NEXT GENERATION CIVIL TILT-ROTOR TECHNOLOGY DEMONSTRATOR (NGCTR-TD) TAIL DESIGN

Carlo Cassinelli, carlo.cassinelli@leonardo.com, Leonardo Helicopters (IT)
Matteo Pecoraro, matteo.pecoraro@leonardo.com, Leonardo Helicopters (IT)

ABSTRACT

Within the Clean Sky 2 Fast Rotorcraft platform, a Next Generation Civil Tilt-Rotor technology demonstrator (NGCTR-TD) is under development (Ref. [1]) within Leonardo Helicopters. Such platform allows to deep investigate the key technologies in development of a future European civil tilt-rotorcraft, starting from the experience of in-flight aircraft, and concept ERICA studies. One of the key technologies analyzed is the empennage solution, as per preliminary phase of a new aircraft configuration: the proper sizing and design of the tail is essential for ensuring performance and handling qualities.

In order to perform this activity, an appropriate aerodynamic toolchain process is adopted for supporting the tail design; further, requirements are appropriately set and tilt-rotor peculiarities addressed.

Aerodynamics analysis on tiltrotor empennage have been deeply validated through computational and experimental activities within Leonardo Helicopter Division programs. Based on validated aerodynamic tools, Vee-tail configuration is properly designed and verified to improve tilt-rotor performances.

Additionally, aerodynamic devices are analyzed for Vee-tail configuration, to possibly improve or modify handling qualities during the advanced development phase: such devices, so called “finlet”, are considered to be a winning factor for the benefit introduced with limited impact on tail design, specifically for Vee-tail configuration.

NOTATION

NGCTR-TD	Next Generation Civil Tilt Rotor Technology Demonstrator
LHD	Leonardo Helicopter Division
AP	Airplane Mode
VTOL	Vertical Take Off and Landing
CFD	Computational Fluid Dynamics
WT	Wind Tunnel
AoA	Angle of Attack
AoS	Angle of Sideslip
LHDWT	Leonardo Helicopter Division Wind Tunnel Test facility
PUWSS	Pitch Up With Sideslip
AR	Aspect Ratio
Γ	Dihedral Angle
Λ	Sweep Angle

INTRODUCTION

Empennage design is driven by different functions, ensuring trimming capabilities, appropriate stability and control performances. Such functions, mostly related to fixed wing design, are directly applicable to tilt-rotor in AP mode configuration, when rotor are used exclusively as propeller (low effects on airframe characteristics), and lifting capabilities are mainly addressed to primary wing surface; when in VTOL configuration, such design need to be properly verified, accounting for specific non-linear effects related to rotor interferences. With the above considerations, the Next Generation Civil Tilt-Rotor Technology Demonstrator (NGCTR-TD) tail design has been conducted.

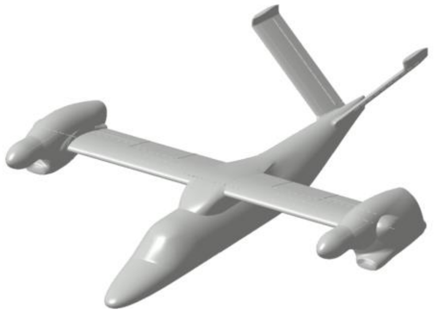

Figure 1 NGCTR-TD rendering in cruise condition.

As first, a solid understanding of the tiltrotor characteristics is assessed, full design and production processes have been understood and analyzed thanks to aerodynamic charcterization from CFD analysis up to a series of experimental wind tunnel tests (Ref [2]), flight mechanics linear and real-time simulations as well as flight test evidences.

The wind tunnel test results and high order CFD are compared against flight test data in few peculiar conditions showing a good match and proving the validity and correlation of the airframe aerodynamics characterization performed by LHD.

Once addressed the main peculiarities of in-flight tilt-rotorcraft, novel tail configuration is suited for specific NGCTR-TD needing, with best trade-off solution represented by Vee-tail geometry.

In order to accomplish a proper design, a dedicated aerodynamic toolchain is settled, with complementary use of CFD and WT tests.

Design workflow is substantiated at different level for aeromechanics analysis, starting with experiences on previous studies (Ref. [3][4][5]) for understanding the definition of main design variables involved (dihedral angle and wetted

Presented at 48th European Rotorcraft Forum, Switzerland, 6-8th September, 2022

surface), as well as undesired effects from empennage mutual effects.

Each “out of design” effect is verified not to be a showstopper for tail configuration, with dedicated processes involving detailed analysis of aeromechanics non-linearity effects and/or wing stall effects (e.g. buffet impingement on tail).

The non-linear regions have been analyzed not only in terms of buffet loads but also regarding wing covering effects (just before the wing stall region), where Vee-tail design have been found effective since maintaining a smooth behavior along the entire envelope avoiding any abrupt change in the aerodynamics characteristics.

As last, a wingtip aerodynamic shape has been detailed studied, if any slight changes in stability requirements are needed during flight phase, and its working principle patented (Ref. [9])

The final design of the NGCTR-TD Vee-tail (including optimized “finlet” device) have been proven (through experimental wind tunnel test and high order simulations) to be optimal along the entire flight envelope of a tiltrotor configuration providing the required aerodynamics characteristics in terms of stability derivatives and guaranteeing a simple architecture and promising drag and weight savings against other tail configurations.

TILTROTOR AERODYNAMICS

The aerodynamics characterization of a tiltrotor configuration is a complex topic. The specific needed compromise to suit both helicopter (vertical take-off and landing) and fixed wing propeller configurations affects the shape of aircraft: not streamlined bodies like nacelles, low aspect ratio thick wing and tail unit have to balance multiple functionalities within VTOL and airplane mode conditions.

The aerodynamic characterization became even further complex since compressibility effects must have been analyzed, even if the speed envelope is limited up to Mach 0.6. Thick wing and non-slender bodies anticipate transonic effects such that it is possible to encounter shock-waves and strong non-linear behavior within the tiltrotor Mach envelope.

The tiltrotor needs such kind of detailed aerodynamic characterization (i.e. fixed airframe at full scale) in order to understand and control the physics and the behavior for each flight condition: the aerodynamics database must be implemented within comprehensive flight mechanics simulation tools in order to check and validate flight control design and loads. Aerodynamics components breakdown is critical, not only for flight mechanics simulation, but also for load purposes, since airframe design loads are derived from those simulations. Both the concentrated and distributed aerodynamic loads must be validated against a reliable experimental source, such as a wind tunnel test campaign, during the certification phase.

In order to determine the tiltrotor aerodynamics database, due to platform criticalities and simulations needs, those aspects must be properly modelled: early transonic effect occurrence, high non-linear Reynolds effects, trailing edge separation stall, high three-dimensional impact on the wing and strong interference moments and forces between fuselage-wing-nacelle.

The tiltrotor configuration implies also two large non-streamlined bodies at the tip of the wing (the nacelles), a relative low arm between wing and tail unit with large tail surfaces and a large span flaperon. Those aspects cause interference between wing and tail such as, for example, a significant downwash from wing to horizontal tail (outside the classical fixed-wing literature range). All those interference effects are strongly dependent on Mach and Reynolds.

The strong bodies interferences imply that is not correct to obtain a component breakdown using the classical wind tunnel approach measuring separately the components and obtaining their value by subtraction: evidences from past experience shows that, for example, the pitch moment sharing between fuselage and wing can be wrongly allocated by 50%. All those aspects on the aerodynamics analysis require a good time-dependent (stall, transonic) resolution (challenging to be obtained by CFD) as well as close to full scale Reynolds conditions (impossible to be obtained with low speed open section wind tunnel).

The aerodynamics characterization of a tiltrotor configuration requires a significant large matrix of test points to be analyzed to cover the angle of attack/angle of sideslip envelope and all the surface deflections as well as nacelle angle: the order of magnitude is 400 angle sweeps with 30 points each one, for a total 12000 analysis points.

The generation of the tiltrotor airframe aerodynamics database is based on CFD, low speed wind tunnel tests and high speed wind tunnel tests and the next table compare the methods strengths and weakness.

CFD	
Pros	**Cons**
• Correct components breakdown • Full Scale Reynolds • No wind tunnel model manufacturing costs	• Mach effect challenging to be obtained • Time-dependent simulation too expensive for industrial application • Non-linear effects strongly dependent to turbulence modelling • Time consuming in order to obtain a full matrix • Small features like Vortex Generators not possible to

	be analyzed in an industrial environment

Figure 2 CFD Pros and cons

Low Speed Inexpensive Wind Tunnel Tests	
Pros	**Cons**
• Time dependency correctly analyzed • Low wind tunnel model manufacturing costs and time • Relative reduced time to obtain a large dataset of points once model manufactured • Small feature like Vortex Generators challenging but feasible to be included	• Correct components breakdown challenging due to model scale (sufficient number of internal balances) • Low Reynolds conditions • Mach effect not captured

Figure 3 Low Speed WT Pros and Cons

High Speed Wind Tunnel Tests	
Pros	**Cons**
• Time dependency correctly analyzed • Full Mach effect representation • Close to full scale Reynolds conditions • Small feature like Vortex Generators included • All the non-linear effects are properly captured • Relative reduced time to obtain a large dataset of points once model manufactured • Reliable source of validation for aerodynamics loads (both distributed and concentrated)	• Correct components breakdown challenging • Wind tunnel and model manufacturing expensive and time consuming

Figure 4 High Speed WT Pros and Cons

All those methods are used and complement each other during the design timeframe and have been exploited and cross-checked balancing accuracy and efficiency within tiltrotor programs.

Previous tiltrotor programs provide the advantage to perform aerodynamics correlation between CFD and Wind Tunnel methods with flight tests evidences.

The Aerodynamics datasets, once correlated against flight tests, shows this key outcomes:

- When implemented within Flight Mechanics simulations tools they capture well flight behavior in all the conditions flown.
- High Speed Wind Tunnel tests well predict stall behavior both in terms of maximum lift and stall angle of attack.
- All the interferences (side-wash / pro-verse) are well predicted in all the Mach envelope.
- All the major non-linarites are captured both by High Speed Wind Tunnel Tests and high order CFD giving deep insights behind flight behavior and physics of the tiltrotor.

As example, full flight tests points time-histories have been produced with high order CFD model using quasi-steady approach for each of time steps for a total of more 300 single CFD runs and compared against flight tests measurements showing a good correlation between components loads derived from flight thanks to calibrated strain gauge.

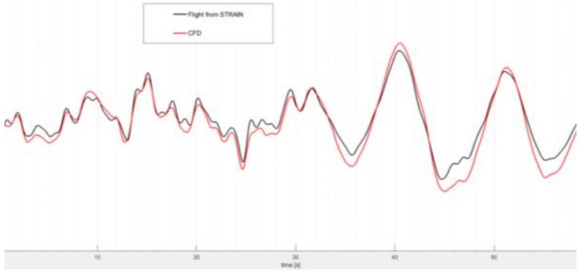

Figure 5 Time history of aerodynamics force from flight test strain gauge measurements compared with time history force reconstruction from high order steady state CFD.

All those aerodynamics characteristics and know-how of the tiltrotor were well known by Leonardo Helicopters during NGCTR-TD design and development phase and this experience have been the strong base for the NGCTR-TD aerodynamics characterization.

NGCTR-TD AERODYNAMICS

NGCTR-TD aircraft have been designed and characterized by full spectrum of CFD analysis to support the design loop, once requirements defined: from CFD 2D simplified analysis up to complex full aircraft analysis with 3D CFD dedicated campaign.

Further, design is confirmed and updated at each project gate with extended experimental wind tunnel test campaign, comprehending:

- Low Speed WT tests, both in isolated tail and complete airframe configuration.
- Low Speed Powered Wind Tunnel tests
- High Speed Wind Tunnel tests.

Computational Fluid Dynamics

CFD simulations have been carried out with ANSYS Fluent commercial software using a pressure-based coupled steady-state RANS scheme with k-ω SST 2-equations turbulence model.

The numerical hybrid grid is constituted by triangular element on the body surface, prism layers to represent the boundary layer and a mix of tetrahedral and hexahedral element on the fluid region to limit the numerical dissipation.

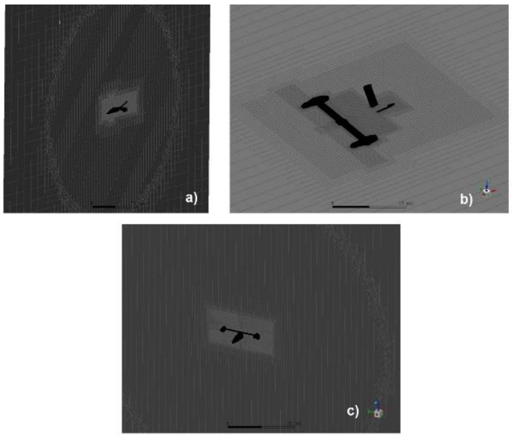

Figure 6 NGCTR-TD Numerical hybrid grid.

Grid sensitivity has been carried out in order to assess the grid which represents the best trade-off between result accuracy and computational costs.

All the numerical models feature: triangular elements on the walls, prismatic elements for the boundary layer grid and hexa-core elements for the remaining fluid zone.

The grid refinement has been performed in 9 different combinations of surface elements size, boundary layer discretization and volume refinements. For clarity of the current paper the main three levels are considered as summarized in following table.

Level	N° surface elements [M]	N° volume elements [M]	y^+
Coarse	0.8	21	wall-functions resolved
Standard	4.7	94	wall-functions resolved
Fine	4.7	188	<1

Figure 7 Grid Sensitivity Details.

The grid sensitivity analysis shows significant difference between coarse, standard and fine levels particularly in the stall region but also subtle differences in lift in the linear region where the fine grid tends to differs due to lower numerical dissipation.

Additionally, in the moment calculation, the fine grid is much more stable and proven more reliable if compared against wind tunnel.

In any case, the standard mesh has been proven to correlate adequately with the high speed wind tunnel test on previous tiltrotor programs and NGCTR-TD, and have been used for the most part of the NGCTR-TD design and development.

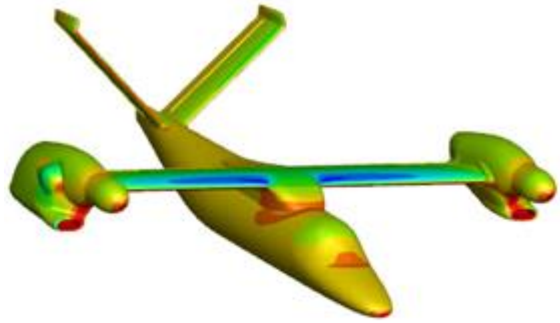

Figure 8. NGCTR-TD CFD results.

Wind Tunnel

Once assessed the CFD methodology, different wind tunnel test campaigns have been conducted, to support the preliminary design, validate the final one and substantiate non-linear effects related to rotor-tail interaction.

Model details and complexity used are proportional to the wind tunnel test aim.

Low Speed Isolated Tail Test

Low Speed WT tests in LHWT are configured in order to assess sensitivity analysis on isolated Vee-tail design variables (dihedral angle, setting angle, span, wingtip devices). Further, complete mapping based on AP mode AoA/AoS range at different ruddervator symmetric (elevator function) and antisymmetric (rudder function) is completed, for mapping main interference effects on such empennage configuration.

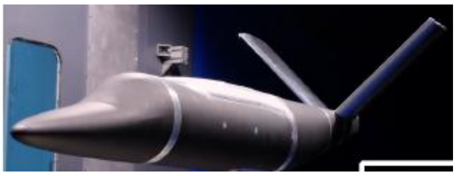

Figure 9 Low Speed Isolated Tail Test in LHDWT facility.

Low Speed Airframe Test

Low Speed WT airframe tests are prepared in Polytechnic of Milano in order to assess airframe and tail capabilities, in a second phase, when aircraft configuration is frozen. Aerodynamic mapping with no rotor effects is performed and, thanks to optimized cost of test campaign, a wide spread of condition was possible to be considered, for proper evaluation of main conditions where abrupt changes can occur: as example, effect of wing and nacelle at different angles on tail characteristics is considered, to verify design robustness.

Figure 10 Low Speed Airframe Test in PoliMi WT facility.

Low Speed Rotor Interactional Test

Low Speed Interactional WT tests (within CleanSky2 CfP06 NEXTTRIP) are settled in DNW LLF facility, to analyze the effect of large pro-rotor wake impingement on tail at different aircraft configuration, from AP to VTOL mode

Particularly. such tests have been used to guarantee proper tail functionality at low speed conditions to avoid the so called phenomena of the Pitch Up with Sideslip (PUWSS).

Figure 11 Interactional Wind Tunnel Test in DNW LLF.

High Speed Airframe Test

High Speed WT tests (within CleanSky2 CfP07 HIGHTRIP) are performed in ONERA S1MA facility, for final assessment of compressibility effects on airframe. Tail design verification is completed, considering compressibility effects and further verification on specific test conditions, as per low speed wind tunnel test lesson learned.

Figure 12 High Speed Wind Tunnel Test in Onera S1MA.

NGCTR-TD TAIL DESIGN

Once reported tools and processes used to support the NGCTR-TD tail design, process is briefly reported and tools application detailed. Such design process is evaluated once the empennage sizing is defined, in terms of contribute on longitudinal and lateral-directional stability, together with control power required in AP mode operations. Based on that, two different phases are considered: design one, in which a trade-off solution is evaluated, and a verification phase, in which results from CFD and WT activities are used to confirm design evaluations.

Design

Regarding the design loop, specs on airfoil are addressed as first. As latter, different parameter are set before starting the iteration loop, based on determination of proper surface, dihedral angle and setting angle for a Vee-tail surface.

Airfoil Analysis

For proper choice of airfoil section, specific requirements have to be adopted in the case of tail design:

- Generation of the required lift with minimum drag and minimum pitching moment
- Airfoil should generically be able to create both positive and negative lift, behaving similarly in both negative and positive angle of attack: for such reason, a symmetric airfoil section is a suitable candidate for a horizontal tail.
- Increase the airfoil lift curve slope as large as possible to reduce the tail size
- Ensure a proper linear range of angle of attack
- Ensuring to have a delayed stall angle of attack, to be sure not to have deep stall phenomena
- Tail must be clean of compressibility effects as per wing profile: specifically, for tilt-rotors, this is accounted for considering an airfoil section thinner than the wing one;

With all the bullets above, an optimization loop, (using a genetic algorithm) is used, to determine any other possible solution than using a standard NACA symmetric airfoil: objective functions addressed are minimization of parasite drag coefficient and maximization of lift slope, with constraint on stall angle. Within the scope, two different solutions are obtained, one with constraint of using a laminar profile solution, and results are shown below: increase in lift capability in both cases, with higher drag reduction in case of laminar solution.

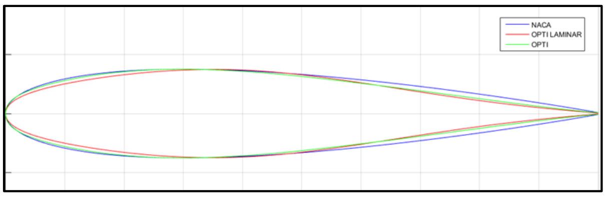

Figure 13 Airfoil analysis overview

Aspect Ratio, Taper and Sweep Angle

Before starting the design loop, that involve iterative process to correctly estimate dihedral angle and wetted surface of the empennage, some design parameters are frozen, with preliminary engineering judgement considerations: AR (aspect ratio), taper ratio and Λ (sweep angle) are considered. Particularly, for a Vee-tail configuration, the first two parameters strongly influence the Vee design, impacting on a deficiency factor on directional performance (described in next sections), and so on design dihedral angle and wetted surface, as reported in the figure below.

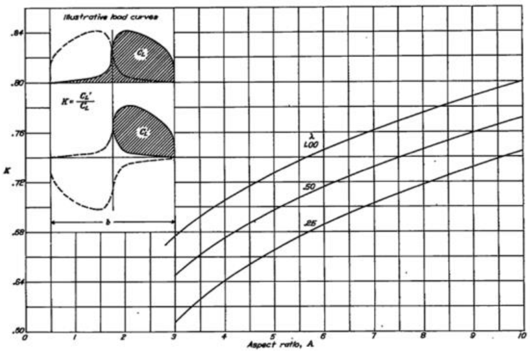

Figure 14 Lateral Deficiency Factor due to Aspect Ratio and Taper.

Taper Ratio:

- Use of low taper ratio, increase the tail efficiency (low margin, for low drag weight with respect to full aircraft)
- Use of low taper ratio decrease the weight, moving the center of gravity near the fuselage and so reducing the bending moment at the wing root
- Use of taper increase the cost of manufacture, with ribs of different shape
- Use of a unitary taper ratio ensure the use of a single mold

Aspect Ratio:

- High AR to increase the surface tail lift slope and, contemporary, ensure that the tail flow field is clean of wake and out of the propeller wash area
- Low AR to decrease large bending moment at the root, especially when coupled with elevator deflection
- Low AR ensure limited destabilizing effects, due to drag nose-up pitching moment

Sweep Angle:

- Ensure higher Mach divergence with respect to wing surface
- Reduce the tail surface, increasing the tail arm
- Reduce the undesired cross-flow effect, from higher sweep angle used

Dihedral Angle and Span

Once defined the above design parameters, dihedral angle and span are defined in the main design algorithm, involving both literature studies, wind tunnel test campaign experience and dedicated CFD loops.

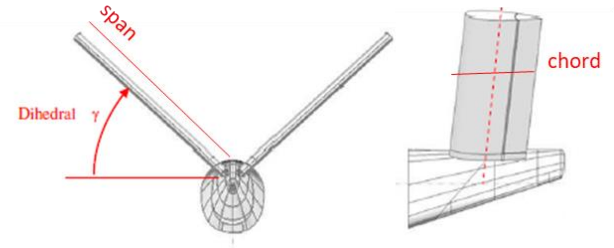

Figure 15 Vee-Tail dihedral angle/span definition (left), chord (right).

Specifically, a first design loop is assessed thanks to analytical formulation, that consider local angle of attack and target pitching moment and yawing moment derivatives.

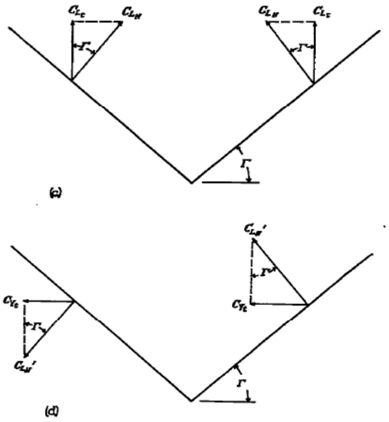

Figure 16 Local force projection: vertical component (top), lateral component (bottom).

Rearranging analytical formulation for small aerodynamic angles, a first guess can be figured out:

$$(1)\ \tan^2\Gamma = -\frac{\frac{b_w}{c_w}\left(1-\frac{\partial\varepsilon}{\partial\alpha}\right)C_{N\beta_t}}{K\,C_{M\alpha_t}}$$

$$(2)\ \frac{S_{vee}}{S_w} = -\frac{C_{M\alpha_t}}{\frac{q_t}{q}\cdot\frac{l_t}{c_w}C_{L\alpha_N}\left(1-\frac{\partial\varepsilon}{\partial\alpha}\right)\cos^2\Gamma}$$

Where K factor is a parameter accounting for mutual empennage interference.

Such parameter need to be carefully considered within a CFD loop, as second phase of dihedral and span design.

Verification

A verification phase is conducted, after design one, to ensure solution robustness in the complete envelope, for conditions ranging from stability and controllability in AP mode, up to specific VTOL conditions.

Static Stability

Different analyses are performed, focusing the attention on two main quantities: undesired AoS effects on longitudinal stability (pitching moment derivative with angle of attack at different angle of sideslip) and AoA effects on directional stability (yawing moment derivative with angle of sideslip at different angle of sideslip). Such quantities are well representative, respectively, of trimming capabilities with residual AoS and of wing covering effects for lateral-directional stability.

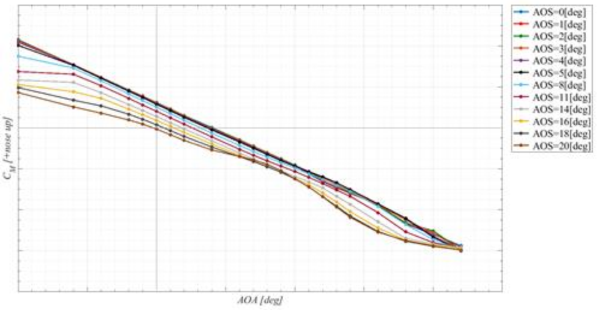

Figure 17 AoS Effect on Pitching Moment Coefficient.

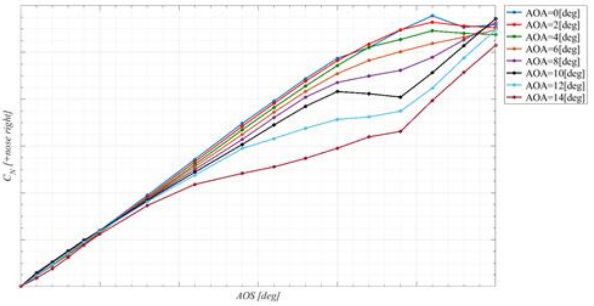

Figure 18 AoA Effect on Yawing moment coefficient.

Longitudinal Controllability

For assessing any undesired effects due to controllability, longitudinal control is inspected as first, looking for major control deterioration with angle or attack or angle of sideslip, together with no major effects on static stability.

No major effect of elevator angle on tail characteristics are highlighted, with non-linearities related to wing capabilities.

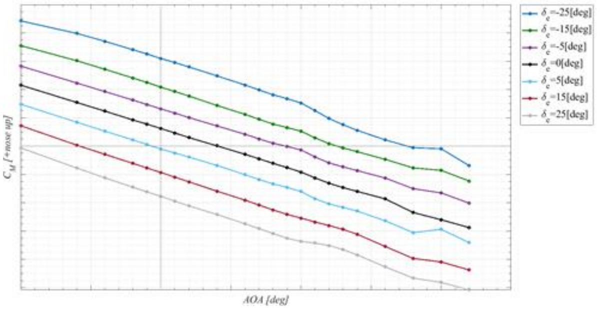

Figure 19 Pitching moment coeff vs aoa at different elevator deflections.

Low Speed Interactional Phenomena

As far as cited in the introduction, rotor effect need to be verified for tilt-rotor configuration, due to rotor radius and low distance rotor/tail, especially for configurations characterized by high rotor thrust and relatively low dynamic pressure value; such range can be well represented by low velocity for VTOL75 and VTOL90.

As proper evaluation method, pitching moment derivative at different angle of sideslip is analyzed, for verification on any abrupt change on longitudinal stability due to rotor wake impingement on tail empennage.

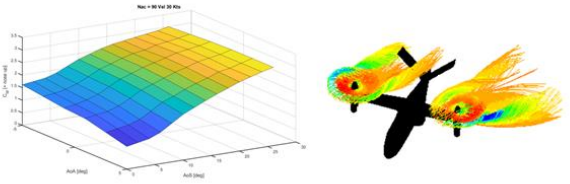

Figure 20 Pitching moment versus angle of attack of sideslip for low speed VTOL90.

NGCTR-TD FINLET DESIGN

From aerodynamic tool and process described, a baseline empennage is obtained; anyway, during the aerodynamic detailed analysis of the empennage, requirement to slightly change the stability characterization of the vee-tail can occur, so that empennage partial modularity needs to be investigated thanks to any additional aerodynamic device.

Such devices need to be efficient (from aerodynamic perspective) and at the same time easy to be installed, in order to avoid the problem arising on requirement of single axis on Vee tail, that will results in:

- Change in dihedral angle, due to different sharing between longitudinal and lateral-directional requirements
- Change in surface, for respecting stability derivatives

The above bullets highlights the difficulties to easily manage changes in one axis requirements for a Vee-tail geometry, so a different device needs to be accounted for: the most efficient way to manage the scope, in a range of 10% variation from original design, is represented from finlets surface. The way the finlets surface works is detailed described in Ref. [9] but essentially, thanks to a small increase in wetted surface and modification of the aerodynamic interferences, they can determine slight change in one axis stability, keeping unchanged the other one

Further, thanks to the use of two opposite configuration, indipendent increase in longitudinal or latero-directional capabilities can be figured with minimum change in geometry.

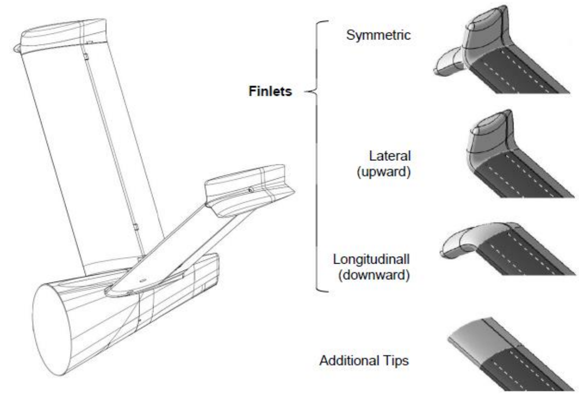

Figure 21 Finlet aerodynamic shape example

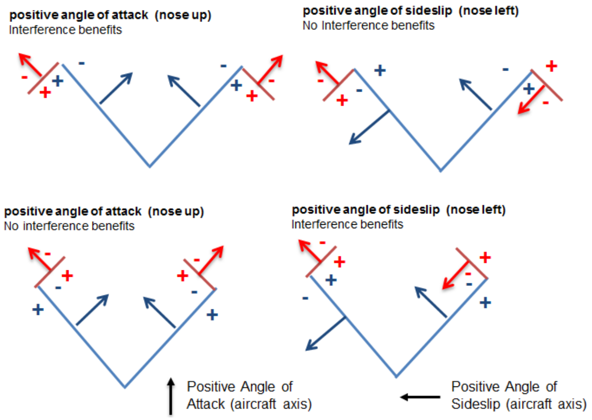

Figure 22 Finlet working principles for increasing longitudinal (top) or lateral-directional stability performances (bottom).

Working principle is simplified in figure above, and airfoil interferences reported.

In a first example, downward finlets are considered and the effects due to a perturbation on angle of attack and angle of sideslip are observed. Particularly, it is illustrated that a positive angle of attack determines an increase in tail longitudinal force characteristics, while a perturbation in angle of sideslip leads not to any increase in lateral force because, even if aerodynamic surface is increased, this does not reflect in an increase on aerodynamic force due to fin interference. As opposite, upward finlets are not efficient for increase in force with angle of attack, but increase lateral force with angle of sideslip.

Such phenomenon is also verified thanks to preliminary CFD and wind tunnel test verification, where it is highlighted how the shape can tune one axis, keeping unchanged the other one, as well shown in figure below.

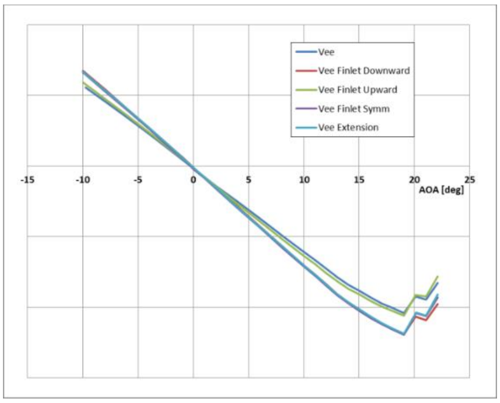

Figure 23 Effect of finlet application on longitudinal axis.

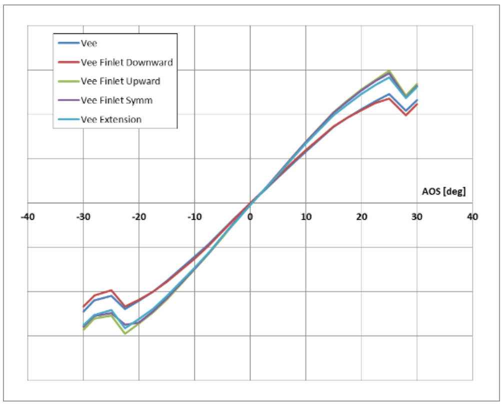

Figure 24 Effect of finlet application on directional axis.

Further, as per winglet surfaces, same parameter can be used to correctly design the surface:

- Endplate shape: use of endplate, with no curvature radius and no airfoil shaped section, decrease the beneficial effects, and increase the parasite drag contribute at same delta lift required, with respect to a smooth surface one;
- Cant Angle: higher cant angle increase the aerodynamic interference but decrease the surface aerodynamic contribute, so that a trade-off is considered;
- Taper: reduce the delta contribute but optimize the drag increase;
- Toe Angle: proper value of toe angle increase the effectiveness of aerodynamic efficiency;
- Configuration: different configuration (lower extension, higher extension, both) can be considering, depending on the case, with results linearly independent.
- Length: surface length increase the effects of the aerodynamic surface, but value greater than 10% of total span are not suggested, for increasing of root bending moment at each empennage

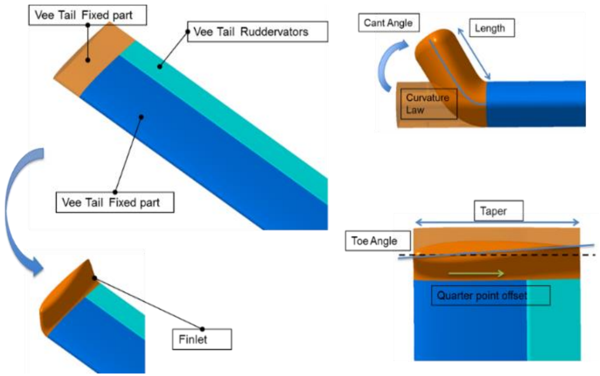

Figure 25 Generic Design parameter for winglet surface

With the above parameters, sensitivity design analysis and optimization loop (see Ref. [10]) is performed and optimized configuration obtained, as reported below.

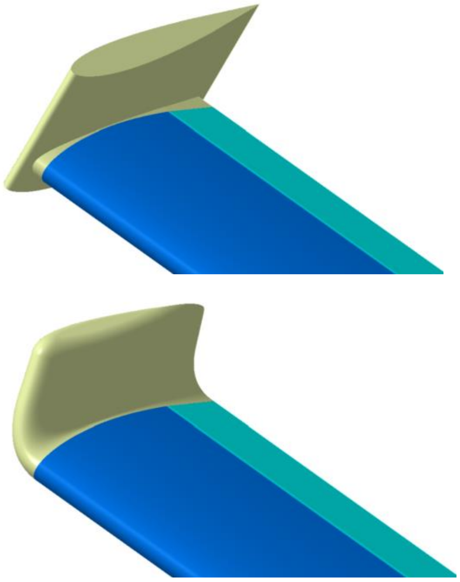

Figure 26 Finlet shape design process: preliminary (left) and final design (right).

CONCLUSIONS

Aerodynamic tool-chain for civil tilt-rotor application has been validated thanks to company experience and CleanSky2 research program activities.

As first, experience has been used to properly set the process for NGCTR-TD tail design; then, a series of tool and test campaign has been properly set to correctly design a Vee-Tail empennage configuration.

Design loop is introduced, and analysis on extended envelope verified; as last, additional aerodynamic device is introduced to properly tune longitudinal and lateral-directional requirements for Vee-tail geometry.

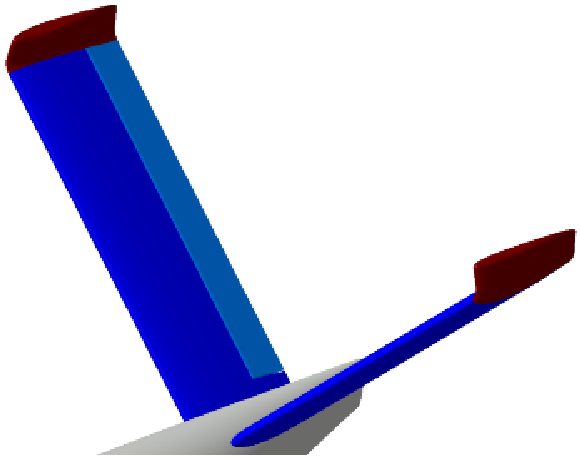

Figure 27 Detail of Vee Tail Geometry

The final design of the NGCTR-TD Vee-tail have been proven (through experimental wind tunnel test and high order simulations) to be optimal along the entire flight envelope of a tiltrotor configuration providing the required aerodynamics characteristics in terms of stability derivatives and guaranteeing a simple architecture and promising drag and weight savings against other tail configurations. NGCTR-TD tail configuration is ready to be manufactured, and tested within first flight test campaign, planned for 2023.

ACKNOWLEDGEMENTS

This work was performed as part of the project TRINIDAT and has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 831810. The JU receives support from the European Union’s Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.

REFERENCES

[1] Horizon 2020, Clean Sky 2, Fast Rotorcraft IADP, https://www.cleansky.eu/fast-rotorcraft-iadp

[2] C. Cassinelli, M. Pecoraro, “A novel approach to the experimental validation of tiltrotor configurations”. International Powered Lift Conference, Bristol, UK, Nov 13-15, 2018

[3] R.O.Schade, “Effect of Geometric Dihedral on the Aerodynamic Characteristics of Two Isolated Vee-Tail Surfaces.

[4] Report No.823, “Experimental Verification of a Simplified Vee-Tail Theory and Analysis of Available data on Complete Models with Vee-Tails”

[5] NACA RML56A06a, “An Experimental Study at High Subsonic Speeds of Several Tail Configuratons on a Model with Unswept Wing”

[6] NASA Technical Memorandum 78729, “Analysis of Stability Contributions of High Dihedral V-Tails”

[7] NACA Technical Note 1369, “Effect of Geometric Dihedral on the Aerodynamic Characteristics of Two Isolated Vee-Tail Surfaces”

[8] M.L. Dall’Aglio, C. Cassinelli, N. Donini, A. Trezzini, “Evolution in Buffet Loads Determination for Tilt Rotor”, Vertical Flight Society’s 78th Annual Forum.

[9] EP 367032A1, “Aircraft and Related Manufacturing Method”

[10] A.Battiston, E.Benini, G.Bernini, M.Pecoraro, “Multi-criteria Multi-constrained Aerodynamic Optimization of civil tiltrotor empennage surfaces”, AIAA Scitech 2022

Copyright Statement

The authors confirm that they, and/or their company or organization, hold copyright on all of the original material included in this paper. The authors also confirm that they have obtained permission, from the copyright holder of any third party material included in this paper, to publish it as part of their paper. The authors confirm that they give permission, or have obtained permission from the copyright holder of this paper, for the publication and distribution of this paper and recorded presentations as part of the ERF proceedings or as individual offprints from the proceedings and for inclusion in a freely accessible web-based repository.