ERICA: THE EUROPEAN ADVANCED TILTROTOR

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ABSTRACT

Driven by the US effort, the tiltrotor vehicle will open a new perspective in the aeronautical market of the next years. After a long development phase, this innovative aircraft will give a new impulse to the civil market, opening new opportunities and creating space for new roles for the exploitation of all the potentialities of the formula.
Today Europe, partner of the US BA609 project, has an unique chance to assume the leadership in this promising technology by improving the tiltrotor architecture, with the aim to even increase its safety, productivity and handling qualities. The European advanced tiltrotor configuration ERICA will be presented in details describing the driving requirements that inspired the design, the goals of the project and the features that make it a real step forward in the V/STOL aircraft landscape. Performance, vehicle general architecture and sizing, rotor aerodynamic and dynamic design, aircraft structural stability will be presented together with a review of the methodologies developed and utilised for the analysis of this innovative concept.
A comparison with a more conventional design will complete the document here proposed.

WHY TILTROTOR?

The continuous growth of the passenger traffic will cause, in the next years as recognised by all the experts in all the Countries, the existing airport congestion. There are two ways to improve the airport capacity: to expand the airport areas themselves, with the related concerns for space, environment and social impact or to improve the efficiency of actual sites. The tiltrotor is a means to pursue this second way. On the contrary of the other commuters, which carry few passengers with respect to the bigger aircraft's, but engage the same runaways and routes, the tiltrotor merges the ability to take off and land in confined narrow areas, that can be prepared within the actual airport borders, and to flight simultaneous non interfering procedures with conventional aeroplanes. The possibility to direct the thrust of its propellers within a range of about 100 degrees from the horizontal position to the vertical one, gives the tiltrotor the opportunity to perform vertical (or short) take off and landing still cruising like an aeroplane.
In the framework of this scenario, the existing tiltrotor vehicles will entry into service in the next 5 to 10 years. They took about 15 years to complete the full development (V22, BA609) and about 45 years of research and vehicle architecture consolidation.

WHY ERICA?

The tiltrotor technology had to come down to a compromise to get the hover and near to hover flight capacities of the helicopters and to achieve the ability to flight like an aeroplane in cruise, such that the performances attainable by an helicopter or an aeroplane, of the same class, are rather far. Nevertheless little changes to the present architecture are envisaged in the next 5 to 10 years. Since it is a compromise, some drawbacks are inherent in the design and, so, there are some possible fields of enhancement: safety, performance (i.e. hover efficiency, productivity, maximum speed), handling qualities.

Present tiltrotor drawbacks

To cruise at higher speed than an helicopter the tiltrotor must pay a tribute in performance: its hover efficiency, and consequently the maximum Pay-Load transportable, is limited by the high download induced by the rotor wake impinging on the wing that is necessary, in forward flight, to furnish the required lift no more guaranteed by the tilted rotors.
On the other hand the productivity of any commercial aircraft, real key parameter able to determine the success of a product on the Market, is a function of Pay-Load and speed; tiltrotor productivity (higher than the one of helicopters but lower than commuters) can be further improved by increasing speed, payload or both. A reduction of the interference phenomena in hover, increasing the

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Pay-Load, can, surely, improve the productivity like any increment of the cruise speed of the aircraft.
The rotor disk loading, together with the aerodynamic efficiency and the dynamic aspects, result to be, so, essential in the definition of aircraft productivity.
The handling qualities suffer troubles especially at low speed: the combination of forward speed with the rotor induced velocity imposes high negative angle of attack to the wing, that experiences stall, wake buffeting, oscillatory loads and high drag. This stall phenomenon affects the width of the conversion corridor at low speeds and also limits the flight path management, claimed as a promising feature for the noise abatement control by the mitigation of blade vortex interaction (BVI) noise radiation during the approach [a]. The helicopter mode autorotation is another outstanding condition: because of the high rates of descent great positive angles of attack are generated on the wing (i.e. high lift) reducing the required rotor thrust needed to balance the vehicle and causing difficulties in reaching stable autorotative conditions.
The large diameter of the rotors, that in actual tiltrotors is necessary to guarantee acceptable hover performance in presence of high wing/rotor interference, prevents the landing in aircraft mode, thus reducing the "perceived level of safety" of such kind of vehicles. Furthermore, the conversion from aircraft to helicopter mode in power-off condition results difficult still maintaining the autorotation status of the rotors. This problem, due to the aerodynamic environment in which the rotors are working, even if extremely remote in real operations, is recognised as a possible limitation and addressed also during the EUROFAR studies.

Way of improvement

Starting from the observations carried out above, Agusta conceived a new architecture, which addresses sensible improvements in those key fields that determine the successful of an aircraft. ERICA (**E**NHANCED **R**OTORCRAFT **I**NNOVATIVE **C**ONCEPT **A**CHIEVEMENT), Figure 1, has been designed following the guide lines of the European Community [EC] technical committee, which issued a draft specification for a tiltrotor of 10 tons, able to range 600 NM to fill the technological gap existing with the US. After a first phase in which different approach to the problem were proposed and compared, the ERICA innovative concept has been selected by the European helicopter Industries to meet the EC requirement and a number of basic research and technological development projects were proposed under the aegis of the European 5th Framework Program with the aim to assess the potentialities of the idea in view of the manufacturing of a flying demonstrator in the next future.

The features that differentiate ERICA from the existing tiltrotor configurations and, collectively, allow the future exploitation of the tiltrotor concept and role can be grouped under three major branches:

- **structural continuity of tilting mechanisms**
  (safety, system simplification, weight reduction)
- **reduced rotor diameter**
  (performance in cruise, delay of instability problems , weight reduction)
- **tiltable wing** (performance, handling qualities)

Figure 1: Artist impression of the ERICA concept

The structural connection of the two proprotors, obtained by mean of a continuous tubular spar that connects the two nacelles and is able to rotate around suitable bearings housed in the fixed part of the structure, leads to a simplification of the system by removing the need of the synchronisation mechanism, thus inherently improving the safety.
The reduced diameter of the rotors has the scope to increase the productivity of the aircraft, because it allows the improvement of the performance in aircraft mode (i.e. speed), due to a better efficiency of the propeller (better disk loading in cruise mode) and to the enhancement of the flight envelope obtained thanks to the enlargement of the stability boundary concerning the whirl flutter phenomenon. Furthermore the small rotor diameter, assuring a consistent clearance of the tip of the blade with the ground, even with the nacelles in A/C mode, allows ERICA to follow the procedures typical of fixed wing aircraft for take off and landing, giving an appreciable improvement in productivity and versatility and improving the safety (especially in emergency condition); as smaller is the rotor diameter as consistent is the weight saving that can be accomplished thanks, both, to the direct effects on the system and to the less demanding pylon stiffness requirements. The reduction of rotor diameter is facilitated by the tiltable wing, that improves "helicopter mode" performance by means of a reduced download and allows an enlargement of the conversion corridor (low speed part) and an improvement of the autorotation characteristics in helicopter mode that can be accomplished

optimising the angle of attack of the tiltable wing inside the flow stream in every condition of flight.

The goals of the ERICA design are to get the minimum rotor diameter, still compatible with high manoeuvrability in helicopter mode, to improve the forward flight efficiency; to reduce to the minimum the interference effects optimising the force sharing of the lifting systems (i.e. wing and rotors) by independently tilting the outboard portions of the wing; to maximise the payload reaching the minimum structural weight and reducing complexity by mean of the optimisation of the load path. The proposed innovations reduces the download from 14% of conventional configuration to less than 1% typical of ERICA, allowing a proportional increment of the payload; improves the speed up to 350 knots at cruise altitude and increases the autorotation performance. The handling qualities are improved thanks to the additional degree of freedom in ERICA; the independent tilting of the wing with respect to the tilting of the nacelles allows the optimisation of the angle of attack both of rotors and wing preventing the stall and wake buffeting of the wing at low speed and improving the rotor performance.

The safety and the operational capabilities reach completely new standards, because the reduction of the rotor diameter allows to follow, when considered suitable or economical, the aircraft landing and take off procedures, option able to dramatically increase the productivity of the vehicle when a Vertical Take Off manoeuvre is not mandatory; this possibility results, as it is simple to understand, really of vital importance in case of complete power loss.

Design Operational Requirements

ERICA has been designed to meet the following requirements:

- Point to point connection
- Limited amount of hover if compared with forward flight (5% vs. 95%)
- High productivity (greater than existing helicopters [H/C] & Tiltrotors [T/R])
- High speed and range (350 knots & 650 N.M.)
- 19 passengers in VTOL & 22 passengers in STOL configuration
- Cruise at high altitude (7500 m)
- VTOW: 10,000 kg; STOW: 11,000 kg
- Adaptability at different roles to expand the market possibilities:
  - Search and rescue (at high/medium radius)
  - Paramilitary
  - Medevac
  - VIP
  - Corporate

Design criteria

The following criteria guided the design:

- Design for noise minimisation (internal and external)
- Design for minimal environmental impact
- Capability to operate with minimal ground infrastructures
- Maximise passengers comfort
- Enhanced public acceptability and "perceived safety"

ARCHITECTURE AND SIZING

ERICA, Figure 36, has been conceived for the passenger transport. It is able to carry up to 22 people with their luggage for an eventual transatlantic cruise; such a requirement for the luggage has been considered foreseeing that one main role of ERICA will be the connection of peripheral areas with intercontinental airports.

The other driving requirements are the range, that shall be greater than 650 Nautical Miles, the cruise altitude fixed at 7500 m to avoid meteorological phenomena and the design cruise speed of 350 knots required to get the highest productivity possible.

These basic design criteria led to the following sizing of the aircraft (masses are in kg):

- Design gross weight (VTOL) 10,000
- Maximum gross weight (STOL) 11,000
- Payload (19 passengers + luggage) 1,900
- Max Payload STOL (22 pax + luggage) 2,200
- Crew (2 + 1) 200 + 100
- Fuel (VTOL) 1,400
- Fuel (STOL) 2,000
- Empty weight 6,500

Fuselage

The shape of the fuselage has been conceived with a double curvature to stow the luggage under the cabin floor in order to gain space and to get an easier control of the aircraft balance. The cabin has been arranged with four seats abreast after a long trade off that considered also the solution with three seats. Both arrangements guarantee a satisfactory height of the aisle for standing people, but the chosen layout appear more efficient form a structural point of view (so lighter); comfortable and safe for passengers (good arrangement of emergency exits, more space for the cabin luggage) and, most of all, allows a better management of centre of gravity position, parameter of extreme importance for a tiltrotor as the EUROFAR studies have highlighted. The cabin is provided with a galley and a toilet; it has 22 seats plus one jump seat for the crew (Figure 37). The fuselage results wider and shorter with the four seats abreast arrangement; this is helpful in gaining the suitable clearance of the propellers from ground, even in aeroplane configuration, but it does not

significantly penalise the aerodynamics efficiency of the aircraft, because the widening is quite acceptable and well balanced by the shortening (less wetted area) of the fuselage.
The preliminary dimension of the present configuration are:

- External dimensions:
  - fuselage length 15.2 m
  - fuselage diameter 2.7 m
- Cabin interior dimensions (passengers):
  - length 6.7 m
  - width, maximum 2.5 m
  - width, at floor level 2.1 m
  - height, maximum 1.95 m
  - volume 31.1 m^3
  - floor area 15.8 m^2
  - number of abreast seats 4

Wing[1]
As for all tiltrotors, ERICA has an high wing to accommodate the propeller dimensions. The wing has tapered platform and thickness to increase efficiency in forward flight. The outboard portion of each half wing, the part directly below the rotor disc, can tilt independently from the nacelles to get an optimised angle of attack in each condition of flight. A tube, structurally continuous, is the main spar of the wing, it supports and rotates the nacelles that are clamped on it; the tilting portions of the wing rotate around this tube. The inner portion of the wing has a conventional composite box structure carrying the bending loads transferred from the outboard portion of the tube. The torsional moments coming from the rotors are reacted by the nacelles tilting actuators grounded on the main structure. The tube, as already said, is structurally continuous through all the wing and connects the nacelles. The inner (fixed) portion of the wing accommodates the fuel tanks. This architecture allows to keep the systems swivel joints far from the hot surfaces near the engines with a sensible improvement in safety. In fact the continuity between the nacelles and the tube allows to connect rigid and continuous hydraulic and fuel pipes to the tube itself so making the designers free to chose the best position for the elastic joints. A key improvement for the performance comes from the reduced thickness of the wing with respect to the conventional tiltrotors, obtained thanks to the smaller diameter of the rotor that drives a less demanding dynamic requirement (whirl flutter) with a substantial reduction of wing required stiffness that permits a less thick airfoil with benefits in terms of aerodynamics and weight.

[1] European patent application N° 00111548.4 filed on 30/05/2000; Us patent application N° 09/585,850 filed on 01/06/2000; Japanese patent application N° 2000-170438 filed on 02/06/2000.

The main characteristics of the wing are summarised below:

- Effective area: 35 m^2
- Span: 14 m
- Root chord: 3 m
- Tip chord: 2 m
- Twist: 0°
- Sweep at 25% chord: 0°
- Thickness / chord ratio at root: 21%
- Airfoil: AG Design

Rotors
The other key characteristic of ERICA is the smaller diameter of its rotors with respect to an actual tiltrotor typical design. The rotor hub, is a new innovative concept patented by Agusta that makes a large usage of composite and elastomeric components; it is an homo-kinetic, gimballed system.
The rotor is a four bladed, stiff in plane type, with the stiffness driven by a tailored chord rigid yoke. The pitch degree of freedom, controlled by an external cuff through an inner pitch arm, is designed to get the most compact arrangement still compliant with the stringent pitch-flap coupling requirements that this kind of vehicle demands.
The four blades of each rotor are highly twisted and highly sculptured to provide optimum performance both in helicopter and in aeroplane flight modes. Their complex platform was studied in order to reduce the compressibility effects in forward flight and to achieve the requirements in terms of the noise emission. The airfoils are design by Agusta.
The rotating controls are conventional, similar to the ones of helicopters; the pitch is imposed to the blades by tracking rod driven by a swashplate. Nevertheless, the control architecture definition is a demanding task, because of the very large range of the blade collective pitch dictated by the high normal inflow seen by the rotor in aircraft mode.
More details on the optimisation process followed will be provided in the paragraph dedicated to the aerodynamic design of ERICA components.
The rotor main characteristics are summarised below:

- New generation Gimbal Homo-kinetic hub
- Stiff in plane rotor
- Blade platform: not conventional with an highly sculptured shape
- Non linear twist distribution, total value: –35°
- Number of blades per rotor 4
- Diameter 7.4 m
- Disc area 43.01 m^2
- Mean blade chord (thrust weighted) 0.522 m
- Solidity (thrust weighted) 0.18

- δ_3 - 18°
- Total twist (non-linear distribution) - 35°
- Airfoils: Agusta 3rd generation airfoils family distributed from 12% to 7% thickness along radius

Tail planes

The trade off brought to a T-tail configuration as the best solution for such kind of aircraft. The tail planes have been designed to trim and control the aircraft in every flight condition avoiding tail stall. This requirement has been applied to each possible combinations of weight, load factor, cg position, speed, altitude, nacelle tilt position, wing tilt position, flap position both for power-on and power-off. Tail planes have been sized to comply with level 1 of ADS33 in terms of stability versus short, long period oscillations and, naturally, Dutch-roll motion both in aeroplane and in helicopter mode.
The resulting areas, at actual stage of the study, are:

- horizontal tail plane 7.5 m^2
- vertical tail plane 7 m^2

AERODYNAMIC DESIGN

Fuselage

The aerodynamic design of the fuselage and the setting-up of the associated data base for the performance prediction, took advantage of the previous project developed in Europe under the aegis of the European Community: the EUROFAR collaboration program.
The data collected during the intensive wind tunnel campaigns used to define the EUROFAR characteristics were adapted to the ERICA configuration by mean of limited new tests, conducted into the Agusta facility, and with the usage of CFD tools to define the matrixes of aerodynamic coefficients necessary to all the flight mechanic codes for the simulation of the manoeuvres and the calculation of the flying qualities and performance.

Wing airfoils

Given the high speed requirements of the ERICA vehicle combined with the stringent capabilities required at low speed to enlarge the conversion corridor and to improve the handling qualities during this critical and delicate phase of the flying envelope of the tiltrotor, particular attention has been devoted to the definition of a new airfoil for the ERICA wing.
The optimisation has been performed by means of the M-SES commercial code; the inverse design capability of this tool has been exploited in conjunction with an in house genetic optimisation algorithm (DESPOTAX) specifically conceived for the aerodynamic problems solution.
The verification of the results and the final refinement of the chosen configuration has been obtained by the ZEN code: a 3D NAVIER-STOKES program developed by CIRA and coupled, again, with the DESPOTAX code.
A multi-objectives optimisation (4 points) technique has been implemented maximising the efficiency of the airfoil at relatively high Mach number (M=0.6) and low angle of attack in cruise (α=3°) and imposing low drag and high lift capabilities at low speed and high angle of attack for the conversion and the landing manoeuvre. A third aerodynamic point of check has been chosen in autorotation being, this situation of flight, surely extremely critical for the tiltrotor aircraft.
The fourth optimisation point concerned the geometrical constraints that were imposed with the aim to control the airfoil internal area, in order to maximise the available space inside the wing for the housing of fuel tanks, while maintaining to a minimum, still compatible with the typical dynamic requirements for the tiltrotor formula, the thickness of the profile to improve the aerodynamic efficiency.
The evaluation of the effects of the trailing edge flaperon completed the developed analysis.
The resulting 21% airfoil shape is shown in Figure 2, below.

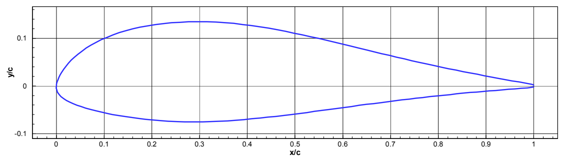
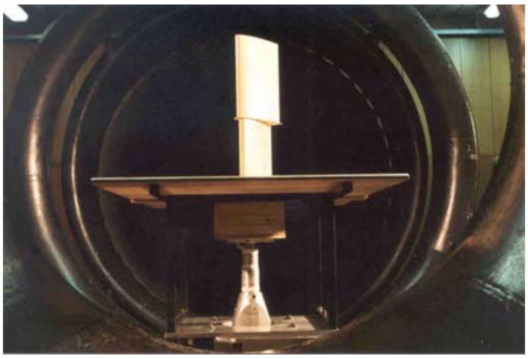


Figure 2: Optimised wing airfoil shape

Interference aspects

As well known, the interference phenomena assume an extreme importance in the definition of the performance and the flying characteristics of a tiltrotor due to the large portion of the wing impinged by the rotor wake. On the other hand the flow distortion seen by the rotor and caused by the presence of the wing itself, can directly affect the performance of the proprotor impacting on the stability, the performance and the loads acting on the system and on the whole aircraft.
For this reason it has been decided to dedicate a large effort to include, as much as possible, all these phenomenology into the design just from the first phase of the study.
The interference model part of the CAMRAD/JA code, the tool utilised all along the predefinition and feasibility part of the ERICA project, was based largely on empirical formulas as is of common practice in the helicopter development.
Being this methodology judged no longer sufficient, a new code, to be used as a pre-processor of CAMRAD/JA, was designed and realised.
The code, named TWICER, by means of recursive iterations, calculates the angle of attack along the

wing span and, with a lifting line method, provides all the aerodynamic coefficients of the fixed and the movable part of the combined surface; the spatial components of the induced velocity are evaluated at the rotor disc and passed to CAMRAD/JA, that provides the calculation of the forces, the flap angles and the moments generated by the rotor subjected to the distorted flow field. These quantities are used in the subsequent aircraft trim.
The intensity of the rotor wake is than assessed and passed to the TWICER for the subsequent external computation. For each trim point the process is recursively repeated until a stable, converged solution is reached (Figure 27).
The code was tested using other commercial programs available in AGUSTA, like VSAERO, and with the experimental results of a wind tunnel campaign dedicated to the interference problems investigation. These tests were set-up in the Agusta wind tunnel with a 1/10 model of the half span wing complete of the fixed and movable parts (see installation photos). The rotor flow field was also simulated using hardware already available in the laboratory.
The correlation with other methodologies and with the experimental data was extremely encouraging, as the following figures show.



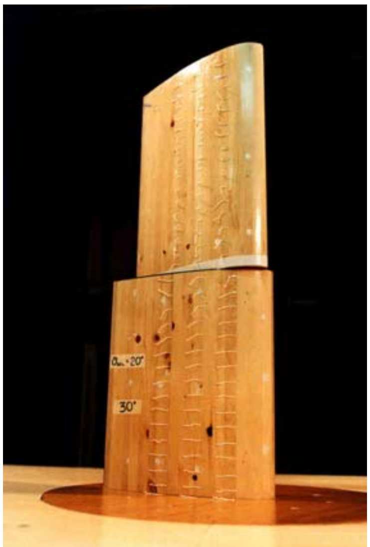


Figure 3: Wind tunnel tests on ERICA wing

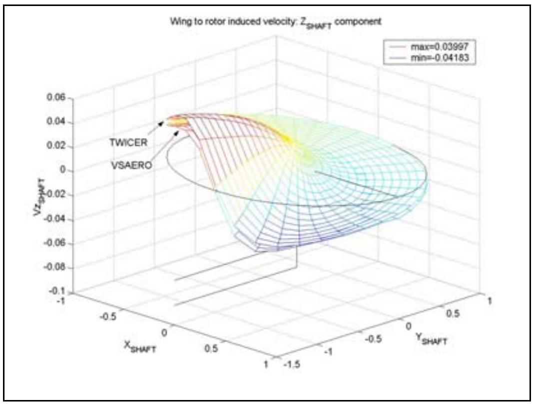


Figure 4: correlation Twicer vs. VSAERO

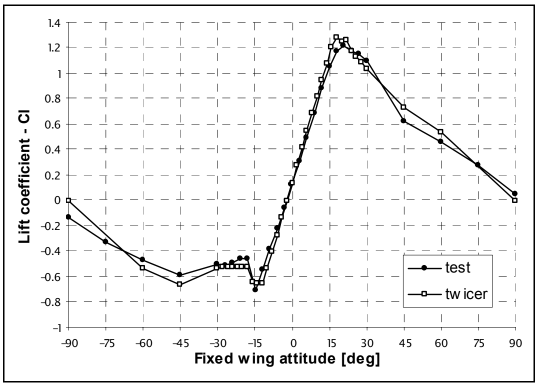


Figure 5: Wing Cl-α for tilt wing at 0 deg.

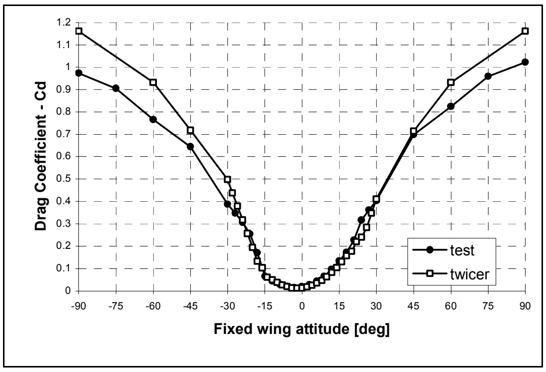


Figure 6: Wing Cd-α for tilt wing at 0 deg.

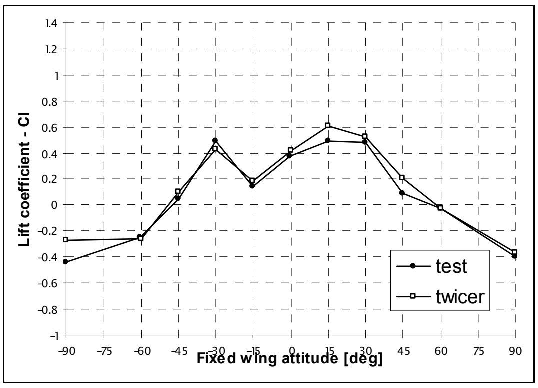


Figure 7: Wing Cl-α for tilt wing at 60 deg.

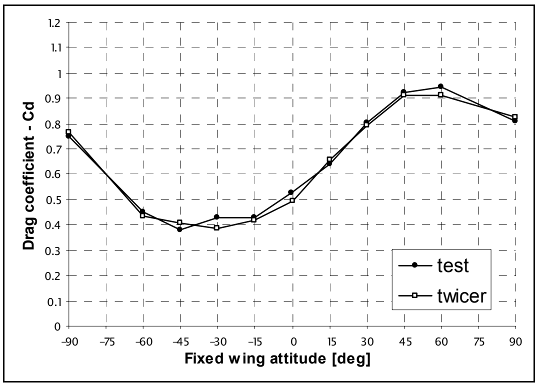


Figure 8: Wing Cd-α for tilt wing at 60 deg.

Rotor aerodynamic optimisation
Due to the innovative concept of the ERICA formula and to the stringent requirements imposed to the concept by the necessity to generate a vehicle more efficient, productive and so profitable for the market of the next ten years, the aerodynamic design of the ERICA rotor was undoubtedly a very demanding task.
As already mentioned the requirement to land and take-off like an aeroplane, the real point of strength of the ERICA concept, able to improve the safety and the productivity of the tiltrotor, with its implications on the rotor diameter, had a deep impact on the rotor design process.
Naturally the previous history of the tiltrotor development has been properly considered trying to avoid or at least to minimise, from an aerodynamic point of view, the known problems of the machine.
The requirements utilised in the ERICA rotor system conception can be summarised as follow:

- **Minimisation of rotor diameter**: to allow take-off and landing in A/C mode with safety and productivity enhancement.
- **Maximisation of the rotor thrust at low speed**: for controllability and vortex ring delay
- **Cruise propulsive efficiency maximised**: for optimum A/C mode performance
- **Noise index minimised**: for comfort and public acceptability
- **Minimum oscillatory loads transmitted to pylon**: for comfort and fatigue life
- **Dynamic de-coupling of rotor/wing modes**: for stability and whirl flutter delay

The DESPOTAX procedure, coupled both with an in house developed code for rotor analysis and with CAMRAD/JA, has been utilised for the definition of the aerodynamic design parameters of the rotor blade including:

- **platform**
- **twist**
- **airfoil distribution**

The design points, according to the goals above described, were:

- Maximisation of the efficiency at high speed high altitude in cruise mode (low rotor RPM)
- Maximisation of the hover figure of merit (high rotor RPM)
- Maximum thrust of the rotor in hover not less than a fixed percentage of the total weight of the aircraft
- Minimisation of the rotor noise index
- Control loads reduction

The results of the optimisation process led to the results already mentioned in the previous chapter.
For the present baseline, Agusta third generation airfoil family has been used in the analysis. A parallel work related to the design of a new generation of airfoil specifically thought for the application on the tiltrotor propulsion system, where the particular conditions of the flow and the wide flight envelope are the dominant aspects, was started in the meanwhile, with the aim to further increase the efficiency of the whole vehicle such to reduce together with the engine installation weight, the power and the fuel consumption, with a net benefit on the aircraft take-off weight and, again, productivity.

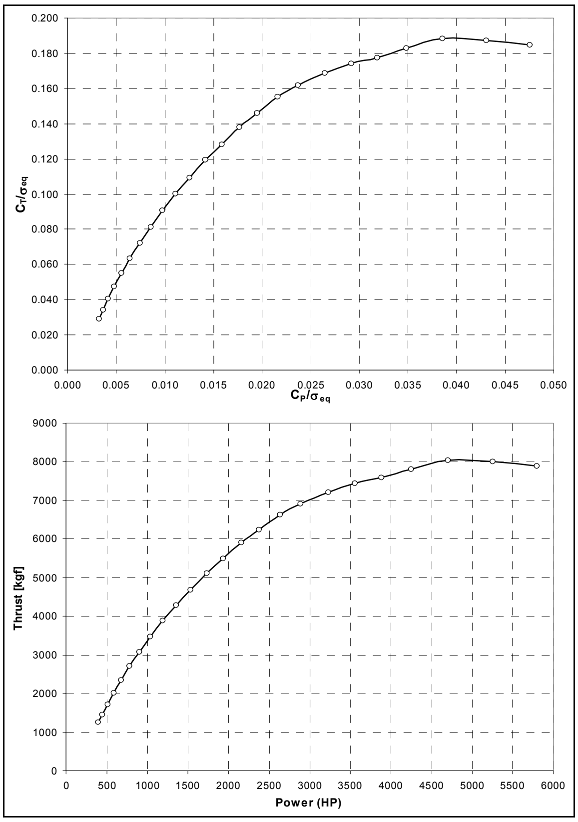


Figure 9: Rotor performance in helicopter mode

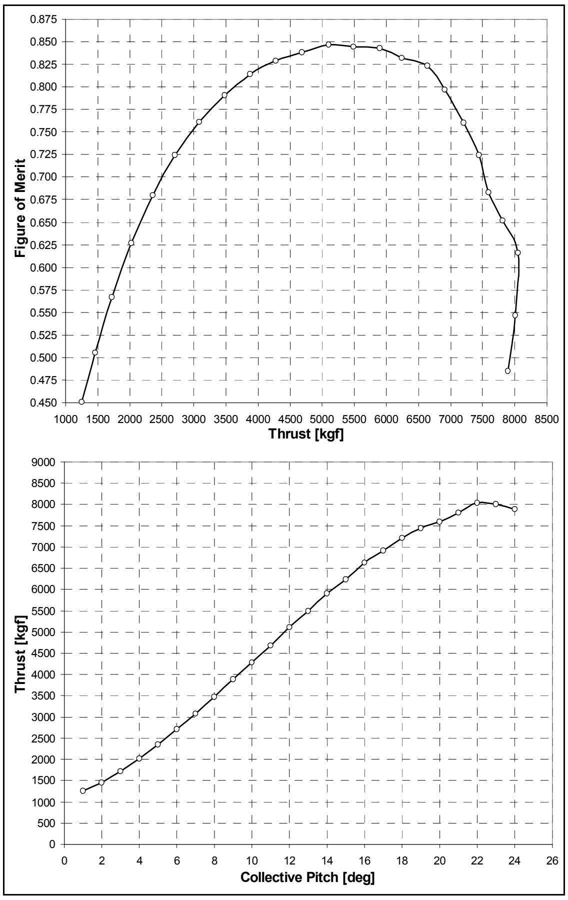


Figure 10: Rotor performance in helicopter mode

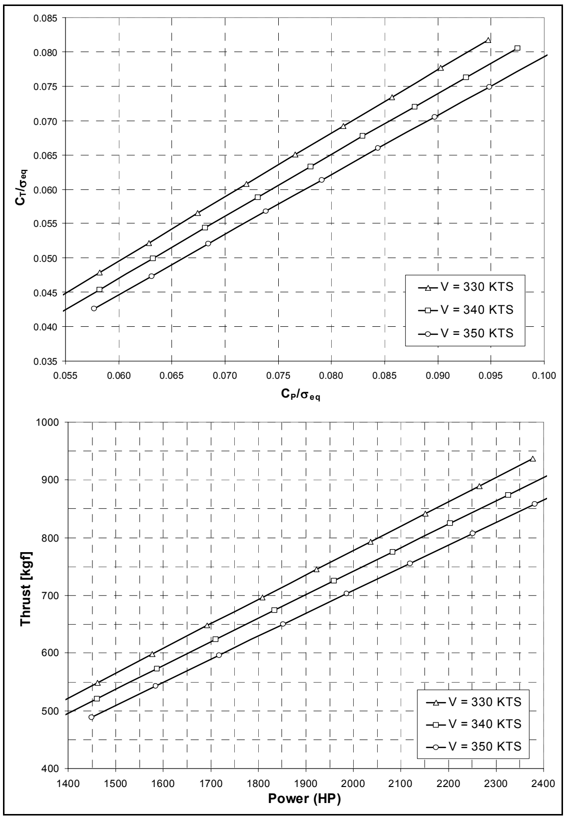


Figure 11: Rotor performance in aircraft mode

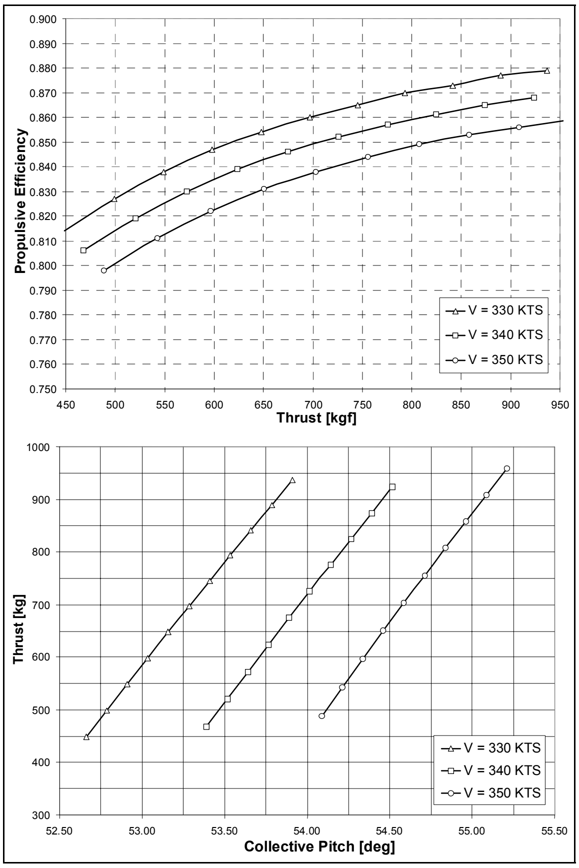


Figure 12: Rotor performance in aircraft mode

DYNAMIC DESIGN

Fifty years of development have taught us that the dynamic design of the tiltrotor is the most important task that engineers have to face with.

This aspect is so important that in some cases the performance of the vehicle, in aircraft mode, are limited by the onset of dynamic instabilities more than by aerodynamic or installed power constraints.

As it is well known, the most important phenomenon is the whirl flutter; a torsion/bending motion of the wing coupled with the rotor flap motion that takes place at high speed and can become unstable at certain flight regimes.

The control of the whirl flutter motion obliged the designer to choice a particular hub configuration (gimballed) and to increase the stiffness of the wing with the related weight increment and the degradation of the aerodynamic efficiency due to the required very high airfoil relative thickness. Naturally the sizing of the rotor has a sensible impact on the boundary of existence of the phenomenon.

In this sense the ERICA configuration can give very high benefits: the reduced rotor diameter can postpone the birth of the instability giving, at the same time, the double benefit of a reduction of the stiffness requirements for the wing (lower weight,

higher aerodynamic performance) and of an allowed higher speed of flight.
A complete analysis of the wing/rotor coupled system has been performed to assess the feasibility of the ERICA particular structural arrangement that can be synthesised in:

- Rotor Type requirements definition and preliminary frequencies placement
- Wing lifting structure (tube) feasibility study and stiffness definition
- Coupled wing / rotor whirl flutter parametric study

The complete analysis has been performed using the NASTRAN and the CAMRAD/JA programs applied to the wing structure and to the rotor itself .
With the CAMRAD/JA code, fed with a NASTRAN-equivalent model for the hub and the blades, the "Hub-Fixed" evaluation of the rotor stability has been obtained; the assessment of the wing characteristics and the modal description of the wing structure have been generated by means of the Finite Elements model, while the coupled wing/rotor stability study has been effectuated, one time more, using CAMRAD/JA.

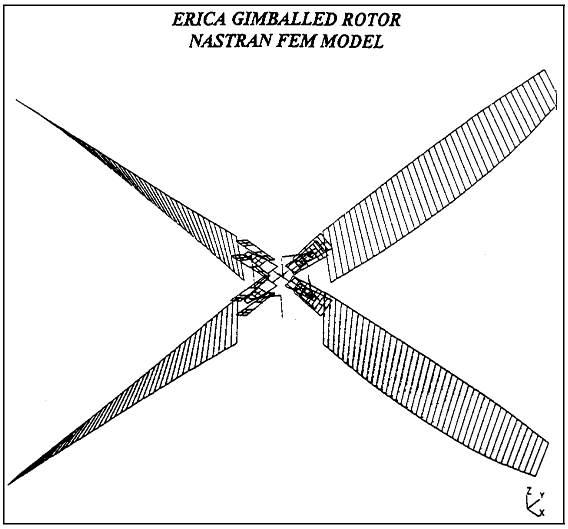


Figure 13: NASTRAN model of the proprotor

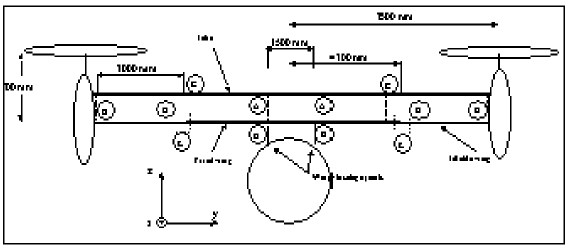


Figure 14: Scheme of wing structure FE model

The stability envelope, calculated with 4 rotor modes (1 collective, gimbal, 1 chord cyclic, 1 torsional cyclic) an the first six symmetric and anti-symmetric modes of the wing, shows that, in terms of bending and torsional stiffness requirements, the tube structure in plenty of margins even at the speed of 350 knots.

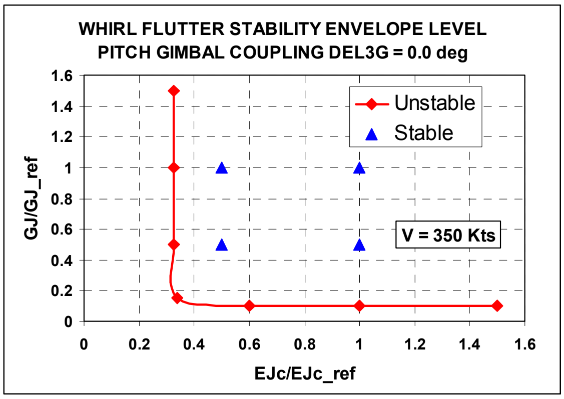


Figure 15: Whirl flutter stability boundary

Very interesting appears the observation of Figure 16, that shows the rotor cyclic modes (rotating) as calculated by CAMRAD/JA and of Figure 17 and Figure 18 showing the wing modes coming from the NASTRAN model; the presence of only two elastic modes, a part from the gimbal frequency (1*rev.), indicates the degree of de-coupling obtained between the two systems guarantee of a good dynamic behaviour.

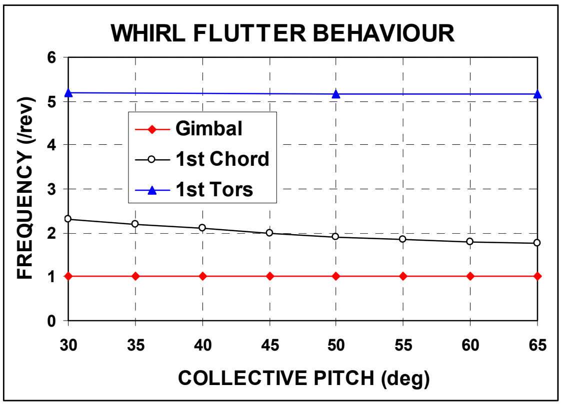


Figure 16: Rotor cyclic modes rotating frequencies

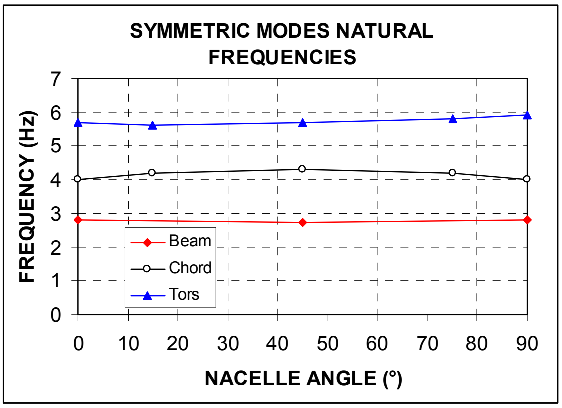


Figure 17: Wing symmetric modes natural frequencies

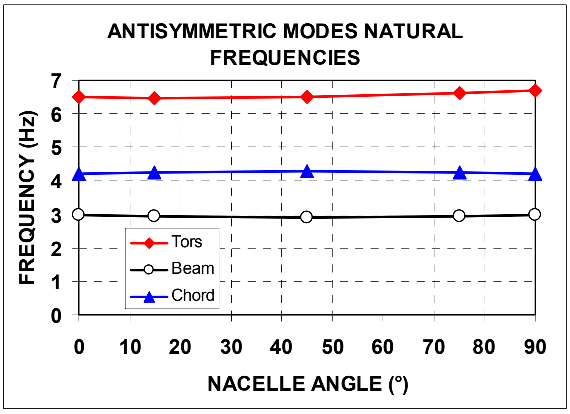


Figure 18: wing anti-symmetric modes natural frequencies

Finally, the Figure 19 shows the whirl flutter stability limit resulting from the CAMRAD/JA verification; the great margins existing are evident at all altitudes; in particular the aircraft results free from any whirl flutter instability up to the Vff speed, 1.5 times higher than the design cruise speed.

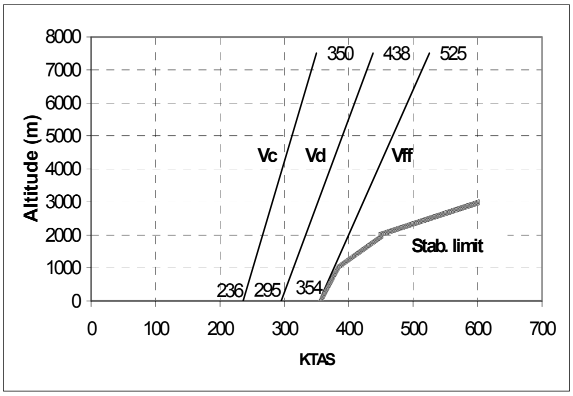


Figure 19: whirl flutter stability limit

PERFORMANCE

The Engine used to study the ERICA performance is the PW127/5 overpowered by 15% (engine growth potential) in accordance with the level of power required in forward flight to reach the design target speed of 350 knots at 7500 m ISA. The following mechanical transmission limitation were taken into account: 5230 hp at Take Off Power rating (TOP), 4800 hp at Maximum Continuous Power (MCP) and 3750 hp at 30” One Engine Inoperative rating (OEI). All the performance, here presented, are compared with those of a conventional tiltrotor, of the same class of ERICA, in which the rotor sizing has been estimated considering characteristics scaled down from the EUROFAR already available data. The engine used for this tiltrotor is the same of ERICA but without the growth, because the general requirements of the vehicle and the aeroelastic limits due to the rotor sizing prevent this test model, based on conventional tiltrotor technology and design, from reaching the same level of speed of ERICA making, in this case, not economical, in terms of weight and fuel consumption, the installation of such a big engine that could not be completely exploited. Consequently the transmission mechanical limitations utilised are the ERICA ones reduced by 10%.

Helicopter mode performance

The hovering performance out of ground effect have been computed for two power ratings (MCP and TOP), while the OEI rating has been utilised for the hover in ground effect (index of emergency situation). The standard air condition at three different temperatures have been presented: ISA+0°C, ISA+10°C, ISA+20°C. For all the analysed cases the higher performance of ERICA is evident as an increment of 15-20% in altitude at which is possible to hover at 10 ton (Figure 20 - Figure 22). The same result is illustrated for the service ceiling in Figure 23, where the One Engine Inoperative condition has been considered.

Figure 24 presents the results concerning the maximum weight at which the take off from an elevated helipad in Category A is possible in helicopter configuration. Also in this case there is an increment in altitude of about 15-20 %, at the same weight. This analysis pointed out that the conventional tiltrotor cannot perform this type of take off at weight larger than 9900 kg while ERICA is able to take off in Category A up to 10200 kg.

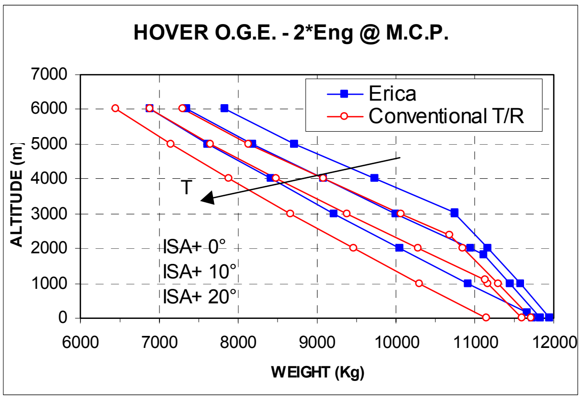


Figure 20: Helicopter mode HOGE at M.C.P.

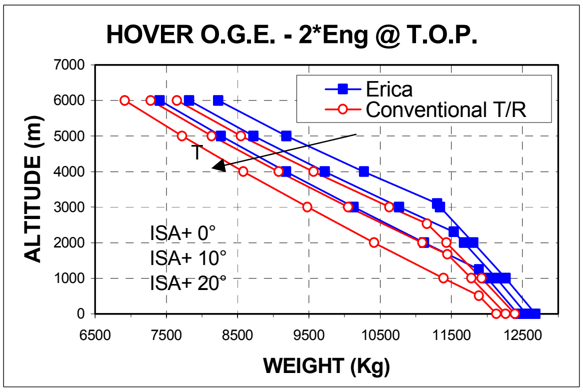


Figure 21: Helicopter mode HOGE at T.O.P.

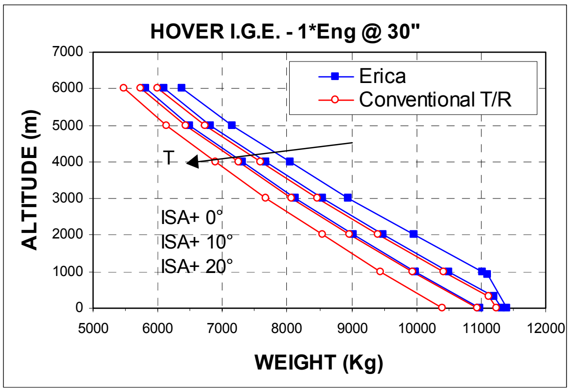


Figure 22: Helicopter mode HIGE O.E.I.

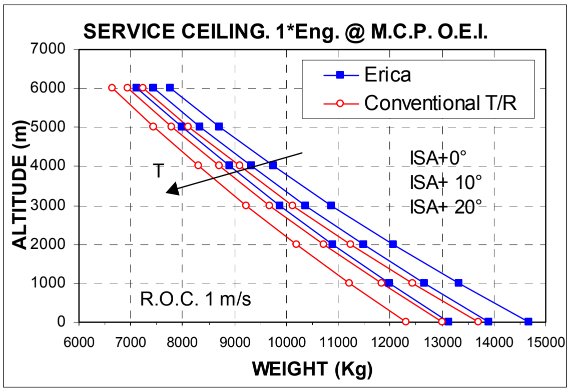


Figure 23: Helicopter mode service ceiling O.E.I.

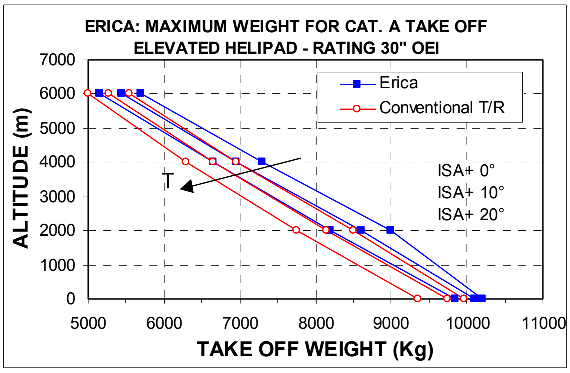


Figure 24: Helicopter mode take off in category A

Aircraft mode performance

The flight envelope for the aeroplane mode is shown in Figure 25. Only maximum power and wing stall are considered, while an evaluation of the other limits (e.g. aeroelastic effects) at different altitude are not considered in this chapter. The figure refers to the available power of the PW127/5 engine improved by 15% with the effect of the gear box limitation at high speed. The flight envelope has been extended to the helicopter configuration and compared with those of an helicopter and of a conventional tiltrotor to emphasise the ERICA capabilities.

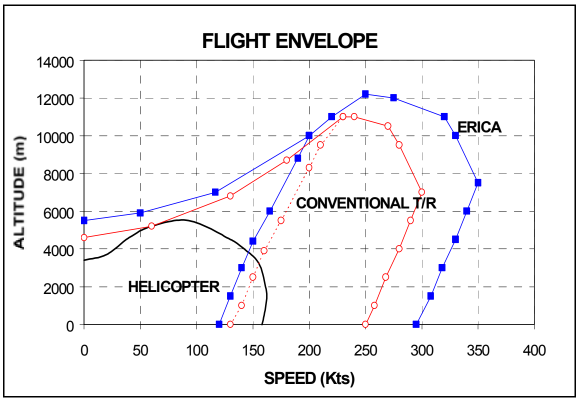


Figure 25: Comparison of flight envelopes

A great advance in ERICA is the capability to take off in aircraft mode that improves payload/range capability: in Figure 26 the run way length trend shows the tiltable wing effect in terms of take off distance reduction.

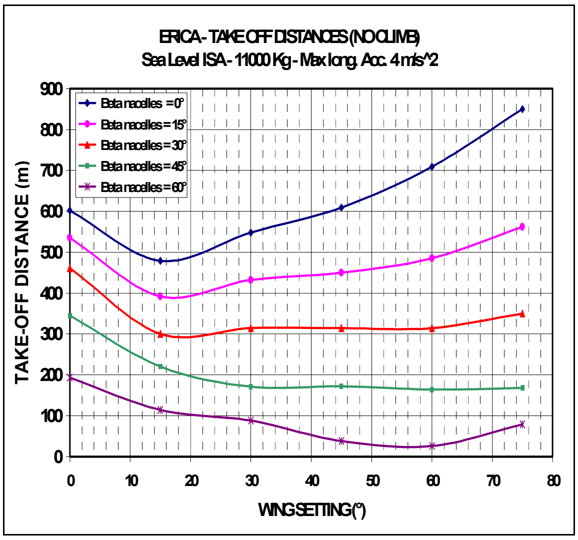


Figure 26: Take off distance vs. tilting wing attitude

Conversion corridor

Theoretically speaking there are infinite combinations of controls to trim a tiltrotor aircraft in a predefined flight condition, but there are mechanical and aerodynamic constraints on flapping angles, elevator angle, cyclic pitch, fuselage pitch and engine power that limit these combinations: the conversion corridor is the border, in terms of the nacelle angle as a function of speed, in which none of these design limitations is exceeded .

The ERICA conversion corridor has been obtained using the CAMRAD/JA code full aircraft model, in which the aerodynamic interference between tiltable wing and fixed wing, rotor and tiltable wing, wing and horizontal tail plane have been accounted for modifying the program according to the flowchart in Figure 27 (as already described).

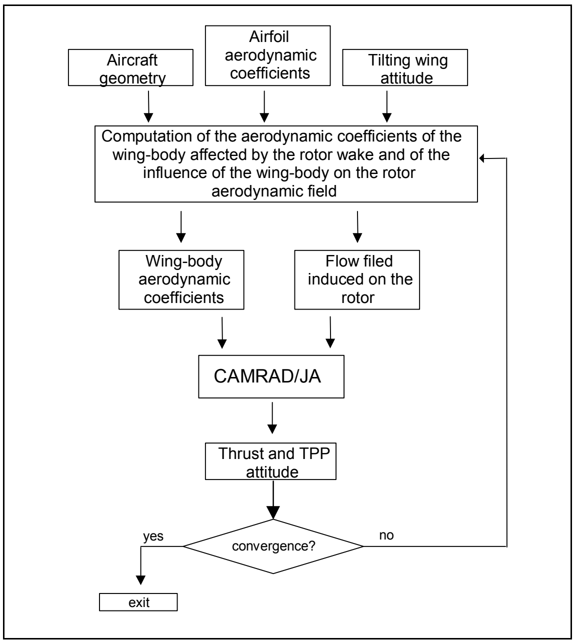


Figure 27: Process of computation of the performance

In Figure 28 the pitch attitude is shown as function of the speed and of the wing-tilt angle (the nacelles are set in helicopter mode) in order to make a little example of the complexity of the parametric analysis performed to optimise the ERICA configuration. To get a complete picture of the possibilities of this vehicle a similar work was applied to all the trim controls and free variables requiring a great effort of calculation and data reduction.

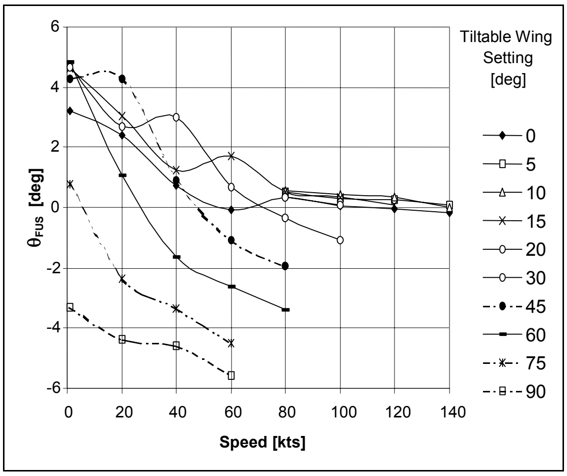


Figure 28: Aircraft attitude as function of speed and wing tilt angle

Figure 29 shows the ERICA conversion corridor, as obtained when the following constrains were considered:

- Elevator angle $|\delta e| \leq 15°$
- Longitudinal cyclic pitch $|\theta 1S| \leq 15°$
- Longitudinal Flapping Angle $|\beta 1C| \leq 6°$
- Fuselage Pitch $|\theta_{FUS}| \leq 12°$
- Shaft Power (at sea level ISA) P ≤ T.O.P.

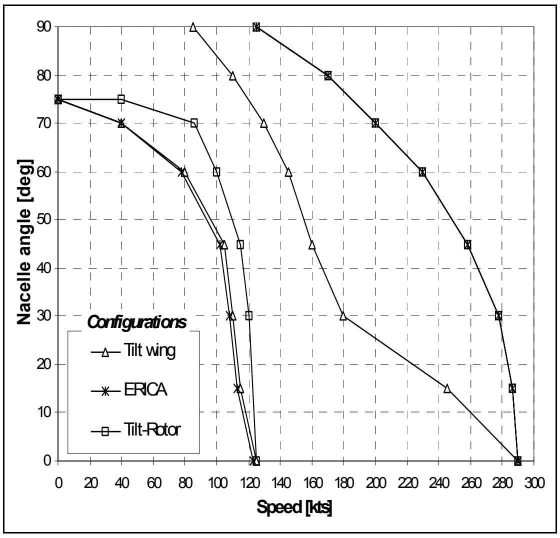


Figure 29: Conversion corridor

Movable wing angle and the control law between the longitudinal control and the horizontal tail plane have been set in order to get a conversion corridor as wide as possible, while, conservatively, no flap deflection has been considered. In the same figure a comparison with a conventional tiltrotor, with the same sizing of ERICA, is pointed out in which is evident how the further degree of freedom of ERICA (i.e. the tiltable wing) produces a wider corridor thanks to the possibility to control the variation of the parameters in a better way. A comparison with a pure tiltwing configuration has been carried out too; it shows how the tiltrotor formula is definitively convenient in the considered flight phase.

In Figure 30 and Figure 31 the conversion corridor is mapped also with iso-parameter curves identifying the values reached by all the other design variables during the conversion manoeuvre.

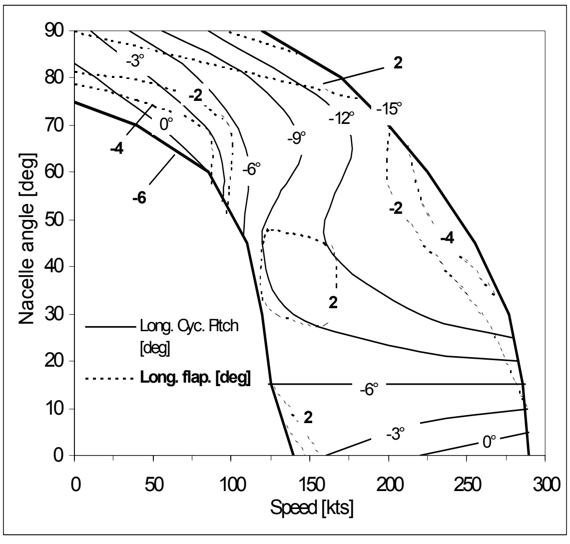


Figure 30: Conversion corridor vs. long. pitch and flap

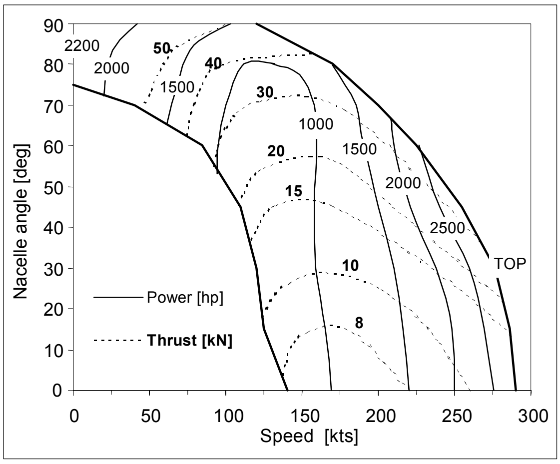


Figure 31: Conversion corridor vs. power and thrust

Figure 33 presents an optimal conversion procedure (blue line), obtained with quasi-static conditions, during which the aircraft never flies near the corridor boundary and the required power is minimised (i.e. locus of minima of Figure 32) while all the other parameters (flapping, cyclic control angles, fuselage pitch, etc.) are asked to be as small as possible and in any case inside the design ranges. The second curve (red line), that represent a dynamic simulation of the complete conversion manoeuvre, was obtained with the NFPATH [m] code a direct/inverse simulation tool developed in AGUSTA, widely used for the simulation of helicopter manoeuvres and now modified to be able to manage also advanced configurations like compounds and tiltrotors. The difference of the two curves is evident especially at the beginning of the conversion in which the necessity to have an initial acceleration requires a quicker tilt of the nacelles and of the wings as shown in Figure 34. An example of the parameters that the NFPATH procedure is able to furnish as output is presented in Figure 35, where the time history of the forces contributing to the vertical equilibrium is shown.

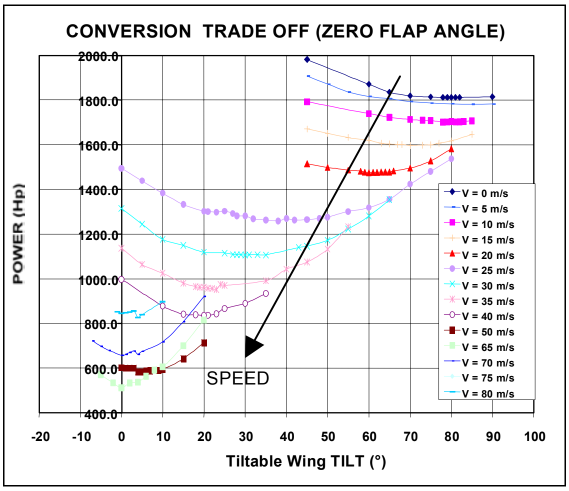


Figure 32: Trade off of the optimum conversion

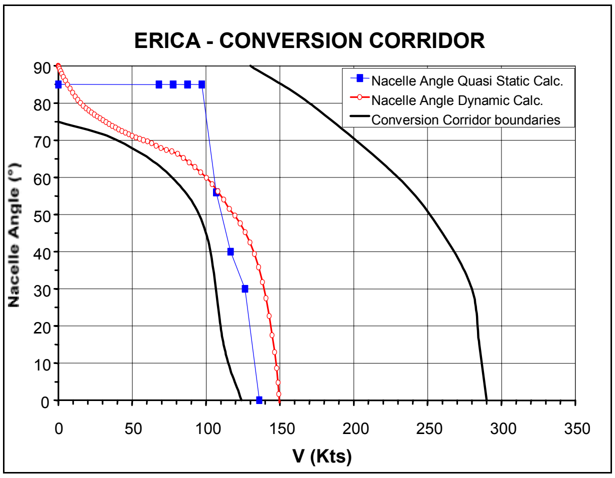


Figure 33: Conversion corridor and optimised path

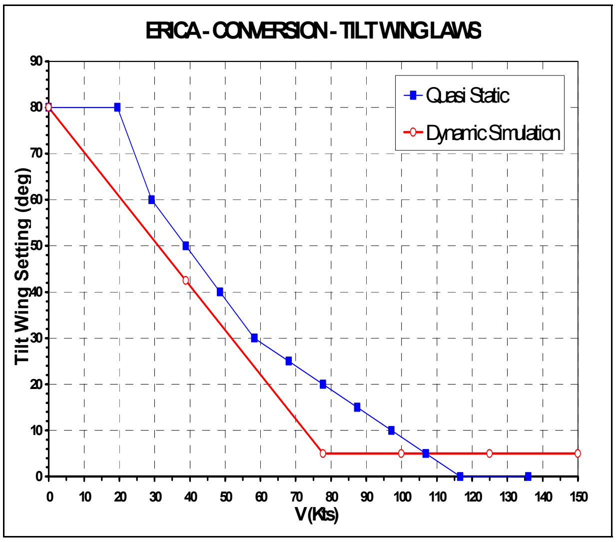


Figure 34: Tilting wing optimised angle

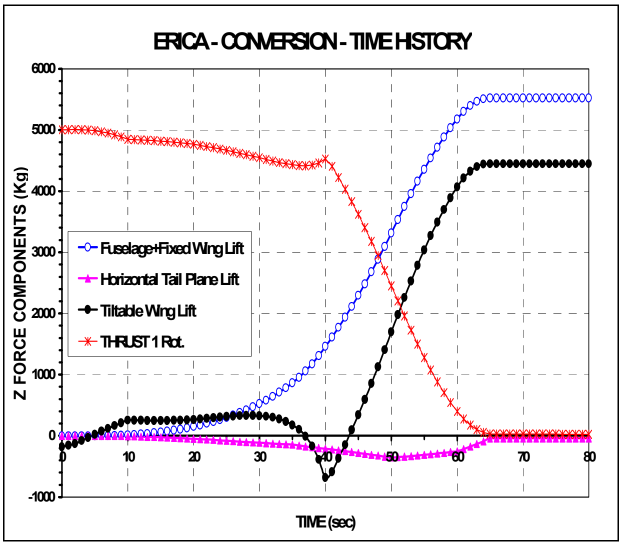


Figure 35: Conversion time history - vertical equilibrium

CONCLUSIONS

The development of an European advanced tiltrotor configuration was presented; a brief description of the driving ideas, of the requirements and of the trade-off process followed to consolidate the formula was given together with a description of the methodologies used, or even newly generated, to simulate this advanced innovative vehicle that represents an exciting challenge for the Engineers. This project offers to the European Industries a unique chance to work together with the shared aim, not only to fill the technological gap that separate us from the US knowledge, but to make a real step forward to be ready to exploit all the opportunities of a market that the BA609 and the V22 will create and open.

ACKNOWLEDGEMENTS

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We would like to thank them for their precious contribution and effort, without which the preparation of this paper would not be possible.

REFERENCES

[a] M. Gervais: "Tiltrotor blade vortex interaction (BVI) noise control through non-unique longitudinal force trim" - AHS Tiltrotor A/C Tech. & Applications March 20th, 2001 Arlington, Texas U.S.A.

[b] H. Otto, K. Rosenkranz: "Wind Tunnel Tests with EUROFAR Model 1A-G Part I: Test Description and Diagrams"

[c] H. Otto, K. Rosenkranz: "Wind Tunnel Tests with EUROFAR Model 1A-G Part II: Tables"

[d] R. Von Mises: "Theory of flight"

[e] Report "Fluid forces and moments on flat plates" Engineering Sciences Data, Item n. 70015

[f] I.H. Abbot, A.E. Von Doenhoff: "Theory of wing section" Dover publication INC. New York

[g] D.P. Rymer: "Aircraft design: a conceptual approach" AIAA Education Series

[h] W. Johnson: "CAMRAD/JA A comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics" Johnson Aeronautics Version – Vol. II

[i] C. Brogi: "Programma di calcolo per l'ottimizzazione d'avanprogetto di velivoli commerciali – Manuale teorico" Pisa 1994

[j] Torenbeek: "Synthesis of subsonic aircraft design"

[k] EUROFAR N° GA. VPT. 040 WPD "Mass, centre of gravity, moments and product of inertia of the baseline 30 passengers"

[l] EUROFAR "Preliminary phase – Technical summary"

[m] F. Nannoni, A. Stabellini – "Simplified inverse simulation for preliminary design purposes" 15^ ERF Paper n. 58 – Amsterdam September 12-15, 1989

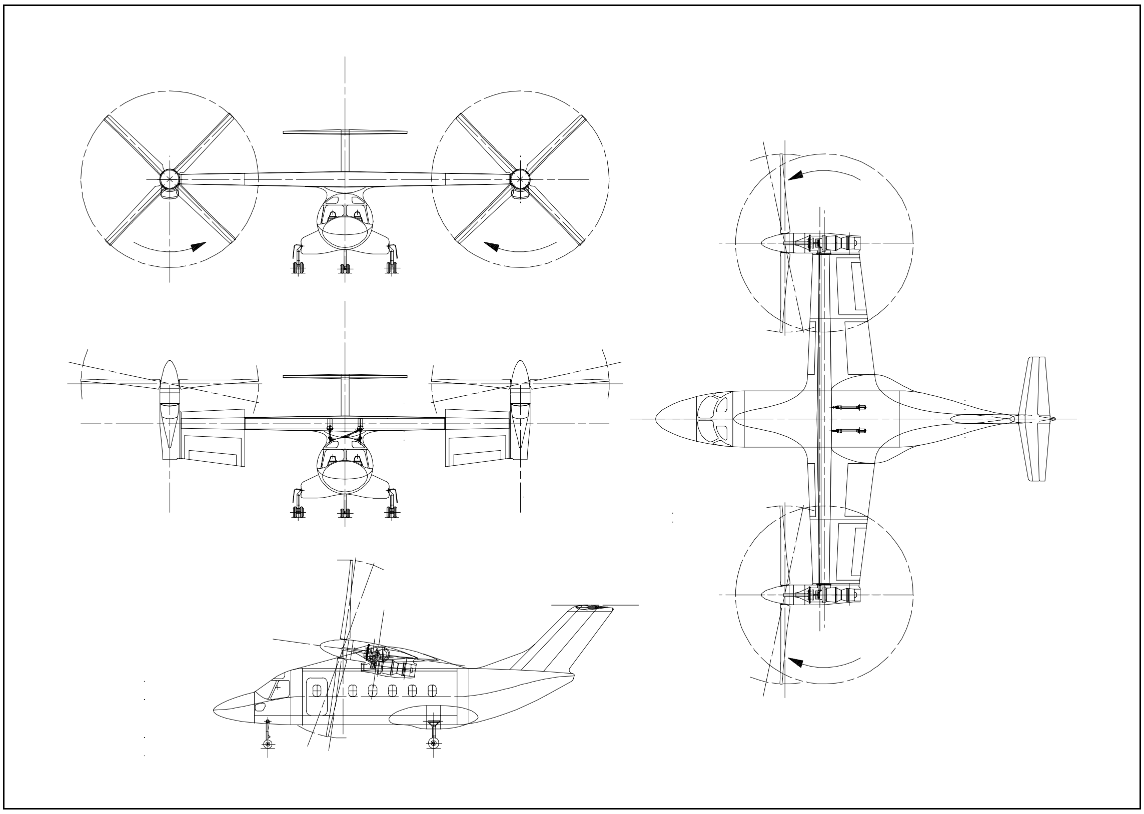

Figure 36: ERICA general layout

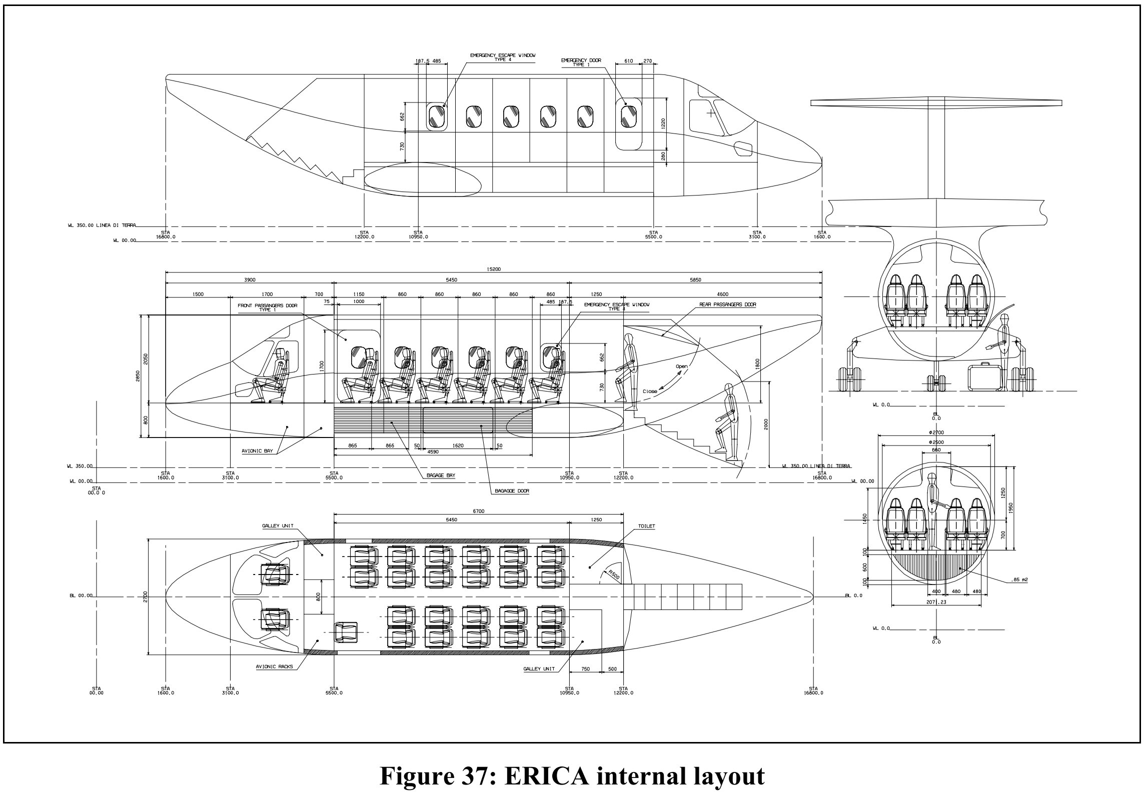

Figure 37: ERICA internal layout