AERODYNAMIC AND AERO-ACOUSTIC DESIGN OF MODERN TILT-ROTORS: THE ONERA EXPERIENCE

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Abstract

ONERA experience in tilt-rotors is presented in this paper. A detailed description of the way to design modern tilt-rotor blades for improved aerodynamic performance in hover and cruise and reduced noise is proposed. A study of specific nacelle-wing aerodynamic interference effects is done. Comparisons with experimental results obtained through the European Adyn and Tiltaero projects validate the numerical results.

1 Introduction

Tilt-rotors represent an attractive alternative to conventional aircrafts, combining the advantage of hover capabilities specific to helicopters, with high speed capabilities similar to propeller driven aircrafts. Most of the studies initiated in Europe since 6 years are based on the Agusta ERICA concept (Fig. 1), which is a tilt-rotor comprising a half tilt-wing design, allowing to reduce the rotor-wing interactions by a proper choice of the outer wing incidence depending on the flight condition. Despite this peculiarity, specific aerodynamic rotor-wing interaction problems can be encountered and have to be carefully studied. Furthermore, because the tilt-rotor blades and rotors remain the main aerodynamic components of the aircraft, their design has to reach a compromise between two very different flight conditions: hover and cruise. Finally, tilt-rotors are characterized by specific aero-acoustic problems, the main challenging one being the blade-vortex interaction noise (BVI) which is of similar nature of the one encountered on conventional helicopters. In the context of European and national programs, ONERA has developed considerable expertise in tilt-rotors, both in the numerical and experimental fields, which are detailed in the present paper.

The paper is split into two parts: rotor design, and aerodynamic interactions. In the first part, emphasis is put on the design of the rotor, focusing first on aerodynamic performance in hover and cruise and in a second step taking into account some acoustic constraints in the design. In the second part, a study of the aerodynamic interactions occurring in low speed flight conditions is done, for different operating points located in the critical tilt-rotor flight phase which lies on between the helicopter hover mode and the airplane level flight mode: the ‘conversion corridor’.

Fig. 1: The ERICA half tilt-wing tilt-rotor of Agusta

2 Rotor Design

Designing a tilt-rotor blade is somewhat different from conventional helicopter blades because the rotor has to be efficient both in hover and cruise conditions. Indeed, the specificity of a tilt-rotor lies in its ability to take-off in helicopter mode, and to fly as an airplane in cruise thanks to the tilting of the nacelles, thus considerably increasing the maximum speed of conventional helicopters (which if of the order of 200KTS). Hover flight is very demanding in terms of rotor disk loading and physics is dominated by vortical structures (tip vortices) that have a direct impact on rotor performance. Considering the high requirement of the ERICA tilt-rotor in cruise (Vmax~350KTS), cruise flight is dominated by transonic effects, so that it is essential that the blade sections operate below the drag divergence Mach number. These simple considerations immediately lead to the following consequences:

- Reduced RPM in cruise compared to hover (Mtip=0.537 in cruise, Mtip=0.630 in hover),
- Blades have to be swept in order to reduce the effective sectional Mach number,
- Specific blade tip design is needed to improve hover performance,
- A compromise has to be found between the optimal twist distributions in cruise and hover.

At the beginning of the Adyn, Dart and Tiltaero European projects, the following objectives were specified for the rotor performance:

- Design objective in hover: Figure of Merit (FM) > 0.86 for rotor thrust coefficient Ct/σ=0.116 and 0.144,
- Design objective in cruise: efficiency η>0.87 for Ct/σ=0.072 (V=250KTS at 7500m).

2.1 From Tiltaero to Adyn blade design

An initial blade design was proposed as a starting point for the design process: the Tiltaero blade plotted in Fig. 2.

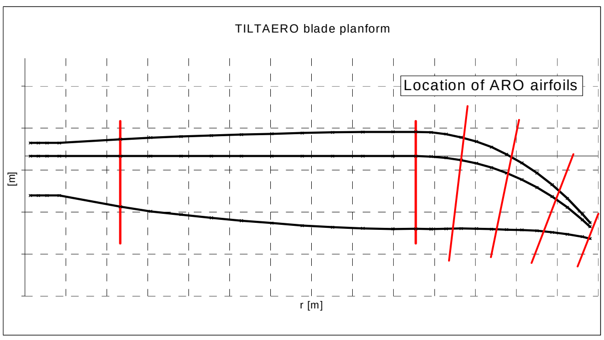

Fig. 2: The reference Tiltaero blade

The first part of the optimization focused on aerodynamic performance, without caring for acoustics. In order to evaluate the rotor performance, the choice of numerical methods already developed and validated for helicopter and propeller applications has been done:

- A CFD RANS solver (*elsA* code developed by ONERA) to predict the hovering performance of the isolated rotor; for this kind of simulation only one blade sector is meshed (Fig. 3) and periodicity conditions are applied to account for the influence of the other blades [1]; the 2 equation k-ω turbulence model of Wilcox with the SST correction was used,
- A fast lifting-line method to predict the cruise performance (HOST code developed by Eurocopter), where the sectional lift and drag coefficients Cl and Cd are read in 2D look-up tables; in this method, the rotor wake is modeled by a set of longitudinal and radial vortex lattices and the Biot&Savart law is used to compute the velocities induced on the blade quarter-chord.

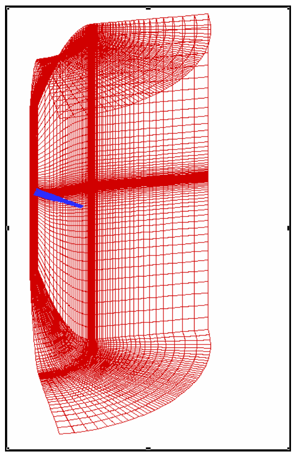

Fig. 3: Typical monoblock grid for RANS analysis of hover flight condition

Because the reference Tiltaero blade performance was already beyond the objective in cruise but did not reach the objective in hover (according to ONERA predictions), the first step was to modify the Tiltaero blade shape in order to improve the hover efficiency. Only the main aerodynamic part of the blade was studied (r/R>0.22).

The first modification to be performed was to replace the initial ARO airfoils of the Tiltaero blade by existing OA airfoils, which were set perpendicular to the pitch axis instead of perpendicular to the local quarter-chord in the Tiltaero blade. This modification resulted in a FM improvement $\Delta FM_{max} \approx 1.5$ cts (with the definition: 1ct=0.01FM).

Then, a modification of the chord distribution and of the quarter-chord line position was applied. The chord was reduced in the inner part of the blade, and increased in the outer part with a maximum chord at r/R≈0.70. The aim was to obtain a more uniform lift distribution (expecting less induced losses) and to benefit from the good behavior of the 12% airfoil, located around r/R=0.70. The modification of the quarter-chord line position resulted in a double sweep concept, with the first part of the blade with forward sweep and the external part with backward sweep. The backward sweep was introduced to reduce the effective sectional Mach number in transonic conditions, and the double sweep was motivated by previous studies on helicopter blades (ERATO program [2]) which indicated a great potential for Blade-Vortex Interaction (BVI) noise reduction thanks to this concept. At that time of the design, no acoustics evaluation was done and introducing the double sweep was just a guess. A parabolic tip similar to that used on most of helicopter blades was also added.

Finally, the twist distribution was optimized in order to better match the theoretical optimal twist distribution in hover. Moreover, in order to increase the maximum figure of merit FM_{max} and the thrust value for which FM_{max} is reached, a 15° anhedral angle was added at the blade tip, since it is a well-known efficient way to improve helicopter hover efficiency. The first optimized blade – called OPT2D15 - resulting from all these modifications is illustrated in Fig. 4. The following table quantifies the impact of the modifications performed during the optimization process, and Fig. 5 confirms that significant improvement in hover efficiency was obtained (+4cts for the OPT2D15 blade compared to the Tiltaero blade with OA airfoils).

	MODIFICATION	EFFECTS	INFLUENCE ON Fmmax	INFLUENCE ON thrust (FMmax)
Tiltaero with OA aifoils				
↓	*chord distribution*	more uniform lift distribution / higher Cl on 12% airfoil	+ 1 count	
↓	*twist adaptation*	more uniform lift distribution / higher Cl on 12% airfoil	+ 1 count	
↓	*anhedral*	more uniform lift distribution at tip / reduction of transonic flows at tip	+ 2 count	+ 15 %
OPT2D15				

This trend was confirmed by other partners of the Adyn project using different numerical methods [3]. At the end of this phase, it was found that the cruise performance of this first optimized blade was slightly lower than the performance of the reference blade, but still in conformity with the requirements.

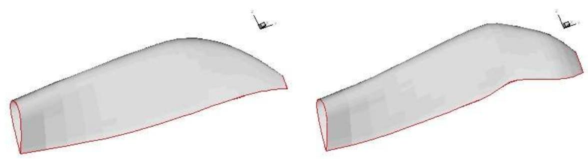

Fig. 4: Reference Tiltaero blade (left) and first optimized blade OPTD15 (right)

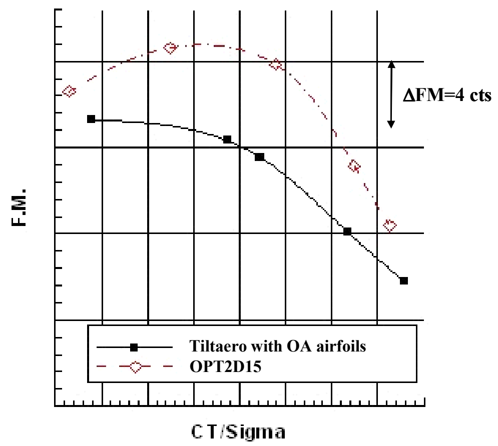

Fig. 5: Hover performance of reference blade and of first optimized blade OPT2D15

2.2 Acoustics Constraints in the Rotor Design

The main objective of the Adyn project in terms of rotor design was to optimize the tilt-rotor blade shape in order to reduce the radiated noise. Similarly to helicopters, the most penalizing noise source is the tone noise generated by Blade-Vortex Interactions (BVI) in low speed descent flight. A typical flight condition to study BVI noise is defined by the following parameters: V=80KTS, nacelle angle=85°. The objective of the optimization was to reduce the BVI noise for different descent flight path angles, ranging from 4 to 8°. The starting point of the optimization was the OPT2D15 rotor defined above.

In order to evaluate the radiated noise, the same aero-acoustics chain as already developed and validated for helicopters was applied. Given the flight condition and resulting isolated rotor trim (HOST code), a free-wake analysis is done (MESIR code) in order to accurately compute the vortex location and intensity. A roll-up model is introduced (MENTHE code) before computing the blade unsteady pressure fluctuations due to BVI (ARHIS singularity method). The radiated noise is finally computed with the PARIS code (Ffowcs-Williams and Hawkings method). Details on this aero-acoustics chain are given in [4]. Although the roll-up process of vortices emitted by tilt-rotor blades is believed to be different from the roll-up of helicopter blades (due to more intense vortices), the aero-acoustic chain was not modified, due to lack of detailed tilt-rotor blade vortex characteristics. This resulted in some uncertainties in the computed noise levels, which were difficult to quantify at the time of the optimization. Detailed characterization of tilt-rotor tip vortices would be necessary to improve the models: such studies, such as [5], have already been launched.

Parametric study

A parametric study [3] was done in order to investigate the influence on the radiated noise of modifications of chord, sweep, anhedral and twist distributions. According to the calculations, the following conclusions were drawn:

- The most important parameter to reduce the noise levels of the OPT2D15 blade is an increase of the geometric twist distribution (which is also beneficial for the aerodynamic performance in hover and cruise conditions),
- Modifying the sweep distribution of the ADYN intermediate blade can result in some noise reductions,
- Only limited noise reductions can be obtained when the anhedral of the ADYN intermediate blade is reduced or suppressed (which unfortunately deteriorates the hover aerodynamic performance),
- Modifying the chord has a limited influence on the radiated noise.

Thus, at this step of the process, 2 parameters were identified as significant for possible noise reduction: the increase of twist, especially near the blade tip, and the reduction, even inversion, of sweep distribution. Two different optimised blade geometries were then envisaged. The Adyn blade candidate 1 has got the same characteristics as the OPT2D15 blade but with an increased twist distribution both in the inner part of the blade and at the blade tip. The Adyn blade candidate 2 has got the same characteristics as the Adyn intermediate blade but with a 40% reduction of the sweep angles and a slightly increased twist.

Fig. 6 presents the decrease of maximum noise level obtained with the two selected blades compared to the OPT2D15 blade for descent flight configurations ranging from 4 to 12° of descent angle. It can be seen that both candidates experience a reduction of noise level around the nominal descent flight conditions (6° descent angle). The main difference between the two calculations is observed for high descent angles (10 and 12°) where blade candidate 2 has got the strongest penalty.

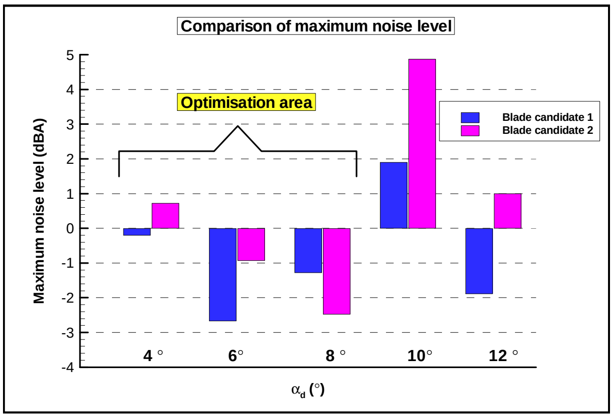

Fig. 6: Maximum noise level of Adyn blade candidates compared to OPT2D15

Fig. 7 and Fig. 8 represent the time derivatives of sectional loads $d(Cn*M^2)/d\psi$, high pass filtered for the 2 blade candidates and for descent angles ranging from 4° to 10°. The differences in the behavior of the interactions are in agreement with the results of Fig. 6. At 10° descent angle for blade candidate 2, the interactions, though occurring at the same azimuth as blade candidate 1, are more intense with larger radial interacting range, thus explaining the higher noise level.

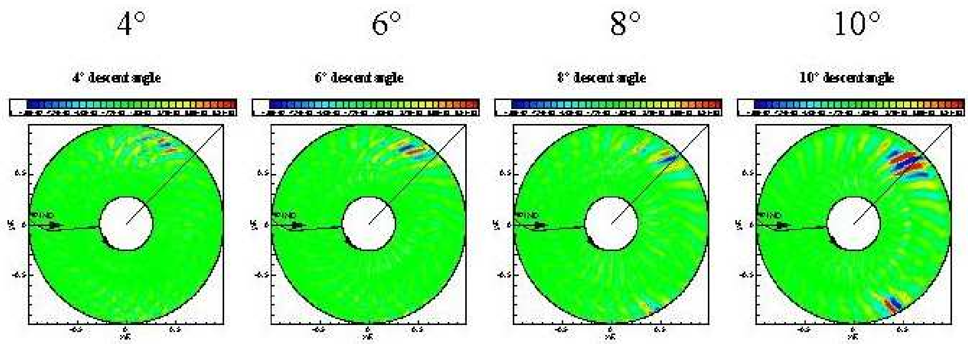

Fig. 7: $d(Cn*M^2)/d\psi$ high pass filtered for blade candidate 1

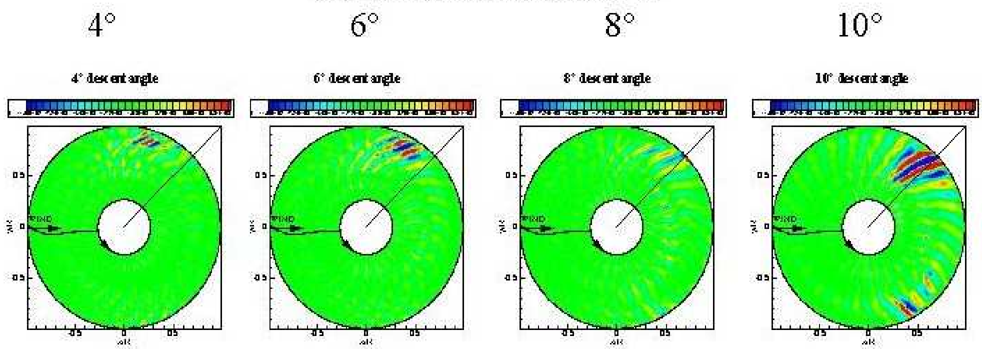

Fig. 8: $d(Cn*M^2)/d\psi$ high pass filtered for blade candidate 2

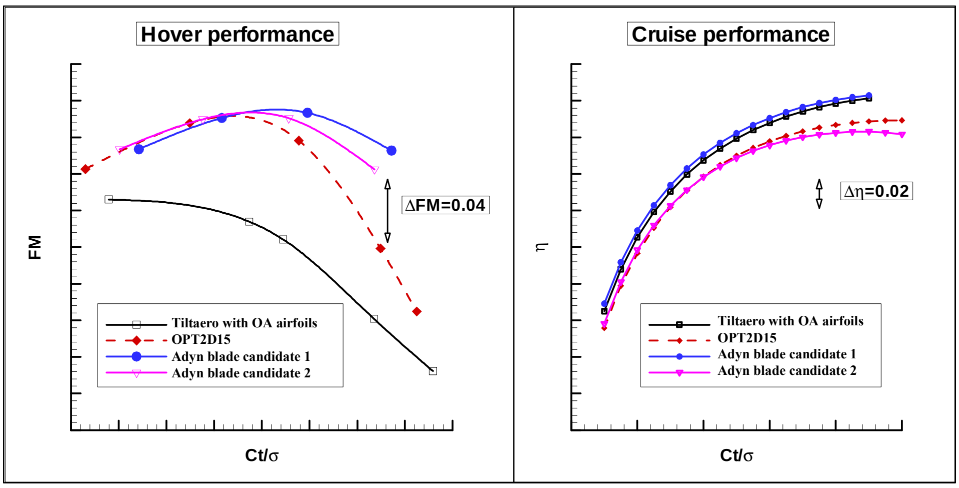

Fig. 9: Aerodynamic performance of Adyn blade candidates

Concerning the aerodynamic performance, both blades show improved performance in hover conditions (Fig. 9, left), with an increase in both FM_{max} and thrust margin compared to the OPT2D15 blade. This improvement is mainly due to blade tip twist modification performed on the 2 candidates. In cruise, blade candidate 1 reaches higher cruise efficiency than the OPT2D15 blade (Fig. 9, right) whereas blade candidate 2 has got cruise efficiency slightly reduced when compared to the OPT2D15 blade.

Blade selection

After the parametric study described in the previous paragraph, the final choice was made taking into account the following criteria: acoustic performance, performance both in hover and cruise and technical feasibility.
According to the previous results, only candidate 1 presents an acceptable noise level reduction compared to the OPT2D15 blade as candidate 2 has a too strong penalty above 8°. Thus selecting blade candidate 1 appears to be less risky from the acoustic point of view as it presents a smoother noise level reduction compared to candidate 2.
From the aerodynamic point of view, blade candidate 1 presents the best advantages. In hover, the blade reaches the highest FM_{max} and the larger thrust margin. In cruise, it is the only candidate to obtain higher cruise efficiency than the OPT2D15 blade.
Since only one optimised blade had to be selected, the ADYN blade candidate 1 was retained as the Adyn optimised blade.

2.3 Validation of the design

In order to validate the performance of the Adyn optimized blade, experimental results are used in this part, taken from two wind-tunnel tests done during the Adyn project:

- The first one made use of the Tiltaero half-span model tested in the DNW-LLF wind-tunnel (Fig. 10); among the data available, only hover measurements are analyzed; although these tests cannot be considered as isolated rotor tests due to the presence of the wings, they will be compared to isolated rotor computations; indeed, due to the fact that the outer wing is tilted 90°, the rotor/wing interference effects are assumed to be small in hover;
- The second one made use of the Eurofar hub installed in the S1MA high speed wind-tunnel (Fig. 11); only cruise conditions with the rotors perpendicular to the free stream are considered here.

In both wind-tunnels, the 2 rotors (Tiltaero and Adyn) were tested.

Fig. 10: The Tiltaero rotor on the Tiltaero model in the DNW-LLF wind-tunnel

Fig. 11: The Adyn rotor on the Eurofar hub in the S1MA wind-tunnel

Hover results

Fig. 12 presents the measured FM vs. rotor thrust coefficient Ct/σ for both rotors (symbols), compared to post-tests predictions done using the same CFD method as used during the optimization phase. These results confirm that the Adyn optimized blade has got approximately 4-5 cts more FM than the reference Tiltaero blade, which is almost perfectly reproduced by CFD calculations.

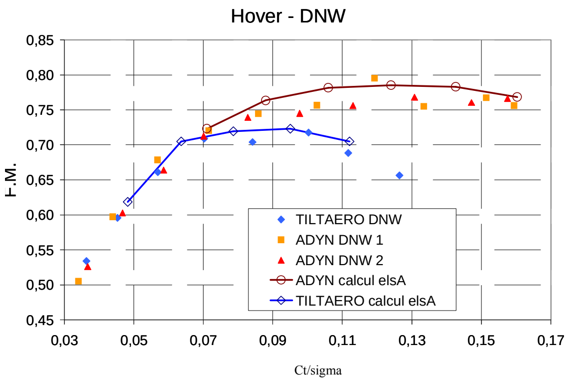

Fig. 12: Hover performance of Tiltaero and Adyn rotors

Cruise results

For a range of Mach numbers between M=0.3 and 0.55, the maximum measured cruise efficiency is plotted in Fig. 13. It can be seen that the Adyn rotor has got 2-3 cts efficiency more than the Tiltaero rotor up to M=0.48, but that this trend is reversed for M>0.48. Calculations done using the HOST lifting-line method always predict a higher efficiency for the Adyn rotor by approximately 2 cts, for the whole range of advancing Mach numbers. To better understand the origin of the trend reversal beyond M=0.48, CFD computations of the Tiltaero and Adyn rotors were performed using the *elsA* RANS solver: the results do not reproduce the trend reversal (Fig. 14) and, similarly to the lifting-line results, indicate that the Adyn rotor has got the highest efficiency, whatever the advancing Mach number is. The pressure distributions computed by CFD are compared to the measured pressure for M=0.5 in Fig. 15 for the Tiltaero rotor and in Fig. 16 for the Adyn rotor. The overall agreement is pretty good. One can observe that supercritical zones appear at the very tip of the Tiltaero rotor, and not on the Adyn rotor. The largest discrepancies between calculations and experiment appear on the lower surface for the most inboard sections (red curves) where the computed pressure are higher than the measured ones. This is certainly due to the effect of the test rig, not accounted for in the predictions. However, this does not explain the reason for the reversal of trend for M>0.48. Further numerical analysis has been done within the Nicetrip project, indicating large separation in the inner part of the blades (Fig. 17), partially due to the interaction with the test rig. Furthermore, a specific optimization of the cuff has to be done to improve the cruise efficiency of the rotors: such an optimization is part of the on-going Nicetrip project.

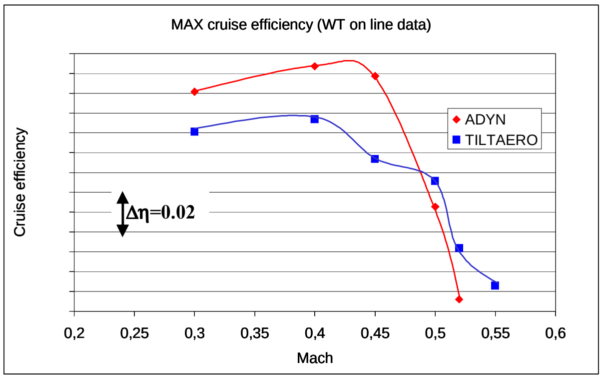

Fig. 13: Measured maximum cruise efficiency vs. advancing Mach number

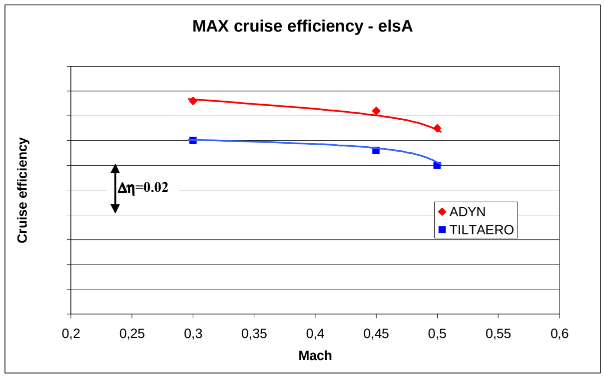

Fig. 14: Maximum cruise efficiency vs. advancing Mach number computed by CFD (*elsA*)

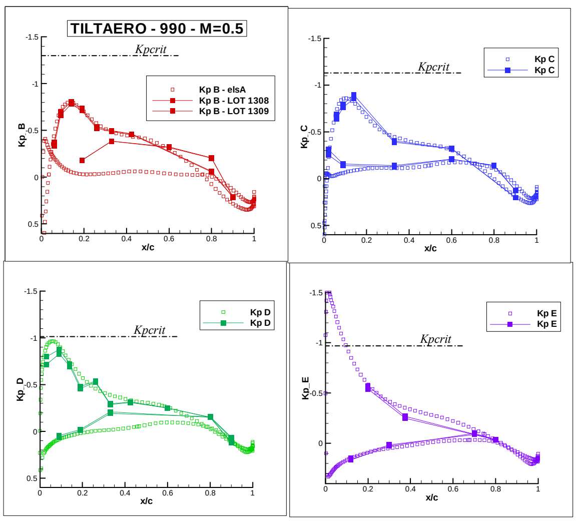

Fig. 15: Comparison of pressure distributions on the Tiltaero rotor at M=0.5

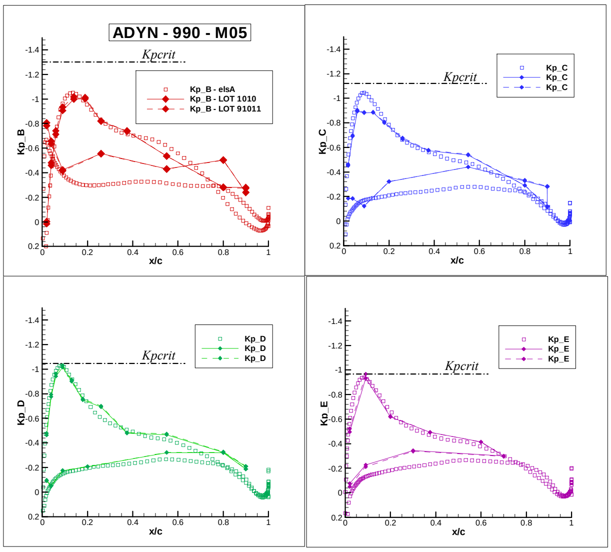

Fig. 16: Comparison of pressure distributions on the Adyn rotor at M=0.5

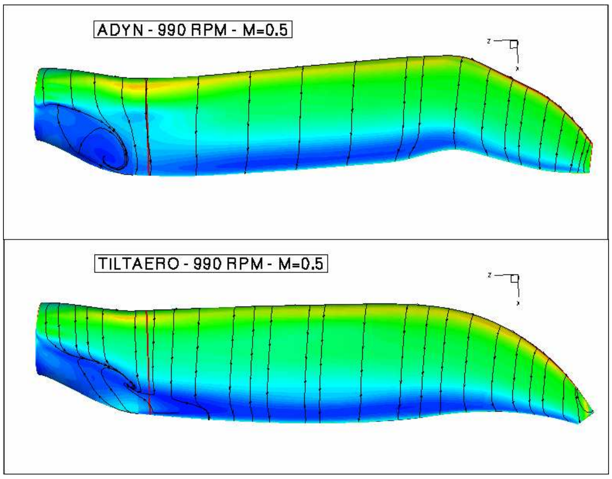

Fig. 17: Skin friction lines on the Adyn and Tiltaero rotors at M=0.5

3 Aerodynamic Interactions at Low Speed

The study of aerodynamic interaction on the ERICA tilt-rotor was the main objective of the Tiltaero tests, which took place in the DNW-LLF, using the half-span model illustrated in Fig. 10. Prior to the tests, a blind-test numerical activity was done [6] during which the Tiltaero partners selected a total of 6 flight conditions located in the conversion corridor for numerical analysis. These conditions are listed in the table below, and have then been tested in the wind-tunnel. While progressing in the conversion corridor, the nacelle angle is of course reduced from quasi vertical position in hover (87°) to horizontal position in level flight (-3°), and the advancing Mach number is progressively increased. Note that test point TP7 is a low speed cruise flight condition. The main aerodynamic interactions occurring for these tests points are analyzed in the following paragraph.

#	Test case	Nacelle angle	advancing Mach number
TP1	Hover	87°	0
TP2	1st conversion	82°	0.078
TP3	2nd conversion	71.9°	0.127
TP4	3rd conversion	57°	0.169
TP5	Last conversion	42°	0.187
TP7	Cruise flight	-3°	0.17

3.1 Rotor-nacelle-wing interactions on the reference geometry

Numerical method

Navier-Stokes computations with the CFD code *elsA* were run with a quasi-steady approach to model the rotor, using an actuator-disk approach [7]. It represents the rotor loads which are averaged in time and applied on a surface grid in a steady flow computation. Due to the steady-state assumption, a great reduction of computation cost is achieved by comparison with an unsteady computation of the flow around rotating blades. The boundary condition formulation behaves like a usual interface and the actuator disk source terms are simply added to the residuals for the cells lying below the actuator disk surface. The source terms which model the discontinuities of the flow field are calculated by blade element theory with the HOST comprehensive code allowing either a uniform global lift or evolutions in the radial and azimuthal directions on the disk (non-uniform actuator disk). In the present study, a uniform actuator disk has been used to perform the different test cases.

The construction of a multi-block mesh around complex geometries is difficult and needs a good know-how. The Chimera method allows simplifying the process of mesh generation by using a cartesian background grid, on which we can overlap additional body parts, the nacelle, the two wings, the wind tunnel support and the actuator disk (Fig. 18). The cartesian background grid contains a total of about 1 Million points distributed in 6 blocks. The nacelle 'O-grid' topology contains a total of

about 3 Million points distributed in 10 blocks. The fixed wing is meshed in a 'C-H' topology and has a total of about 1.4 Million points distributed in 8 blocks whereas the tiltable wing has a total of about 1.3 Million points distributed in 8 blocks. The wind tunnel support is meshed in a 'C-H' topology and has a total of about 500.000 points distributed in 10 blocks. The gaps between the wind tunnel support, the two half wings and the nacelle are also modelled. The actuator disk grid has a total of 150.000 points distributed in 4 blocks. The computations require about 2µs/point/iteration CPU time on a NEC SX-8 computer with about 10Go memory (3000 iterations require about 14 CPU hours for a total of 7.3 Million points).
Among the several turbulence models available in *elsA*, the Wilcox k-ω model with SST correction was chosen.

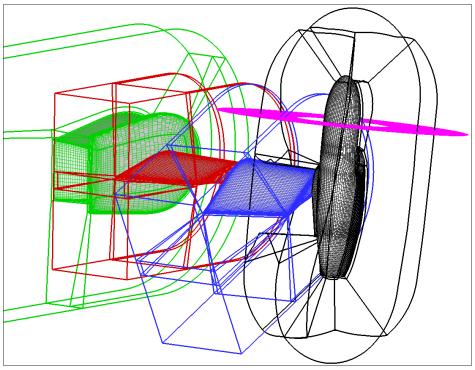

Fig. 18: The TILTAERO half-span grid system

Discussion

A view of the computed flow-field for the 4 conversion tests points is presented in Fig. 19. The solid surfaces are colored by density values, and streamlines in vertical planes perpendicular to the outer tilt-wing (the one close to the nacelle) are plotted. For the very low speed cases (mainly TP2 and TP3), very clear flow recirculation is observed on a large part of the tiltable wing. The recirculation tends to be progressively eliminated when the nacelle is more tilted (TP4 and TP5), and disappears completely in level flight (TP7). The induced flow separation generates oscillations on the lift and drags coefficients of the tiltable wing, and may create some instability for the corresponding flight conditions.

The computed lift distribution on the wings is compared to experiment in Fig. 20 for TP4 and TP7: the agreement is fair (averaged value is correctly predicted). Improvement can be expected thanks to the use of a non-uniform actuator disk modeling.
Quite interesting is the comparison of the pressure distributions in Fig. 21 for TP4. The lift over-estimation for the most inboard sections A and C is confirmed, and the separation on section H close to the nacelle junction is illustrated in the experimental pressure distribution by an almost constant pressure area. On section H, predicted pressure distributions show some oscillations, due to the unsteady nature of the flow which would only be correctly captured by a time accurate computation (instead of steady one used here).
The origin of the outer wing separation has been carefully studied during the blind-test numerical activity of Tiltaero. It has been shown that it is not due to rotor-wing interference, since similar flow recirculation is obtained even without actuator disk in the calculation. It has been shown that the origin of the separation lies in the nacelle-wing interaction.

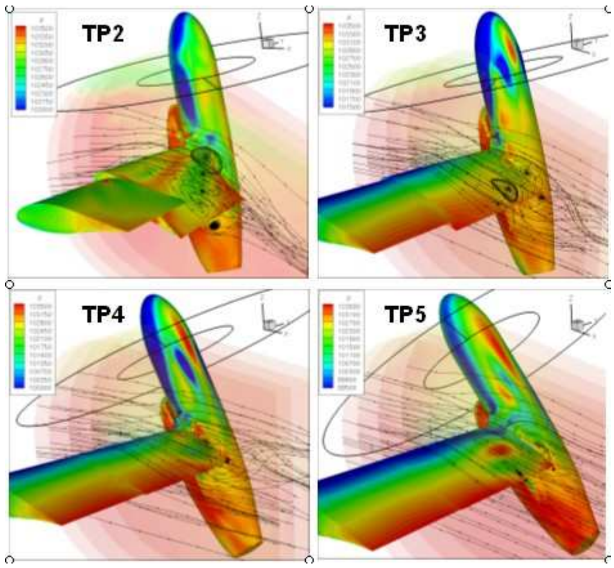

Fig. 19: Flow-field analysis of test points in the conversion corridor

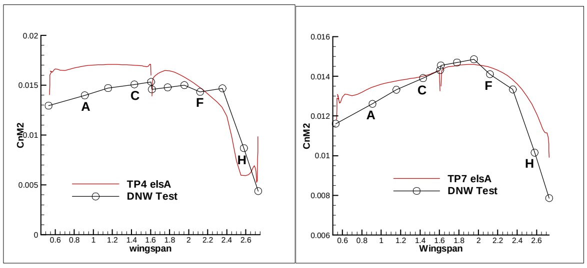

Fig. 20: Lift distribution for TP4 and TP7

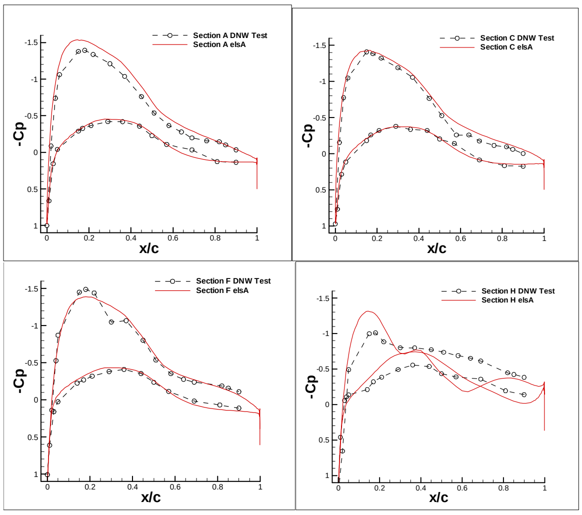

Fig. 21: Pressure distributions for TP4

3.2 Possible geometry improvements

Two modifications of the reference Tiltaero geometry have been investigated in order to try to limit the flow separation occurring of the tiltable wing for low speed conditions. The first one consists in eliminating the wing-nacelle junction plotted in red in Fig. 22, which originally rotated with the nacelle, and to fill the corresponding gap by an extension of the outer wing (which does not rotate with the nacelle). The second one was to add an end plate (black part in Fig. 23) at the most outboard part of the tiltable wing.

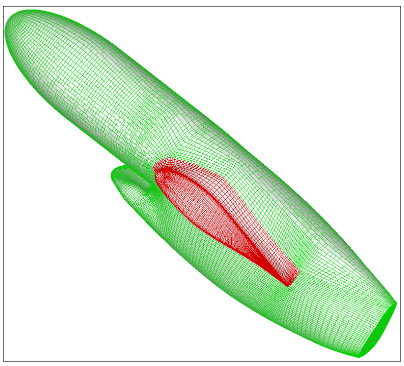
Fig. 22: Original wing-nacelle junction in red

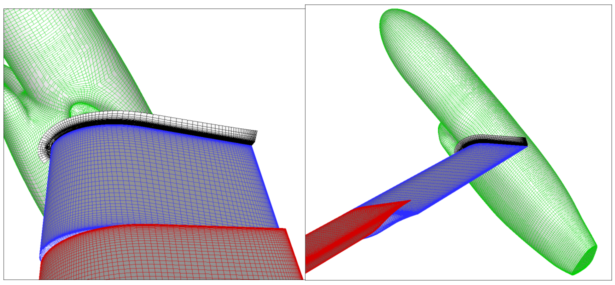
Fig. 23: End plate in black (left). End plate and smooth wing-nacelle junction (right).

The result of the cumulated modifications is presented in Fig. 24, where it can be seen that the flow separation is almost completely eliminated on TP3. Similar results have been obtained for all tests points in the conversion corridor.

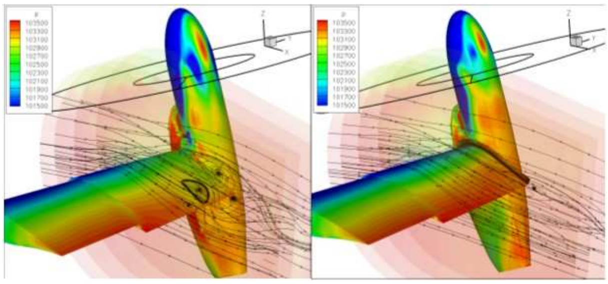
Fig. 24: Influence of end-plate and smooth wing-fuselage nacelle on TP3. Left: original geometry. Right: improved geometry

The influence of these modifications on the lift and drag coefficients of the configuration has been quantified. A 20 to 30% nacelle drag reduction is predicted, together with a 25% lift increase of the tiltable wing. Furthermore, the modifications make the low speed flight cases more stable, since loads fluctuations are almost eliminated. These modifications are likely to be introduced in the next versions of the ERICA tilt-rotor to be studied in the Nicetrip project.

4 Concluding Remarks

Thanks to several European programs, considerable expertise on tilt-rotor has been gathered at ONERA.

The numerical methodologies already developed for helicopters and propellers have been successfully applied to design aerodynamically and acoustically efficient tilt-rotor blades. The experimental results obtained in the Tiltaero and Adyn projects confirmed the high hover and cruise performance of the Adyn blade design, however emphasizing the need for a specific optimization of the cuff (inner part of the blade) to reduce flow separation in high speed cruise flight: such an activity is part of the on-going Nicetrip project.

A study of the aerodynamic interactions on the Tiltaero half-span model revealed significant flow separation on the tiltable wing, for the first tests conditions of the conversion corridor (very low speed). This separation was confirmed by the wind-tunnel tests. Promising modifications of the design have been investigated, which almost eliminate the observed flow separation, and should be accounted for in the next ERICA versions studied in the Nicetrip project.

The numerical activities also underlined all the benefit that can be taken by applying CFD methods as early as possible in the design process.

References

[1] Beaumier P and Bousquet J-M. Applied CFD for analysing aerodynamic flows around helicopters, *24th International Congress of the Aeronautical Sciences*, Yokohama (Japan), September 2004

[2] Prieur J and Splettstoesser W.R. ERATO: an ONERA-DLR co-operative programme on aeroacoustic rotor optimization, *25th European Rotorcraft Forum*, Roma (Italy), September 1999

[3] Lefebvre T et al. Aerodynamic and aero-acoustic optimization of modern tilt-rotor blades within the ADYN project. *ECCOMAS 2004*, Jyväskylä (Finland), July 2004

[4] Beaumier P and Delrieux Y. Description and validation of the ONERA computational method for the prediction of blade-vortex interaction noise, *29th European Rotorcraft Forum*, Friedrichshafen (Germany), September 2003

[5] Lefebvre T et al. Experimental investigation of aerodynamic interactions on a tilt-rotor configuration and comparison with Navier-Stokes computations. *33rd European Rotorcraft Forum*, Kazan (Russia), September 2007

[6] Visingardi A, Khier W and Decours J. The blind-test activity of Tiltaero project for the numerical aerodynamic investigation of a tilt rotor. *ECCOMAS 2004*, Jyväskylä (Finland), July 2004

[7] Decours J and Lefebvre T. Navier-Stokes computations applied to tilt-rotors. *33rd European Rotorcraft Forum*, Kazan (Russia), September 2007

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