PROPULSION SYSTEM CONCEPT FOR THE EUROFAR TILT ROTOR AIRCRAFT

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Abstract

Currently a three year preliminary working phase (beginning of 1988 until end of 1990) is being carried out in order to define the baseline for the european tilt rotor aircraft EUROFAR (fig. 1).

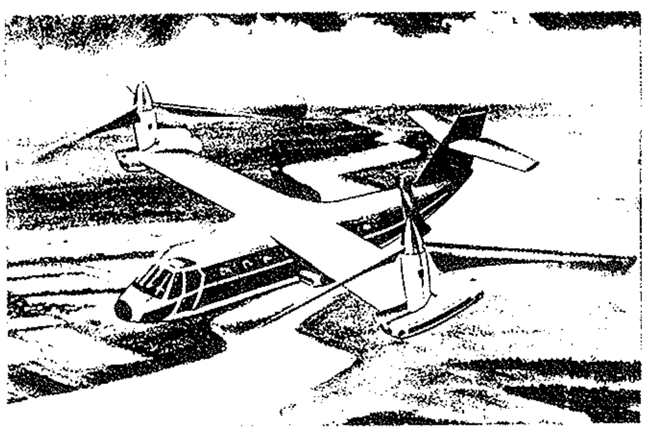

Fig. 1 EUROFAR Tilt Rotor Aircraft

This program is commonly conducted by the following european partners:
Aerospatiale (France), Agusta (Italy), Casa (Spain), Westland (UK) and MBB (Germany).

A vital part of the tiltrotor aircraft is the propulsion system.
In contrast to the american V22 tiltrotor (completely tiltable propulsion nacelles) the EUROFAR team has mainly concentrated on a nacelle concept with stationary engines.

This paper will give a first overview about findings gained up to now and the current status of design investigations comprising:

° tilt concepts
° propulsion nacelle arrangement
° main gearbox design
° cross shaft design
° engine
° nacelle structure design

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Introduction

Background The information presented in this paper is based on results gained by co-operation of the following companies:

° Aerospatiale
° Westland Helicopters
° CASA
° Agusta
° MBB

The target for this international working group is to define a baseline propulsion system for the european tilt rotor aircraft EUROFAR under consideration of the following system data:

° Maximum aircraft AUW 13650 kg
° Cruise speed 335 kts
° Cruise conditions 7500 m/ISA
° Rotor speed 375 min^{-1}
° transmission system design power limit 2x2000 kW

General Propulsion System Architecture
The total arrangement of a tiltrotor propulsion system is shown in fig. 2

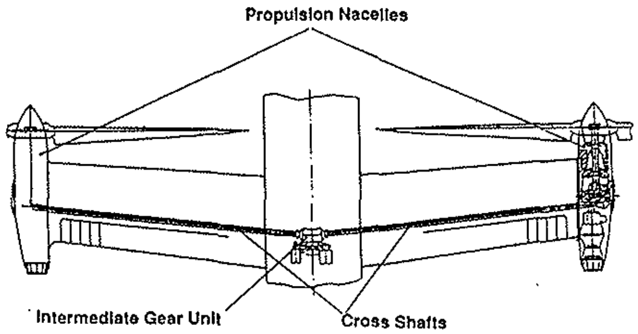

Fig. 2 Tilt Rotor Propulsion System

The vital components of such a system are:
two propulsion nacelles, each comprising
° main gearbox system
° accessories
° engine;

two cross shaft units providing a connection between the two propulsion nacelles; this arrangement ensures continued two-rotor-operation in case of one-engine-failure (OEI);

one intermediate gear unit for the connection of the two cross shaft units within the center fuselage; this gearbox also provides additional accessory drive capability.

Tilt Concepts and Concept Selection Philosophy

Tilt Concepts The basis configuration for the design of the propulsion nacelles can be selected from two possible main concepts:
° Completely tilting nacelle (tiltable engine);
° Partially tilting nacelle (stationary engine).

The two main concepts are shown in fig.3

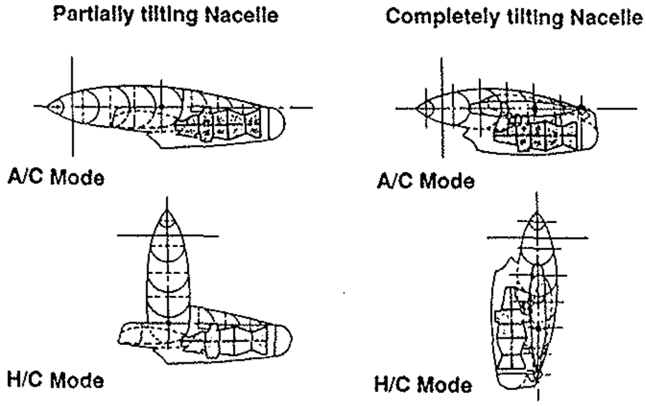

Fig. 3 Tilt Concepts

Tilt Concept Features

a) Completely tilting nacelle:

the entire nacelle is tilted as one unit; this leads to
° simple nacelle structure (in particular cowlings);
° only one main gearbox unit (no tilt interface within the gearbox system);

a special engine design is necessary (engine has to be operated in horizontal position and in addition to be operated, stopped and started in vertical position; safe engine operation must be provided during tilting);

due to special requirements for the engine the selection flexibility is reduced (not every engine providing suitable power can be used);

a more complex engine installation system is necessary (flexible interfaces for fuel-, air- and electrical lines);

in case of an engine turbine burst the area of likely impact (structural damage) is larger compared to a fixed engine concept since all possible positions of the nacelles have to be taken in consideration.

b) Partially tilting nacelle:

the nacelle has to be divided up into two sections:
° stationary nacelle unit comprising engine, high speed reduction gear unit and cross shaft output;
° tilting nacelle unit comprising rotor output gear section, rotor and its control system;

the two nacelle sections lead to a more complex nacelle structure (in particular cowlings);
also for the main gearbox two units are necessary:
° stationary unit (high speed reduction and cross shaft output)
° tilting unit (rotor output section);

a conventional engine installation can be used and thus no special engine design is necessary (each turboshaft engine which meets the power requirements can be used without modification);

the stationary engine concept provides some design flexibility:
° for general aircraft design high wing - or low wing configuration is possible;
° it is not necessary to have the cross shaft location coaxial to the nacelle-tilt axis (as it is for the completely tilting nacelle);

with the stationary engine the exhaust blast is not directly directed to the ground; in helicopter mode this will lead to increased ground operation safety.

Conclusion from Tilt Concept Comparison While the completely tilting nacelle concept has its problems more on the engine side, the implementation of the partially tilting nacelle requires more design efforts on the structure and gearbox side.

Tilt Concept Selection Philosophy
Since the completely tilting nacelle concept has already been proven as feasible (XV15; V22) it was a challenge for the european tilt rotor activities to concentrate on a study for a nacelle concept with stationary engines (completely tilting nacelle as a back-up solution) in order to define a tiltrotor propulsion system which provides the following essential advantages for total aircraft design and operation:
° increased flexibility for engine selection/better engine availability;
° conventional engine installation
° increased flexibility for total aircraft design
° increased ground operation safety
° gain of new experience for gearbox- and structure design.

Basis Requirements for Propulsion System Design

Safety / Reliability To be successful on the market the tilt rotor must achieve the safety level of the fixed wing aircraft.
As far as the propulsion system is concerned a finite contribution to safety can be provided; therefore the remaining systems must achieve enhanced safety levels.
To assist the efforts from the propulsion system side to reach the overall safety target, the design of propulsion system components must be such that a maximum safety level can be achieved under consideration of all other design- and operational requirements.

Overall Aircraft Design Requirements
The overall aircraft layout involves certain requirements which have to be considered for propulsion system design:
° tilt axis position
° accessory drives (type, size and location)
° wing geometry/design

Weight Since the propulsion system provides an essential contribution to the overall aircraft weight, light-weight design must be applied as far as possible.

Dimensions As far as the propulsion system is concerned the nacelles provide an essential contribution to aircraft drag. For that reason in particular the nacelle front face must be kept as small as possible.
Consequently those units accommodated within the nacelles (main gearbox, accessories) and also the nacelle structure must be designed such that a compact nacelle configuration can be achieved.

Maintainability Since a tilt rotor has a more complex propulsion system than a helicopter or a fixed wing aircraft enhanced maintenance expense can be expected.
In order to keep the operating costs for a tilt rotor on an acceptable level the propulsion system must provide improved maintainability.

Stiffness The nacelle structure has to support vital parts of rotor drive and tilt mechanism, further the nacelle serves as a structural connecting device between rotor and wing. In order to provide safe aircraft operation for all specified maneuvers and under the expected environmental conditions, the nacelle structure must be designed such that the required stiffness will be achieved.

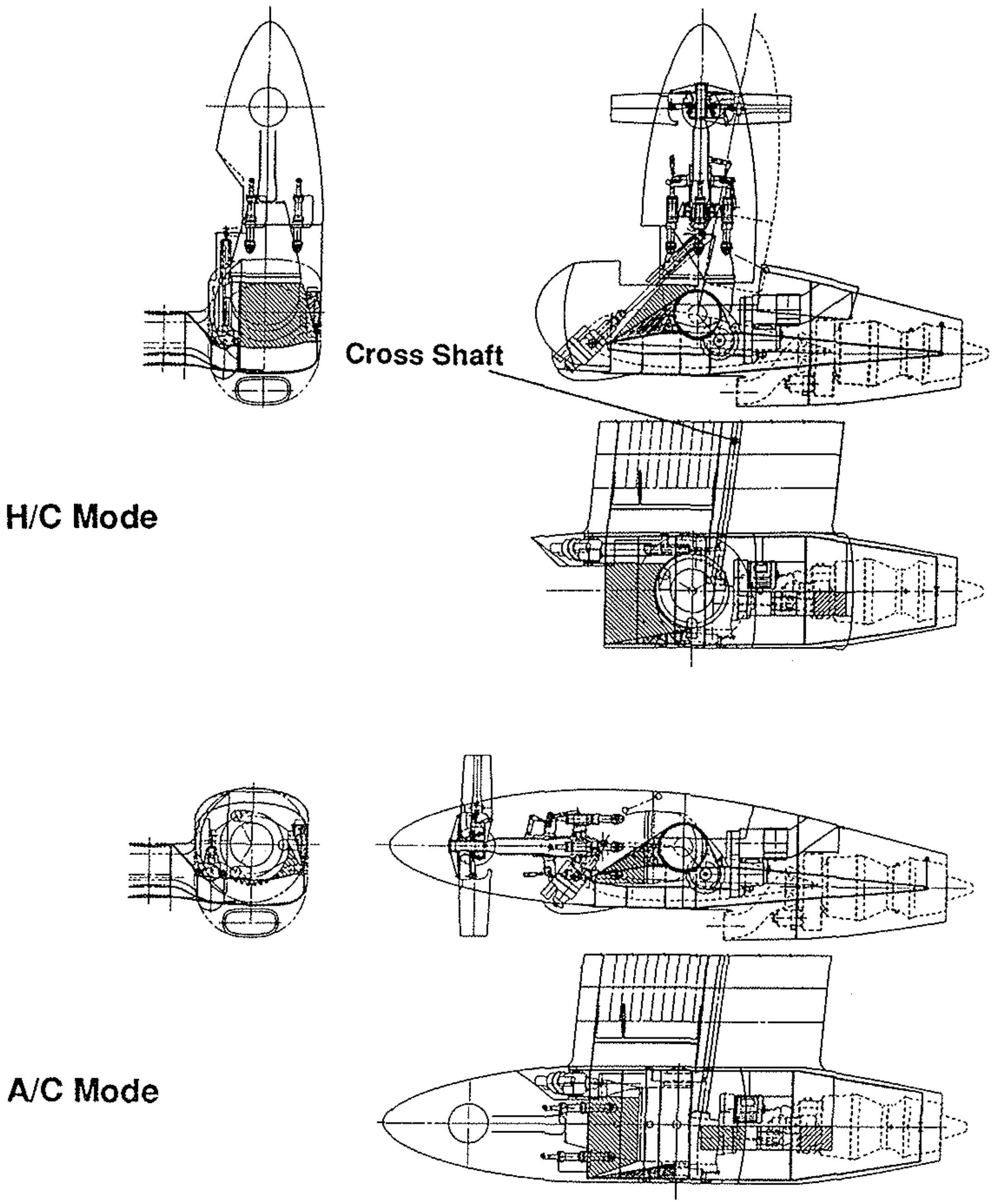

Fig. 4 Single Nacelle Arrangement

Propulsion Nacelle Arrangements for the stationary Engine Concept

Two major arrangements can be envisaged:

a) Single nacelle: on each side all systems are accommodated within one common nacelle; the nacelle structure has to be opened for tilting wherefore a more complex cowling design will be necessary; however, the single nacelle provides a good structural attachment to the wing:

- ° monocoque concept for primary nacelle structure
- ° nacelle structure designed as extension of supporting wing structure
- ° light-weight-design providing high stiffness and reliability

(single nacelle arrangement: see fig. 4)

b) Double nacelle: on each side all systems are accommodated in a combination of two separate nacelles comprising:

- ° a stationary nacelle containing engine and stationary gear section
- ° a tiltable nacelle containing tiltable gear section, rotor support and rotor mast.

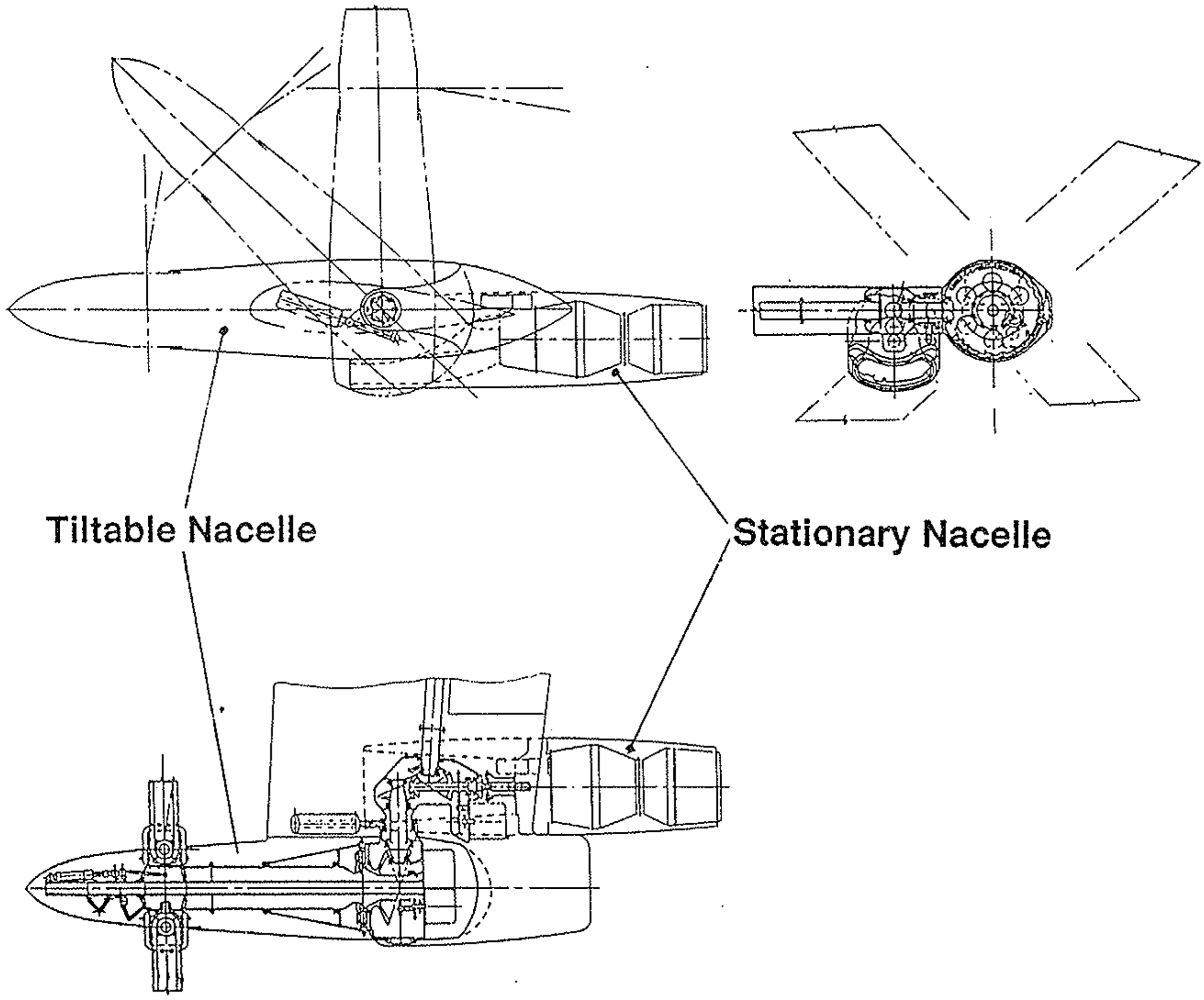

Fig. 5 Double Nacelle Arrangement

The double nacelle arrangement combines the advantages of the stationary engine concept and the completely tilting nacelle which are in particular:

° fixed engine position and all advantages for design and operation related to this configuration
° simple cowling arrangement (secondary structure) since nacelle structure needs not to be opened for tilting
° clear nacelle contour for all flight phases.

However, for the double nacelle, primary structure and attachment to the supporting wing structure will be more complex (double nacelle arrangement see fig. 5)

As far as gearbox design is concerned the nacelle arrangement creates no major differences; solely the space arrangement of the gearbox units has to be adapted.

Previous EUROFAR-activities (up to the current state of work) were mainly concentrated on the single nacelle arrangement.

For final concept comparison/selection further design investigations will be done for the double nacelle solution.

Propulsion System Design

General For the design of the propulsion system the basis design requirements have to be considered at which the safety/reliability aspects have the highest priority. This is based on the fact that compared to a helicopter a tilt rotor aircraft is inherently less reliable and that particularly for following reasons:

° two main gearboxes instead of one
° two cross-shaft systems instead of one tail drive shaft
° more complex system architecture due to tilting mechanism.

Since the stopping of one rotor is a catastrophic failure (safe landing is not possible with one rotor) all propulsion system components the failure of which could cause such an event have to be considered as critical:

° main gearbox
° cross-shaft system*
° intermediate gearbox*
* during OEI operation only

The engines including the main gearbox input section (up to the freewheel, see section "Gearbox Design") need not to be considered as critical, however, the engines need sufficient OEI capability, since tilt rotor operations from confined urban centers must be considered.

Design Philosophy Since for the tiltrotor propulsion system a great number of requirements has to be considered (at which some of them even require oppositely oriented design activities), a final design status which gives a well balanced solution for all items can only be achieved by a carefully performed approach process.

Gearbox Design On principle the tiltrotor transmission system can be divided up into five sections:

° gear system between engine and freewheel (1)
° gear system between freewheel and rotor (2)
° cross shaft drive (3)
° intermediate gearbox (4)
° accessory drive (5)

Fig. 6 shows the main gearbox design for EUROFAR-application (stationary engine concept). This design presents an intermediate status (conservative design) which is not yet finally optimized.

Since the gear system is designed for the stationary engine concept it is divided up into two major units:

° stationary unit comprising engine input, high speed reduction stage, freewheel, cross shaft drive, accessory drive;
° tilting unit comprising output gear stage (planetary gearing) and rotor mast support.

The tilt axis is integrated into the gear system. Tilting happens via the so-called interface stage, a bevel gear connection between stationary and tilting gear unit (fig. 6).

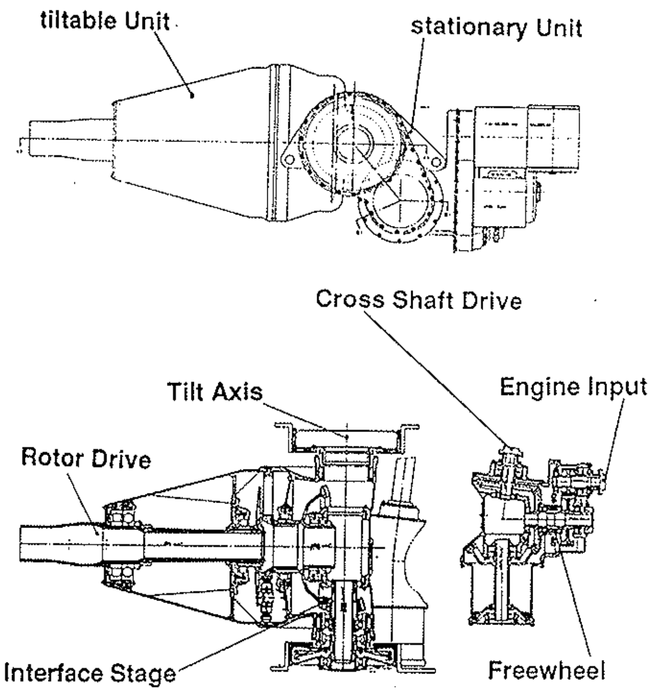

Fig. 6 Main Gearbox Design

In order to increase gearsystem reliability the following guidelines have to be considered:
° cross shaft output stage located as close as possible to the rotor output stage (main gearbox output)
° freewheel located as close as possible to the cross shaft output (however, not beyond it).

The reasons for these measures are as follows:
° all gear components between engine and freewheel are not safety critical since the freewheel ensures isolation of any failure within this section.
° continued rotor operation is ensured via the cross shaft drive and the remaining gear section (between cross shaft drive and rotor output) by OEI-operation of opposite engine.

On the other hand these measures will produce weight penalty since

° a greater section of the gear-system has to be designed for OEI power

° the cross shafts will operate with lower speed and thus will require increased dimensions.

For further optimization of tilt- rotor gearbox design the following should be considered:

° Number of critical items - particularly within the gear unit between freewheel and rotor - should be reduced: minimum gears (stages) and bearings (increase of reliability, weight reduction)

° Reduction of stress levels (increase of reliability, however, weight increase)

° Application of damage tolerant design (as far as possible).

<u>Cross Shaft Design</u> The cross shaft system including the intermediate gearbox will be subjected to the following load conditions:

° transfer of balance loads between the two rotors (nacelles) during flight
° load transfer during start-up and shut-down
° load transfer for accessory drive (if required at the intermediate gearbox)

Full rotor power has only to be transmitted during OEI operation.
Unlike helicopter tail drive shafts torque can be transmitted in either direction.
Each cross shaft unit (left hand side/right hand side) comprises
° shaft sections
° bearings
° couplings
° dampers (for supercritical shaft operation) (see fig. 7)

For the cross shaft a low weight design with high reliability has to be achieved. Reliability can be increased by

° using a minimum number of bearings and couplings
° keeping the stress level low
° using damage tolerant features for critical areas.

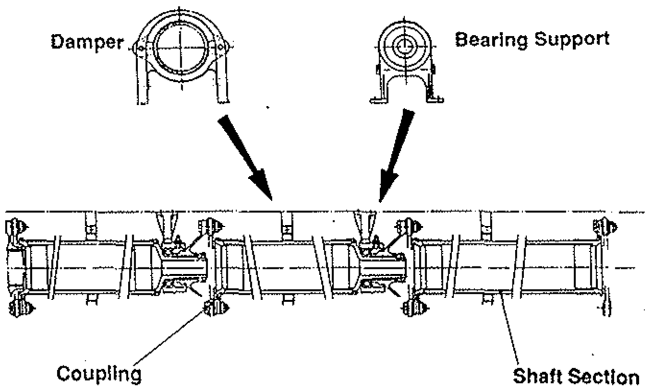

Fig. 7 Cross Shaft Design

For given shaft speed and dimensions the number of bearings, couplings and shaft sections depends on the shaft operating conditions (subcritical or supercrirtical) at which supercritical operation will result in a reduced number of bearings etc.
(see fig.8).
The best weight/stress combination which also provides compact dimensions will be achieved by using carbon composite material for the shaft structure.
These facts result in the selection of a supercritical carbon composite cross shaft design.

In the current overall design the cross shaft is located approximately within the wing structure's middle section (see fig.4).
This location provides two major advantages:
° increased safety against shaft damage (e.g. a shaft installed within the wing leading edge area could be subjected to FOD);
° the cross shaft can be directly connected to the stationary gear unit's cross shaft drive; no additional offset-gearsection will be necessary.

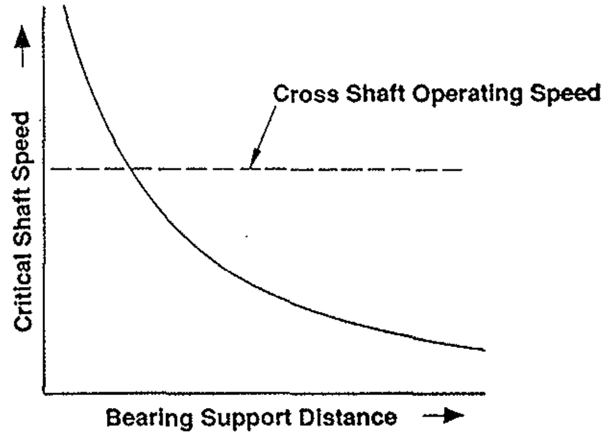

Fig. 8 Effect of critical Shaft Speed on Bearing Arrangement

Engine

Based on the power- and operating requirements for the EUROFAR - tiltrotor the PW 300 turboshaft engine was selected (fig. 9).
This engine is a derivative of the PW 300 turbofan engine developed in co-operation by Pratt and Whitney Canada and MTU Munich.

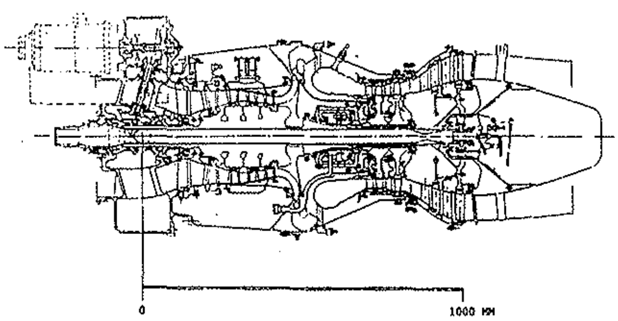

Fig. 9 PW 300 Turboshaft Engine

The turboshaft version is currently designed for operation in horizontal position, however, it can also be available for a tiltable engine concept.

Major engine features:
° FADEC-control
° self-contained oil system
° growth and down-rating potential
° low maintenance cost
° good safety/reliability.

The engine is installed in the rear section of the propulsion nacelle. This engine compartment section could be completely removed from the nacelle as one separate module (in order to improve maintenance conditions).
Engine air inlet design and location are not yet finally defined.
Due to the variable rotor position engine air inlet conditions cannot directly be compared to those of a conventional turboprop nacelle.
Different rotor thrust in helicopter mode, aircraft mode and during tilting may influence engine air inlet conditions.

In order to define an optimum air inlet location and design under consideration of these conditions, corresponding detailed aerodynamic investigations are necessay.

Some Ideas concerning Operating Costs

At first sight the tiltrotor propulsion system seems to produce much more operating costs than those of normal helicopters due to
° increased system complexity
° more stringent reliability requirements

However, the mission of a civil tiltrotor includes only a 4%-portion for operation in helicopter mode. For the remaining mission time the tilt rotor operates in aircraft mode with a less severe operating environment for the propulsion system.

In order to achieve increased reliability, the dimensioning of the gearsystem is done such that lower stress levels than for current helicopter gearboxes will be obtained.

These facts provide improved operating conditions for a tiltrotor propulsion system compared to a helicopter.
Consequently component wear will be reduced, leading to extended maintenance periods.

A further optimization of propulsion system operation will be obtained by implementation of corresponding monitoring systems which can lead to on-condition maintenance an thus will provide an essential reduction of operating costs.

Nacelle Structure Design

Up to now three nacelle concepts (fig. 10) were investigated at which each concept provides completely different primary and secondary structure design.

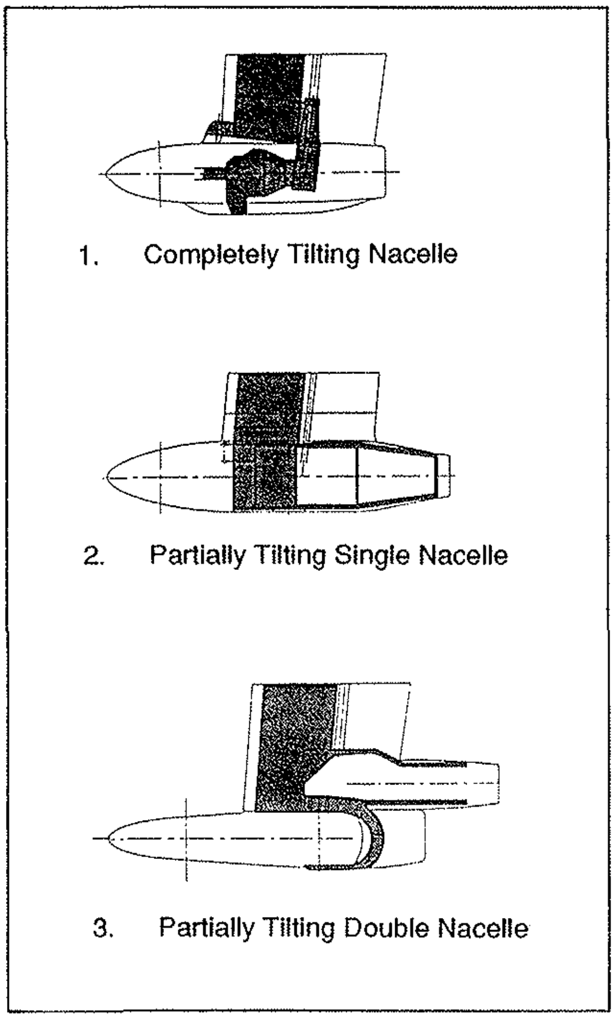

Fig. 10: Typical Primary Structure Arrangements of Tiltrotor Nacelles

1. The completely tilting nacelle has a compact and a primary structure integrated in the main gearbox which is connected to the wing with 2 bearings and a tilting actuator. This type of nacelle is used at the actual V-22 tiltrotor.

   The tilting interface between the fixed wing and the tiltable nacelle is located within a plane parallel to the flight direction.

   The secondary structure shapes the loft contour of the whole nacelle and is steadily fixed to the gearbox.

   This concept allows simple integration of maintenance holes and access doors. The disadvantages of the propulsion system are shown under "Tilt Concept Features" (a) Completely tilting nacelle.

2. To avoid these disadvantages a stationary engine concept has been studied to show the dynamical, integration and layout problems. The main activities have been done on the single nacelle structure integration (see fig. 11). It was clear from the beginning that the structure/gearbox integration has to be done in close cooperation to get an optimized solution. The very high stiffness requirements of the wing structure (to withstand whirl flutter effects) have to be fulfilled in the nacelle torsion box, too. In order to get this stiffness simultaneous with optimum weight and safety aspects (fail safe) the nacelle primary structure will be designed as a carbon fibre monocoque.
   By varying the number and the distribution of the carbon layers the stiffness of the structure can be adapted. If the requirements change there will be only minor influence in the production/ tooling concept. Additionally the damage tolerance capability of the layers affects the structural redundancy of the monocoque and therefore the safety degree of the total structure.

The path for forces coming from the rotor, the tilting actuator and the engine support structure into the nacelle/wing torsion box will be provided by 2 longerons. The lower tilting actuator hinge fitting is very close to the torsion box to minimize the torsion stresses. This hinge position enables a nearly complete integration of the tilting actuator into the loft contour.
Due to handling, maintenance and production aspects a simple connection by a flange type fitting to the wing is necessary (fig. 11).

In order to have protection against ice and foreign objects (FOD) - only necessary in the transition and helicopter mode - a simple stretched elastomeric cover is installed between front spar of the torsion box and the main gearbox (see fig. 11).

The secondary structure shapes the loft contour of the nacelle and is made of mainly reinforced fibre plastics. Because of the "folding" of the nacelle during the transition and helicopter mode (4% of flight time only) a complex interface between stationary and tiltable structure is necessary.

To ensure simple production and good exchangeability/maintainability the complete nacelle is divided into 3 functional subassemblies:

- centre section (torsion box, stationary gearbox, fittings for the tiltable section, flange type fitting, tilting actuator, movable fairings)

- engine section (engine, engine support structure, firewalls, air inlet, exhaust)

- tiltable section (tiltable gearbox, rotor and control systems, fairings, FOD protection).

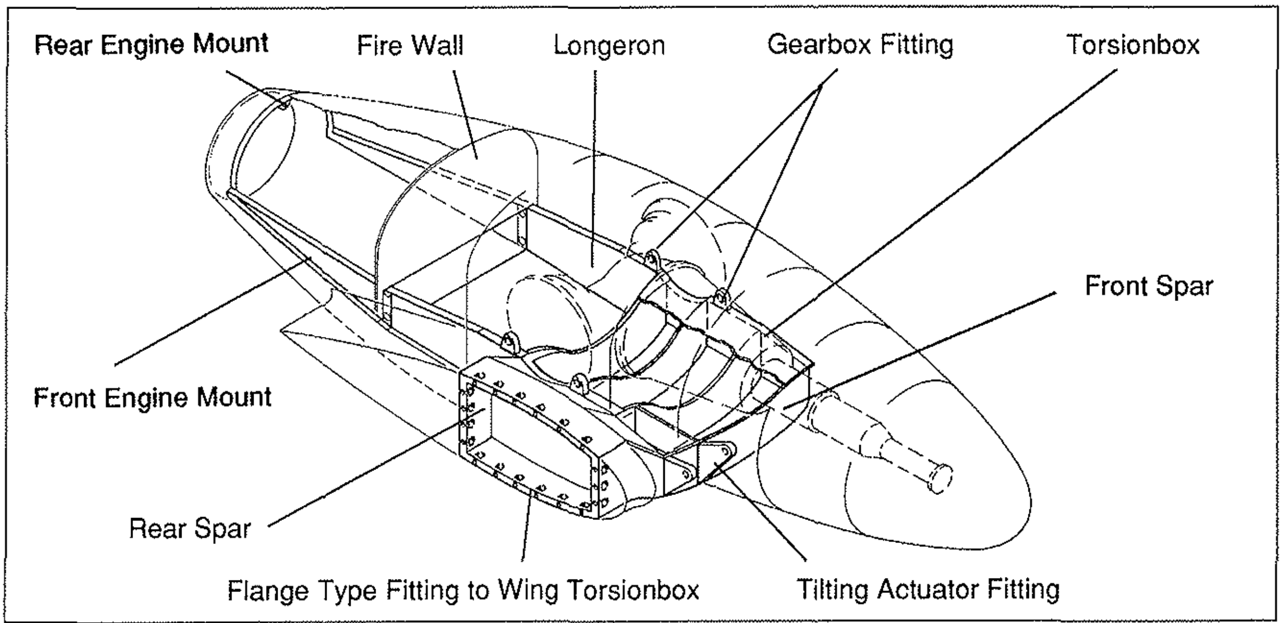

Fig. 11: Primary Structure of Partially Tilting Single Nacelle

3. To avoid the complexity of the folding interface at the fairing of the single nacelle a double nacelle configuration (fig. 10) is in progress. This configuration promises at first sight to be a simple solution. However the very high stiffness requirements to withstand the whirl flutter will lead to difficult implementation of the primary structure and must be studied more in detail.

For all configurations the most important structure design criteria are given in fig. 12.

required	achieved by
- High structure stiffness	monocoque torsion box in CFC
- Crashworthiness	use of materials with high specific tensile strength (CFC, AFC)
- Damage tolerance	ply distribution of fibres
- Redundant loadpath	monocoque design
- Fire proofness	fire resistant materials (titanium, steel and ceramics)
- Ice and F.O.D. protection	elastomeric material with large temperature applications
- Low drag area	high degree of integration
- Maintainability	large access doors, movable fairings, modular construction

Fig. 12: Structure Design Criteria

<u>References</u>

(1) Andres, J., Huber, H., and Renaud. J.
"The Tilt-Rotor Aircraft: A Response to the Future? From european Interrogations to EUROFAR Actions"
12th EUROPEAN ROTORCRAFT FORUM, Garmisch-Patenkirchen, September 1986

(2) von Reth, R.D., Hagmann, U. and Huber, H.
"EUROFAR-Projekt für ein senkrecht startendes Reiseflugzeug"
Symposium
"Luftfahrt-Städtebau-Umwelt (II)"
Essen, January 1989

(3) Muggli, W., von Reth, R.D. and Huber H.
"EUROFAR-Europäisches Projekt für ein senkrecht startendes Verkehrsflugzeug"
DGLR-Jahrestagung, Hamburg, October 1989

(4) Monti. G. "EUROFAR-General Vehicle Layout"
Roayal Aeronatical Society Symposium on EUROFAR, London, April 1989

(5) Renaud, J., Monti, G. and Venn, J.
"Advocating international Cooperation - The EUROFAR Program: An Example and a Hope"
San Francisco, January 1990

(6) MTU/Deutsche Aerospace - Pratt and Whitney Canada
"PW 300 Turboshaft Engine for EUROFAR Tiltrotor Aircraft"
Presentation to EUROFAR Industrial Program Group, Amsterdam, Septermber 1989