AERODYNAMIC DESIGN OF THE NH90 HELICOPTER STABILIZER

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Abstract

The definition of an horizontal stabilizer is constrained by a large number of criteria. Some of those are purely mission related (overall dimensions, weight, tail boom folding etc) and are external inputs as far as aerodynamicists are concerned; however, most of them are related to helicopter flight mechanics.

The high speed characteristics throughout the whole weight / CG range and the dynamic stability advocate for a large size stabilizer. On the contrary, the pitch-up phenomenon due to the interactions between the main rotor and the stabilizer in the low speed envelope asks for a reduced area, and this point is all the more important in a Navy helicopter during deck landing when the pilot workload can be drastically increased with large nose-up attitudes.

Special attention was paid to the compromise regarding horizontal stabilizer size during the NH90 helicopter definition phase.

The dynamic stability criterion, made less stringent by the choice of a Fly-by-Wire control system, as well as high speed were addressed with the Eurocopter simulation model.

This model has little predictive capability as regards low speed pitch-up behavior. Tests were thus conducted in the DNW wind tunnel with a large scale powered model while taking advantage of an existing Mach scaled rotor. These helped derive the low speed trim characteristics of the NH90 helicopter.

Both analytical and experimental studies oriented the stabilizer configuration choice for the first flight in December 1995. One year later, the predicted characteristics were confirmed by the flight tests results.

This paper covers the whole development procedure, from the theoretical calculations and wind tunnel experiments to the flight tests data validation.

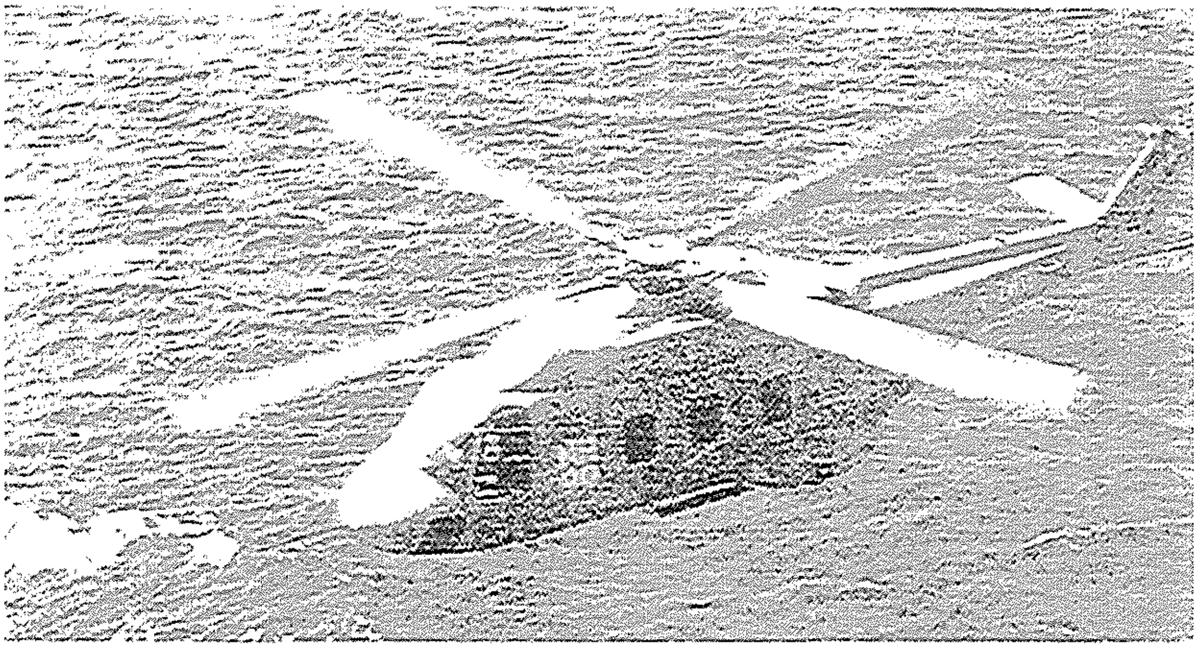

Figure 1: The NH90 helicopter

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Introduction

The Design and Development phase of the NH90 helicopter program launched at the end of 1992 involves two versions: the Tactical Transport Helicopter (TTH) and the NATO Frigate Helicopter (NFH) with as many common basic systems and subsystems as possible [0].

From a handling qualities standpoint, the design of the horizontal stabilizer for a new helicopter is a high risk. The rotorcraft community is used to see numerous stabilizer configurations flight tested in the same helicopter, and this is both time consuming and expensive

NH90 is, with Comanche, the first helicopter undergoing development that is equipped with a Fly-By-Wire (FBW) control system. It was important in this probramme not only to have the maiden flight at the end of 1995 but also to be in a position to freeze, as soon as possible, the aerodynamic design of the helicopter and have enough time left for the FBW development.

It was thus decided from the beginning to devote special care to the design of this significant element, taking into account the presence of the FBW control system which imposed adapting the design methods and criteria that were used in the past for conventional helicopters.

This paper presents the entire stabilizer development studies, from the selection of the criteria to the first flight test validations through simulation and wind tunnel activities.

Helicopter description

NH90 (Fig.1) is a single main rotor, 9-ton class helicopter designed for transport and AntiSubmarine/Anti Surface Unit Warfare missions. It will be the first in this in this class to be equipped with a FBW control system.

NH Industries (NHI) is in charge of design, development and qualification as well as subcontracts to Eurocopter, Agusta and Fokker.

A three-view drawing is presented on Figure 2 and the main geometrical characteristics are listed below.

Main rotor:

SPHERIFLEX Hub	
Blades:	4
Radius:	8.15 m
Shaft tilt:	5°
Flapping hinge offset:	3.7%

Tail rotor

SPHERIFLEX Hub	
Blades:	4
Radius:	1.6 m

Horizontal Stabilizer (first flight configuration)

Airfoil:	GAW-1 inverted
Span:	2.70 m
Chord:	0.80 m
Setting	-3° (adjustable between -10 and +5°)

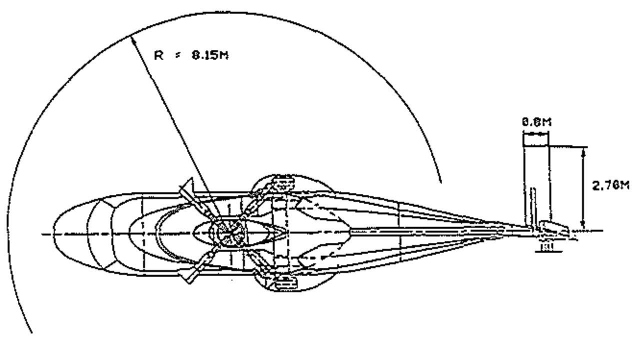
Design criteria

Design criteria were carefully selected from the customer Weapon System Development Specification (WSDS) as well as Eurocopter Super Puma experience. Most of those criteria are directly derived from flight mechanics requirements whereas technological constraints strongly restrict the designer's degrees of freedom.

Technological criteria

Tail boom folding:

Three typical positions are available for a stabilizer:



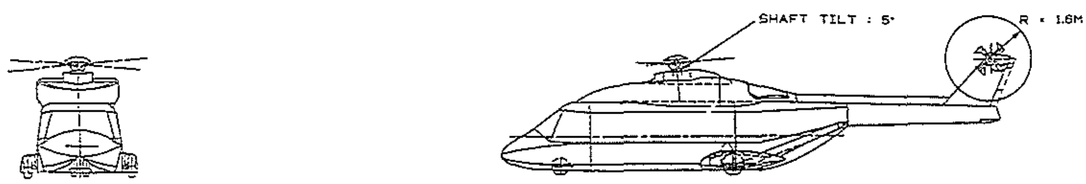


Figure 2: NH90 helicopter 3-view drawing

- low, forward
- low, aft
- top of the fin, aft

Tail boom folding as well as size limitations in the folded configuration penalized the first and the third options. This imposed folding the stabilizer itself before the tail boom. The complexity and weight of such an automatic system favored the low, aft position. However, the other options were also considered in the flight mechanics analysis.

Fixed stabilizer

A stabilator can be used to facilitate the designer's choice of an horizontal stabilizer. Reducing the drawbacks inherent to a large area, it expands the range of acceptable solutions.

The quest for simplicity and cost reduction strongly argued for a fixed stabilizer, knowing that a solution could prove easier to find regarding stability thanks to the FBW controls. This solution thus became a program requirement.

Stabilizer de-icing

The provisions for a stabilizer leading edge de-icing device required a wide installation space and a thick airfoil was consequently recommended.

Overall dimensions

Even a transport helicopter sometimes needs to be air-lifted. Transport aircraft cargo compartment size as well as ship hangar dimensions obviously limited the permissible span range.

<u>Flight Mechanics criteria</u>

Dynamic stability

This is part of a general Handling Qualities (HQ) requirement. It was decided to base Flight control System (FCS) development and HQ evaluation on a specific "tailored" version of ADS33 [2].

With a FBW control system [4] come new functions and capabilities that make this criterion less stringent. The goal is naturally to achieve Level 1 with FCS in nominal state but the most degraded FCS state i.e. a simple SAS in pitch and roll must be taken into account in aerodynamic design case, an HQ Level 3 at least is required to allow for a safe return even in the very unlikely case of a complete FCS failure.

The longitudinal mode with lower damping is the phugoid oscillation. In this slow mode, the limit between Level 2 and Level 3 tolerates instability but with a constraint of at least 5s for time to double amplitude. This value was taken as a design goal.

Low Speed pitch up

This phenomenon appears when the helicopter begins its transition from hover to forward flight. The main rotor wake then strikes the stabilizer and increases the nose up attitude. This reduces visibility especially when combined with extreme aft CG. The most critical case involves Navy helicopters during shipdeck landing. Considering the pilot experience and airframe geometrical parameters, the stabilizer contribution to pitch-up was set to 3° maximum as a design objective.

High speed trim

Several aspects are considered here. They may involve the stabilizer area and its setting at the same time. The following points then need to be considered:

- trim attitudes which influence crew comfort and airframe drag with speed performance penalties
- cyclic margin at VNE (JAR29)
- main rotor shaft loads

Crew comfort and performance considerations both require that the helicopter be flown as close as possible to the 0° attitude. Cyclic margin and shaft loads ask for reduced longitudinal rotor flapping, which means that the helicopter attitude follows the nose down rotor trend at high speed. This is one of the compromises the stabilizer designer has to challenge. The requirement for a compromise between strength and comfort/performance was considered.

Steep climb

The best rate of climb is achieved for intermediate airspeed (Vy). During this phase and because of a high speed component on the vertical axis associated with a moderate horizontal one, the airframe is subjected to high negative incidences that can generate a stabilizer stall.

A leading edge slat was adapted to avoid this in the Super Puma helicopter. This solution was felt less appropriate for the NH90 helicopter because previous experiences [1] had shown that slat performances may be degraded in the flow conditions of a low tail position.

As a consequence, this problem could only be solved by the selection of the airfoil and its setting. The high installed power in the NH90 made the problem more difficult because of the high achievable rate of climb and the increased angle of attack range that had to be considered as a result.

Seeking a compromise

All the criteria listed are not only antagonistic but each individual criterion can also involve a very different aerodynamic environment for the stabilizer. In fact, the horizontal stabilizer is faced with the whole range of incidence when the flight envelope of an helicopter is explored

In cruise conditions, the moderate angle of attack implies a linear behavior. In steep climb, stall may be encountered because of the combination between vertical speed and the main rotor downwash. During low speed pitch-up, the stabilizer struck by the main rotor wake works well beyond the stall incidence and can consequently be considered as a flat plate.

The predictive methods associated with these three different conditions do not have the same quality level. The first domain is generally well estimated, especially for the on-axis behavior. The relevant static and dynamic aspects have been the subject of many validation studies. The second point is more difficult to predict. Stall often goes hand in hand with an hysteresis effect which may interfere with dynamic stability. Associated with the turbulence of the main rotor downwash, this gives a rather non-linear behavior. This occurs by chance at a moderate translation speed (Vy) which reduces the critical character of the airframe aerodynamics. Concerning the low speed pitch-up, this last point mainly depends on the main rotor wake. Some predictive simulation models exist [5] but they are still very much research based and extra efforts will have to be made to arrive at a valid industrial tool.

Simulation models were used during NH90 development to address the first two problems but were judged to afford little help regarding the pitch-up phenomenon. Since this has a high influence on the pilot workload during shipdeck landing, a judgment had to be passed regarding NH90 behavior in this field. Specific wind tunnel tests were conducted to compare the proposed stabilizer configurations. These tests as well as simulation results were used for the final choice.

Use of simulation tools

Simulation was extensively used to compute the design criteria within the stall incidence limit. Each of those was calculated separately in the most critical weight, Center of Gravity (CG) location and speed condition.

Eurocopter Simulation Model

For Handling Qualities studies, Eurocopter has developed a generic rotorcraft simulation software called HOST (Helicopter Overall Simulation Tool). This program is operated in an off-line version for design tasks. A real time version has also been derived for the development of control laws and implemented in the SPHERE simulator of the Marignane facility.

The ability to compute flight mechanics parameters is not enough. An accurate simulation model is indeed a key point in the design of a Fly-By-Wire rotorcraft and the knowledge of the qualities and limits of the tools is of utmost interest.

The methodology the HOST model uses to estimate the stabilizer design criteria (attitudes and controls, loads, dynamic stability) has already been validated for a helicopter of similar size with the Super Puma experience. The latest step dealt with, for example, the validation of dynamic behavior using frequency domain identification [3].

In HOST, the main rotor can be represented either as a disk model or a blade element model. The disk model was considered sufficient because both models are very closely matched within the flight domain involved by the stabilizer design criteria.

The inflow is based on the Meijer-Drees equation with a first order variation of the mean induced velocity.

The airframe is divided into elements including the fuselage, horizontal stabilizer and vertical fin. Each element is associated with a full set of six aerodynamic coefficients derived from wind tunnel data. Concerning the tail surfaces, it is possible to change their setting or efficiency in order to simulate design modifications. When both angle of attack and sideslip are low (typically below 20°), measurements cover a complete coupled matrix. Out of this low angle area, measurements are limited to incidence sweeps with constant sideslip and sideslip sweeps with constant incidence.

Wind tunnel test campaigns

A series of seven wind tunnel test campaigns were run in the Low Speed wind Tunnel (LST) of the National Lucht- en Ruimtevaartlaboratorium (NLR) in the Netherlands [6].

The wind tunnel tests included in the Design and Development (D&D) phase began in December 1992 and continued until the first prototype flight. The first tests were devoted to the evaluation of the basic airframe characteristics in order to identify potential problems, to the optimization of drag and stability and to the search for the best compromise for the stabilizer. The next step helped measure a complete matrix of aerodynamic coefficients in order to support the control laws design and to perform real time simulations. The last campaign point was to measure the effect of some limited modifications on the selected stabilizer should problems arise during flight tests.

The model used was a scale 1/10 representation of the NH90 helicopter without main or tail rotor blades as shown in figure 3. The model consisted in a set of removable components: bare fuselage, engine cowlings, sponsons... This helped to evaluate the contribution of each element to aerodynamics and to change the airframe configuration easily [6].

The first wind tunnel tests quickly gave an accurate measurement of the fuselage instability.

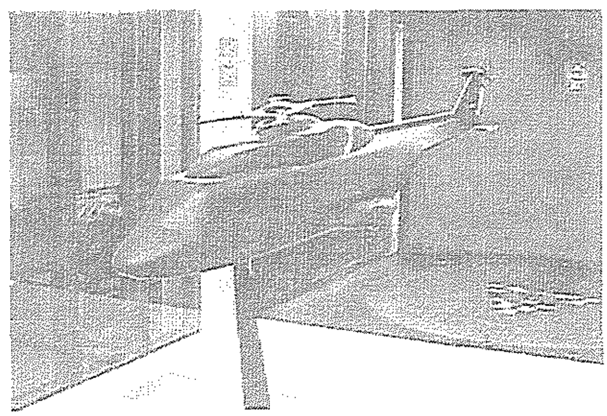


Figure 3: The 1/10 scale wind tunnel model in the LST test section (photo NLR)

This instability mainly depends on the fuselage volume and general shape, but these two parameters mainly result from mission requirements or structural design constraints and are external inputs as far as the handling qualities engineer is concerned.

It is possible to reduce drag with optimized fairings but the means to act significantly on fuselage instability are few. Moreover, drag reduction and stability improvement do not always impose the same modifications. Compromises between these two topics sometimes had to be found.

Calculation of the stabilizer aerodynamic parameters

These fuselage characteristics made it possible to begin parametric studies and obtain a specification of the stabilizer efficiency.

An horizontal stabilizer can be characterized with two parameters:

- Its efficiency that can be measured by the slope of the pitching moment coefficient as a function of the angle of attack. This effect directly counteracts the fuselage instability and prevents the airframe from divergence upon incidence perturbation (gust, pilot input etc.).
- Its setting which allows adjusting the pitch attitude and the main rotor bending moment in cruise condition for a given weight, CG etc. configuration

Selection of stabilizer efficiency and setting

Within the stall incidence limit, design criteria can be separated into two kinds :

- the first kind is relevant to structural or aerodynamic quantitative requirements such as bending moment limits. The simulation tool proved very well adapted to calculate and compare to each other these criteria and evidence a compromise in spite of their their large number and the very different associated conditions of calculation. An important conclusion of this first step was that the compromise had to be found between static criteria since the simulation results had shown that the FBW control system is able to remove the dynamic stability from critical points.
- the second kind involves crew comfort or visibility and thus can be more subjective. As regards reference point (neutral CG, mission maximum gross weight), it was easy to set an objective (a 3° nose down attitude in cruise conditions was considered acceptable), but transport helicopter generally have large CG ranges which may take the actual attitude far away from this reference. The problem was solved by calculating a gradient representative of the sensitivity of pitch attitude to the CG location. As shown in Figure 4, the attitude range of an unstable airframe will be highly influenced by the CG location changes. This would make the necessary balance between strength and performance/comfort far more difficult. Based on Eurocopter experience, the objective in this case was to have the same sensitivity as in the Super Puma helicopter.

Finally, a -1.4 efficiency coefficient (ratio to fuselage instability) coupled with a -3° setting was chosen as an objective. This definition met the comfort criterion while retaining some margin in terms of stability. This margin had to cover the methodological uncertainties as well as future evolutions in the aerodynamic configuration of the rotorcraft.

Stabilizer stall in steep climb

The stabilizer stall problem in climb was approached in the SPHERE simulator. The wind tunnel data contained a detailed and complete sweep in incidence. It was thus possible to reproduce the stabilizer stall in this flight configuration by simulation. The pilot naturally felt the phenomenon but without any significant workload increase. It was therefore decided to limit negative setting values only and to wait for the flight test results to evaluate the need for a correction.

Converging onto a stabilizer definition

Once the stabilizer objectives had been defined, they had to be transformed into geometrical characteristics. Keeping in mind the constraints inherent to a minimum area for low speed pitch up and the low aft position imposed by tail boom folding, the NLR wind tunnel tests quickly converged towards a fully asymmetrical configuration with a 2.16 m^2 area.

The first partially (1/4 - 3/4) asymmetrical configuration derived from the previous Project Definition Phase was rejected. The part located near the airframe symmetry plane had a low efficiency in terms of stability because of an interaction with the fuselage wake, although it was

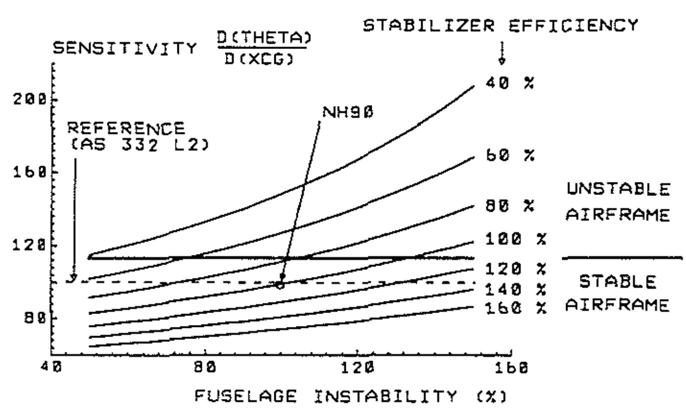


Figure 4: Influence of the airframe stability on the attitude sensitivity to CG location

very influent on the low speed pitch up.

It was naturally felt that an asymmetrical stabilizer would increase the pitch-to-roll coupling, but the dynamic aspects of this point were planned to be easily solved with the Fly-By-Wire control system. As regards the trim attitude, the simulation showed that the sensitivity of pitch attitude to sideslip would remain within acceptable limits and even be comparable to that of the rotorcraft equipped with symmetrical stabilizers.

Wind tunnel analysis of the pitch-up phenomenon

The pitch-up phenomenon due to interactions between the main rotor wake and the horizontal stabilizer can be a critical aspect of helicopter design. It can lead to a change in stabilizer size and location on the prototype with high resulting costs and delays [7] or to the selection of a movable stabilator of greater complexity [8].

Pitch-up occurs in the low speed range. With rigid rotors its main consequence is high mast bending moments, but the pitch attitude change is limited, because of the high control power available. With hinged rotor designs, it is evidenced by a significant nose-up then nose-down attitude change when speed increases. It can be all the more unpleasant in a Navy helicopter with an aft center of gravity during deck approach and landing. The natural nose-up attitude can increase to such an extent that the pilot will only have poor visual cues during this high workload maneuver. In extreme weather conditions, the first contact can also occur with the tail skid rather than the landing gear due to the relative motion of the ship and the helicopter, and this is not a comfortable situation for a pilot.

This topic had to be addressed, if only for the NFH version.

Different solutions for pitch-up investigation

As many other interactional problems, computer pitch-up simulation is not easy. Current helicopter models only have empirical means to modelize pitch-up. They are tuned with flight test data that provide a good precision to characterize the helicopter's behavior. The drawback of such an approach is its poor predictive capability.

An empirical model tuned in one helicopter could be used to estimate the pitch-up response in another with a similar stabilizer location. It was not however an easy exercise and required flight test results with an aircraft not too far from the one being developed.

Flight tests with a simulated stabilizer in the same location as in NH90 in an existing helicopter have equally been considered. This led to configuration approximations which would have made the method less accurate. Moreover, the pitch-up analysis was expected to provide data to choose the final stabilizer configuration and different sizes and locations were investigated. Installing models of all the candidates on the same structure was quite an undertaking.

The choice was made so as to handle the NH90 pitch-up through wind tunnel tests. An existing research rotor could be used the characteristics of which were very close to those of the NH90 main rotor: the number of blades, chord to radius ratio, shape and twist were similar; only the spanwise profile distribution was somewhat different but it was not judged significant as regards the problem to be addressed.

Test model and procedure

A fuselage model was built of a scale close to 1/4, imposed by the existing rotor radius. It could be equipped with stabilizers of different size in different locations. The MWM rotor test rig operated by DLR was used to drive the rotor system [6]. The research rotor hub was oversized when compared to that of the NH90 but this was regarded as having a minor effect in the low speed range covered by these tests. Figure 5 shows the model installed in the DNW test section.

The test instrumentation helped, in particular, to acquire the 6 force and moment components on the fuselage and the rotor and the stabilizer attachment bending moment.

Figure 5: The 1/4 scale model in the DNW test section (photo NLR)

The full helicopter trim cannot be applied in the wind tunnel because the control moment of the rotor is not scaled to the same value as the aerodynamic forces. The pitch attitude of the fuselage was fixed for a given test point. The collective pitch was adjusted to counterbalance the simulated helicopter weight, lateral flapping was set to zero with the lateral cyclic pitch and the drag trim of the helicopter was reached by tuning the longitudinal cyclic pitch. The forces and moments acting on the fuselage were measured. The pitch attitude was then varied to cover the trim range expected at different CG locations.

Wind tunnel test results processing

The test result was thus for one point (one stabilizer configuration, one forward speed) the variation of the different force and moment components on the fuselage, taking the main rotor interactions into account.

These data were then processed with a very simple model to consider the center of gravity location and the rotor moments and arrive to a complete helicopter trim.

Figure 6 gives an example of these final trim result comparing different stabilizer configurations of

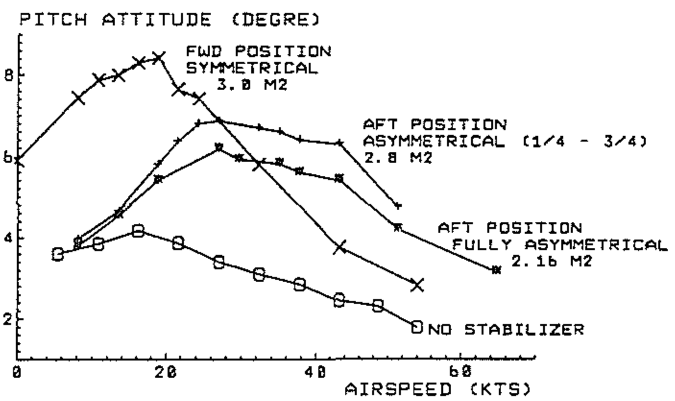


Figure 6: Wind tunnel determined pitch-up behavior of the NH90 helicopter

similar efficiency in high speed conditions: the more forward the stabilizer is, the larger it needs to be.

Pitch-up does not completely disappear when the stabilizer is totally removed but the longitudinal attitude variation is limited to approximately 0.5° attributed to the tail boom download. With a large symmetrical stabilizer in forward position, the hover pitch attitude is increased by about 3°, and the maximum deviation from the no-stabilizer curve reaches 4.5° in the 20 Kts range.

In aft position, the stabilizer is out of the rotor wake in hover. The maximum pitch attitude curve is moved towards a higher speed and the deviation from the no-stabilizer results is reduced to 3.5° for a 2.8m^2 stabilizer (located 1/4 on the left hand side and 3/4 on the right hand side of the helicopter) and even less than 3° with a 2.16 m^2 stabilizer (located on the right side of the helicopter only).

The 2.16m^2 stabilizer favored by the simulation analysis was proven to have an adequate pitch-up behavior within the 3° amplitude criterion and was selected for NH90.

Flight tests

The first prototype of the NH90 helicopter (PT1) devoted to vehicle development had its maiden flight in December 1995. It thus had to address dynamics, aerodynamics, engines integration, loads etc among other things

PT1 equipped with mechanical controls partially covers handling qualities. The development of the FBW control system will be supported by the second prototype (PT2).

Although the stabilizer was designed for a FBW helicopter, simulation studies have shown that PT1 safety was not jeopardized by its classical configuration. PT1 was naturally not designed to demonstrate Level 1 as far as handling qualities are performed; this shall be PT2's responsibility.

Flight tests program

Most of the design criteria cover static aspects. Since the Fly-By-Wire system has no influence on trim attitudes, one of PT1's first missions was to validate the stabilizer design. To do that, the dynamic stability (phugoid mode) had to be identified and compared with the simulation results to confirm that the minimum HQ level required could be met with a simple pitch/roll SAS.

In anticipation of the modifications to the configuration to solve potential problems, the horizontal stabilizer presented some modular characteristics:

- 15° adjustable setting range
- capability to reduce the span and the chord,
- capability to adapt an endplate to improve the stabilizer efficiency,
- capability to adapt a leading edge slat.

A full flight test program was set up with the flight test team with the intention to fit the recommended stabilizer in the NH90 while observing every design criterion, and then to adapt the stabilizer's design to improve the helicopter's behavior.

Some key points are presented here. The flight test results are compared to the simulation data to show how analytical tools can estimate the helicopter's behavior. Simulation data were calculated afterwards to match the exact flight conditions.

Flight tests results

Low speed pitch up

The pitch-up phenomenon occurs in the transition speed range. Since flight tests always begin with low speed, this was the first point under test.

Trim points were measured with and without the horizontal stabilizer. Measurements without stabilizer help evaluate the stabilizer's contribution to this phenomenon to estimate the potential advantages of any stabilizer modification. Flying without horizontal stabilizer is without danger in the low speed domain (at least below 50 Kts which is sufficient for demonstration purposes).

The results of the pitch up evaluation are presented in Figure 7. These results cannot be directly compared to the data derived from wind tunnel

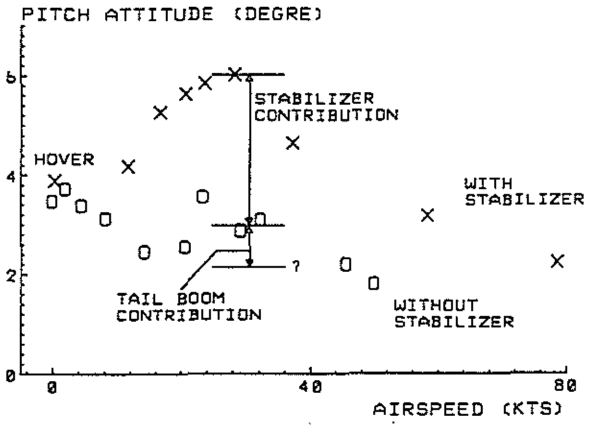


Figure 7: Low speed pitch up: flight test result

tests and presented in Figure 6 because the CG location is different in each case. However, in both cases, the flight tests confirmed the results obtained during the 1/4 scale wind tunnel assessment. The tail boom generates a slight 1° estimated peak and the stabilizer's contribution does not exceed the 3° objective at a 30 Kts speed.

Static tests were also completed with acceleration/deceleration maneuvers between hover and 60 Kts. The aggressiveness of the maneuvers was moderate. No uncommanded pitch attitude change was noticed, and a moderate pilot workload only was required.

High speed level flight

These measurements were intended to validate the computed reference configuration (neutral CG) and the influence of the CG. Comparison between flight and simulation are shown in Figure 8. These points were compared without sideslip.

The trim attitudes as well as the control positions are accurately predicted.

Only a slight difference can be detected in hover in the collective pitch plot. The hovering flight was performed in ground effect whereas the simulation was computed out of ground effect.

The fully asymmetrical stabilizer generates a rolling moment which contributes to the reduction of the lateral trim attitude. As a consequence, the NH90 helicopter achieves zero sideslip and a small bank angle in cruise condition at the same time, and this is not a common situation for single main rotor helicopters. Optimum performance and crew comfort are thus combined.

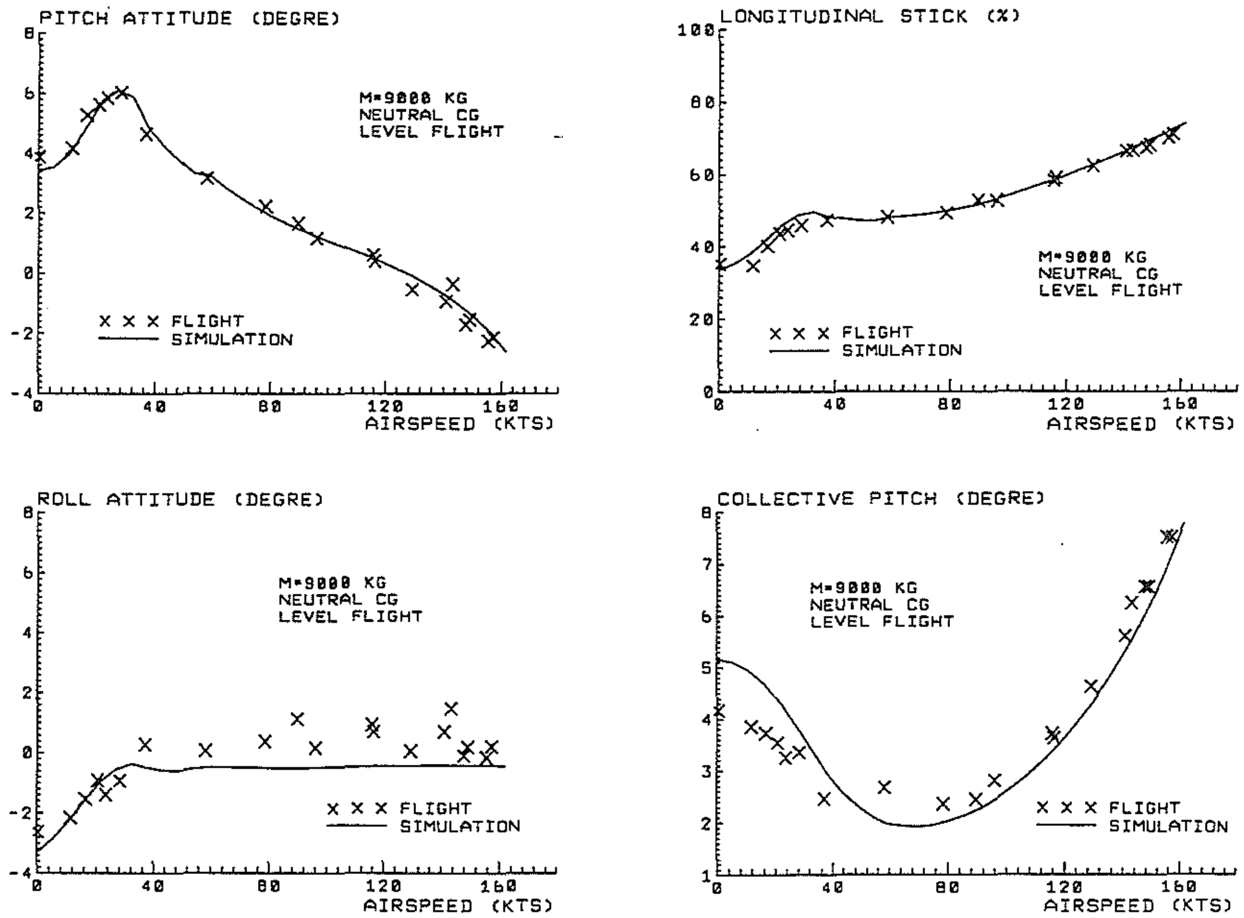


Figure 8: NH90 level flight trim versus airspeed (9000kg, neutral CG, zero sideslip)

design, the influence of sideslip on the helicopter's trim has also been measured and is presented in Figure 10, in a 120Kts level flight configuration. Sideslip effect on pitch attitude is moderate.

These results validate the ability of the model to deal with the mast moment, performance and comfort criteria.

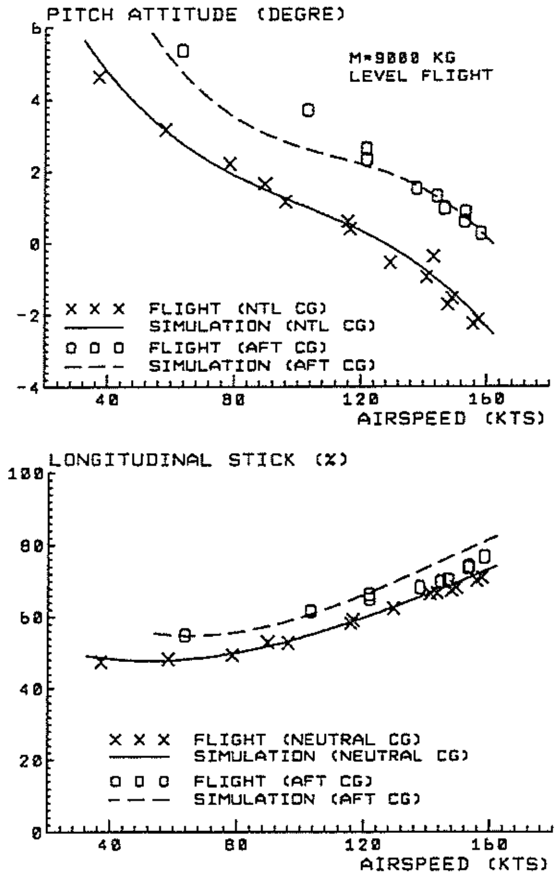


Figure 9: Prediction of the CG influence (9000kg, zero sideslip)

Figure 9 confirms the prediction regarding CG influence on both pitch attitude and stick position. It is a key parameter in the stabilizer's design. Each criterion needs to be calculated in the critical CG position and it is essential that the simulation model to be able to determine which is the most severe loading condition.

Although this is not significant in the stabilizer's

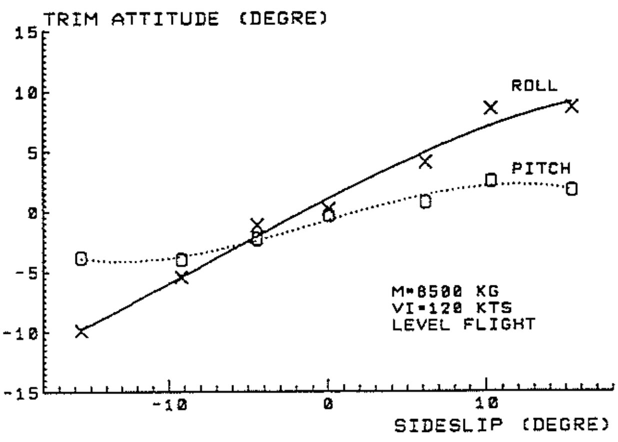


Figure 10: Sideslip influence (9500kg, neutral CG, 120Kts level flight)

Dynamic stability

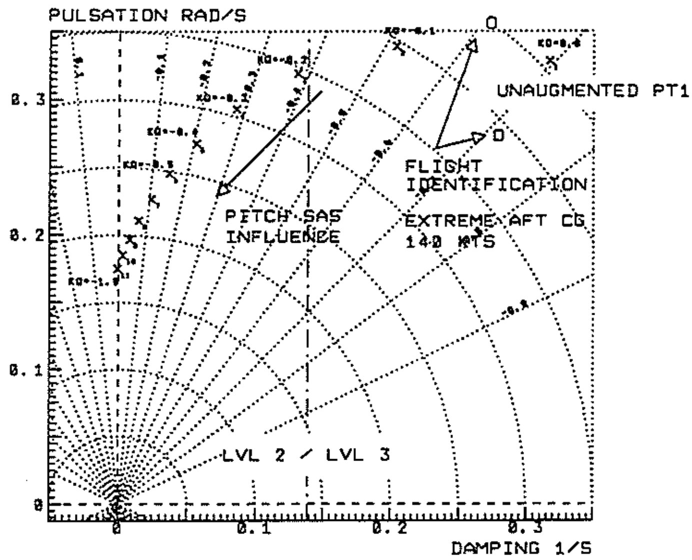


Figure 11: Prediction of the dynamic stability - adjustment of the basic SAS gain

The phugoid mode was identified. The intention was to evaluate the unaugmented stability of the helicopter in the most critical configuration (extreme aft CG, heavy weight).

The phugoid characteristics of the unaugmented helicopter measured in a 140 Kts flight condition (small circles) are plotted in the Evans locus (Figure 11). The crosses indicate the simulation results with varying SAS pitch rate gain in the same flight conditions.

Without SAS (Kq=0), the simulation resuls are not far from the flight data and the discrepancies between the two measuring points are of the same order of magnitude.

The error due to the simulation model can also be represented as an effect on the SAS gain: Figure 11 evidences that less than 0.05s/° is necessary to compensate the simulation inaccuracy.

This was confirmed by the flight evaluation undertaken for the basic SAS. The gain derived from the theoretical analyses was tested and did not have to be modified during PT1 flights

Steep climb

The rate of climb envelope was also investigated because the simulation results did not completely exclude stabilizer stall risks in steep climb. Although the NH90 helicopter can reach high vertical rates, no unpleasant behavior was reported during climb tests at Vy.

Several explanations are available here. Firstly, Vy is a moderate airspeed for which the aerodynamic forces of the airframe are less important. Secondly, the fuselage instability decreases when approaching large angles of attack.

Another possible explanation can be found in Figure 12. This flight measurement represents the non-dimensional vertical force of the stabilizer derived from its root bending moment as a function of its local incidence. This vertical airframe axis force is derived from lift and drag that can both contribute to the stabilizing moment created by a tail surface. Even once the stall angle has been exceeded, the drag effect compensates the loss of lift and maintains a stable slope. This could explain the lack of discontinuity in the vertical force curve noted in Figure 12 and the satisfactory behavior recorded in flight.

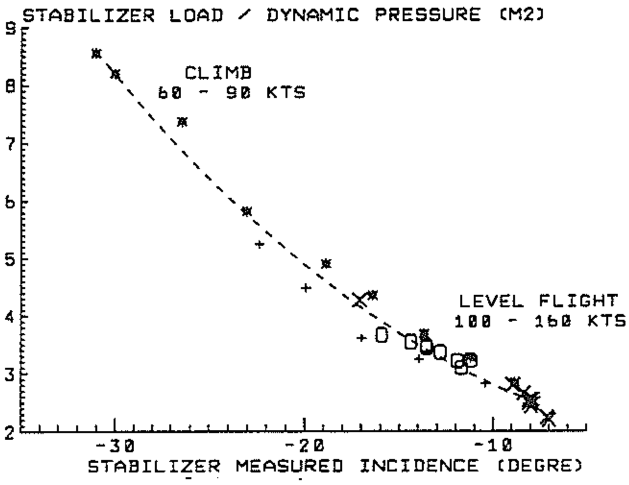


Figure 12: measurement of stabilizer load versus local incidence

Conclusion

Special efforts were devoted to the design of the horizontal stabilizer during the NH90 helicopter development.

Simulation tools were used extensively and the design criteria were carefully addressed. The pitch-up behavior that could not be definitely calculated was estimated with wind tunnel tests of a large scale powered model.

The flight tests of the prototype confirmed that the quantitative criteria were met and no problem had occurred. Comparisons between flight and simulation demonstrate that analytical tools give an accurate estimation of the helicopter longitudinal behavior.

18 months after NH90 maiden flight in december 1995, the stabilizer definition and the associated SAS gain have not been modified.

The combined operation of analytical and wind tunnel tools today allows anticipating most of the problems linked to the design of an horizontal stabilizer. We are not yet in the same position than the fixed-wing aircraft manufacturers who are used to certify a new airplane one year after its first flight. There is however no doubt that in the future helicopter stabilizers will more and more seldom be moved during flight tests as it was done in the past and this will allow for large savings in prototype flight testing.

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