The biplane stabilizer of the H160 helicopter – Design & Development

Manousos Kelaidis
Flight mechanics engineer
AIRBUS Helicopters
Marignane, France

Marc Allongue
Head of the H175 programme
AIRBUS Helicopters
Marignane, France

Samuel Leyder
H160, Head of general studies
AIRBUS Helicopters
Marignane, France

ABSTRACT

Most modern helicopters comprise at least one horizontal stabilizer, a component that provides the desired high speed trim and longitudinal stability. At low speeds however, and depending on its position, the stabilizer is pushed by the main rotor flow and produces an undesired downforce and a corresponding positive pitch attitude, called "pitch-up". This phenomenon has a negative impact on handling qualities at critical flight segments, such as the final approach. It also causes high mast moment, and performance penalties. During the H160 development it has been decided to address this issue using a novel geometry, where the stabilizer surface is split into two superimposed wings, in order to reduce the total downforce. In this paper we focus on the H160 biplane, by starting with a general discussion on stabilizers design and constraints, and by presenting past examples where the stabilizer had to be redesigned after the first flight. Furthermore, the "pitch-up" phenomenon is explained, and the biplane concept is described in detail. In the main part of this paper, preliminary CFD and wind tunnel tests that proved a significant reduction in downforce are presented, along with the final phase of the development sequence: the exploration of the flight envelope using a H155 flying test bed, and the demonstration in flight of the pitch-up reduction. In the present paper, only the aerodynamic and flight mechanics aspects of the biplane stabilizer are presented.

NOTATIONS

Symbol	Unit	Description
AFCS		Automatic Flight Control System
CFD		Computational Fluid Dynamics
CG		Center of Gravity
DDM	%	Longitudinal cyclic (% of total range)
LDP		Landing Decision Point
M	*Nm*	Pitching moment
My	*Nm*	Y-component of mast moment
OEI		One engine inoperative
q	*Pa*	Dynamic pressure
SAS		Stability Augmentation System
TPP		Tip Path Plane
WTT		Wind Tunnel Test
α	*deg*	aerodynamic incidence
$\boldsymbol{\beta_{1C}}$	*deg*	longitudinal blade flapping (1st harmonic)
θ	*deg*	pitch attitude
δθ, Δθ	*deg*	pitch attitude variation (max minus hover)

INTRODUCTION

The aerodynamic design of all modern single main rotor helicopters comprises a horizontal stabilizer whose main function is to provide adequate trim and longitudinal stability throughout the flight envelope, similarly to fixed wing aircrafts. However, at low speed, the main rotor almost vertical downwash acts on the stabilizer surface and generates an unwanted strong download, which causes the nose of the helicopter to pitch-up (Fig.1). Because of that particular phenomenon, the horizontal stabilizer design process is largely dominated by a fundamental conflict between two constraints: a large surface is required at high speed for good stability, while at low speed it is much preferable to have the smallest possible exposed surface (small pitch-up) in order to improve handling and visibility during the critical landing segment, but also lower the mast bending moment deriving from increased pitch attitude, and generally obtain better take-off performance.

The associated complexity to this problem is best illustrated by two general observations throughout the history of helicopter developments from the early 50's up to this day: firstly, one can encounter several and very heterogeneous stabilizer configurations in the global helicopter fleet, and secondly, many of the white sheet designs ended up a different stabilizer between prototype and serial model. This simply means that, (a) there is no "do-

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it-all" –optimal– recipe for the stabilizer configuration, and (b) the predictive sizing/positioning capabilities are clearly limited, mostly due to poor predictions of the aerodynamic interactions. As a result, many of the horizontal stabilizers are either marginally adequate for high speed stability, or they produce high levels of pitch-up at low speeds, or, in some cases, are placed high on the vertical stabilizer in an attempt to satisfy both constraints (high/low speed), but with significant penalties in weight, cost, and local vibratory response. Active stabilizers constitute an exception, but they are seen solely on a small number of military applications, due to the added complexity.

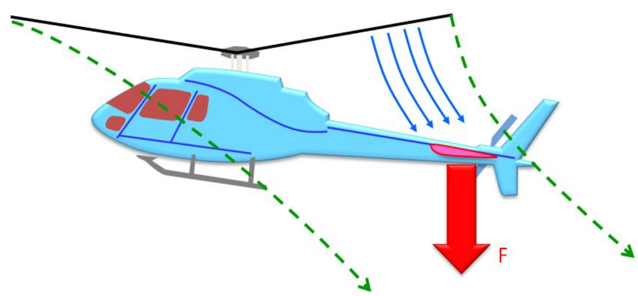

Fig.1: Schematic representation of the rotor downwash impinging on the horizontal stabilizer and producing a downforce, which, by simple equilibrium force the nose of the aircraft to pitch up.

In this paper we discuss the initial motivation behind the choice of a biplane configuration for the H160 horizontal stabilizer, the development process, and the testing sequence that allowed for validation of this component and, consequently, integration on the serial configuration standard. In the first introductory part, we present through a historical perspective some white sheet designs, along with a short analysis on why large scale modifications were required in the prototype helicopters after first flight. The large variety of adopted stabilizer geometries and mounting positions is also discussed. The complexity of the horizontal stabilizer sizing is then further explained, as we mainly focus on the low speed pitch-up problem and its significant impact on handling qualities during the critical flight segment of approach/landing and the associated dynamic loads. With these elements in mind, we move on to the description of physics of the biplane concept and its unique characteristics against pitch-up. The theoretical gains of the biplane concept are then cross-checked using CFD simulations and wind tunnel tests. The final confirmation came from flight tests, using a dedicated flight demonstrator, which showed that the low speed pitch-up reduction (in terms of pitch attitude variation from hover) was of the order of 40%, when compared to an equivalent conventional stabilizer. The flight test sequence was completed with an exploration of the whole flight envelope, and a verification that the biplane stabilizer operates no differently from any other stabilizer, in terms of static and dynamic stability, stall margins, and aerodynamic behavior during strong load factor maneuvers.

STABILIZER DESIGN CONSTRAINTS

The horizontal stabilizer size, shape, and position are subject to a multitude of design constraints, which vary with type of H/C (i.e. small or large), civil or military, with canted tail rotor or not (and associated CG envelope), SAS/AFCS capabilities, acceptable vibrations thresholds, ground crew safety considerations, maintenance and tail rotor accessibility, empty weight objectives, low speed performance, and general cost and complexity.

In terms of handling qualities and stability, the major design criteria fall into two categories: all of those that require a large surface on one side, and "pitch-up" (obviously requiring the smallest possible) on the other. Some of the sizing criteria that require a large surface are the following:

- A strong damping of the short period mode (oscillations in incidence with a period of a few seconds).
- Good static stability (airspeed variation for a given stick displacement).
- Good maneuvering stability (aft cyclic for increasing load factor during a turn).

The more the fuselage inherent instability is increased, or the CG shifts rearwards, or the dynamic pressure on the stabilizer is degraded, the more these requirements become hard to meet. Moreover, it is quite different to size a stabilizer for a max cruise speed of 160kts than 120kts, as instabilities tend to increase with airspeed. Therefore, in many cases the stabilizer required surface ends-up so large that it may pose a real problem for low speed pitch-up. If this is not predicted in an early stage of the development process, it may lead to unpleasant surprises during the first few flights of the prototype, and (often in the past) a complete redesign or relocation of the stabilizer.

HISTORICAL REVIEW

As helicopters come out of the embryonic state of the '40s, one observes a generalized implementation of horizontal stabilizers in the early '50s models, such as the famous Bell 204/5, the Kaman K-20, the Sikorsky S55, S56A and S58, Mil's Mi-1/2/6, and Sud-Aviation's Alouettes II/III. The stabilizer is usually symmetrical and traverses the tail boom in front of the tail rotor pylon. In the '60s however, as helicopter models increase in numbers and variety, so do the stabilizers in terms of position and shape. We now find also asymmetrical stabilizers far aft and high on the tail boom (opposite to the tail rotor), such as the

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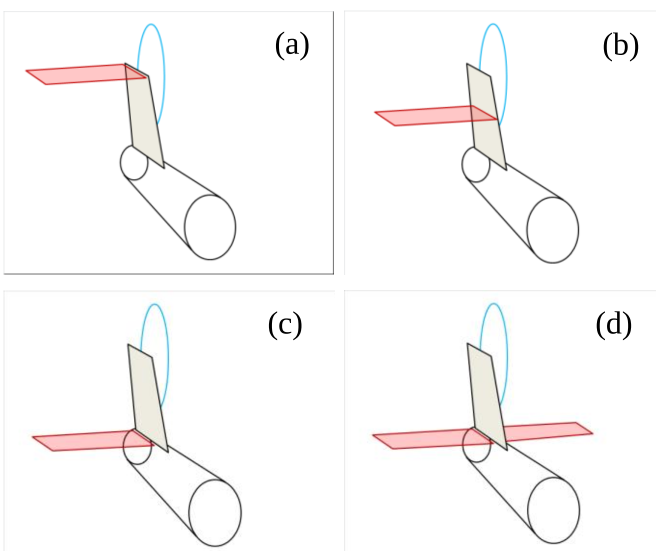
Sikorsky S56B[1] the S61 and S65, in a clear attempt to reduce pitch-up, although this position is not ideal from a structural and vibrational point of view: the stabilizer spends most of its "life" inside the rotor wake, in cruise, which is a highly turbulent environment. Sud-Aviation followed the Sikorsky path with its medium/heavy lifters, such as the SA321 and SA330, but kept the conventional position for its first Fenestron equipped SA342 Gazelle. Bell (206/209) and Mil (Mi-8/24/26) continued with the previous architecture. Hughes' Little Bird (mod.369) switched from a low aft asymmetrical stabilizer on the OH-6A, to the first widely produced model with a T-tail (OH-6B/MD500).

During the '70s and the '80s (incl. the latest designs), all possible positions and forms of stabilizers have been explored: low aft symmetrical (S76, H175, AW139/89/69, Bell 525) or asymmetrical (AW101, NH90, S92, Bell 505), high aft asymmetrical (Mi28, S80) and T-tail (Ka62), together with the more "classical" low forward position. We have also seen stabilizers with large end-plates (i.e. AS365, BK117) to improve efficiency and yaw stability, with fixed slats (AS332/H225) to delay stall in climb, and even all-moving stabilators as the ultimate means to mitigate pitch-up (S70 & AH64). This variety is a clear indicator that the compromise between pitch-up and large surface for stability does not have an absolute optimum. High placed stabilizers will add weight (structural reinforcements) and possibly vibrations but with little pitch-up, while low placed stabilizers will produce significant pitch-up but with a simpler structural integration. A schematic representation of the possible stabilizer positions can be found in Fig.2 below:



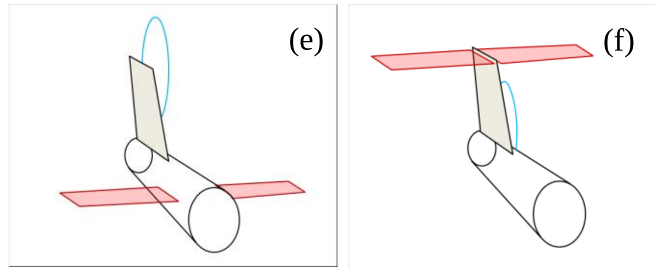


Fig.2: (a) High aft asymmetrical (also "**Γ-tail**"), (b) Mid aft asymmetrical, (c) Low aft asymmetrical (also "**L-tail**"), (d) low aft symmetrical, (e) forward symmetrical, (f) high aft symmetrical (also "**T-tail**").

Another strong indicator of the difficulty of the stabilizer choice of positioning is the numerous examples of "clean sheet" designs where major redesign was required after the first few flights of the prototypes. One can take the three-engine evolution of the S65 (S80 model), where a low symmetrical stabilizer was initially tested[2], only to end-up with a larger high aft asymmetrical on the serial product because of excessive pitch-up [Ref.1]. Similar was the case of the S70 Blackhawk, which started with a fixed symmetrical low aft stabilizer, and finished development with an all-moving stabilator in the same position. The added complexity, cost, and weight of the stabilator have been considered acceptable in order to eliminate pitch-up issues [Ref.1]. Another "victim" of pitch-up was the EH101 (now AW101), where, once more, the low aft symmetrical stabilizer has been abandoned for an asymmetrical one, leading to a clear reduction of pitch-up [Ref.2]. Smaller helicopters are no exception to mishaps in the design, with the AS350 as an example, where the initial aft asymmetrical stabilizer (opposite to the tail rotor) was replaced by a forward symmetrical. Inversely to S80, during the S92 development one sees the stabilizer moving from a high aft position, to a low one (still asymmetrical) on the opposite side, which should probably generate more pitch-up. Apparently, vibrations and weight brakedown (along with associated aft CG) may have led to this decision.

It goes without saying that design modifications of such amplitude generate significant delays and additional costs. Other examples of extensive work (and re-work) around the stabilizer include the Eurocopter Tiger (EC665) with low aft and low forward positions (Fig.3) tested in flight [Ref.5], and both the Airbus Helicopters H175 and H145T2, where stabilizer surface reduction was deemed necessary in order to reduce pitch-up to the desired levels. On the other hand, one should also mention new helicopter models, where extensive preparatory studies using various tools, such as fully motorized large scale mock-ups, led to good results in the early flight testing phase. This was the documented case of the S76 Spirit [Ref. 6] and the NH-90 [Ref.7]. Finally,

[1] contrary to "A" model's low forward position

[2] Contrary to the high aft asymmetrical stabilizer of the S65

and most recently, one observes an interesting evolution between the 6-7t AW139, and its scaled-up "cousin", the 7-8t AW189, where the 4m+ wide stabilizer of the AW139 sees a large chuck of its inner surface removed on the AW189, most probably as a means to reduce pitch-up.

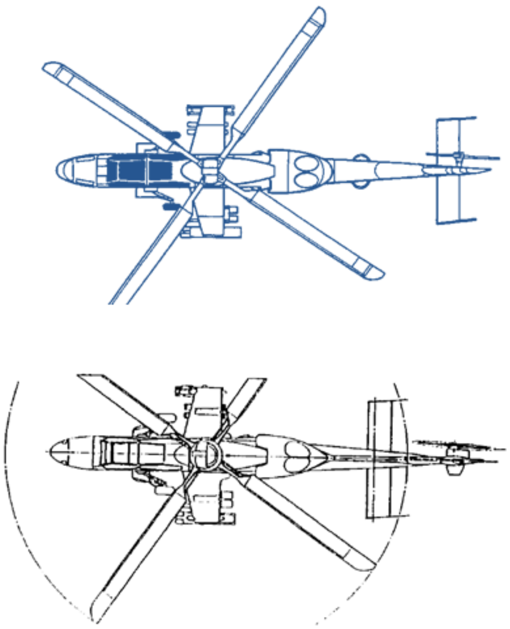


Fig.3: (upper) Final stabilizer configuration of the EC665 Tiger, (lower) forward position also tested in flight.

LOW SPEED PITCH-UP

From the handling qualities point of view, the pitch-up effect is a longitudinal instability of the main flight mechanics parameters: pitch attitude, longitudinal flapping (and corresponding TPP[3]), and cyclic displacement. Starting from hover, as airspeed slowly increases[4] the main rotor flow will skew backwards and eventually arrive at the stabilizer location (sooner or later, depending on its position). Local almost vertical velocity vectors of more than 30m/s or 40m/s create a strong download, which, in turn, pushes the nose upwards. The pilot has to counter this tendency with more forward cyclic until the downwash of the rotor is swept even further away (higher), leaving the empennage and reducing the download. Then, in a counter-intuitive manner, if the pilot aims to continue at the same rate of acceleration, he/she has to pull on the cyclic, as the helicopter goes on a nose-down attitude. Once the pitch-up instability is surpassed (usually around 30-50kts for low position) the H/C returns to normal operation, where pushing the cyclic means acceleration and vice-versa.

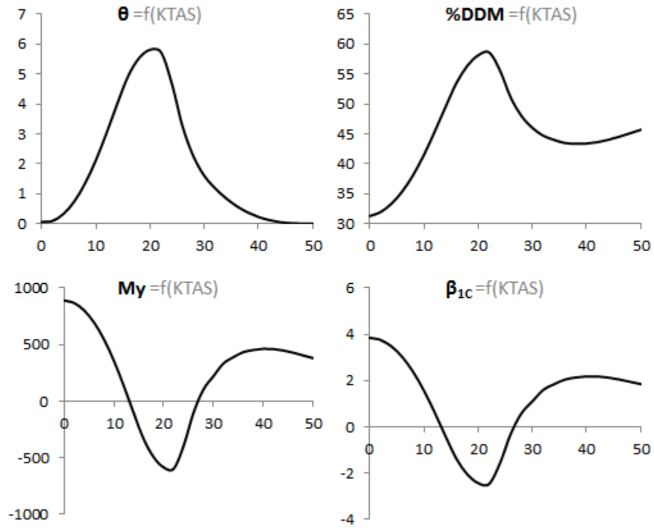


Fig.4: Main flight mechanics parameters in the low-speed pitch-up zone. Pitch and flapping angles in deg, and My moment in daNm.

In this example (Fig.4) a 6° pitch-up (= max minus hover attitude) is directly reflected on blade flapping, corresponding mast moment, and cyclic displacement. One can easily deduce that instability of this amplitude will render the deceleration management during approach-landing a difficult task. This is the most critical aspect of a strong pitch-up: increased pilot workload and associated safety margins, especially in case of engine failure, confined areas, and spot landings (i.e. oil platforms or frigate helipads). When in the final approach segment, the H/C crosses the LDP window at 30kts, -500fpm, around 100m from the landing spot, and with less than 10sec remaining for touch-down. Besides the vertical axis management (stopping the rate of descent), the pilot must simultaneously manage the deceleration through the pitch attitude. If the deceleration is too strong the H/C will consume all of its airspeed before arriving above the landing spot, which means lower power margins (especially in OEI conditions). On the contrary, if the deceleration is light, the pilot will have to add a lot of pitch attitude to stop the H/C just a few feet above the ground with the imminent danger of a tail strike. It is therefore understandable that any perturbation on deceleration management, coming from the pitch-up instability, can make the landing manoeuver very difficult to accomplish safely. Moreover, the pitch-up worsens the visibility by adding pitch-attitude and eventually hiding the landing spot behind the instruments panel. In the above mentioned example (now with +5° hover attitude, and +6° pitch-up) one has to add 12°-15° coming from the deceleration (4-5 kts/sec in some cases). The H/C will reach momentarily attitudes of 20°-25°, causing the pilot to lose sight of his/her target point and with that a great part of the ability to correctly manage the landing trajectory. In order to conceive more broadly the graveness of the situation described above, one has to add bad weather conditions, poor visibility, crew fatigue, various obstacles, wind gusts, and the additional stress deriving from an OEI condition.

[3] this is the sum of pitch attitude, longitudinal flapping, and mast inclination

[4] this example describes a light acceleration

From a structural point of view, pitch-up can be harmful for H/C with aft CG. In our example, a flat pitch attitude in hover becomes +6° at 20kts, and the blade flapping goes from +4° to -2°. If a helicopter has +5° hover attitude and the same pitch-up (+6°), it will end with +11° at 20kts and -7° of blade flapping. This will create great amounts of mast bending moment and of all the fatigue loads related to that. It is reminded here that 20kts airspeed is not encountered only in transition but also in stabilized cases, such as hover with head wind and low speed translations (i.e. hoist operation or following a naval vessel). Another less known negative effect of pitch-up is the stabilizer's download itself which degrades low speed performance and, by consequence, maximum useful load on take-off for a given set of environmental conditions and obstacles.

Given these elements, and the accumulated knowledge of previous developments, it has been decided for the H160 that a solution had to be found in order to reduce pitch-up to a minimum: first of all having safety in mind, secondly for lower mast loads, and thirdly for better performance.

THE BIPLANE STABILIZER DEVELOPMENT

The concept of a biplane stabilizer

The main idea behind the biplane is to split chord-wise the main wing of a conventional stabilizer, into to two "sub-wings", each having roughly half of the initial chord, retain the same span, and place one sub-wing on top of the other (Fig.5) at an appropriate distance that allows: (a) good stabilizing efficiency at high speeds, and (b) reduction of pitch-up at low speeds, by having the lower sub-wing operating inside the wake of the upper one, thus producing much less download. 3

Fig.5: General view of a biplane stabilizer

Additionally, in order to account for the rotor wake skew angle at the critical pitch-up speed (where max pitch-up occurs, i.e. 20° at 15kts), a horizontal offset is chosen between the two sub-wings (Fig.6). This allows for the lower sub-wing to be better "masked" behind the upper one. In this way, the two parts operate almost independently at small angles of attack (cruise), while at low speeds pitch-up is generated almost solely by the upper sub-wing, which represents half of the total stabilizer surface. The pitch-up is then, theoretically, reduced by 50%. The general arrangement is completed with canted end-plates that link the two sub-wings for better structural stiffness. The junction of the upper sub-wing and the end-plates is rounded. This produces a spanwise acceleration of the flow near the tip, in pitch-up conditions, and helps to reduce the download of this part of the stabilizer.

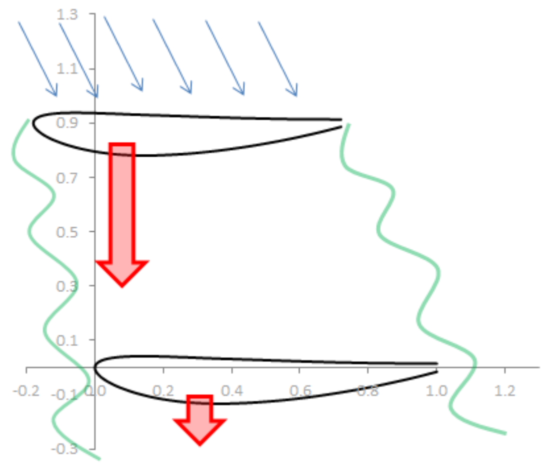


Fig.6: In pitch-up conditions, when the rotor flow attacks the stabilizer from above, the upper sub-wing generates a nominal download, while the lower one is "hidden" inside the wake of the upper one, thus producing very little download.

Geometry optimization and wind tunnel testing

The aerodynamic performance of a horizontal stabilizer is defined by two key parameters: stabilizing efficiency at high speeds, and pitch-up generation at low speeds. The stabilizing efficiency is measured in the small incidence range (say ±10°) as the dCm/dα slope (or simply, Cmα), where Cm is the reduced pitching moment (Cm=M/q) generated by the stabilizer and applied to the CG. The pitch-up moment is the value of Cm of large negative incidences (around -50° to -80°), which are typical at low speeds under the main rotor flow influence. In Fig.7 the two zones of interest are shown for a conventional stabilizer.

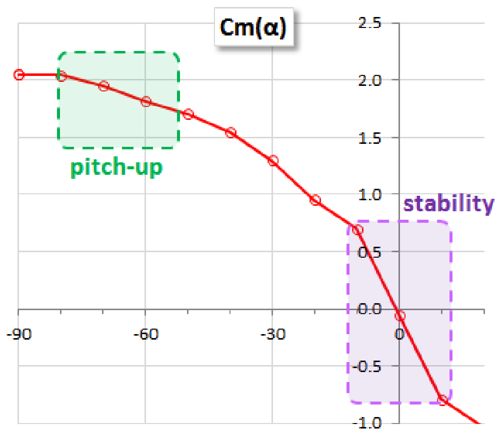


Fig.7: Reduced pitching moment evolution of a conventional stabilizer with local incidence.

The optimum stabilizer would have a strong Cmα slope (the required value to comply with trim/stability criteria), and a minimal Cm at large negative incidences for small pitch-up.

Once the biplane concept feasibility was validated, the design phase began through a fast optimization of the main geometry parameters of an isolated stabilizer[5]: (1) ratio of upper to lower chord, (2) horizontal offset, (3) airfoils differential setting, and most of all (4) spacing between the two sub-wings. In the example below (Fig.8) a schematic representation of efficiency and pitch-up is shown, as a function of reduced vertical spacing (h/c, c being the average chord).

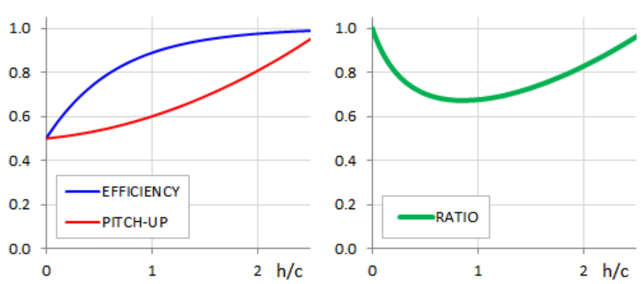


Fig.8: Example of evolution of efficiency and associated pitch-up with vertical spacing of the two sub-wings (left), and ratio between the two (right). The optimum spacing is defined by the minimum value for the ratio.

Assuming that for infinite spacing, the efficiency is equal to 1 (regardless of units), and pitch-up also equal to 1, it is obvious that both values are reduced to 0.5 when the two sub-wings merge into one half-chord wing. The ratio between pitch-up value and efficiency provides a preliminary objective function for the spacing optimization. In this example, given the evolutions of efficiency and pitch-up, the ratio would lead to a spacing of about 1 chord. The optimization process also included all the above mentioned four parameters, aiming at a (theoretical) 50% reduction of pitch-up.

After having converged to the optimum set of geometrical parameters, several homothetic stabilizers have been tested in wind tunnel, mounted on a H160 mock-up (1/9 scale). Variations were made in span and aspect ratio in order to match the required efficiency value. In parallel, conventional (monoplane) stabilizers were mounted at the same position and measured. The objective was to determine how much pitch-up reduction was achieved with a biplane, compared to a monoplane with the same efficiency.

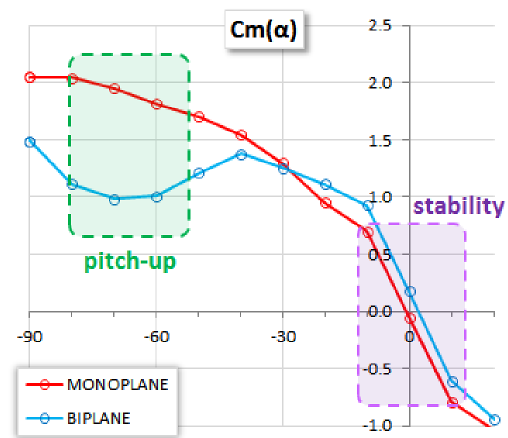


Fig.9: Comparison of Cm polar curves (WTT) between a monoplane (conventional) and a biplane stabilizer, with the same efficiency (dCm/dα slope at small angles). The biplane significantly reduces the pitching moment in the large negative incidence range.

In order to achieve the same efficiency as the baseline monoplane stabilizer, it has been found that 30% more wetted surface (end-plates excluded) was needed for the biplane (with very similar span). However, as pitch-up is almost solely created by the upper sub-wing of the biplane the overall reduction of pitching moment at large negative incidences was of the order of 40% (Fig.9). This percentage was considered satisfactory and the biplane geometry was validated. The next step was to verify also in real flight conditions that the gains were similar, and that the biplane stabilizer shows a normal aerodynamic behavior in the whole flight envelope.

Flight testing

The H155 (Fig.10) has been chosen as a flying test bed, in order to evaluate the biplane aerodynamics and loads in real conditions, because of its similar size (10-12pax cabin), weight (5 tons), and configuration (smooth junction with tail boom, and Fenestron). The conventional monoplane with the large end-plates has been replaced by a heavily instrumented biplane.

[5] meaning, not mounted behind a fuselage, thus not taking into account the fuselage wake effect, or the part of the stabilizer inside the tail boom

Fig.10: The H155 model that served as a flying test bed for the biplane stabilizer, among other innovations destined for the H160.

The main objectives of the flight test campaign were the following:

- Exploration of the full flight envelope with focus on fast climbs/descents, hard turns and pull-ups (stabilizer in stall or post-stall conditions).
- Evaluation of longitudinal stability without AFCS or SAS in the loop.
- Cruise trim tuning with different low sub-wing settings, and/or asymmetrical Gurney tabs.
- Low speed-pitch reduction (compared to baseline monoplane)
- Performance gains at low speeds (stabilizer download) converted to main rotor required power reduction.
- Air-loads distribution, vibratory environment, and skin temperature (hot gases coming from engine nozzles).
- Tail strike assessment during OEI landings with a hard flare.

The instrumentation included multiple strain gages, accelerometers, and thermo-papers. Several weathercocks were also installed in four positions (Fig.11) in order to measure local incidence and sideslip deviation, due to deflection caused by the main rotor wake and the fuselage volume. This instrumentation allowed for a faster convergence regarding the setting angle of the stabilizer for correct trim, a measurement of the average temperature on the skin (important for composite structures), and an easy calculation of load paths and compare with finite elements models.

Fig.11: Installation of weathercocks on the outer part of the biplane stabilizer of the H155 flying test bed.

Lastly, specialized instrumentation has been used in order to monitor ground clearance of the lower part of the Fenestron shroud during OEI landings (hard flare) simulation. Previous experience has shown that stabilizer download and aft CG contribute negatively on pitch attitude at touch down, and consequently raise the probability of a tail strike. The particular geometry of the biplane had to be checked for that aspect as well. Two backward looking cameras (Fig.12) and a miniature laser range-finder were employed for this purpose. It has been found that the biplane does not deteriorate ground clearance during OEI landings.

Fig.12: Frame taken from video recording of the left camera that monitors ground clearance around the Fenestron area. The rear guard absorbs the last part of the impact and the Fenestron shroud does not come in contact with the ground.

The analysis of the flight data and the crew feedback did not reveal any objectionable aerodynamic behavior whatsoever for the biplane stabilizer: in the whole flight domain (Vne, altitude, load factors, low speeds) the biplane geometry was completely transparent for the crew. It was as if a conventional stabilizer was mounted. The helicopter was stable from all the handling qualities aspects. Regarding cruise trim, the stabilizer has been responsive to setting angle variations and Gurney tab effects. This experience has been useful for the biplane setting consolidation on the H160 PT1. However, the most important outcome about the biplane stabilizer flight tests campaign was the low speed pitch-up reduction. On days with "zero wind conditions" (below 2kts) stabilized points have been performed from 0 to 40kts with both the baseline monoplane and biplane stabilizer, in and out of ground effect. Despite the fact that the biplane was somehow oversized for the H155, the 40% reduction in pitch-up has been confirmed (Fig.13).

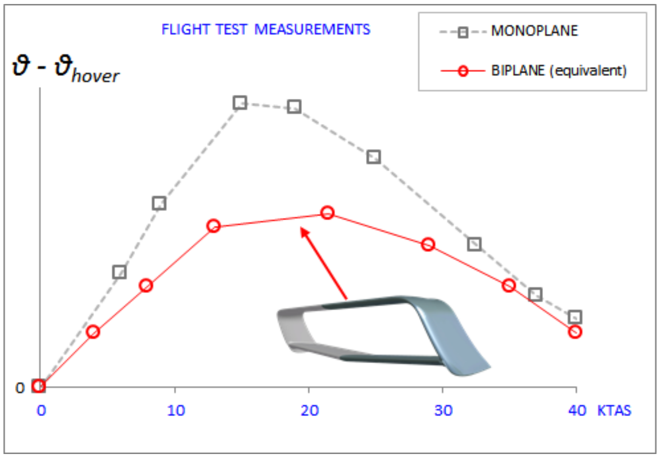


Fig.13: Evolution of pitch attitude (minus that of hover) with airspeed for the monoplane (grey), and biplane (red) stabilizers. Between 15kts and 20kts (max. pitch-up) a 40% reduction was achieved.

Moreover, the qualitative assessment of the crew included mentions of a much more "linear" behavior of the helicopter during the deceleration management of the final approach phase. The beneficial pitch-up reduction has also been reflected on the cyclic stick evolution with speed, the mast bending moment, and the power consumption. At that point it has been decided that the biplane configuration would be the reference stabilizer. One last study before the 1st flight of the H160, a complete helicopter CFD simulation with free-flight trim and aerodynamic load coupling on rotor blades and fuselage has been carried out in order to verify that the overall pitch attitude (hover + pitch-up) would not exceed the threshold of +7° on the H160 (Fig.14).

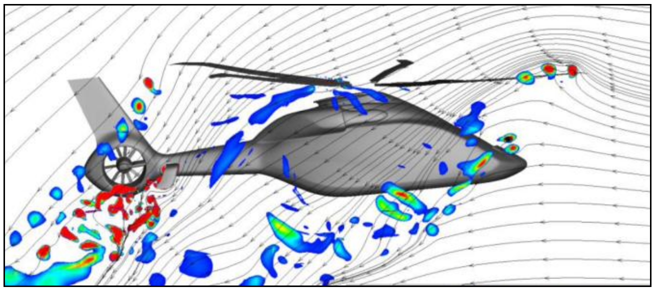


Fig.14: Complete helicopter CFD simulation at low forward speed. Streamlines and λ2 criterion for vortices visualization in a plane perpendicular to the spanwise direction of the stabilizer 1.2m to the right of the symmetry plane.

The computation showed that the expected pitch attitude would be of the order of 5°-6° for a given set of weight and CG position. This was later on confirmed by the first flights of the H160 prototype (Fig.15), and ultimately validated the choice of the biplane stabilizer.

Fig.15: The biplane stabilizer on the H160 prototype during flight testing.

CONCLUSIONS

The low speed pitch-up phenomenon has been the main cause of major design modifications of several new helicopter developments in the past, often after the 1st flight of the prototype. The biplane stabilizer has been developed for the H160 as an answer to this problem, having in mind to reduce pilot workload during the critical final approach segment, and thus increasing safety margins. Other benefits include performance improvement and loads reduction. The reduction of download comes from the simple fact that the lower sub-wing is "hidden" behind the upper one, when the rotor flow attacks from above. Thus, pitch-up is only generated by the upper sub-wing. The biplane geometry has been initially optimized through CFD calculations, then measured in WTT, and finally taken to flight using a H155 flying test bed. Predictions of 40% reduction of pitch-up, compared to an equivalent monoplane, have been confirmed during the flight tests campaign. Additionally the biplane stabilizer has presented the same aerodynamic behavior as a conventional one throughout the flight envelope. After the completion of this process it has been decided that the biplane shall be the reference stabilizer for the H160 PT1. Early flight tests on this helicopter demonstrated small pitch-up values and an excellent stabilizing performance. Generally, the biplane architecture offers numerous advantages without significantly increasing the complexity of the component. This opens a new perspective in the stabilizers development that could lead to even more efficient designs in the future.

ACKNOWLEDGMENTS

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PATENTS

The biplane stabilizer is protected by the following international patents:

- FR2962972 / EP2409917 / US2012/0018570 (inventors: M.Allongue, S.Leyder, S.Borie)
- EP2878536 / KR20150062948 / US2015307182 (inventors: S.Mores, A.D'Alascio, U.Kiesewetter, S.Probst, C.Wehle, M.Bebesel)

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[2] Mark Hazzard, "The EH101 development programme", GKN Westland Helicopters.

[3] Flight International, 18-24 April 2000, page 17.

[4] Website: sikorskyarchives.com

[5] A. Cassier, R. Weneckers, J-M Pouradier, "Aerodynamic development of the Tiger helicopter", AHS 50th annual forum, Washington DC, 1994

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