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The NH90 helicopter development wind tunnel programme

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ABSTRACT

In the framework of the Design & Development (D&D) phase of the NH90 helicopter programme,a wind tunnel test programme is carried out using various subscale models to determine the aerodynamic behaviour of the vehicle. The NH90 helicopter is being developed in a co-operative programme by four European nations: France, Germany, Italy and The Netherlands.

Approximately 1900 hours of wind tunnel tests have been conducted since 1987 in the Netherlands (Low Speed wind Tunnel LST and German Dutch Wind tunnel DNW) and in France (Eurocopter France ECF low speed wind tunnel). Execution of these wind tunnel tests was a substantial contribution to the development risk reduction effort performed for the multinational NH90 helicopter programme.

One of the test activities performed in the D&D phase of the NH90 programme included testing a scale 1:4 model equipped with a powered main rotor in the German-Dutch Wind DNW. The model comprises of a fuselage hull, powered main rotor and engine air intake and exhaust systems. Powered tail rotor model tests were performed in the DNW-LST to assess the tail rotor efficiency at extreme sidewind conditions. Nine test campaigns are performed with a fuselage model in the DNW-LST.
At ECF a recirculation model was used to evaluate the exhaust gas reingestion in the air intakes and airframe heating. Detailed engine air intake flow characteristics were obtained using a dedicated engine intake model.

The paper gives an overview of the wind tunnel models applied. Model instrumentation and measurement techniques are highlighted.

THE NH90 HELICOPTER DEVELOPMENT WIND TUNNEL PROGRAMME

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Abstract

In the framework of the Design & Development (D&D) phase of the NH90 helicopter programme, a wind tunnel test programme is carried out using various sub-scale models to determine the aerodynamic behaviour of the vehicle. The NH90 helicopter is being developed in a co-operative programme by four European nations: France, Germany, Italy and The Netherlands.

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Notation

ADS	Air Data System
AIP	Aerodynamic Interface Plane
D&D	Design & Development
DLR	Deutsche Versuchsanstalt für Luft und Raumfahrt
DNW	Duits Nederlandse Windtunnel (German Dutch Wind tunnel)
ECD	Eurocopter Deutschland
ECF	Eurocopter France
IR(S)	Infra Red (System)
LH	Left Hand
LST	Low Speed wind Tunnel
MWM	Modular Wind tunnel Model
NAHEMA	NATO Helicopter Management Agency
NFH	NATO Frigate Helicopter
NH90	NATO Helicopter for the 90-ties
NLR	Nationaal Lucht- en Ruimtevaart Laboratorium
OA	ONERA
PCM	Pulse Code Modulation
PCB	Printed Circuit Board
PDP	Project Definition Phase
RH	Right Hand
TTH	Tactical Transport Helicopter

NH90 helicopter development programme

The four participating Governments (France, Italy, Germany and The Netherlands) constituted an international programme office, called NAHEMA (NATO Helicopter Management Agency) in 1992. The four companies sharing the Design and Development of the NH90 programme (Agusta, Eurocopter Deutschland, Eurocopter France and Fokker Aerostructures) established a joint venture, the company NHIndustries, to ensure international industrial programme management. The Dutch industrial participation is shared between Fokker Aerostructures, SP Aerospace and Vehicle Systems (former DAF SP) and the National Aerospace Laboratory NLR. In September 1992, the NH90 Design & Development contract was signed. The estimated need of the Governments was 726 aircrafts; 544 in the Tactical Transport version (TTH) and 182 in the Naval version (NFH). The industrial share during the Design and Development phase is configured in proportion to the national needs (ECF 42.4 %, Agusta 26.9 %, ECD 24.0 % and Fokker 6.7 %).

The NH90 is a twin engine helicopter in the 9 ton class. It is a unique integrated weapon system developed in two mission variants from a common basic model (figure 1). The Tactical Transport Helicopter (TTH) is the transport version, primarily for tactical transport of personnel (14-20 troops) and material (more than 2500 kg of cargo). This version is optimised for low signatures (acoustic, radar, infrared) and it will be equipped with a night vision system, Obstacle Warning System, defensive weapons suite, passive and active measures against the threat.

Fig.1: NH90 prototype 1 (PT1) in flight

The TTH is designed for high manoeuvrability in Nap of the Earth operations. Because of its features, characteristics and systems integration, it is capable of operating successfully by day and night/adverse weather conditions in any environment.

The NATO Frigate Helicopter (NFH) is the naval version, primarily for autonomous Anti-Submarine Warfare, Anti Surface Unit Warfare missions. The helicopter is designed for day & night/adverse weather /severe ship motion environment operations. Equipped with a basic and mission avionics system, the NFH version will be capable of performing the mission autonomously with a crew of three. Its capabilities include launch and recovery from small vessels in extreme adverse weather conditions.

The NH90 helicopter (first of five prototypes) made its public debut on February 15, 1996 at Eurocopter France's facility in Marignane (France). This first prototype represents a basic airframe design, based on thorough tests (both laboratory and wind tunnel) and evaluations to reduce development risks.

Overview of wind tunnel test programme

First wind tunnel testing was already performed prior to the start of the Design & Development phase. Low speed wind tunnel investigations were carried out in the DNW-LST at a scale 1:10 drag model to determine the aerodynamic characteristics of various NH90 helicopter component configurations.

To minimize the technical development risk and demonstrate the feasibility of stringent technical objectives in an early stage of the development, a wind tunnel programme was included in the scope of work for the Design and Development phase. At the beginning of the D&D wind tunnel test needs were assessed. Various wind tunnel model configurations were defined that could fulfil the high priority test needs in the most efficient way. In summary this lead to the following model definitions (table 1):

- a 1:3.881 scale fuselage fitted to a powered main rotor for testing in the DNW;
- a 1:3.881 scale tail model fitted with a powered tail rotor (DNW-LST);
- a 1:3 scale air intake model (ECF wind tunnel);
- a 1:10 scale engine recirculation model fitted with a 2-bladed powered main rotor and engine flow simulation in the ECF wind tunnel;
- a 1:10 scale fuselage (drag) model for testing in the DNW-LST.

Up to now approximately 1900 hours of wind tunnel testing has been spent in the NLR and ECF wind tunnels.

Powered main rotor model (scale 1:3.881)

Test activities

The first test campaign in DNW with the powered main rotor model primarily was devoted to the low speed flight characteristics.

Primary test objectives were the determination of the helicopter trim attitude at low speed for various horizontal tail configurations and the investigation of the fuselage aerodynamic and stability characteristics in the presence of the rotor wake.

The model scale (1:3.881) was dictated by the fact that use was made of an existing model main rotor system (owned by Eurocopter). Because of the reversed sense of rotation of the main rotor as compared to the actual NH90 main rotor, the aft part of the tail boom and the vertical fin are manufactured as mirrored images with respect to the actual fuselage.

The second test, performed in December 1996, focused on high speed flight conditions and engine air intake pressure losses. Air intake susceptibility to exhaust gas recirculation and airframe heating tests were done at low speed lateral and rearward flight. Also exhaust gas IR (Infra Red) signature was measured. For this test entry in DNW, a dedicated NH90 powered main rotor model has been developed by NLR, to properly represent the rotor system high speed behaviour.

Test set-up

During the first test campaign in DNW, the model was supported by a sting leaving the model at the aft part of the fuselage. Inside the fuselage this sting was attached to the DLR (Deutsche Versuchsanstalt für Luft und Raumfahrt) rotor drive system MWM (Modular Wind tunnel Model) and at its other end the sting was connected to the standard sting support system of the DNW (figure 2). This allowed to change both the model's angle of attack (+10 /-30) and the sideslip angle (± 30) during the testing.

For the engine installation test the so-called common support system (vertical sting) has been applied, for testing in a wide range of sidewind conditions (270) and a limited angle of attack range (±10).

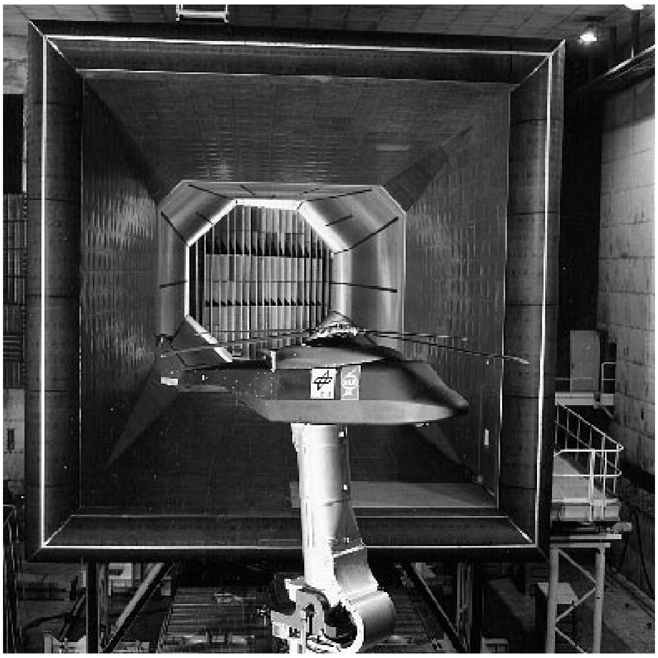


Fig.2: Powered main rotor model in DNW (photo: DNW)

The model support basically consists of the DNW open jet common support housing structure, a vertical mast, angle of attack hinge point and vertical sting. The MWM mounting adaptor interfaces the support system with the MWM rotor drive system. The vacuum duct connects the intakes to a vacuum pump, located in the testing hall. Pressurized air is supplied by the air supply system (ADS), transferred through flexible hoses to the air heating system (located above the alpha knee). The central component of the air heating system (developed by DNW) is the burner can, in which propane gas is burned to heat the pressurized air to 600 C. The fuel controller is located inside the common support housing. All supply pipes are routed along the vertical strut and covered with a cylindrical fairing between fuselage model and alpha-knee.

Model description

The NH90 mode rotor hub is of the fully articulated type, which utilizes single spherical elastomeric bearings (development by Lord) to allow the blade to pitch, lead-lag and flap. The spring rates of the bearing, which are scaled down, are based primarily on the stiffness and deflection of the internal elastomeric layers. A set of elastomeric inter-blade lead-lag dampers (also developed by Lord), located between each 2 sleeves, has been worked into the hub design. Static and dynamic damping characteristics are matched to control the rotor system ground resonance.

The sleeve attaches the rotor blade to the rotor hub. It also provides attachments for the pitch lever and flapping stops. Flapping stops limit the blade angles. The rotor torque is transmitted to the rotor drive system MWM via the rotor mast (by bushings). The mast is hollow to allow for internal routing of the instrumentation cables.

The rotor blades are geometrically and dynamically scaled copies of the full scale blade. The model blade D-spar graphite epoxy layer distribution and orientation has been defined such that the full scale blade properties (mass and stiffness distribution) are matched closely. The blades are constructed of a foam D-spar core (torsion box), wrapped with uni-directional graphite epoxy prepreg material and a foam trailing edge core covered with a skin. OA series airfoils are applied, with linear transition between the various airfoil sections. Blade tip shape is parabolic with anhedral.

Rotor instrumentation wiring is plugged onto a printed circuit board (PCB), which is mounted inside the rotor beanie. This dedicated printed circuit board is the front-end of the DLR data acquisition system (Pulse Code Modulation PCM-unit).

The model fuselage is manufactured from glass fibre reinforced resin in order to obtain a light weight, but stiff structure. The model was built up as a modular structure. It can be equipped with a variety of horizontal stabilizers, varying in configuration (e.g. with slat), size and/or location.

The engine installation model hardware has been integrated in the fuselage hull. It consists of geometrically scaled down engine air intake and exhaust modules (external and internal geometry) and a capability to simulate representative engine intake and exhaust (of 600 C) gas flow conditions.
The engine cowlings are made of high temperature resistant glass reinforced epoxy. The air intake sub system consists of a detachable dynamic scoop, intake caisson, bellmouth and engine duct. The scoop, intake opening and bellmouth are covered with intake screens. The model compressor entry cross section area has been adapted to obtain the scaled mass flow capability of 0.4 kg/sec.
The exhaust subsystem consists of a plenum settling chamber, perforated plate, which reduces the exhaust pressure from 6.5 to 1.0 bar, and a stainless steel nozzle.

Model instrumentation and measurement techniques

The instrumentation used for this wind tunnel test campaign can be separated into rotor system, engine and fuselage related sensors.

Rotor system related instrumentation consists of:
- MWM rotor balance (strain gauge load cells), to measure the rotor loads (3 forces and 3 bending moments);
- torque meter, located between the MWM hydraulic drive motor and gearbox;
- rotor mast bending moment (strain gauge bridges on rotor shaft);
- rotor rpm measurement (accuracy: ±3 rpm) and azimuth marker;
- blade strain gauge bending bridges to measure

local flap, lead-lag and torsional moments (2 fully instrumented blades gauged at 5 radial positions, 2 blades only instrumented in the blade root area);

- 2 pitch link load cells (piezo element to measure dynamic control loads);
- 2 blade angle measurement systems, which determine blade pitch (resolver), flapping and lead-lag angles (strain gauge bridges).

The blade angle measurement system is a unique flexure system, developed to fit in the hollow blade sleeve. The measuring device for the flap and lead-lag angles consists of two sets of measuring flexures (two flapping flexures and two lead-lag flexures, figure 3).

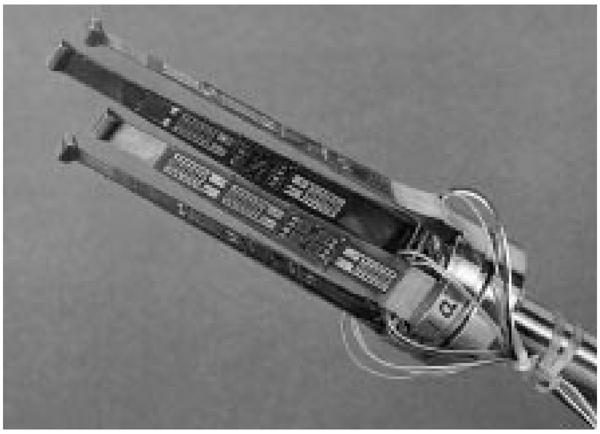


Fig.3: Blade angle flexure system (photo: NLR)

The flexures of a set have an off-set in radial direction. On each flexure a strain gage bridge has been placed. The blade angle measurement system is not sensitive to any translation of the sleeve, which during operation is introduced due to the elasticity of the elastomeric bearing. Radial translation (under influence of centrifugal forces) is compensated for by the fact that the flexures can slide in radial direction at the hub side. If translation of the sleeve in or out of plane occurs, both flexures of a set will bend in the same amount with respect to their reference position and consequently the additional output of the strain gage bridges will be equal. By using the difference between the two signals, the influence of translation on the measuring signal can be eliminated. Achieved average accuracy of the angle measurement system is ±0.10 (lead-lag) and ±0.15 (flapping).

The engine installation related instrumentation comprises of:

- 2*9 temperature sensors (open type T, equipped with ventilation socket) on the bellmouth screen (range: -20 to +90 C, accuracy: 0.2 C, response time: 0.1 [sec]);
- 2*6 compressor entry rakes, each containing 2 total pressure tubes and 1 five hole probe (range 5 PSI full scale, accuracy: pressure 0.2% or 0.4 [m/sec] at 140 [m/s], flow angle 0.2 within ±20);
- 2*6 temperature sensors (closed type K, equipped with ventilation socket) in the exhaust nozzle plane (range: +200 to +600 C, accuracy: class 1, 2.4 C);
- 2*4 temperature sensors (closed type K, no ventilation) mounted on the exhaust top plate (range: +200 to +600 C, accuracy: class 1, 2.4 C);
- 2*2 temperature sensors and 2*2 static pressure holes, located in the settling chamber;
- 76 thermo couples (open type T, no ventilation), mounted on the fuselage and cowling skin, extending 10 [mm] out of the contour (range: -20 to +200 C, accuracy below 100 C: 1 C).

Global fuselage loads are determined by a 6 component Emmen balance. During engine installation testing, the Emmen balance is not used. The horizontal tail vertical force is measured by a dedicated strain gage balance. Static pressure holes (22) and 6 unsteady pressure sensors are integrated into the fuselage hull.

The IR signature of the wind tunnel model and exhaust gas plume were recorded by two (ECD and NLR) AGEMA "Thermovision 900 Series" infrared surface temperature measurement systems with spectral response scanners in the range of 3-5 m (so-called short wave band II) and 8-12 m (so-called long wave band I). A sample IR image picture taken with the ECD scanner system is shown in figure 4.

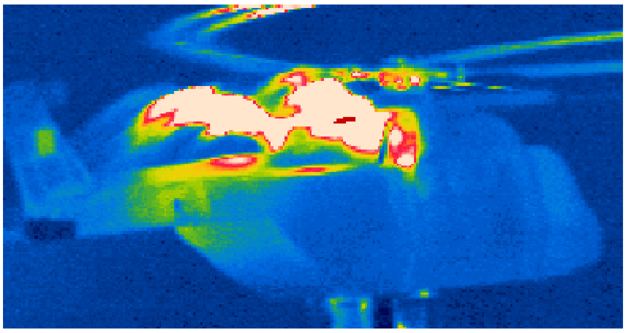


Fig.4: Sample IR image of exhaust gases

The scanners were mounted on an elevated platform at the height of rotor system in the test section. During the tests the two imaging systems were located at various positions on either side of the model.

For monitoring purposes the following sensors are included:

- 2 temperature sensors located on the elastomeric bearings;
- 2 temperature sensors located on the lead-lag dampers;
- accelerometers inside the model;
- 8 temperature sensors located in the fuselage hull.

Powered tail rotor model (scale 1:3.881)

Test activities

Powered tail rotor model tests were performed in the DNW-LST to assess the tail rotor efficiency at extreme sidewind conditions and tail rotor - vertical tail interference effects. Tests were performed in a large range of wind tunnel speed and sideslip conditions, covering the NH90 helicopter flight envelope.

Test set-up

The empennage and tail rotor modules are connected to a support structure, which is mounted to the external tunnel balance of the DNW-LST (figure 5).

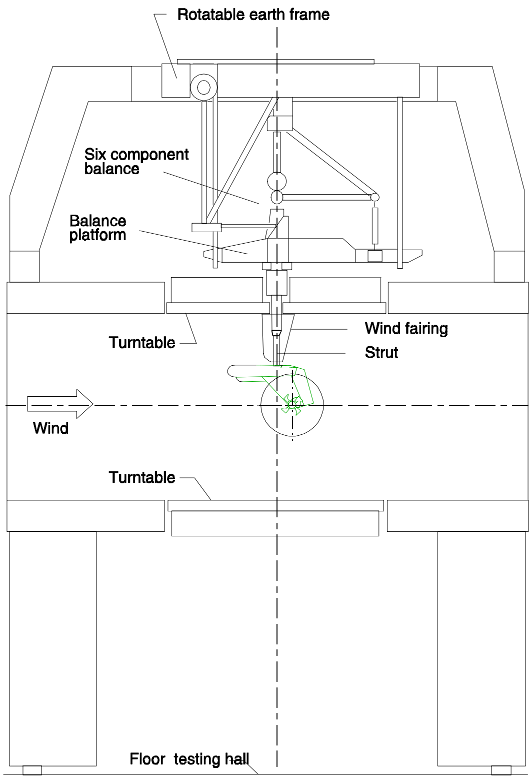


Fig.5: Powered tail rotor model test set-up in DNW-LST

This support structure, being hollow to allow routing of hydraulic and gearbox lubrication lines and instrumentation wiring, has a minimum volume to reduce the interference effects on the tail rotor as much as possible. To avoid tare forces on the strut, it was shielded from the wind by a (non-rotating) wind fairing.

The sideslip angle of the model can be changed by rotating the complete system. This set-up allows a variation of the sideslip angle of the tail rotor model over a range of 315 .

Prior to testing the non-rotating natural frequencies of the tail rotor test stand were determined experimentally to verify a finite element model prediction. Test results showed that no potential resonance problems between rotor rotational frequencies and test stand eigenfrequencies existed.

Model description

The powered tail rotor model is a partial model of the NH90, consisting of a powered tail rotor module (hub and blades), vertical tail and the aft part of the tail boom (from tail folding line onwards). The part in front of the tail boom folding hinge is contoured such, that a sound air flow is realized over the empennage part. The empennage consists of the basic vertical fin configuration and two extensions (on top and trailing edge). The model allows for limited "isolated" tail rotor testing, since aerodynamic interference of the internal wiring and tubes is large. At the aft part of the tail boom a horizontal tail can be mounted (figure 6).

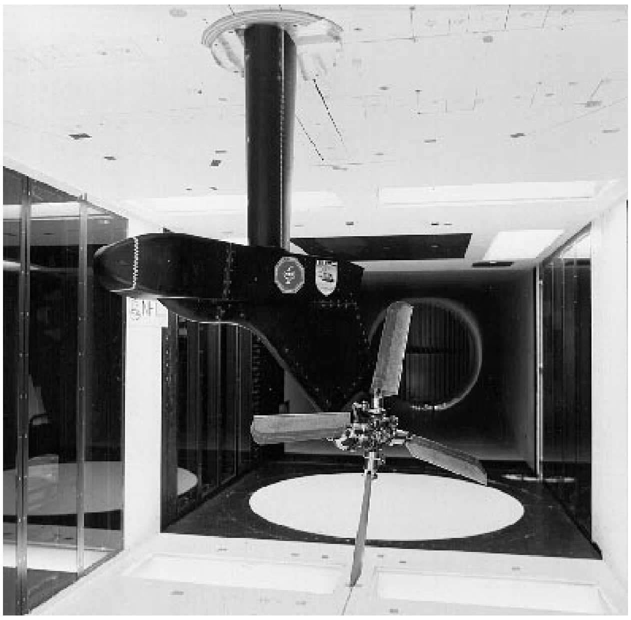
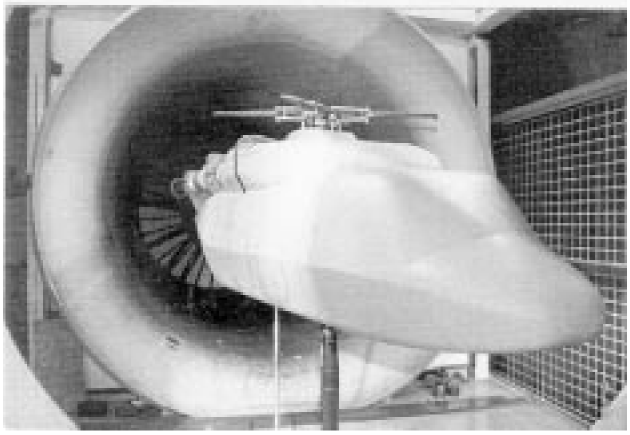


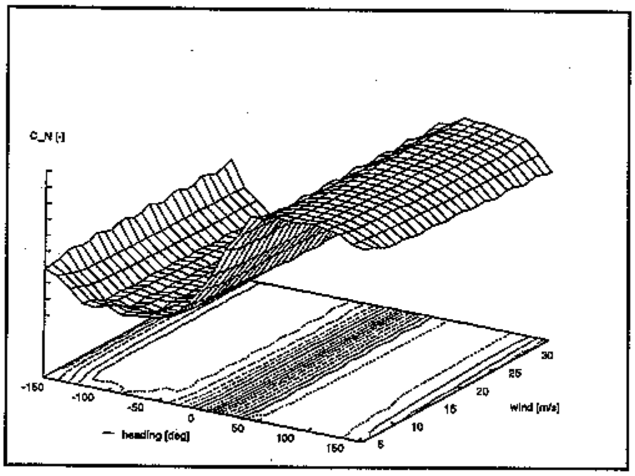
Fig.6: Powered tail rotor model in DNW-LST (photo: NLR)

The model design and manufacturing (partially) was subcontracted to Dynamic Engineering Incorporated (DEI). The model was designed to meet specific model tail rotor thrust, power and rpm requirements.

The rotor is to be considered as a thrust generator. Consequently the (fully articulated) hub design could be simplified. The model hub is a flat plate to which the four blades are connected through pins and bearings. The hub is mounted to the end of the rotor drive shaft. The composite tail rotor blades are scaled geometrically (linear twist distribution, OA313 and OARA9M airfoil types). Blades are furthermore light and stiff. The flapping hinge (hinge offset) is at the scaled down location. Geometrical scaling of the blade geometry and flapping hinge location ensures generation of a full scale representative rotor downwash, which is important for the assessment of tail rotor fin interaction characteristics.

The drive motor for the rotor system is a Dowty hydraulic motor, integrated in the aft tail boom (rated at 13 kW @ 3000 rpm, being appr. 40% of Mach scaling). Drive motor output torque is transmitted through a drive shaft to





the tail rotor transmission (gearbox input shaft). The vendor supplied 90 gearbox is lubricated with oil. The drive shaft tube is attached to the model strongback, which on its turn is connected to the model strut base.

Rotor thrust can be varied by means of remote controlled blade pitch angle control device. The collective blade pitch range (at blade sleeve) is from -25 to +25 .

Model instrumentation and measurement techniques

Global model loads were read by the DNW-LST external balance. Figure 7 shows the model side force coefficient at a wide range of sideslip and wind speed conditions (at a constant tail rotor pitch angle).

Fig.7: Sample side force coefficient cartography at constant pitch setting

The tail rotor thrust and torque are measured with an internal load balance, mounted on the tail rotor gearbox. It uses the reaction principle for all forces including rotating moments. The balance reads all external applied model loads, these loads come from two major sources. The first being the desired hub loads, the second being an undesired but unavoidable gearbox input load. The absorbed rotor torque is an external air load and is read by the balance, while the shaft bearing friction in the gearbox is an internal load creating an equal and opposite load on the shaft and gearbox case. Because both the rotor shaft and the gearbox case are on the balance metric side, no output shaft friction loads are read.

For this 90 gearbox configuration the input and output shaft loads are read in separate axes by the balance as. The gearbox characteristics create a ratio relationship between the input torque and the output torque. For resolution of the 2 primarily loads (thrust/torque), all other load components are measured to provide full load interaction compensation. Measurement accuracy is 0.5% of its full load range.

Blade pitch and flapping angle sensors (on two opposite blades) are non-contact devices, using a magnet and a Hall effect transistor (Bell FH-301-20 magnetic field sensitive device) to provide an analog output that is proportional to angle position. Sensor to magnet position was a trial and error set-up, searching for a magnet position that provides a linear sensor output. Measurement accuracy is approximately 0.15 . Sensor read-out (rotational system) is fed to a small size slipring, fitted to the gearbox (opposite to rotor shaft), allowing transmission of electrical signals from the rotating system to the stationary structure.

Blade pitch angle back-up measurement redundancy is provided by a LVDT, which measures pitch actuator displacement. For hydraulic motor rpm control, drive shaft rotational speed is determined by an electro magnetic pick-up, which also features blade azimuth marking.

Air intake model (scale 1:3)

Test activities

In December 1995 and September 1996, during two entries of the air intake model in the ECF wind tunnel, engine inflow characteristics and installation losses were investigated. The NH90 air intake wind tunnel tests were aimed at preliminary checking of the engine inflow characteristics (pressure loss and distortion, flow gyration) and estimation of the engine installation losses. Air intake definition was then optimised to comply with the helicopter/engine interface requirements.

Test set-up

The model is mounted on top of the all purpose ECF wind tunnel sting (figure 8).

The model was built in such a way that modifications of air intake geometry were easily feasible. In consequence, optimization of the intake versus performance and inflow quality criteria was performed.

Because of the heavy weight of the model, an additional support is attached to the tunnel hard points by means of rods, connected to the model and tunnel by rod eyes.

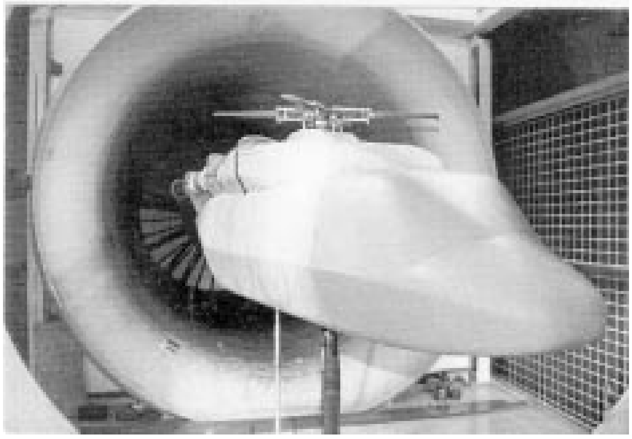


Fig.8: Air intake model in ECF wind tunnel (photo: Eurocopter)

In consequence the 6 components external balance can give an estimation of the drag of the model.

Model description

The model represents the forward part of the fuselage and the cowlings from nose radome to dog kennel. The skin is manufactured from glass-reinforced plastic. It is fixed on a rigid steel frame on which also the hub system and the test apparatus are mounted.

The air intakes are accurately scaled down from the NH90 definition from the openings in the cowlings to the engine compressor entries (on the NH90, the bellmouth is considered as an helicopter part).

The NH90 air intake opening is on the upper side of the cowlings and is protected by an outside grid.

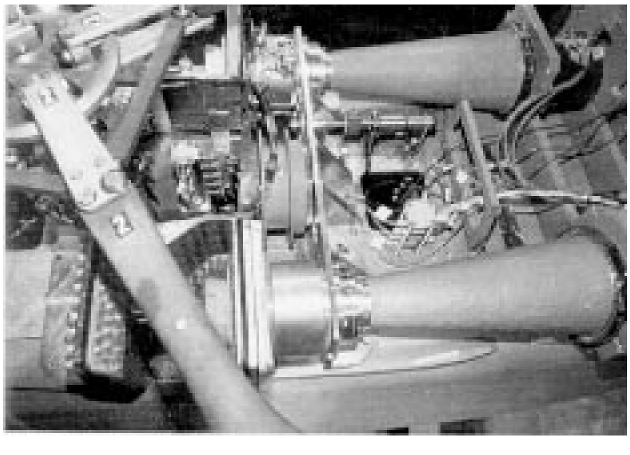


Fig.9: Air intake model details (photo: Eurocopter)

Inside the cowlings, the intake consists of a box like settling chamber, also called "caisson". A bellmouth on which a secondary protective grid is fitted, leads to engine compressor entry (figure 9).

A rotor hub with blade stubs is also present. The installation of a hub scaled from NH90 definition was not considered as mandatory. Therefore an existing hub system was applied. This hub is rotating at a speed close to the one of NH90 main rotor.

For each of the left and right air intakes, AIRSCREW 7PL161-1224 (three-phase power supply and variable frequency) ventilators generate the scaled engine mass flow. For some configurations, because a high mass flow was desired while significant obstruction was present, it was necessary to install the two ventilators one behind the other (on the right side).

Model instrumentation and measurement techniques

Only the right intake was instrumented, the other intake is connected to the ventilator to insure the proper symmetry of the airflow around the model.

The reference pressure was the atmospheric static pressure during the test sequence. It is measured by a JAEGER altimeter, the reference temperature is the tunnel temperature.

In the intake, the static pressure is measured with a Celesco 2PSI sensor and an additional reference temperature is measured with a thermocouple.

The velocity field in the engine compressor entry plane (also called aerodynamic interface plane AIP) is measured with a METRAFLU five hole probe. The velocity field consists of magnitude and direction of the local airflow at any location in the AIP.

This probe is mounted on a sting movable along a radius, the position is controlled by a step-by-step motor. This sub-assembly is fixed onto a rotating section which allows an accurate azimuth positioning. In consequence, any radius/azimuth combination can be reached and the whole compressor entry plane can be explored. The probe is calibrated prior to each test campaign, the calibration accuracy is 1% for pressure measurements and 0.5 for gyration angle measurements (for the latter, the data remains valid up to 30 angles).

The flow angles are calculated from the difference of pressures measured on two opposite locations on the probe: 4 Celesco sensors (1PSI and 2PSI) give the differential pressures between top and bottom locations, left and right locations, right location and central (total) pressure value, total and static pressures. The tangential airspeed (gyration) is given by left minus right pressure measurements (through calibration curve) and the radial airspeed by top minus bottom pressure measurements.

Figure 10 presents a sample swirl angle map, measured in the aerodynamic interface plane of a air intake definition.

Fluctuations (typical swirl distortions around a mean value) shown indicate that the airflow is not homogeneous.

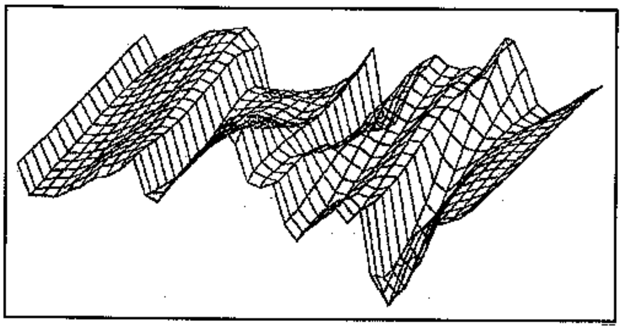


Fig.10: Sample air intake swirl angle cartography at 300 km/h (x-axis: azimuthal position, y-axis: radial position)

The mass flows generated by the ventilators were monitored through venturi's. The mass flows were corrected for the temperature increase in the ventilators (thanks to a dedicated temperature measurement).

Recirculation model (scale 1:10)

Test activities

One engine recirculation test campaign was conducted in the ECF wind tunnel early 1995 to explore air intake susceptibility to recirculation for various exhaust configurations (figure 11).

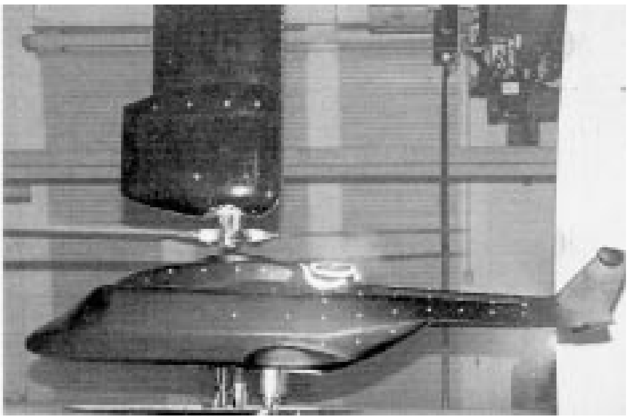


Fig.11: Engine recirculation model in ECF wind tunnel (photo: Eurocopter)

These tests were also useful to measure the impact of different exhausts, including IRS on the airframe heating. Testing of various configurations allows design optimisation in an early stage of the development.

Fuselage heating by exhaust hot gases in the flight phases near hover (i.e. with sideward or rearward wind) were explored and the infra-red signature was measured. The flight envelope explored in the wind tunnel corresponds to the wind envelope specified in the development contract.

sTest set-up

The model is installed in the centre of the test section of the ECF wind-tunnel in Marignane (Eiffel wind-tunnel). The fuselage is fitted to the lower mast via the support plate. The 6 component balance is not used, since no force or moment are to be measured during the testing campaign.

A platform is located below the fuselage in order to place the model inside ground effect. The distance between the model and the platform can be adjusted in order to simulate a height of around 10 ft.

Model description

The model consists of the following parts produced to scale 1:10:

- the assembly representing the NH90 airframe consisting of the fuselage, landing gear fairings, the fin and tail plane, engine cowlings incorporating openings to simulate the air intakes (manufactured from glass-reinforced plastic), engine exhaust jet-pipes, attached to the rear fairing (manufactured from sheet steel); different jet-pipe geometries can be adapted to the rear fairing, the jet-pipes are directionally adjustable;
- a generic twin-bladed rotor, fitted above the airframe, in order to simulate the mean induced airflow (the 1.5 [m] rotor diameter is close to the size of the NH90 main rotor at model scale);
- the air suction system, connected to the air intakes, enabling various engine inlet flows to be simulated, which at this scale are quite low; the suction is generated by a simple industrial vacuum cleaner;
- the hot gas exhaust system, connected to the jet-pipes, enabling the engine exhaust flow and the exhaust gas temperatures to be simulated.

Additionally, possible exhaust gas dilution can be represented by increasing the flow and decreasing the temperature. The exhaust gases are heated by 2 gas burners.

Model instrumentation and measurement techniques

The fuselage is fitted with approximately 75 thermocouples distributed over the engine cowlings and the rear part of the fuselage (dog kennel, tailboom, fin and tail-plane). The distribution of these sensors was optimised by a simplified preliminary calculation of the exhaust gas trajectories.

In order to avoid the effects of heat conduction in the model skin, which is not thermodynamically representative of the actual aircraft, the thermocouples are positioned a few millimetres away from the surface of the model, in order to measure the temperature of the surrounding airflow. The airframe temperature is then deduced from this measurement by calculation (figure 12).

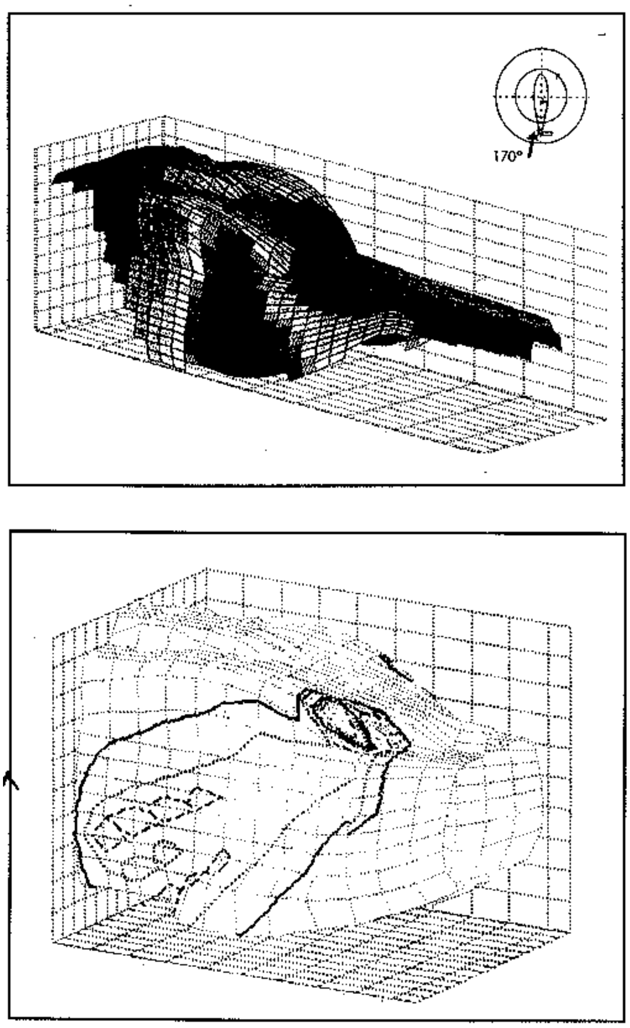


Fig.12: Airframe structural heating

For a tail wind condition, the structural heating is presented in the form of a map (top) and temperature contour plot (bottom).

Additionally, the air inlet ducts are equipped with six thermocouples per side. It is therefore possible to measure not only the average temperature rise during flight in the event of exhaust gas re-ingestion, but also to evaluate the temperature distortion. These two parameters (average and distortion) affect the installation losses and the engine operation.

Each jet-pipe is fitted with a thermocouple in order to provide real-time measurement of the exhaust gas temperature. In fact the test procedure involves measuring the temperatures dynamically during the exhaust gas temperature rise, data acquisition occurs as soon as the latter reaches the required temperature.
The cold (suction) and hot (exhaust) airflows are measured using venturi's (satisfying the requirements of standard NF X10.104).

Fuselage model (scale 1:10)

Test activities

Fuselage model testing in the DNW-LST comprises approximately 50% of the test effort, accumulated during nine campaigns. The tests focused mainly on the external aerodynamic characteristics (especially drag and stability) of the NH90 helicopter. One campaign was dedicated to the rear ramp. Influence of rear ramp position (open, intermediate or closed) on global aerodynamic loads for handling qualities and performance evaluations purposes and on rear ramp and hatch loads for design load verification was assessed.

In 1995 a fuselage model campaign was devoted to the tail shake phenominum. The wake characteristics of the fuselage and cowlings were measured at the vertical fin location.
During the course of the project, an extensive aerodynamic database (sideslip angle sweeps at various angles of attack) has been built-up for handling quality simulation modelling purposes.

Test set-up

The model, connected to the internal six component strain gauge balance, is mounted on a sting which on its turn is mounted on the -mechanism below the floor of the DNW-LST test section (see figure 13).

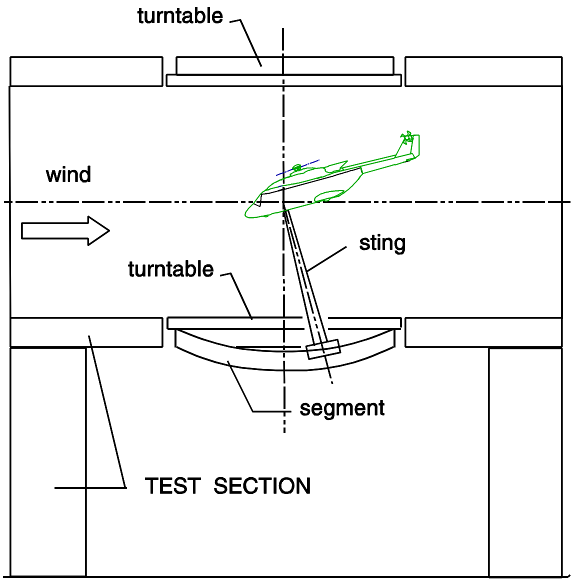


Fig.13: Fuselage model test set-up in DNW-LST

The angle of attack ( ) of the model is adjusted by moving the sting attachment along a cylindrical segment (±20). The side slip angle (ß) can be adjusted by rotating the turntable with sting support system about its vertical axis (±180). By mounting the model in a 90 rolled position, the angle of attack range also can be extended from -180 to +180 . Besides the possibility to perform sting interference tests and to enlarge the angle of attack range, the possibility to roll the model is also used to guaranty a sound airflow around the bottom (or side) of the fuselage and tailboom.

To be able to cover a large number of test conditions (configurations and model attitudes) the data is in general acquired in a so-called "continuous" testing mode. This means that the model attitude in or changes at a constant rate (about 0.08 per second) and the model data are sampled at a fixed interval of or . Depending on the measurement grid required, the force and pressure data is acquired every 0.5 to 5 .

Model description

The fuselage (drag) model is a representation on scale 1:10 of the external contour of the NH90 helicopter (figure 14).

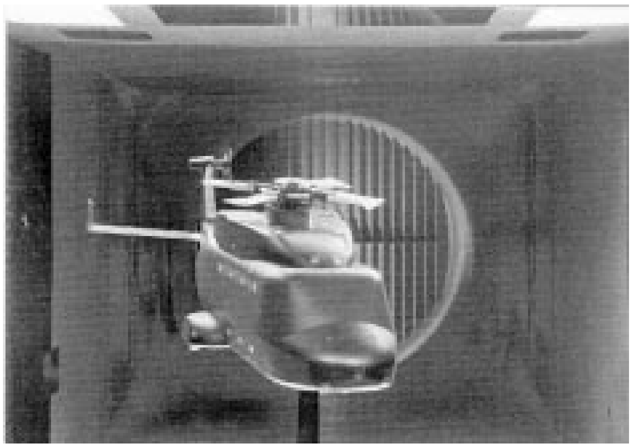


Fig.14: Fuselage model (1:10) in DNW-LST (photo: NLR)

The model comprises of the fuselage, rotating main rotor hub (including blade stubs), tail surfaces and other protuberances. No main, nor tail rotor blades are present.
The model has a highly modular structure facilitating exchange of components and investigation of contour modifications.

The main structural element of the model is a box-like structure, which contains an internal six component strain gauge balance connected to a sting support. The box has a hole in the bottom with such a dimension, that the sting can pass without contact to the box even when the sting and balance deform under load.
The external contour consists of a large number of modules like engine cowlings (with intakes and exhausts), fairing of the main rotor axis (main rotor pylon), main rotor hub, rear fuselage, tail boom, sponsons (inclusive the cavities for the undercarriage), undercarriage (consisting of the main wheels and the nose wheels), horizontal tail surface (with variable setting angle), vertical tail surface, tail rotor hub (not rotating) and various external stores. The ramp module consist of two modules (ramp and hatch) which can be opened in various angles (figure 15).

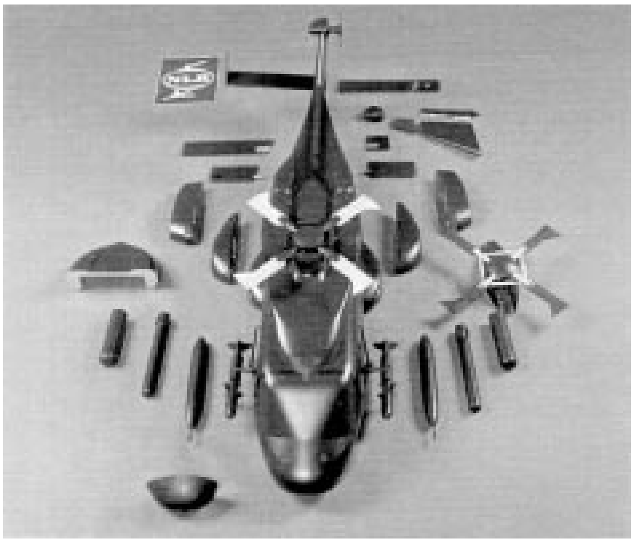


Fig.15: Components of fuselage model (photo: NLR)

The main rotor hub, equipped with rounded blade stubs, has the capability to rotate upto 1200 rpm. The drive power is provided by a, water cooled, electrical engine (0.3 Kw). The blade stub angles, both collective and cyclic, are settable.

Model instrumentation and measurement techniques

The aerodynamic loads acting on the model are measured with an internal six component strain gauge balance. Both 1.5" and 2" TASK balances can be mounted inside the model. Dedicated balance calibrations have been performed to adjust the balance calibration range to the expected model loads.

Over 125 pressure holes are drilled into the model at the nose and rear ramp locations. The model surface pressures can be measured with conventional transducers or with an electronic scanning system. The most salient features of this electronic scanning system are the one transducer per orifice concept and the capability to perform in situ calibrations. The transducers are mounted inside the model. The electronic scanning system also allows for "continuous" testing.

To measure the angle of attack accurately, a Q-flex is mounted inside the model. The non-linearity and possible drift of the Q-flex makes it necessary to record the Q-flex readings at zero angle of attack at regular intervals. Therefore a so-called electro-level is mounted inside the model. This device measures the absolute angle of attack very accurately around ± 0 .

Main rotor hub rpm is measured on the shaft of the hub with a slotted opto-switch in combination with a copper disk with six equidistant holes. The opto-switch consists of an infra-red source and an integrated photo-detector.

The wake behaviour (pressure loss and frequency content) is measured by a dedicated wake rake. It is equipped with 59 total pressure and two unsteady pressure probes at a pitch of 10 mm. During the tail shake test the pressures of only 31 total pressure tubes (with a pitch of 20 mm) were recorded.

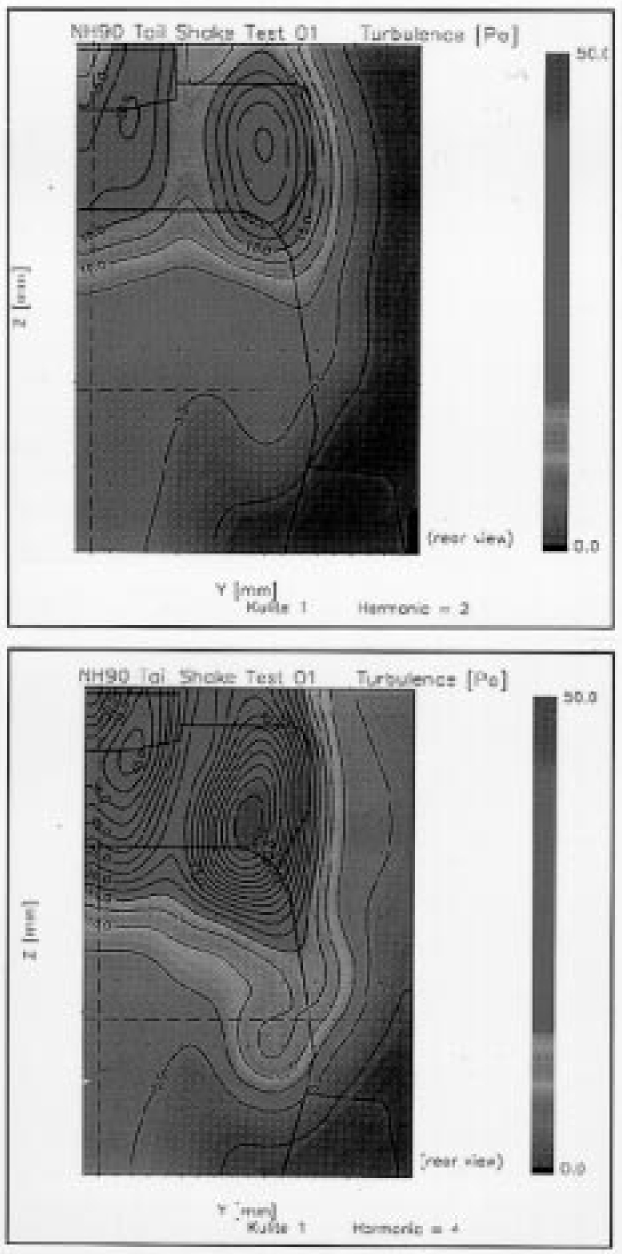


Fig.16: Sample wake turbulence level for second (top) and fourth (bottom) harmonic of the rotor rpm

To be able to traverse the wake rake continuously, optimizing testing time, the data was acquired with an electronic scanning system. The signals of the two unsteady probes were analyzed with a Fourier system to determine the occurring frequencies. Figure 16 shows a sample wake turbulence level plot.

Sting interference

The internal balance measures the forces on the model only. The aerodynamic loads on the sting itself are not measured with the internal balance. However, the sting disturbs the flow around the model by its displacement flow and the direct effect of the sting on the boundary-layer flow over the bottom of the fuselage model. This support interference has been obtained from the difference of two measurements: one with the model inverted (upside-down) and the sting of the sting support through the roof of the model, one with an additional dummy sting through the bottom of the fuselage.

The dummy sting is not attached to the model, but to the main sting support (it is a kind of extension of the main sting). The dummy sting has the same external shape as the main sting (see sketch of figure 17 below). Therefore, the forces on the sting and dummy sting are not measured by the internal balance.

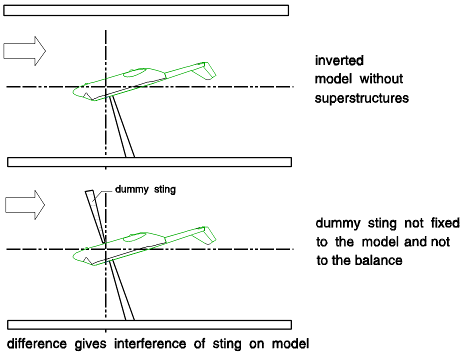


Fig.17: Sting interference measurement approach

During the actual tests the correction is subtracted from the results, measured with a corresponding configuration at the same and in the normal (upside-up) position, on-line.

Conclusions

A series of wind tunnel test campaigns with both powered and unpowered models have been performed to support the NH90 design and development activities. The wind tunnel models were equipped with numerous sensors and a wide range of test techniques was applied, dedicated to the specific goals of the test activities.

As a result of the wind tunnel experiments conducted, the NH90 helicopter external geometry was refined, tail surfaces were sized and positioned, air intake and exhaust configurations were optimized.

Table 1: NH90 wind tunnel model synthesis

Characteristic\Model	Fuselage	Tail rotor	Main rotor	Recirculation	Intake
MAIN ROTOR					
scaling law (factor)	geometry (10)		geometry/Mach/Lock	mu	geometry
no. blades	4		4	2	4
radius	stubs only		2.10 [m]		stubs only
control angle(s)	coll & cyclic (preset)		coll & cyclic (remote)	collective (remote)	coll & cyclic (preset)
load balance	(see fuselage)		6 components	-	-
no. sensors	-		50		-
power @rpm	0.3 kW @ 1200 rpm		135 kW @ 1050 rpm	25 kW @ 1275 rpm	1 kW @ 340 rpm
FUSELAGE					
configuration	complete fuselage	tail cone, vertical fin and stabilizer	fuselage without sponson	complete fuselage	fuselage without sponsons/tail
scaling law (factor)	geometry (10)	geometry (3.881)	geometry (3.881)	geometry (10)	geometry (3)
no. stabilizer positions	4	1	3	1	-
load balance	6 component balance	6 component	6 component, 1 component stabilizer balance	-	-
no. pressure holes	125	-	22 (of which 6 unsteady)	-	-
no. temperature sensors	-	-	76	75	-
TAIL ROTOR					
scaling law (factor)	geometry (10)	geometry/Mach (3.881)	-	-	-
no. blades	4	4			
radius	blade stubs only	0.41 [m]			
control angle(s)	-	collective			
load balance	(see fuselage)	2 component			
no. sensors	-	6			
power @ rpm	-	13 kW @ 3000 rpm			
ENGINE					
scaling law (factor)			geometry (3.881)	geometry (10)	geometry (3)
air intake			air suction @ 0.40 kg/sec	air suction @ 0.020 kg/sec	air suction @ 0.65 kg/sec
exhaust			exhaust gas @ 600 C	exhaust gas @ 600 C	-
no. temperature sensors			18	2*6	-
no. pressure sensors			12 five-hole probes 24 total pres. probes	-	1 five-hole probe (movable), 2 total pres. probes
MODEL SUPPORT					
type	forward vertical belly sting	vertical sting	aft vertical/skewed belly sting	vertical sting	vertical sting
angle of attack range	± 20 ± 180 ; rolled model	-	± 10 /± 30	-	± 10
sideslip range	± 180 ± 20 ; rolled model	± 180	270 /± 30	360	± 10