THE LONG WAY TO THE
TILT-ROTOR IMPLEMENATION

J.RENAUD - JM.KLEIN
EUROCOPTER MARIGNANE - FRANCE*

Abstract

This paper summarizes some European views related to the technical economic operational and programatic issues related to the implementation of the (civil) tilt-rotor.

## 1. The tilt-rotor : already a long history

The tilt-rotor aircraft has been flying for four decades. The highlights of this type of aircraft, combining the V.T.O.L. characteristics of the helicopter and the level of cruise performance of the turbopropeller aircraft are now well recognized, fully demonstrated, and applied within currently being developed military & civil programs (in the U.S.A.). These appreciated characteristics are first and foremost related to a good basic functionality allowing the T/R to properly cover the sum of the helicopter and fixed-wing aircraft flight envelopes. The corresponding technical and architectural features mainly include moderate rotor disc loading (for V.T.O.L., hover and low speed performance), rotor cyclic control (for hover and low speed aircraft control) and substantially reduced aircraft drag as regards the helicopter (for high cruise performance). On these bases, the T/R technical viability has fully been in demonstrated flight since the seventies with the U.S. XV15 Program, without the introduction of modern technologies. However, it is clear that the elicitation of advanced technologies could help the aircraft optimization and adaptation to requirements (including operational, economics, safety and environmental issues).

Consequently, it is obvious that a demonstration phase is needed within such a development program, to assess, tune and integrate these advanced and sometimes highly coupled technologies. Finally, the T/R appears both as a research driver for the helicopter sector and as an aircraft submitted to a stretched development process.

These features are still obvious in the operational and commercial fields, the introduction of the T/R being a break strategy (for both civil and military utilization) as regards past classical rotorcraft and turbopropeller aircraft operations. Therefore, the operational and commercial issues will have to be carefully examined and assessed, at both the manufacturer's level and the operator's.

Once again, a long process will be needed to assess the A/C viability and efficiency when used within its civil or military global air system. For this purpose, a flying demonstrator will have to be finally used, after computational and simulation studies. These reasons, together with technical considerations explain the long way to the Civil Tilt-Rotor (C.T.R.) implementation.

## 2. Main technical issues

By many aspects, the T/R general architecture looks like the classical turbopropeller, despite specificities. However, most limitations and technical constraints are of the helicopter type (Ref. 1). This duality is one of the T/R design (and manufacturing) difficulties. For Eurofar, these main technical issues were evaluated during the feasibility phase (Ref. 2) with the pre-definition of the Baseline Aircraft (Fig. 1). The European Research Agencies, rotorcraft & fixed-wing companies conducted computational & experimental studies to propose technical solutions enhancing several aircraft characteristics (Fig. 2).

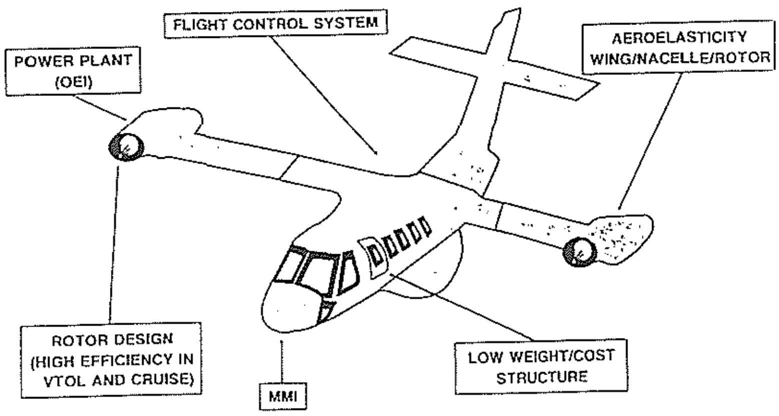


*Fig. 1 : Tilt-Rotor Main Technical Issues*

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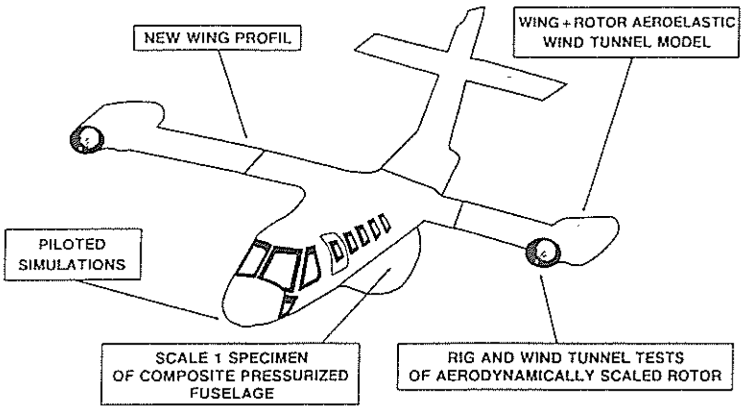


*Fig. 2 : Eurofar Tilt-Rotor Technical Studies*

Requirements & General Architecture of Eurofar Baseline A/C

The feasibility phase of the Eurofar Program included technology evaluation, selection & integration within the predefinition of the so-called « Baseline Aircraft », with the following main requirements :

- 30 Pax + 1 Pilots + 1 Flight attendant
- Cruise speed : > 300 Kts
- Range : about 600 Nm
- Category A takeoff
- Good internal comfort

The corresponding sizing & architectural studies gave a 13.6 T A/C, powered by two PW300 TS engines (max. cont. SL/ISM 3185 km) providing a 335 Kts cruise speed at 7500 m ISA. An architectural configuration (high-wing, T-tail, fixed engines) was selected with the introduction of some advanced technologies to overcome foreseen the limitations dealt with hereafter.

Rotor System

The rotor system definition has to cope with opposite requirements for VTOL/Hover conditions and high speed cruise. A balanced solution has to be achieved through blade geometry (planform, twist, section airfoil) and RPM variation.

A simple and quick solution was adopted for Eurofar with the utilization of existing helicopter airfoils for the outboard blade (OA family) and the definition (and W.T. test) of a 28 % thick airfoil for the blade root. The result was a hover figure of merit of FM = 0.8 and a cruise efficiency ns = 0.83.

This aerodynamic tailoring was complemented by a an innovative rotor system, including an homokinetic hub with a composite membrane and a flexbeam type rotor blade, intending to provide good dynamic characteristics.

Aeroelasticity

The Wing/Nacelle/Rotor coupling may affect the MR safety and restrict its flight envelope (Eurofar 335 Kts maximum cruise speed is related to an aeroelastic limitation). A computational evaluation and dynamically scaled model wing-tunnel tests (undertaken with Sikorsky Aircraft) gave indication for Eurofar Baseline predesign. A thicker composite wing provided the needed tortional characteristics, the aerodynamic tailoring being achieved with the definition and wind-tunnel test of a high performance, low drag, 23 % thick airfoil (CDO = (?) at M = (?).

Structure

The A/C empty weight dramatic issue needs a fresh innovative solution for VTOL. Within the aeronautical industry, the rotorcraft sector satisfactorily handles the design and manufacturering of a full composite structure. For the T/R, an additional complexity is related to the high altitude cruise with the corresponding need for pressurization. Scale 1 pressurized full composite section of Eurofar Baseline was designed and ground tested during the feasibility phase. However, manufacturing and economic issues have to be comprehensively examined. New technologies (as fiber placement technique) will have therefore to be evaluated.

Powerplant

Main issues are related to engine integration and control and drive train architecture, with an installed power sufficient to cover all flight conditions (including O.E.I. during take-off). The basic architectural Eurofar feature is related to the fixed-engine (relatively to the wing). A general enhancement could be expected with the future utilization of engine active control technologies.

Flight Control System

The introduction of new « fly-by » technologies with the associated pilot aids are of paramount interest for the T/R (despite the fact that this A/C viability has been demonstrated by the XV15 A/C without these new technologies). The system architecture as well as corresponding hardware issues have to be comprehensively considered, with the corresponding operational safety and cost issues. The system envisaged for Eurofar was a quadruplex system.

### Man-Machine interface

MMI is a fundamental issue for the practical T/R implementation, considering the level of mission difficulties for this hybrid A/C. Feasibility activities conducted by Eurofar included cockpit studies (including ergonomic/operational consi-derations for panels/inceptors), the utilization of new technologies (digital avionics, new displays) and the definition of advanced controls laws. Piloted simulation is a key element to these issues.

## 3. Economic considerations

Even if the aeronautic community hold the scientific background and handles the key technologies needed for the T/R development, this aircraft is a challenge for the industry and the civil & military operators. As a matter of fact, the T/R consequently induces a « break strategy » for these communities ; beyond the technology handling, a methodological approach for risk assessment related to economics (as well as for operational - civil & military - issues) is absolutely requested.

The T/R first « apparent mystery and contradiction » relates to the fact that it is somewhat more sophisticated and then more expensive than a classical helicopter. Nevertheless, the T/R could be more efficient for the operator when properly used for appropriate missions. Actually, a current U.P.C. (Unit Production Cost) of about 1.3/1.35 the equivalent helicopter (same size, technology, equipments and equivalent program « framework ») is currently admitted. A survey of the U.P.C. segmentation is shown in Fig. 3 for the Eurofar Baseline A/C.

As expected for a very well equipped aircraft (IFR, all-weather capabilities) having a complicated architecture (two rotors and main gearboxes with an interconnecting shaft, two tilting nacelles ...), the shares related to equipments (29 %) and t100 (25 %) are the largest, while the engines part (20 %) is lower, as usual for a large aircraft.

A methodological approach to reduce the manu-facturing cost (as well as the design cost when considering its amortization included in the sales price) should intensively be used through concurrent engineering process. Similarly, the equipment costs will be reduced through an « off-the-shelf » policy. It is then expected to curb the U.P.C. and the sales price.

Turning now to the operator's point of view, an appropriate preliminary economic quantification will be achieved with the D.O.C. (Direct Operating Cost).

The D.O.C. used below is made from costs « proportional » to the aircraft (amortization, financing, insurance), plus the D.M.C. (Direct Maintenance Cost), the fuel and the crew, with the following set of hypotheses :

- Amortization : 12 years, 20 % residual value
- Financing : 55 % loan, 12 years, 12 %/year
- Insurance : 4 %/year
- Intensive utilization : 2000 hours/year

Finally, the D.O.C. which is one of the major parameters for the operators depends on the type of aircraft (size, type of technology ...) but also on the type of mission (quantitatively and « qualitatively » ...). Within this framework, Fig. 4 describes the segmentation of the Baseline A/C DOC/Flight hour.

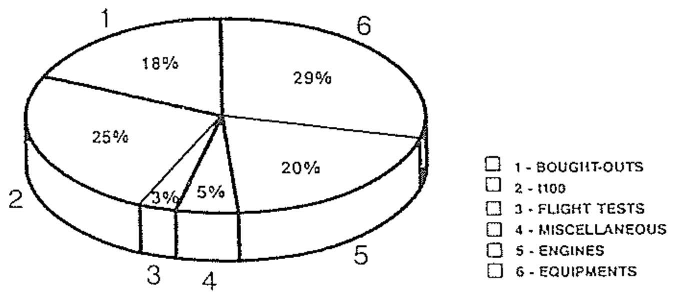


*Fig. 3 : EUROFAR Baseline A/C Unit production cost*

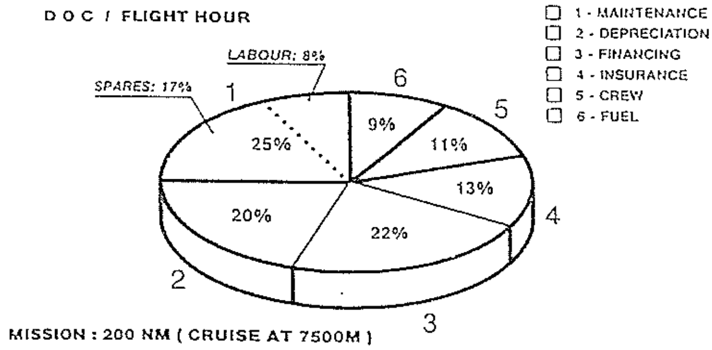


*Fig. 4 : Eurofar Baseline A/C DOC segmentation*

The D.O.C./Flight hour is currently used for classical helicopters, as it is well adapted to their usual missions (with a large part of hover or very short mission range). Within this framework, the segmentation described on (Fig. 4) is typical of rotor, with large parts dedicated to costs proportional to the aircraft (due to its high sales price) and a high D.M.C. (mainly due to the basic functionality of rotorcraft coping with fatigue and hard life limitations). The T/R is however expected to be in a better situation for the D.M.C., when missions include a large part of airplane mode operations (more favourable in terms of fatigue).

Nevertheless, the T/R economics have to be examined through parameters well adapted to the typical mission of this aircraft. In this respect, the T/R speed and range could lead this aircraft to play a role in transport missions. Therefore, the DOC/Seat/Nm is a more adapted economic parameter. Fig. 5 shows the segmentation of the DOC/Seat/Nm for three aircraft (Helicopter, Tilt-Rotor, Turboprop) on a 300 Nm mission (results have to be read separately for each A/C).

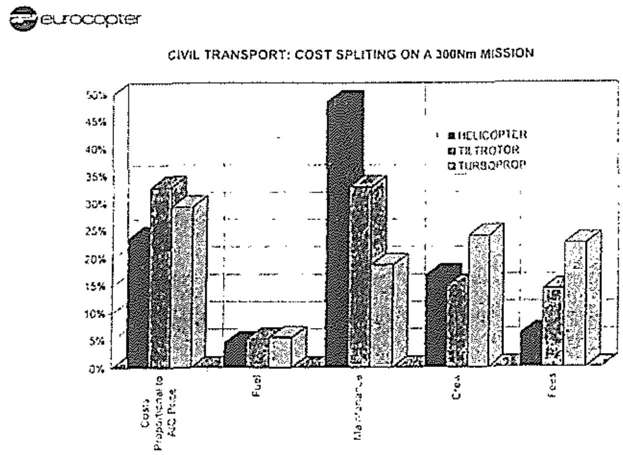


*Fig. 5 : Civil transport :*
*Cost splitting on a 300 Nm mission*

The very great importance of the maintenance (more especially for helicopters) should be noticed. The maintenance part for the T/R is reduced (by the operating mode in cruise and by the higher part of cost proportional to A/C price which is higher for the helicopter).

Finally the A/C price and maintenance are the two main issues for the T/R just as for the helicopter, for a given mission (turbopropeller A/C). Globally speaking, when the turbopropeller DOC/Seat/Nm for a given mission is « 1 », it is « 2 » for the T/R on the same mission and it could raise up to « 10 » for the classical helicopter.

The last economic issue relates to the adaptation of each type of aircraft to its mission niche, as it is shown in fig. 6 describing the mission length effect on the DOC of the helicopter and T/R. It is shown that for a given utilization (1000 flight hours/year) the tilt-rotor takes advantage over the helicopter when the mission length increases (due to T/R cruise speed which is twice the helicopter).

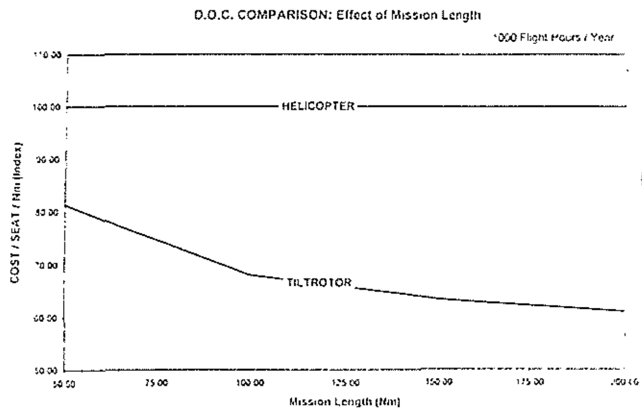


*Fig. 6 : Mission length effect on DOC*

### 4. Operational issues

The main operational considerations relate to the cost-efficiency of the global transport system (including issues on safety and environment).

For an operator, when considering these issues for different kinds of aircraft performing the same mission, the economics are not only related to the intrinsic characteristics of this A/C but also to the operational environment (the air and ground delays consequently reducing for instance the cost efficiency of a given aircraft (or fleet) operating on a given length, with the same « type » of yearly utilization. Consequently, even the DOC/Nm/Seat does not give an accurate picture of the aircraft in operation. If the « flight hours » include the airborne part of the missions plus taxiing (in fact the « block time »), ground stopping is not taken into account when using such a parameter. In fact, the delays related to air-congestion, traffic limitations, airport management, aircraft refuelling and cleaning dramatically increase ground stopping and consequently induce a drop for the aircraft economic efficiency. To introduce these effects, Eurofar has adapted and used a so-called « allocated-time » method taking care of ground stopping for the definition of a stage (and not only the air delays) and including indirect costs, for maintenance (burden) and navigation and airport fees.

A total of 3600 allocated hours/year is currently used by airlines. Fig. 7 shows, in these conditions, the comparison of the block time and cost/seat for a 300 Nm mission with the present air congestion level and the same comparison with an increased congestion for F/W and special regulation for V.T.O.L.

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**COMPARISON OF CIVIL AIR TRANSPORT MODES EFFICIENCY**

*ALLOCATED TIME METHOD*

• ALLOCATED TIME: 3600 H/AN
• MISSION : 300 Nm

■ AIR CONGESTION: PRESENT STATUS

| | EUROFAR | HELICOPTER | TURBOPROP |
|---|---|---|---|
| BLOCK TIME *(INDEX)* | 100 | 186 | 130 |
| COST / SEAT *(INDEX)* | 100 | 270 | 55 |

■ INCREASED AIR CONGESTION FOR F/W AND SPECIAL REGULATION FOR V.T.O.L.

| | EUROFAR | HELICOPTER | TURBOPROP |
|---|---|---|---|
| BLOCK TIME *(INDEX)* | 100 | 186 | 193 |
| COST / SEAT *(INDEX)* | 100 | 270 | 76 |

Fig. 7 : Comparison of civil air transport modes efficiency

Compared to T/R, the helicopter has a poor block-time (due to low speed and high cost per seat mainly related to maintenance). The turbopropeller remains cheaper, but with a block-time greater than the T/R, which is due to the utilization of crowdy corridors and airport zones with a lower cruise speed. In the second case the advantage of the turbopropeller against T/R is significantly reduced, which shows the very large impact of the operational features on the aircraft economics.

Therefore, the ways of introducing the rotorcraft within A.T.M./CNS systems for « en route » flight and terminal operation have to be carefully examined. That will lead to a proper balance, in the future, between the efforts to be made on operational issues and aircraft enhancement. For the operator, the economic issues are related to the characteristics of the overall system. As a typical example, Fig. 8 shows the « rate-of-exchange » between D.M.C. and air delays.

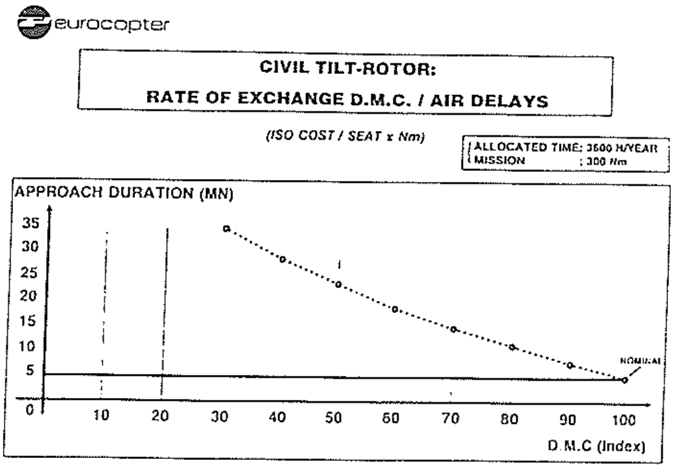



*Fig. 8 : Civil Tilt-Rotor*
*Rate of exchange DMC/air delays*

For a T/R performing a given 300 Nm mission in the same conditions of yearly operation (allocated - time 3600 h/year) there is a baseline case with nominal aircraft characteristics (including a given DMC) and a standard mission (including a 5 MN nominal time to approach). If there are air delays doubling for instance the approach duration (5 to 10 MN), a tremendous DMC drop by about 20 % is necessary to keep the same Cost/Seat/Nm, which shows that efforts must be made on the overall system.

Finally, these operational features must globally be examined with main issues related to the traffic/passengers flow and the implementation/ enhancement of infrastructures and ATM/CNS systems. Within this evolving framework, it is of paramount importance for the rotorcraft industry to assess whether the VTOL aircraft will play a role in the future transportation system, will perform new missions and will help solve outstanding problems such as, for instance, the great airport capacity bottle neck. In this respect, the European Economic Commission in Brussels has launched a preliminary program on the evaluation of the effects of introducing the helicopter and tilt-rotor on a large airport (Ref. 3).

All the european helicopter industries took part in this program together with research/aeronautic agencies and airport organizations (DLR, TUBS, DFS, ADP).

It has been shown (fig. 9), through 12 simulation scenarios that the VTOL utilization strategy (add-on, replacement and slot fill) has a great impact on airport global capacity, in various situations (time horizon and congestion, meteorology, ground terminal location, operated rumways).

It has been demonstrated that a proper traffic segregation between F/W and VTOL together with an adequate terminal location and a slot fill strategy could provide Frankfurt Airport with a slot capacity increased up to 50 % and a slot weight capacity up to 30 %.

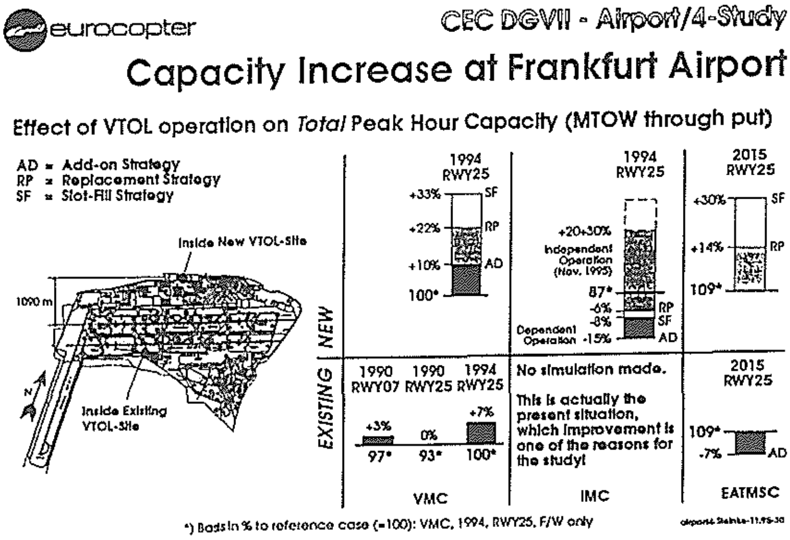



*Fig. 9 : Capacity increase at Frankfurt airports*

In the same way, the practicability of new optimized procedures taking care of safety and noise abatement issues were defined and assessed on the « SPHERE » flight simulator located at Eurocopter-Marignane (Fig. 10).

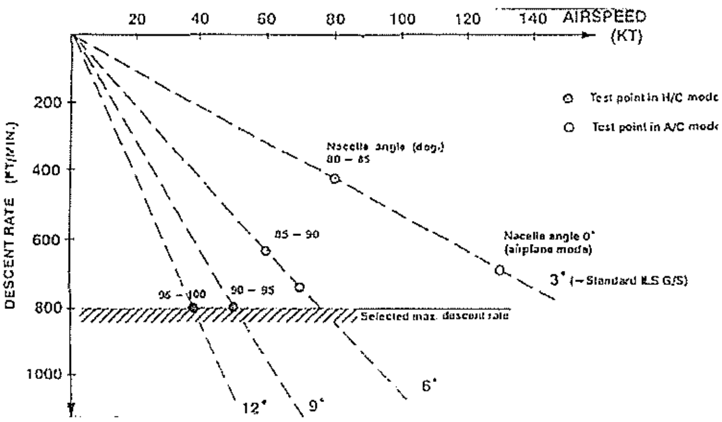



*Fig. 10 : Eurofar Simulations Activities STEEP Instrument Approaches*

## 5. Programmatic issues

All these technical economic and operational issues have proven the need for a demonstrator within the development process of a T/R. such a demonstrator is needed both for technical aspects (validation of the design methodology, integration/in flight assessment of advanced technologies identification of the development risks) and for commercial & operational aspects (practical demonstrations, new procedures, general lobbying ...).

With this respect, feasibility studies on an aircraft fitted with two RTM 322 engines are launched, with sizing activities (Fig. 11) and experimental activities conducted by Eurocopter with the French MOD support within CEAT Toulouse wind-tunnel (Fig. 12).

These experimental activities are related to the wing-section test (airfoil OACV23 with its lap) and to the glider (1/6 scale) aerodynamic evaluation in the CEAT S4 WT, with different architectural configurations.

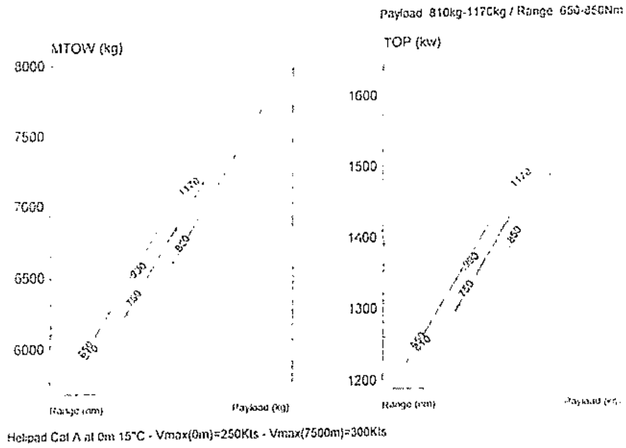
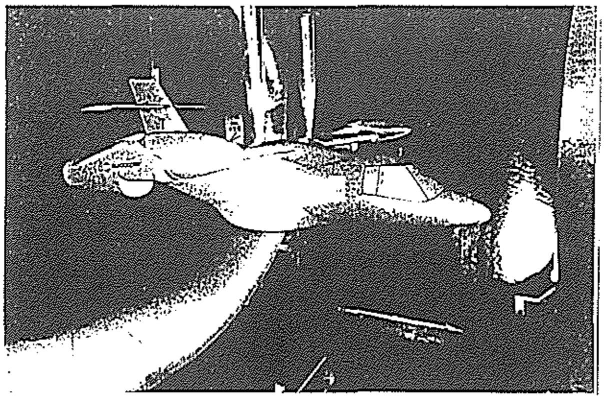



*Fig. 11 : Demonstrator Aircraft Sizing*



*Fig; 12 : Eurofar Demonstrator W.T. tests*

## 6. Concluding remarks

Technical, economic and operational issues have to be comprehensivelly examined for T/R (civil) implementation. If Europe handles the key technologies needed for T/R development, it is obvious that a large participation of research organizations, industrial sectors and aeronautic agencies is necessary for T/R success. Within this framework, a demonstrator is compulsorily requested before commercial A/C launching. These programmatic issues are presently under consideration in Europe.

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