous test reports make clear that Von Baumhauer and the people involved in the development of his helicopter had to fight a battle against an opponent that for the greater part was unknown at that time. This is the world of uncoupled and coupled motions in non-rotating and rotating parts in a helicopter, being a mass-spring-damper system. After Von Baumhauer many others have continued the research in this complicated problem area[8].

3. The Kolibrie helicopter

The beginning of a new helicopter project in the Netherlands is some 30 years after the Von Baumhauer helicopter. Here again the tenacity and believe of one or two young men is the driving force. The outcome is a helicopter with some unique features and characteristics, which is certified and taken into production. Two young engineers cross their paths after the Second World War. One of them, Gerard Verhage, is an electro technical engineer graduated from the Delft University of Technology working for the Dutch Postal Services (PTT). During the Second World War he is fascinated by the inherent capability of a helicopter to make a safe autorotation and landing after failure of the engine. An important condition however is that the pilot immediately after the engine failure lowers the collective pitch of the blades, so that the airflow passing the rotor provides the driving force of the rotor blades. If the pilot reacts too slowly the rotor RPM will rapidly decay and the helicopter becomes uncontrollable. Verhage is pondering about a technical solution that automatically reduces the helicopter blade pitch angle after the engine failure, so without any pilot intervention. His idea is that a torsionally soft-in-plane rotor blade might be the solution.

The other person is Jan Meijer Drees, who is an aeronautical engineer, also graduated from the Delft University of Technology and is working at the National Aeronautical Laboratory (NLL) as a flight test engineer (fig. 10). Verhage asks Meijer Drees to help him to further develop and test his new rotor concept in the wind tunnel of NLL.

3.1. The Helicopter Foundation and Sikorsky S-51

At that time the Dutch government and industry have a growing interest in helicopters and in particular their operational use. In 1947 the “Helicopter Foundation” is established and a Sikorsky S-51 is acquired, including the flight training of a crew.

Figure 9 Sikorsky S-51 during operational tests

A series of tests is made to assess the operational benefits of the helicopter for the respective participants in the foundation (fig.9). The NLL is assigned to set up and execute the flight test program, mostly by making pictures of the instrument panel at short time intervals. Meijer Drees is highly involved in this test period and on one occasion he is able to record a real autorotation on board of the S-51 which suffered an engine failure during a hover at high altitude[9].

Figure 10 Jan Meijer Drees

He is the author of the paper on helicopter rotors: “A theory of airflow through rotors and its application to some helicopter problems”, a study about the airflow through a helicopter rotor in different flow conditions, including the vortex ring state, visualized with smoke[10]. For this type of research he receives the Cierva Memorial Price in 1949. The theory is the basis to determine performance and stability characteristics of the Sikorsky S-51. Validation of the theory is now possible against the real flight test results collected with the S-51. At least 10 NLL reports are written from 1948-1951 on the S-51 period, addressing various theoretical and operational aspects.

3.2. Research on the Verhage rotor concept

A dynamically scaled model of Verhages rotor with a diameter of 1 m is tested in the NLL wind tunnel. The basic characteristics he had expected are proven. The rotation of the blade around the longitudinal blade axis is determined by flapping and through the elastic connection of the blade with the control system. As a consequence this type of blade does not have a fixed relation between a control deflection and the blade pitch[11.] During the wind tunnel test the model rotor becomes unstable and appears to be sensitive to flutter type oscillations. One day a fatigue failure caused one of the blades to break off. So a thorough investigation in the flutter mechanism is made and solved by the flutter department of NLL

3.3. The Foundation SOBEH

In 1950 a third young engineer also graduated from Delft University, with the name Will Kuipers, becomes involved in the project. He in 1991 writes the book:

”The Kolibry Story”[12]. This book proved to be very valuable to prepare this paper. Kuipers meets Jan Meijer Drees. He is an expert on rotor and transmission design. They have lengthy discussions on helicopter concepts and conclude that the best way to test and evaluate Verhages torsionally soft-in-plane rotor is to build a full-size helicopter test bed. In the mean time the objectives of the ”Helicopter Foundation” are met and to the opinion of the participants the outcome justifies continued work on helicopters. The remaining funds are allocated to a new organization called: ”Foundation for the Development and Building of an Experimental Helicopter (SOBEH)”. The task of the foundation is to build and develop an experimental helicopter. A design team headed by Meijer Drees starts the work. An important design consideration is not to use a conventional reciprocating engine in the small helicopter, because of the complexity. McDonnell and Hiller had already used experimental concepts with blade driven rotor systems. So the new SOBEH helicopter will have a soft-in-plane two bladed rotor system with ramjet engines at the tip. This choice introduces a considerable amount of complexity, namely development of the helicopter together with the engines. The choice of the propulsion system explains that a tail rotor is considered unnecessary.

3.4. Development of the H-1 helicopter

The first design activity is the engine. A simple test stand is set up in one of the buildings of the NLL. Two large capacity blowers are used and a simple stove pipe type ducting. This early engine variant is designated as Tj-1 (fig.11).

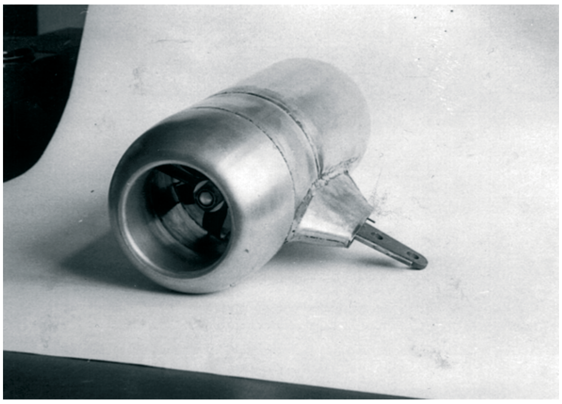

Figure 11 Tj-1 ramjet

A problem is the ignition of the fuel, which for financial reasons is simply kerosene. However a Dutch inventor is able to help and solve the ignition problem. The next step is to test the Tj-1 on a rotary test stand (fig.12). This requires special provisions, such as a whirling arm with a length of 3,64 m, the same as for the intended rotor blade, a counter weight and a powerful electric motor to drive the system. A concrete pit at the NLL premises in Amsterdam is available. Because of the centrifugal force it appears that the igniter location within the engine is not good and that the flame holder shape is not correct either. Extensive research is made on the behavior of the fuel, which is subjected to very high centrifugal forces during its way from the center of the rotor to the fast rotating engines Some modifications are made to the Tj-1.

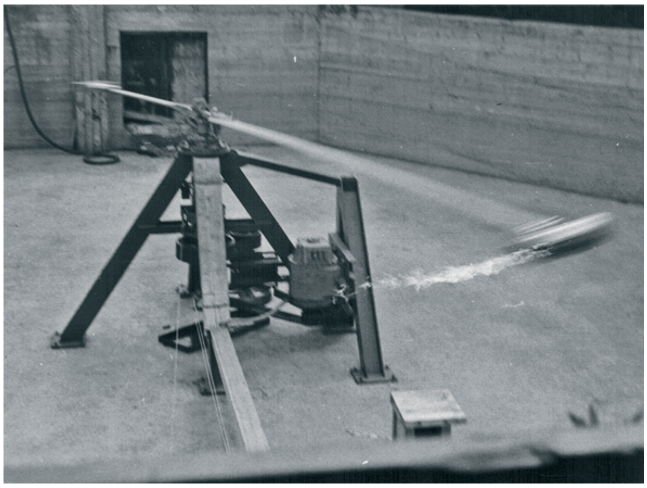

Figure 12 Rotary test stand at NLL

The next engine variant becomes Tj-2, which is totally destroyed when the counter weight during a test run breaks-off and enters into the engine inlet. A new engine is built and designated Tj-3. Design work of the first helicopter called H-1 progresses, where the Hiller Hornet is used as a guideline. The rotor hub is an aluminum casting which allows for feathering or pitch control, through a torsion bar according to the Verhage design concept. Cyclic control is by means of a hanging control stick to a swash plate and the torsion bar. Collective control is with a collective stick connected to a push-pull tube and a yoke attached to the outboard ends of the torsion bar (fig.13). Directional control is with a vertical rudder controlled by foot pedals. The blades have a main spar, composed of U-shaped sheet metal profiles, bonded together. The metal upper and lower blade surfaces are also bonded on this spar. Rotor blades are produced this way for the first time. This process is a spin-off of the extensive research work by Fokker and is applied already in the Fokker F-27. The blade profile is NACA 0012, which at that time is commonly used in helicopters. Because of the tip mounted engines the fuel lines to the engines run inside the blade.

Particular attention is given to the interaction of the dynamic rotating system and the dynamic non-rotating system. Such systematic analysis of this subject could not be made yet at the time of the Von Baumhauer helicopter. In particular the flexible rotor design with the heavy tip mounted engines can easily cause unexpected problems. Therefore, supported by the PTT, an analog computer, called SOBEHTRON, is developed. The outcome is that in the H-1 design no dangerous resonances exist, when the helicopter is in operation. The H-1 nears completion and the test runs can start.

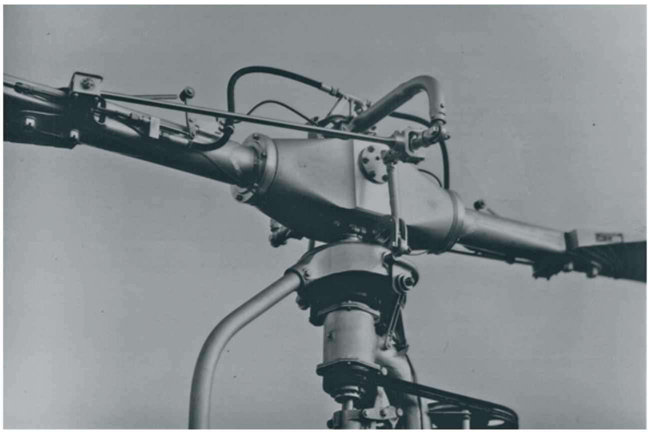

Figure 13 Rotor hub and controls of the H-1

Unlike other engine types a ram jet first has to be accelerated to the operating speed before fuel can be supplied for ignition. In the beginning a simple hand operated crank type system is used, however this cannot attain the minimum rotor RPM needed. Therefore a starter cart is used driving a flexible shaft. At the first runs it is clear that there is an unequal fuel supply between the engines, which is rectified by a design change. After a series of ground runs at normal rotor operating speed the team is sufficiently confident to call up an experienced naval helicopter pilot to continue the program.

After a number of uneventful familiarization hops (fig.14) the H-1 suddenly experiences a flame-out during one such short flight. The forced landing that follows causes severe damage as the helicopter turned over.

Figure 14 The H-1 in flight

An analysis makes clear that the cause of the flame-out of one of the engines is that it had passed the flame-out limit. This could happen as on the rotary test stand not all real-flight inlet flow conditions could be tested. In real flight the air flow enters the inlet at various angles, which change rapidly. Another important observation after the forced landing is that the overturning of the H-1 must have been caused by ground resonance initiated by the rotor.

This phenomenon may arise in case of an off centre condition of the rotor center of gravity to the axis of rotation. If the rotor RPM is roughly the same as the natural frequency of the helicopter, resting on the undercarriage, a heavy oscillation may be the result with most of the times a disastrous result. As is mentioned before many of the test runs of the Von Baumhauer helicopter were aimed at controlling the risk of ground resonance. It is concluded that the combination of the heavy ram jets at the blade tips and the soft-in-plane rotor design has contributed very much to the accident. The in-plane rotor stiffness appeared to be less than was expected. This extreme condition had not been taken into aaccount in the SOBEHTRON computer calculations.

3.5. A design step forward: the H-2

It is 1954 when it becomes clear that the H-1 rotor must be totally redesigned to avoid the risk of ground resonance. The design change makes that the longitudinal feathering axis of the blade remains parallel to the longitudinal blade axis. The rotor hub becomes a packet of laminated steel plates (fig. 15).

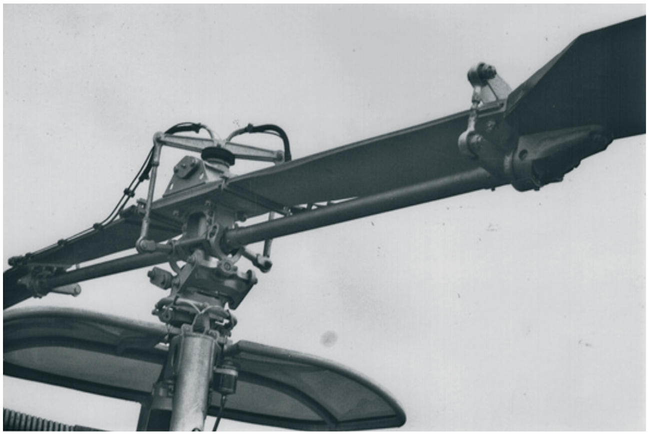

Figure 15 Rotor hub of the H-2

On either end a blade is fitted. In the middle of this packet the see-saw type rotor mast passes through a hole. In spite of these changes the bearingless rotor could retain the original soft characteristics.

The H-2 also has redesigned Tj-4 engines provided with two flame holders (two engines) in one body (fig.16). The reason for this change is that the Tj-3 ”plus” engine of the H-1 had not enough power.

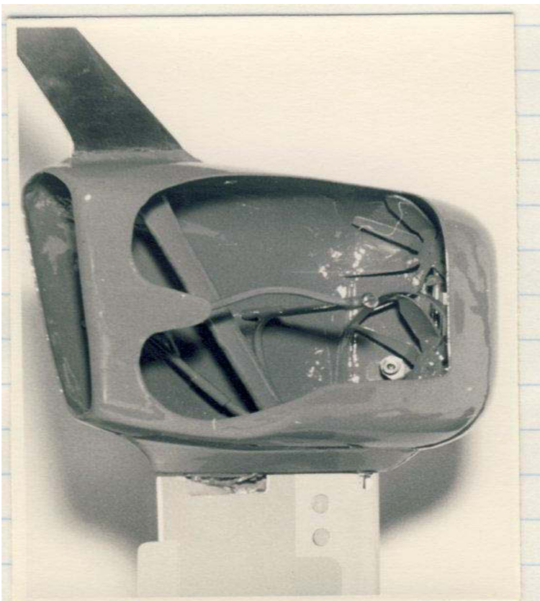

Figure 16 Tj-4 with two flame holders

The increase in power allows to increase the rotor diameter to 10 m, which gives improved hover performance. As a temporary measure the original blades are retained, however an extension with a blade like shape is made to the engine nacelles. A modification of the engine attachment lugs is necessary as well as a change in the fuel lines to the engine. At the first test run of the H-2 with the new Tj-4 engines a strong vibration is felt.

The reason is that the engine nacelles at the upper and lower side are more flat than with the Tj-3, thus producing lift at their front end making the rotor unstable. A mass balance weight (fig.17) is fitted on the leading edge of the blades to counter act this tendency. In order to move the aerodynamic centre of the blade more aft a horizontal stabilizer fin is fitted to the outer surface of each engine. The vibration problem is solved and it appears that the rotor allows a higher speed. It is decided to introduce a completely dual fuel system because like before problems arise with the fuel distribution between the engines.

During the flight tests it becomes clear that directional control of the helicopter by the small self adjusting rudder is inadequate. This means that a tail rotor must be fitted. A single-blade solution is chosen, made of wood and driven with a flexible cable connected to the main rotor shaft. In this configuration the H-2 started to make longer flights until the horizontal fins on the ramjets developed cracks as a result of fatigue and deformations. This means that the engines have to be

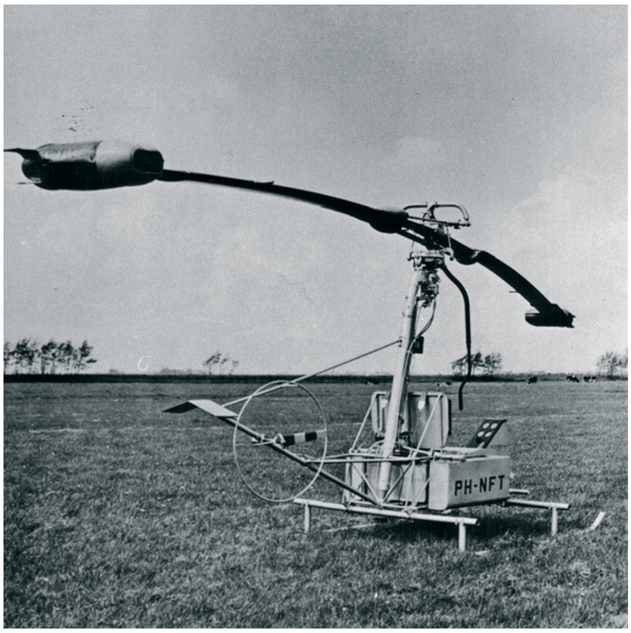

Figure 17 H-2 with tail rotor and mass balance weights

redesigned again. In particular the fin attachment and the body to avoid deformation as a result of the enormous centrifugal forces of 800 g. This new engine becomes Tj-5 with a tension bar connecting the stabilizer fin with the blade attachment fitting.

3.6. Final improvements of the H-2 with Tj-5 engine

During the winter of 1955-56 the H-2 with the Tj-5 engines is running and flying successfully (fig.18).

Figure 18 H-2 flying hands off

So far different pilots were involved in the program. Being operational pilots at the Royal Netherlands Navy they were not available full-time. A new pilot, René van der Harten, an ex-naval pilot, from that moment on can fully take part in the further development of the helicopter. A windshield is installed as well as a passenger seat. A vibration suppressor is mounted on the cyclic to reduce the so called “two per rev.” vibration. An on board engine starter is mounted. These improvements result in a weight increase. A weight saving activity is started, as performance characteristics of the tip jet driven helicopter are already marginal, because of the high fuel consumption and the resulting low payload.

Until that time the NLL engine test stand at a distance over 100 km is used to tune the engines, which is very time consuming. It is decided to build a simple test stand at the development site of the helicopter at Rotterdam airport.

4. Launch of the Netherlands Helicopter Industry

In August 1956 a successful demonstration is given to the NIV. So far the program is financed with funds from the “Helicopter Foundation”. However this budget is now depleted, but has resulted in a potentially, commercially attractive helicopter. The moment has arrived to set up an industrial organization. According to their rules the foundation NIV can only finance further research and development, but not the production. Therefore In October 1955 the “Netherlands Helicopter Industry” (NHI) is founded. It is decided that a batch of 10 H-3 models will be built. One will be a ground endurance test vehicle and one a demonstrator. The first main task is the certification of the H-3 production prototype. The certification basis is the United States Civil Airworthiness Requirement for (small) Rotorcraft. The NLL is assigned by the NIV to perform the flight test measurement and to development a data recording package (fig.19).

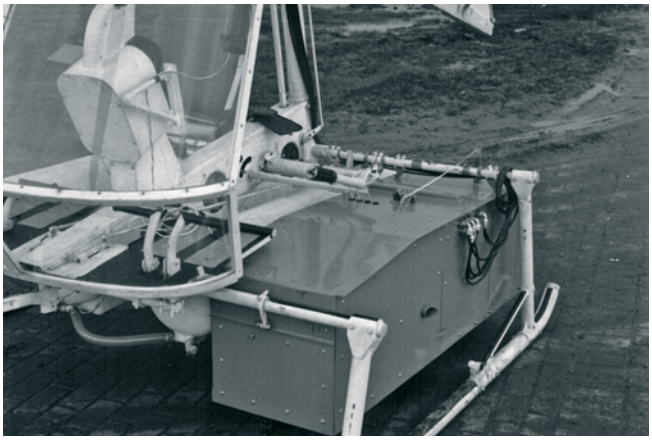

Figure 19 NLL developed flight test equipment box

For the development group, which so far is used to do the development and testing almost autonomously, this organizational change is a big step. They are faced with a much more formal process, which leads to the production of much more paperwork than before. One of the certification requirements is to perform a 500 hrs rotor endurance test. During this test one of the engines breaks off and NIV decides that the test must be continued to 1000 hrs. On 4 May 1958 a Certificate of Airworthiness is granted (fig.20). In his speech on that occasion the chairman of the NIV, Professor Van der Maas, stresses the importance of continued research, following the development of the Kolibrie thus far. This opinion is not always well understood by the design team, as they struggle with a lack of funds to do the promotion and production of the helicopter. However undoubtedly Van der Maas at that moment had in mind the development of the Fokker F-27 where NLL had performed a lot of fundamental research and testing. Possibly he also was thinking of the trial and error type of tests with the Von Baumhauer helicopter, which he had seen some 20 years earlier when he was working for the RSL.

Figure 20 Certificate of Airworthiness handed over

NLL has made a vast amount of research on the SOBEH helicopter, later called Kolibrie, in the following main disciplines:

- wind tunnel testing
- rotor aerodynamics
- engine testing
- fuel system
- rotor flutter
- vibration
- stability and control
- development of flight test equipment
- flight testing
- performance calculation
- structures testing
- fatigue testing

In the archives of the NLR museum the result of this work, mostly in the Dutch language, can be found in more than 100 reports.

Figure 21 Kolibrie in customer configuration

At the end of 1958 the British CAA has granted a Certificate of Equivalency. Although sold to one national and some international customers (fig.21) the Kolibrie is not a commercial success. The primary reason is the high fuel consumption, which leads to a short range and endurance. The simple construction, ease of maintenance and the favorable stability and control characteristics cannot compensate this drawback[13]. In 1961 the Kolibrie project is terminated

5. The NATO Helicopter for the nineties (NH90)

Figure 22 NH90 Frigate configuration

After the end of the Kolibrie project the helicopter remained on the agenda in the Netherlands. The helicopter researchers at the NLR (in 1961 NLL changed its name into National Aerospace Laboratory NLR) continued their work for specific helicopter subjects. On the scientific side people like Professor Hans Wittenberg of the Delft University of Technology and Louis Lucassen of NLR kept the Netherlands connected to the international helicopter community. Their network included scientists in countries with their own helicopter industry. A younger generation scientists in Delft and at NLR has continued their work until today. On the operational side René van der Harten, who as a pilot played such important role in the Kolibrie development, continued this type of work at KLM Helicopters. He amongst others has developed flight procedures for the approach and landing of helicopters to oil rigs under IFR conditions. NLR since many decades is involved in the so called helicopter-ship qualification for the Royal Netherlands Navy. The introduction of more military helicopter types means an increase in the operational research and support in that field.

In view of the above it is no great surprise that the Netherlands, together with the United Kingdom, Germany, France and Italy decided to organize a yearly event called the European Rotorcraft Forum. The first ERF was held in the United Kingdom in 1975.

In the beginning of the 1980's the first steps are made leading to the NH90 project[14]. Participating countries at that time are United Kingdom, which shortly thereafter withdraws as a participant, France, Italy, Germany and the Netherlands, the only country not having a helicopter industry. Two Dutch industries, Fokker and DAF Special Products, together with NLR take care of the Dutch industrial share of around 5%. The Royal Netherlands Navy is the Dutch government partner as the NH90 will replace the Westland Lynx helicopter. In the early phases of the project, many configuration tests are executed in the wind tunnels of NLR (fig.24). To the Design and Development share of the Netherlands belong amongst others the landing gear, the foldable tail section in composite and the Intermediate Gear Box. These parts have been successfully tested (fig.25) and are components which can be found in the NH90 production helicopters. Other NH90 work has been amongst others on the development on avionic systems, fusion of sensor information and on research of pilot work load.

Figure 24 NH90 in German Dutch Wind tunnel

Figure 23 Fatigue testing of NH90 composite tail at NLR

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