DEVELOPMENT OF ACTIVE HORIZONTAL STABILIZER

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Abstract

In frame of the European research project ‘JTI Clean Sky – Green Rotorcraft’, an active horizontal stabilizer for helicopter is being investigated. Based on the specifications provided by Eurocopter and AgustaWestland [1], the research focuses on a fully movable stabilizer. The research activities constitute of aerodynamic studies and the development of a remotely controlled wind tunnel model to validate the studies. The latter will be integrated with the existing GOAHEAD [2] model for wind tunnel testing. Currently, the aerodynamic studies have been completed by ONERA and pre-design studies for the control and actuation mechanism have been performed by LMS with support PZL-Swidnik (now AgustaWestland). NLR will finalize the design and manufacture the remotely controlled horizontal stabiliser for the wind tunnel model by the end of 2012. The wind tunnel tests themselves are planned in 2014.

1. Introduction

This paper reports on the investigations about an active horizontal stabilizer for a helicopter wind tunnel model. The research is conducted within the European research project ‘JTI Clean Sky – Green Rotorcraft ITD (GRC)’. This project aims at investigating innovative technologies and methods that can potentially reduce fuel consumption and the noise footprint while maintaining or improving the performance of a helicopter. One objective of this project is to investigate systems that can reduce the drag of a helicopter. One of the systems that are investigated is an active horizontal stabilizer for a helicopter belonging to the twin engine heavy weight class. The down-force of such a stabilizer movable in pitch can be changed during flight. This additional degree of freedom shall allow trimming the helicopter in cruise flight at attitude angles, where the helicopter features lower drag values, consequently lower required power and fuel consumption. Another benefit of such a movable horizontal stabiliser is the possibility of alleviating the pitch-up phenomenon in conversion flight from hover to cruise flight. A task was defined in the sub-project GRC2 to design, dimension, manufacture and test in the wind tunnel an active horizontal stabilizers for the wind tunnel (WT) model already used in the former EU funded project GOAHEAD [2]. Beside the prediction of the benefits of active stabilizer, the aim is also to investigate the mechanical design and actuation of an active horizontal stabilizer and consequently estimate the weight and power-consumption penalties of such a system.

The specifications were drawn up by the project leaders, Eurocopter and AgustaWestland [1]. This specified that the wind tunnel model needed to be a fully movable horizontal stabilizer for which the inclination can be adapted during the testing with a remote control system. Therefore the development of the remote control system for the wind tunnel model will also support the investigation actuation system. Furthermore, it was specified that the movable stabilizer model needed to be integrated in the tailboom of the existing GOAHEAD WT model for testing.

This task is a collaboration between several partners and is divided in several sub-tasks. First, ONERA predicted the aerodynamic load on the stabilizer by means of CFD (computational Fluid Dynamics). Second, LMS performed pre-design studies for the actuation system and mechanism, and was the overall task leader. The third sub-task consisted in the final design the actuation system and stabilizer together with its manufacturing. This is under NLR responsibility with the support of PZL-Swidnik. PZL-Swidnik updated the CAD drawing of the existing GOAHEAD WT model and performed strengths calculations and flutter analysis for the existing model. If required, based on these calculations, PZL will propose modifications for the tail boom, stabilizer and interface. In the final subtask, laboratory tests will be performed to validate the model before wind tunnel testing. The wind tunnel tests will be performed as part of a test campaign at the end of the research project together with other drag reduction systems that are investigated. This paper will focus on the tasks, which have been mostly completed, namely the aerodynamic studies and pre-design studies of the actuation mechanism.

2. Aerodynamic studies

Aerodynamic load calculations have been performed by ONERA using the *elsA* CFD software with an advanced Chimera meshing strategy. The wind tunnel model will be equipped with a moveable horizontal stabilizer whose angular displacement will vary from -10º to +10º. Three fuselage angles of attack have been considered (-10º, -5º, +10º) for steady-state RANS simulations without rotor and the stabilizer pitch angle set from -10º to +10º by 5º step. Finally several fully turbulent simulations have been done with the k-ω turbulence model at 75m/s, corresponding to stabilizer effective angle of attack varying from -20º to +20º.

An advanced Chimera meshing strategy [3] has been used to simulate the different configurations with the same near body grids. A near body fuselage grid containing about 7.5 million points generated by ONERA in another GRC2 Task has been used. In addition, a specific Chimera stabilizer grid allowing -10º +10º rotations with a 7mm gap has been realized to complete the near body grid (Figure 1). Then a Cartesian background grid containing about 7 million points has been automatically generated and refined around the stabilizer (Figure 2).

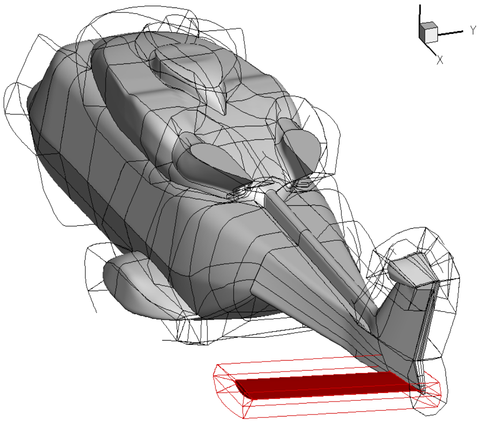


Figure 1: Near body fuselage and stabilizer grid

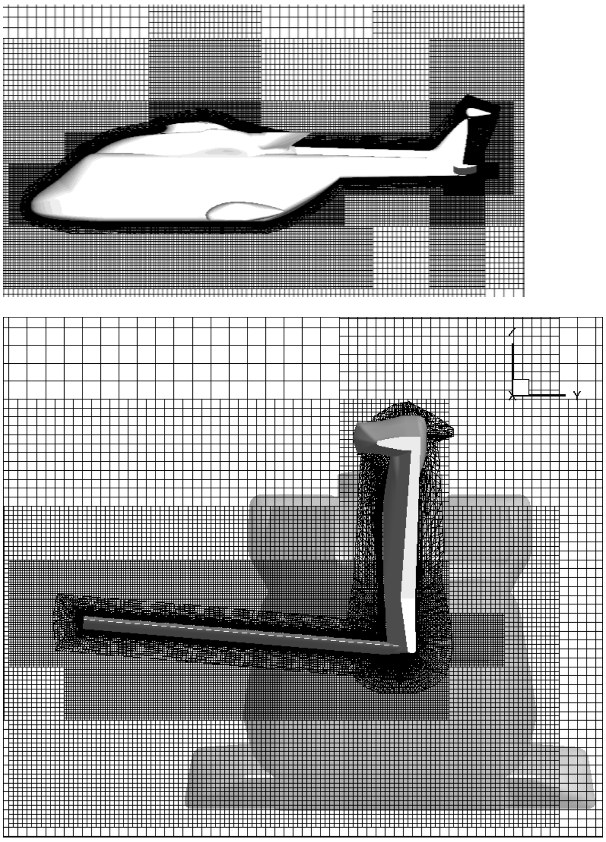


Figure 2: Cartesian background grid refined around the stabilizer

Those computations allow plotting the stabilizer vertical force and the pitching moment versus the stabilizer effective angle of attack varying from -20º to +20º (Figure 3 and 4).

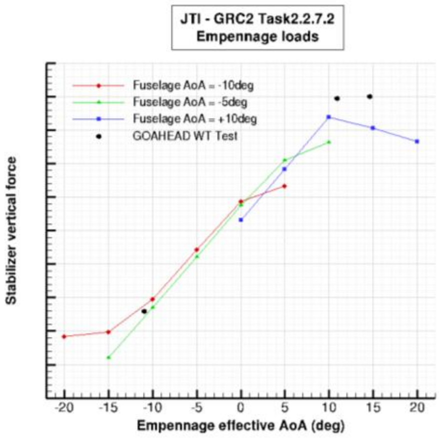


Figure 3: Stabilizer vertical force polar

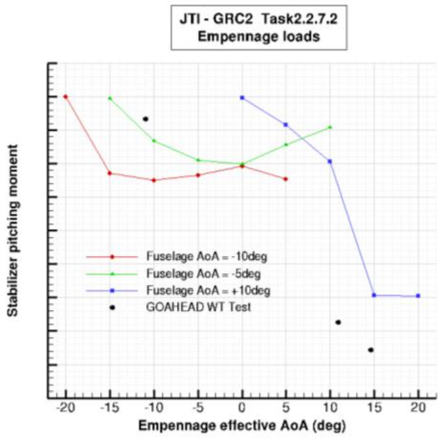


Figure 4: Stabilizer pitching moment polar

Even if the GOAHEAD wind tunnel test has been performed with a fixed horizontal stabilizer, the stabilizer loads are comparable since its effective angle of attack is the same. In addition, one can notice that the stabilizer is stalled for an effective angle of attack greater than 10º and lower than -15º.

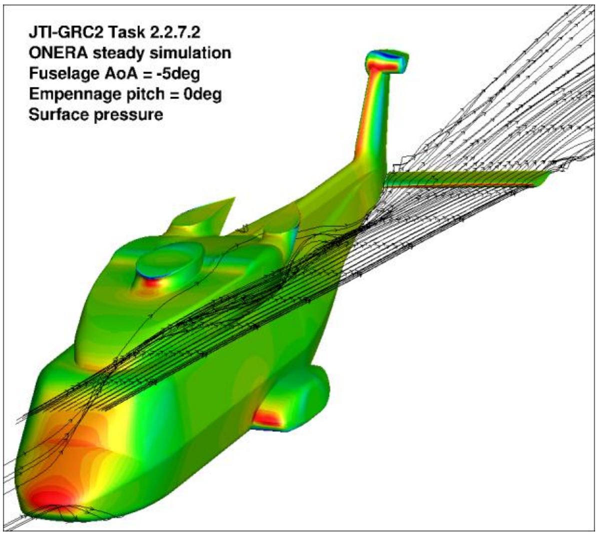


Figure 5: Surface pressure and stream traces for the nominal angle of attack (-5º)

For the nominal stabilizer effective angle of attack of -5º, there is no separation on the stabilizer in addition to weak interactions with the engine fairing and the exhaust nozzle for the inner part of the stabilizer (Figure 5). On the contrary, for the minimum stabilizer effective angle of attack (-20º), a large separation appears at mid-span due to important interactions with the engine fairing and the exhaust nozzle (Figure 6).

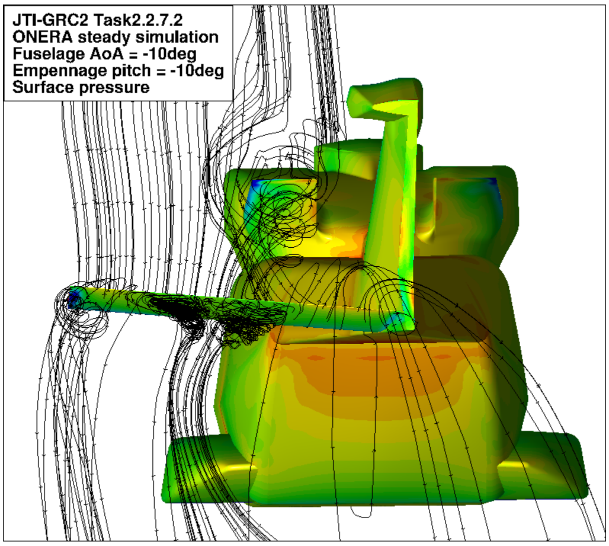


Figure 6: Surface pressure and stream traces for the minimal effective angle of attack (-20º)

At last, for the maximum effective angle of attack (+20º) the horizontal stabilizer is deeply stalled and there is an important interaction with the sponson for the inner part of the stabilizer (Figure 7).

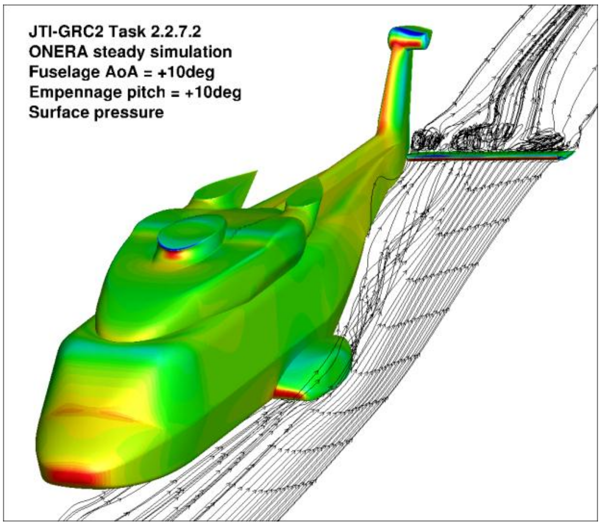


Figure 7: Surface pressure and stream traces for the maximal effective angle of attack (+20º)

The work done by ONERA has allowed quantifying the limit loads and moments acting on the horizontal stabilizer for all the configurations that could be tested on the wind tunnel model. These data will be used to dimension the structure of the staibiliser axle and to select the actuator.

3. Geometric modelling and flutter analysis

PZL-Swidnik contributed to the activities by performing detailed measurements of the existing

GOAHEAD wind tunnel model in the mounting area with bracket for the stabilizer at the rear of the tailboom.

Figure 8: Empennage of GOAHEAD wind tunnel model

This resulted in a detailed geometric model of the rear of the tailboom, delivered to LMS for predesign and NLR for the final design of NLR. The exact geometric constraints could be so taken into account.

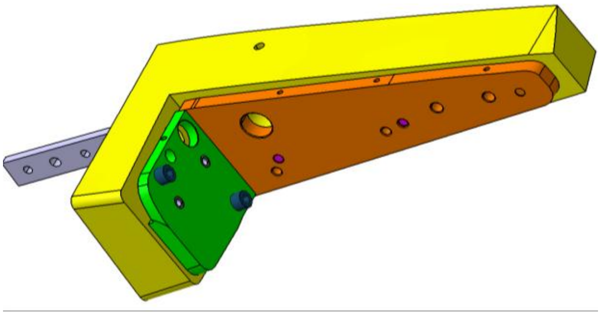


Figure 9: Geometric model of stabilizer mounting area

Furthermore, a finite element model was created to validate the structural strength of the current design of the stabilizer with the increase aerodynamic loading due to possible higher incidence angles. The results showed that a safety factor of 3 is still achieved.

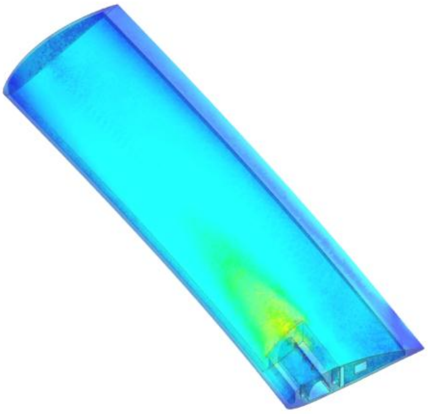
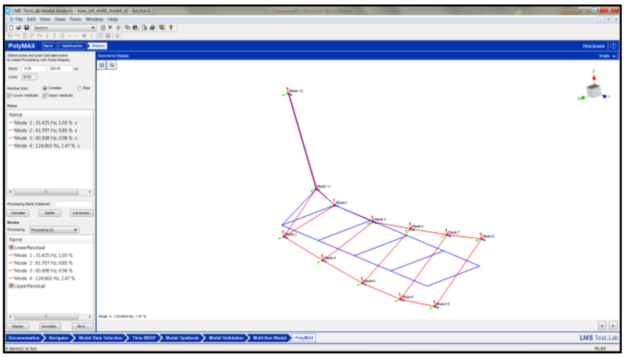


Figure 10: FE model of current stabilizer with distributed aerodynamic loads

Moreover, PZL-Swidnik is currently performing a flutter analysis. Therefore, also a detailed geometric model of the existing stabilizer was made together with mass property estimation. Vibration tests were performed with LMS Test.Lab on the original stabilizer to identify the first bending and torsional eigen frequencies and mode shapes.



Mode 1 : 31.425 Hz, 1.03 %

Mode 2 : 61.707 Hz, 0.85 %

Mode 3 : 65.508 Hz, 0.96 %

Mode 4 : 124.663 Hz, 1.47 %

Figure 11: Resonance frequency analysis of current stabilizer

These results will be used together with the mass properties to estimate the minimum torsion rigidity that is needed for the new stabilizer interface using a flutter analysis program.

4. Mechanism pre-design studies

LMS performed pre-design studies for the stabilizer axle and possible actuation mechanisms using its multi-body simulation software LMS Virtual.Lab Motion. The main challenge in the design of the actuation system of the horizontal stabiliser model is fitting it in the available room inside the tailboom of the GOAHEAD wind tunnel model.

4.1 Design of stabilizer axle

First, the redesign of the stabilizer axle was performed based on the original axle with clamped stabilizers. The original axle had a diameter of 30mm with a flatted section at the end that is connect to the stabilizer. The axle is not mounted horizontal but at an angle with respect to the horizon and is located at the bottom of the tailboom. As a result, the diameter could not be increased even though the aerodynamic loading will be higher, due to the higher incidence angles of the movable stabilizer. However, initial analytical calculations indicated, with original diameter and the high-grade steel, that a safety margin of 3 could still be achieved for the worst loading conditions predicted by ONERA. Therefore, the original diameter of the axle is maintained.

The axle needs to be supported by 2 bearings in the empennage. In between the bearings, a transmission system needs to be attached. A preliminary estimation of the bearing loads can be done with a simple analytical beam model. Subsequently, the two bearings can be selected to support the axle. The main restriction in bearing choice is the outer diameter, because the available space between the axle and the bottom of the empennage is very limited. Three solutions are considered: needle bearings, bushings and a tapered roller bearing. Eventually, a needle roller bearing with the smallest possible outer diameter that fits over the original axle diameter is selected at the stabilizer side. At the other end, the axle diameter is reduced to fit the tapered roller bearing. In between the bearings, there is a gap of 15mm that can be used to attach a gear of lever for the actuation system (Figure 12).

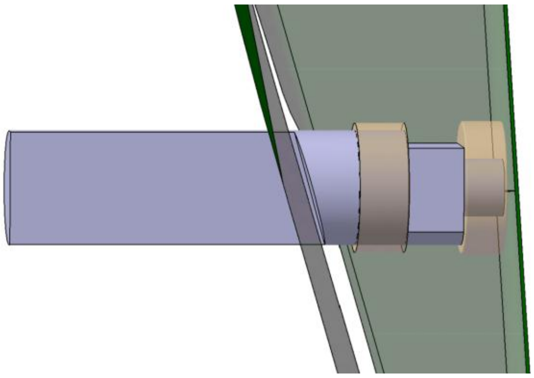


Figure 12: Stabilizer axle in tailboom

At last, a finite element analysis was performed which confirmed that the stress levels in the axle were still accepted at the worst loading condition (Figure 13).

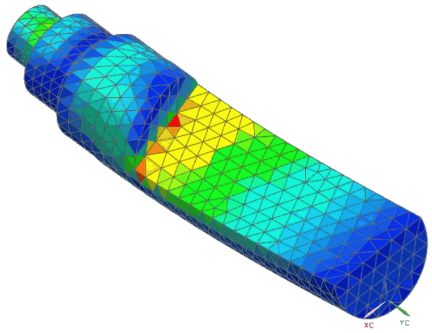


Figure 13: FE analysis of stabilizer axle

4.2 Review of concepts for actuation mechanisms

There are three main restrictions for the mechanisms that greatly reduce the number of feasible mechanisms.

Available space: This is the main restriction for the mechanism. The available space is roughly 70x35x200mm. If the motor needs to fit in the available space, the only possible position is above and quasi but not completely perpendicular to the stabilizer axle. There is a possibility for the motor to exceed the available space if a hole is made in the upper or front panel. This is however not ideal and everything must be accessible when only the 4 other sides are removed.

Very thick and short stabilizer axle: Due to the high forces and moments on the axle, it is required to be as thick as possible and two bearings are needed to sufficiently support the axle. This limits the space on the axle for connecting any levers or gears. Additionally the axle is only few millimetres away from the bottom plate. Therefore, it does not seem possible to fit a gear on the axle.

Misalignment of motor-axle and stabilizer axle: As an indirect effect of the available space, it is very difficult to align the motor perpendicularly or parallel to the HS-axle. Due to this restriction, simple mechanisms with gears are excluded.

With the above considerations in mind, it was concluded that it would not be possible to mount a complete gear or even a gear section gear on the axle. Therefore, it would not be possible to use directly a motor. Instead, the predesign studies would focus on lever mechanisms with a linear actuator. In particular, a concept with fixed motor and moving spindle head and a concept with a moving motor and fixed spindle head would be investigated. Two other variations of these concepts will also be investigated with the motor protruding through the upper and front panel.

4.3 Pre-design studies of actuation mechanisms

4.3.1 Predesign 1

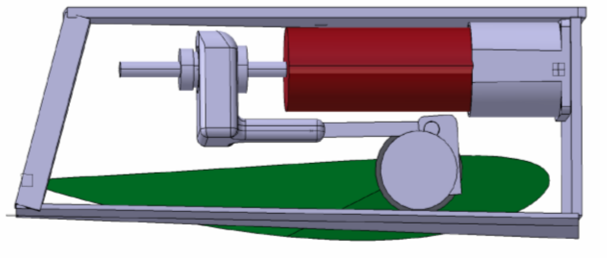


Figure 14: Predesign 1

At first, a preliminary type of motor was chosen taking into account the necessary power (about 0.5W) to rotate the horizontal stabilizer. This was chosen from the Maxon catalogue. The selected motor had a diameter of 32mm and a length of 106.5 mm. The motor is fixed in the most upper-right corner to allow the maximum lever arm, which is the vertical distance between the spindle and the point of rotation of the stabilizer axle. A horizontal link with one cylindrical joint and one spherical joint are needed to allow enough degrees of freedom. A major advantage of this mechanism is that it fits the available space. The disadvantage is that small parts with small joints are needed. Another possible disadvantage is that the spindle head forces are not solely along the axle of the motor. This is because the total length of the motor and motor-axle is too long to align it in the space available. Therefore, another support at the end of the motor axle or another guide arm for the spindle might be needed to counter the radial forces.

A multi-body simulation with rigid bodies has been done with LMS Virtual.Lab Motion where a harmonic displacement is applied to the spindle and the aerodynamic force is applied to the stabilizer as a function of the incidence angle. The amplitude of the spindle head displacement is chosen such that the required rotation of the stabilizer is achieved. For this design, the spindle head needs a total displacement of 5.52 mm to go from the lowest position to the highest HS inclination.

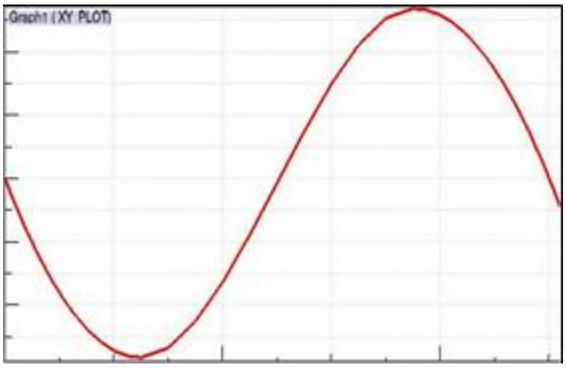


Figure 15: Predesign 1 – Spindle head displacement

The required force on the spindle head can also be identified and can be decomposed in the axial load and lateral load on the spindle where the former is the equal to the required actuator force.

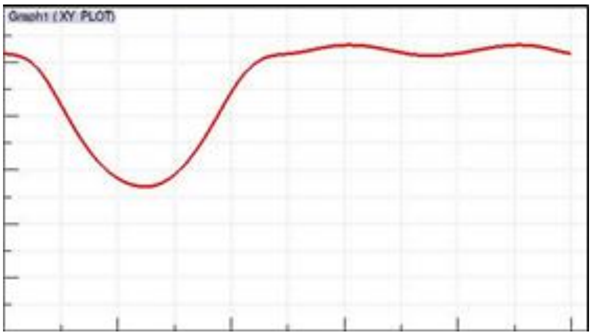


Figure 16: Predesign 1 - Required actuator force

Since there is no space for a brake in this mechanism, the spindle drive with a trapezoidal spindle head is selected because it automatically locks when it is not powered. This motor produces 1530N at a speed of 0.5 mm/s which results in a safety factor (SF) of just below 3 for the actuation force. Since the maximum spindle speed is 0.5mm/s, this mechanism will need 11.04s to complete a full rotation of the HS. The axial accuracy of the spindle head is 0.037 mm. This corresponds to an angular accuracy of the HS of 0.134°. Spindle drives with other gearboxes are also possible which results in a higher speed but will give a lower actuation force.

4.4.2 Predesign 2

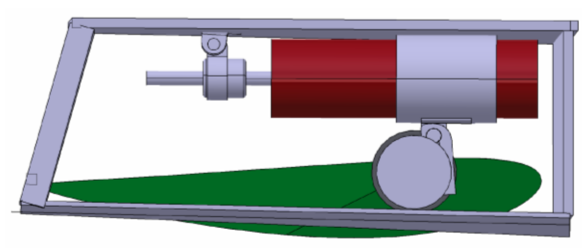


Figure 17: Predesign 2

The second predesign constitutes of the same 32mm-diameter-motor with spindle drive as in predesign 1. However, in this case the motor housing is attached to the horizontal stabilizer axle with a small lever. The spindle head is fixed with a hinge to the top plate. The advantage is that less parts and joints are needed than in Predesign 1 but still the parts need to be very small.

Multi-body simulations of this design show that a slightly larger spindle head range is required compared to Predesign 1. The larger displacement is achieved thanks to a longer effective lever arm. This also means that the axial force on the spindle head and hence the maximum actuator force is a bit lower.

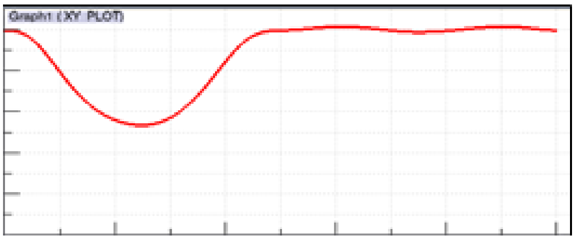


Figure 18: Predesign 2 - Required Actuator Force

Due to the forces being slightly lower than in Predesign 1, a higher SF is possible. On the other hand, the time needed to complete a full cycle is 13.1s because a longer stroke is required. The angular accuracy is also 0.113°.

4.4.3 Predesign 3

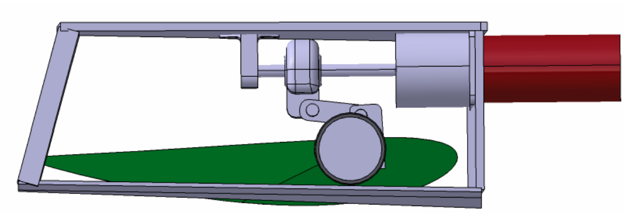


Figure 19: Predesign 3

The third predesign is much similar to predesign 1 but the motor protrudes the front panel. This is an advantage because it allows the motor to be positioned perpendicular to the stabilizer axle which results in simpler transmission system and therefore the different components can be designed larger than before due to the space available (Figure 20). The problem is that it is not clear yet if there are structural elements in the tailboom behind the panel which may interfere with the motor. Also problems with wiring need to be solved.

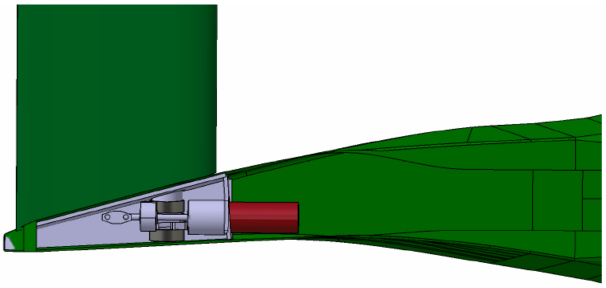


Figure 20: Predesign 3 - top view

Simulations show that an actuator stroke is needed that is between the previous two predesign studies. However, the maximum actuator force on the spindle head is lower than in the previous predesigns. In particular, it is lower than in predesign 1 because the alignment is better and hence there is no lateral force.

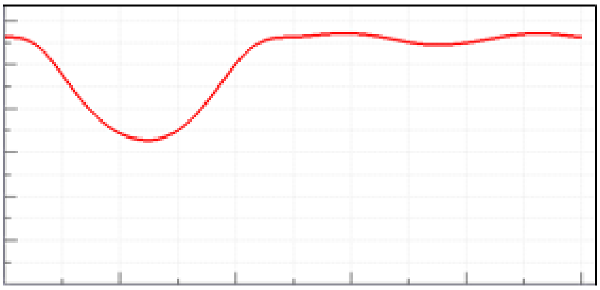


Figure 21: Predesign 3 - Required actuator force

Adding a brake and thus increasing the total length of the motor will pose no problem in this design.

Therefore, a ball screw spindle head is proposed which result in a higher actuation force. This gives a higher safety factor of and will need only 5.24s to cover the full range. The angular accuracy is similar as before.

4.4.4 Predesign 4

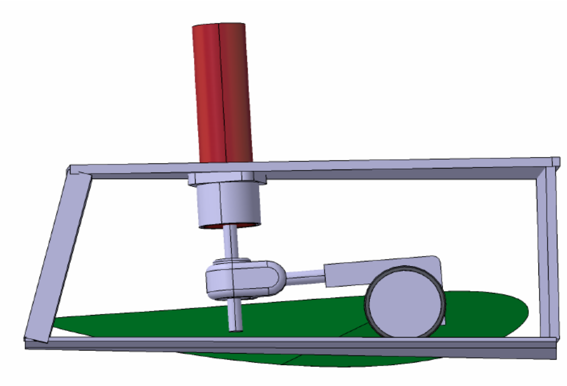


Figure 22: Predesign 4

This predesign is a variation of the previous design. In this case, the motor is positioned vertically and sticks through the upper panel. The motor is placed at the back of the empennage so that the lever arm of the mechanism can be as large as possible. As a result, the main advantage of this mechanism is that the lever arm is very large and therefore the actuator force and the forces in the mechanism are smaller. This also means that the spindle head must travel a large distance, which will result in a slower system. However, because the actuator is positioned far back in the empennage, there is not enough space to fit the motor used in the previous design. Therefore, a smaller motor is selected with a diameter of 22mm.

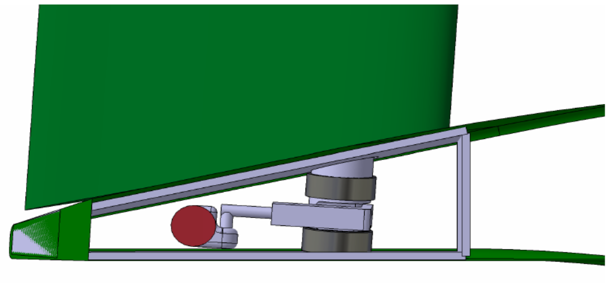


Figure 23: Predesign 4 - Top view

To connect the spindle head bracket to the stabilizer axle bracket, an L-shaped rod (Figure 24) is used. This rod is connected to both brackets with cylindrical joints. The principle of an L-shaped rod with two cylindrical joints can also be used in the previous predesigns.

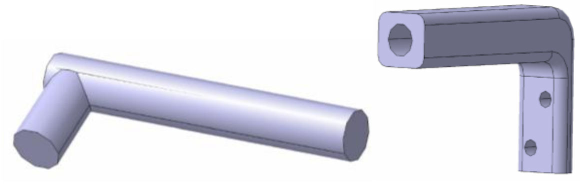


Figure 24: Connection rod and stabilizer axle bracket

In case of this design, the spindle head needs a total displacement of 19mm. The axial force on the spindle head is now much lower than compared to the previous designs.

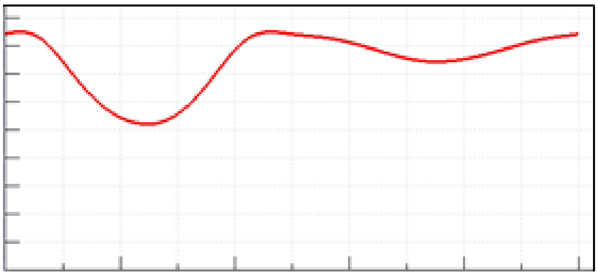


Figure 25: Required actuator force

The spindle drive with ball screw that produces a continuous force of 500N at a speed of 0.6mm/s is possible. This results in a cycle time of 32s. Although some faster spindles are available, the actuation force would be lower. An angular accuracy of 0.046° can be achieved.

5. Conclusions and future work

Several fully turbulent simulations of the complete model at 75m/s have been done by ONERA, corresponding to stabilizer effective angle of attack varying from -20º to +20º. This work has allowed quantifying the limit loads and moments acting on the horizontal stabilizer for all the configurations that will be tested in wind tunnel. Since the rotation axle of the horizontal stabilizer is too close to the bottom of the tailboom, it was conceived that the use of a direct rotation actuation was not possible. Therefore, so far four conceptual designs were made of mechanisms with levers and a linear actuator. The feasibility of these designs was evaluated using the multi-body simulation software LMS Virtual.Lab Motion. This included assessing the space constraints, the structural strength of the main axle and the power required for the actuator. It shows that the design where the actuator protrude any of the side panels, have better performance or a higher safety factor. However, it is still to be seen if that is possible. Furthermore, all design proposals suffer problem that the supporting bearing are close to each other, which may lead to reduced installation stiffness of the stabilizer, which could lead to inaccurate control and possibly flutter. Therefore, some more predesign studies are currently undertaken to investigate if these issues can be avoided. As described in the introduction, NLR will make the decision for the final design. After the wind tunnel, the simulation model will be up-scaled by LMS to estimate the mass and power requirement of a full-scale flight system.

6. Acknowledgement

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