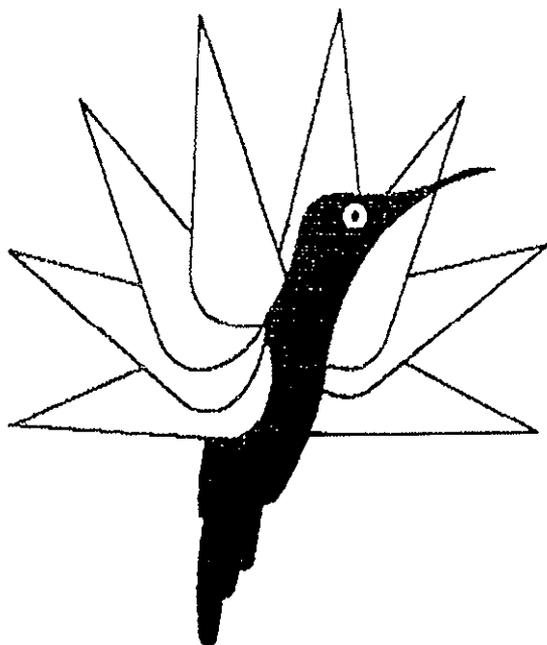


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**LOW WEIGHT TECHNOLOGY
FOR HELICOPTER TRANSMISSIONS**

by

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CONTENTS:

1. INTRODUCTION
2. HOUSINGS
 - 2.1 Housing material
 - 2.2 Housing design
 - 2.3 The transmission housing as a structural component
3. SHAFTS
4. BEARINGS
 - 4.1 Integrated raceways
 - 4.2 Combined bearings
 - 4.3 Cage materials
5. CONCLUSION

1. INTRODUCTION

The list below gives some reasons for continuing efforts to reduce weight, especially in the aircraft industry:

- Increased demand for transport capacity (useful load) whilst at the same time reducing operating costs.
- Consistent and technically rational lightweight construction increases the available useful load capacity and also reduces fuel consumption.
- Reducing overhead costs allows more efficient operation.
- A favourable cost/use relationship ensures the supplier will remain competitive in the future.
- New technologies must continuously be introduced to protect a technological lead or to break into the open market.
- In addition to costs, unit weight is a particularly important decision criteria - especially in the aircraft industry. For the gearbox industry, this means having to take large development risks in order to retain competitiveness.

2. HOUSINGS

The following criteria are particularly important in the design of gearbox housings in order to optimize weight:

2.1 Housing material

The two major factors in reducing weight are housing design and the correct choice of material for the housing. Magnesium alloys allow weight reductions of up to 33% over aluminium alloys. However, magnesium alloy housings are less able to absorb loading than the same housing made of aluminium alloy.

Although magnesium alloy housings may require reinforcing sections to be included in the design, magnesium currently represents the lightest structural material which can be used in the manufacture of gearbox housings.

Composite materials have not yet been sufficiently tested to allow reliable practical measurements to be used in development work. In addition, composite materials demonstrate very poor heat conduction capacity which would require additional measures to rectify, thus increasing weight.

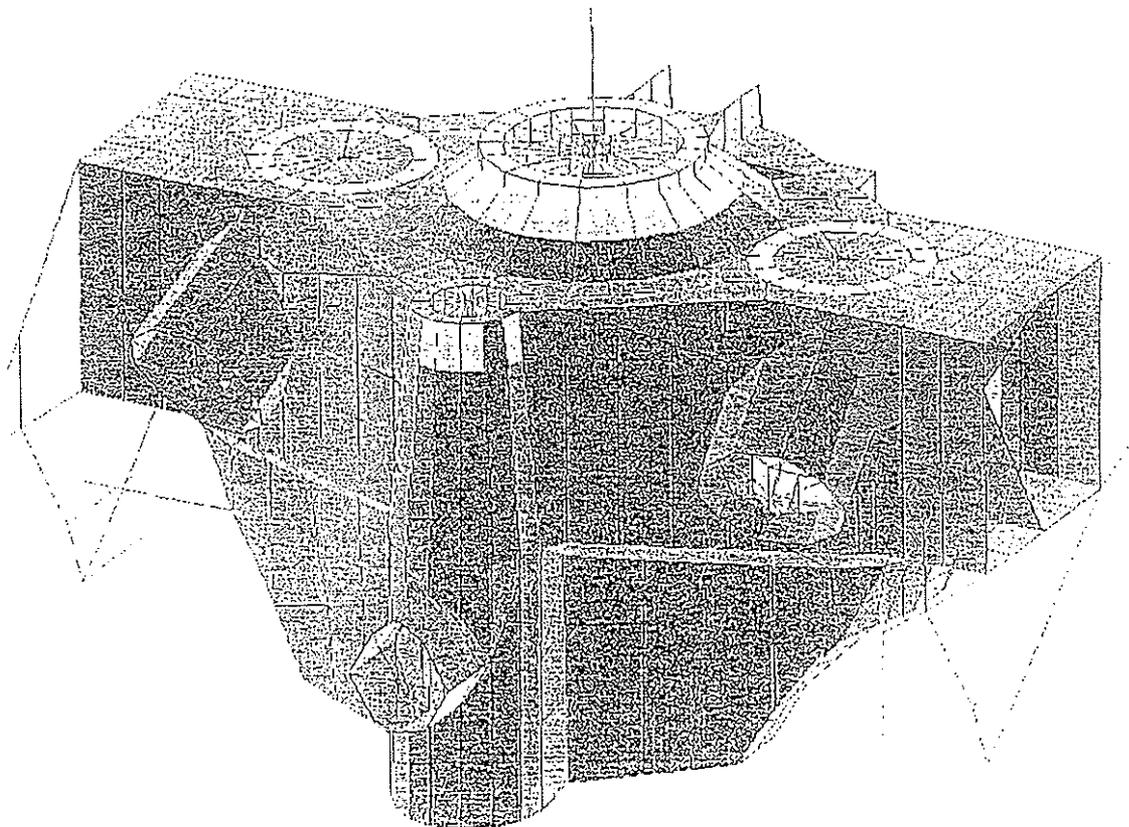
2.2 Housing design

During the design phase, housings are optimized using finite element calculations, e.g. webs or reinforcements can be specifically dimensioned and incorporated.

This makes it possible to influence housing deformations under load to an optimum degree.

Stress levels are kept as even as possible, thus eliminating stress peaks.

Such comprehensive investigations carried out in the drafting and design phases are in many cases considerably expensive. However, they do reduce the development risk during the testing phase.



Finite element model/main gearbox housing

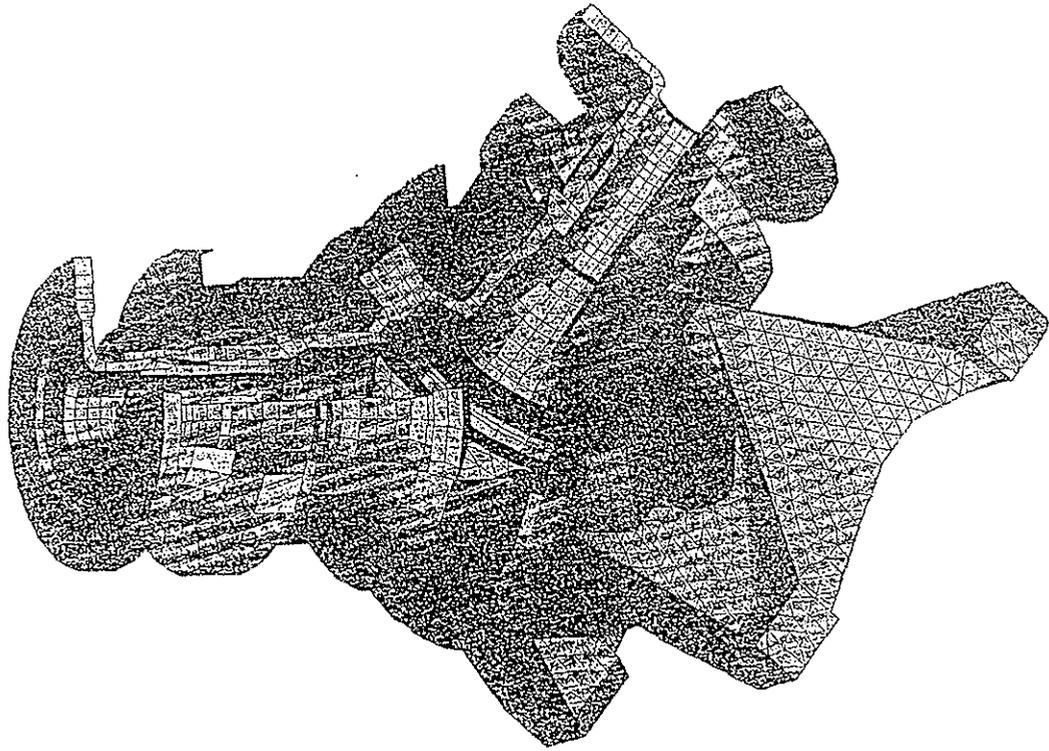
This finite element model (housing only) was used to calculate housing stress and deformations as a function of external and internal forces.

External forces:

- Rotor mast forces (bending torque and axial forces)
- Loadings during flight; the mass forces of the helicopter feed directly into the transmission housing, e.g. the housing takes on the function of a structural component of the helicopter fuselage.

Internal forces:

- Bearing forces resulting from torque transmission.



Finite element model of an intermediate bevel gearbox

In this extended finite element model of an intermediate bevel gearbox, tooth meshing was also simulated, meaning that the input of bearing reaction forces on the bearing points could also be analyzed.

The integration of shafts and flanges into the overall finite element model allowed resulting imperfections in the bearing area and gear tooth mesh to be calculated and corrected.

It was possible to reduce stress peaks over the entire load spectrum by means of targeted design modification.

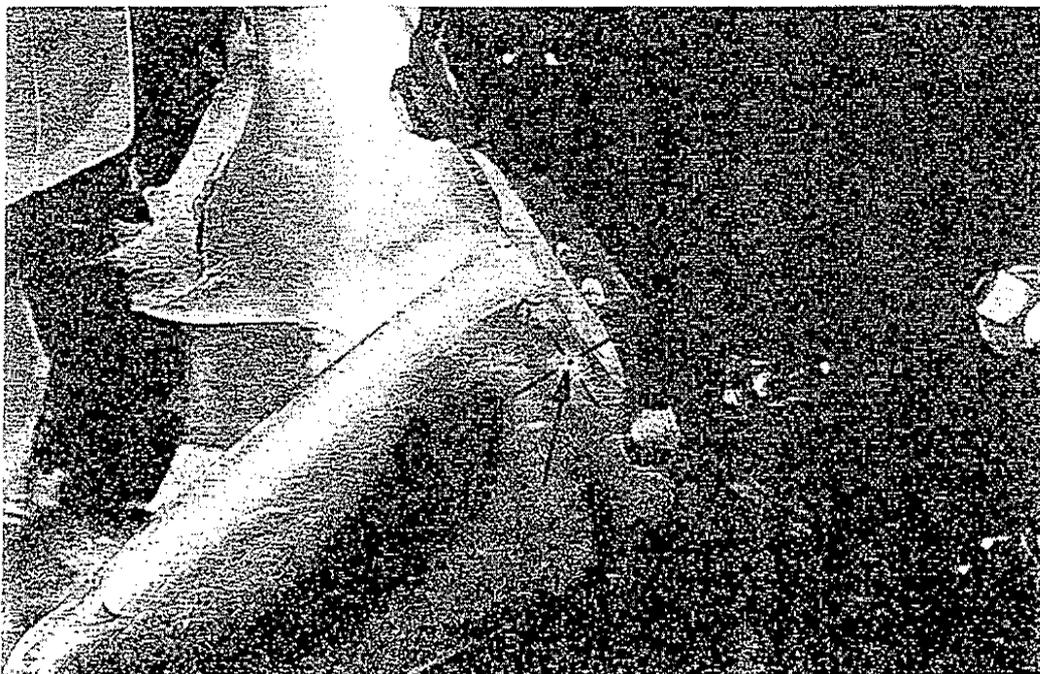
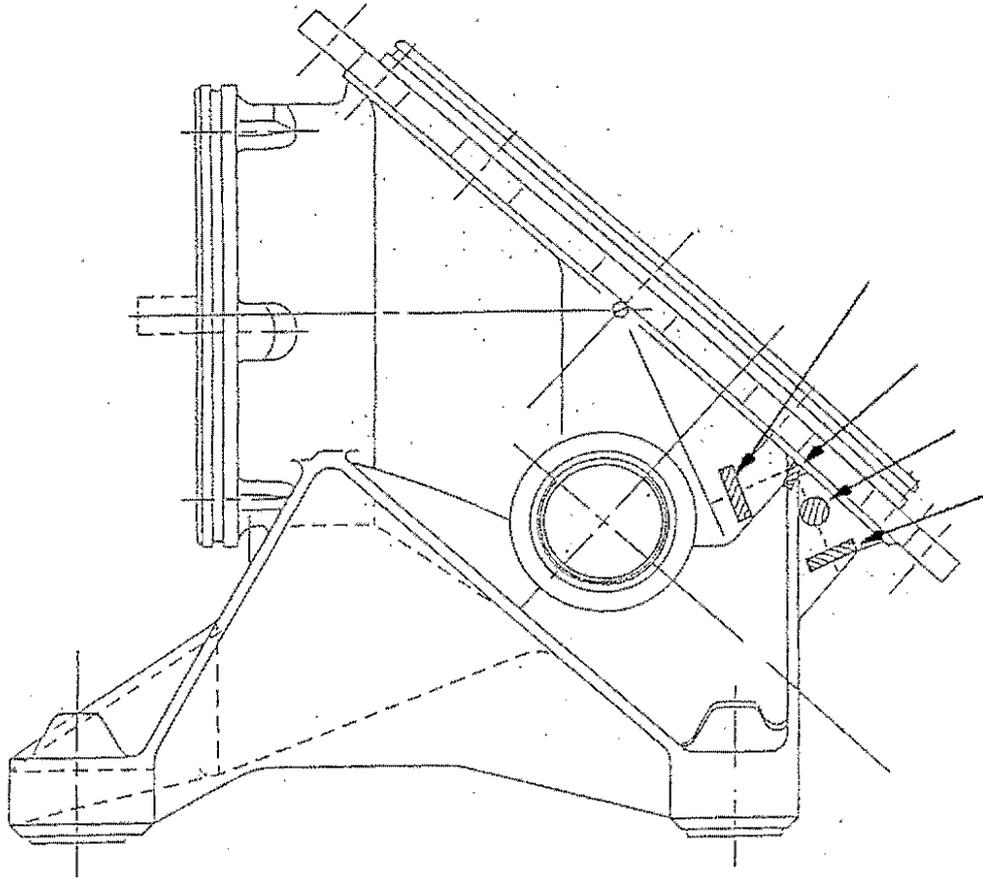


Photo-stress investigation

To confirm the finite element calculation, additional investigations are usually performed using the photo-stress method.

Stress measurement accuracy is $\pm 10\%$.



Strain gauges

To calculate the effect of dynamic conditions, stress gauges are fixed to the most stressed points on test gearboxes as required.

2.3 The transmission housing as a structural component

The tendency in helicopter construction is to integrate as many auxiliary components as possible.

Advantages:

Weight saving due to

- lower number of interfaces
- fewer connection elements
- improved introduction of power

Disadvantages:

- high strength and rigidity requirements
- calculation procedures have to be time consuming in order to ensure reliability
- component testing (static/dynamic)

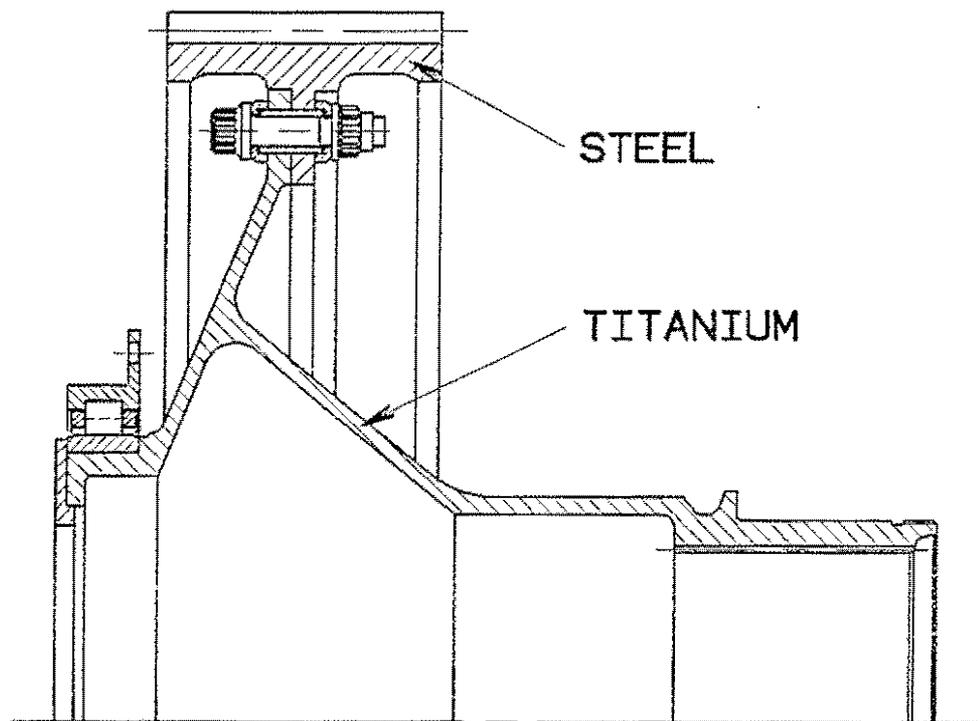
3. SHAFTS

Optimizing the weight of shafts normally involves taking the following considerations into account.

- Function
- Selection of material
- Loading
- Deformation
- Integration of functions
- Ease of manufacture / costs

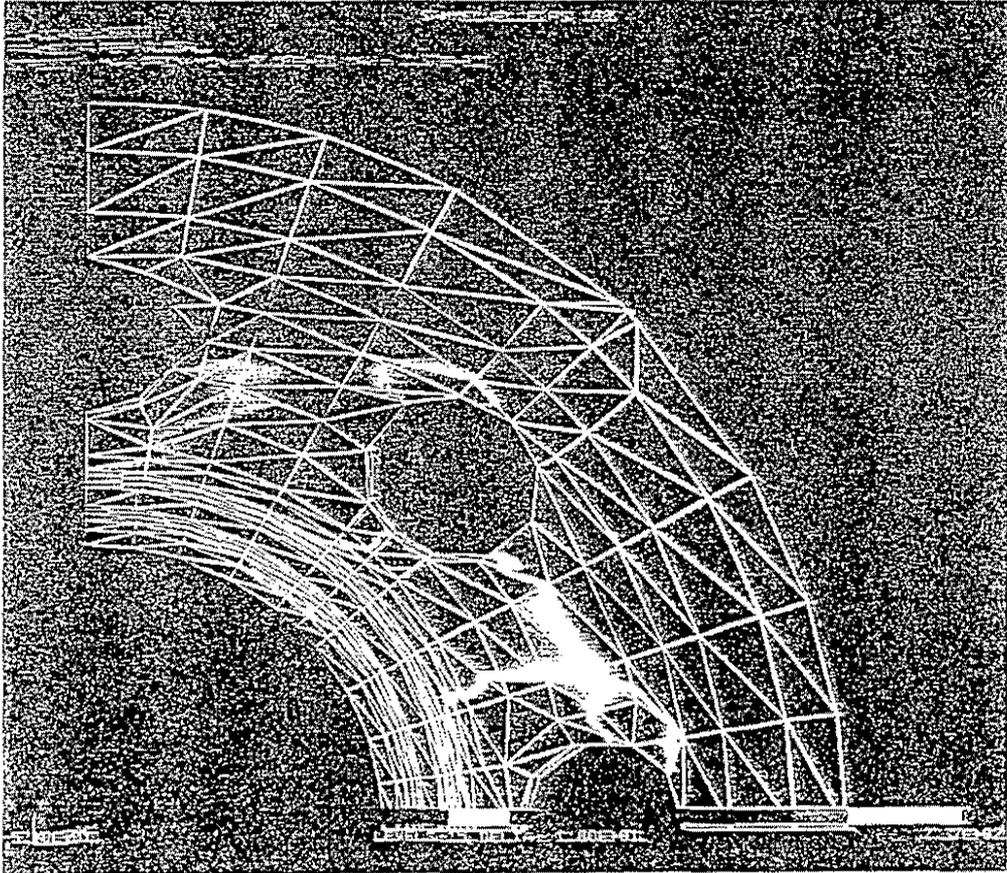
The following diagrams give examples for the above criteria:

FUNKTION SELECTION OF MATERIAL



COLLECTOR SHAFT (BOLTED)

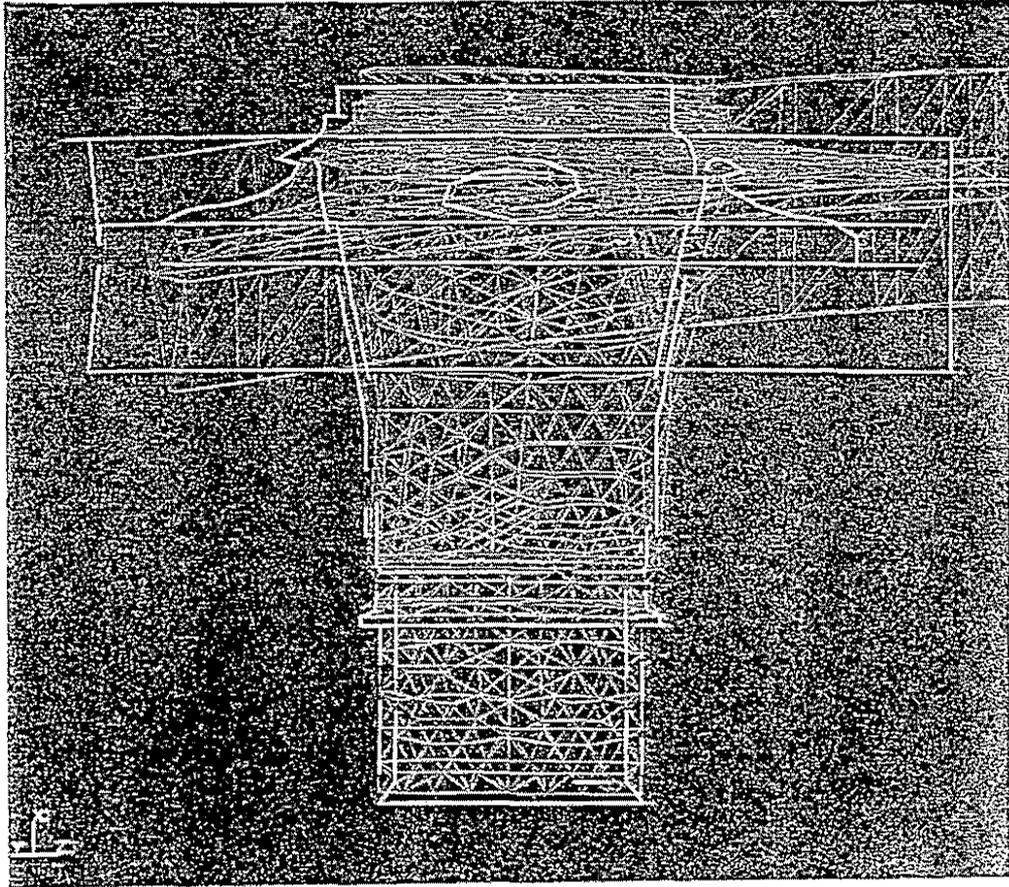
- WITH BEARING INNER RING
- TITANIUM SHAFT
- STEEL RING GEAR



Loading

Finite element model of a 90_ sector of a bolted collector shaft.

Stress peaks around the bores can clearly be seen.

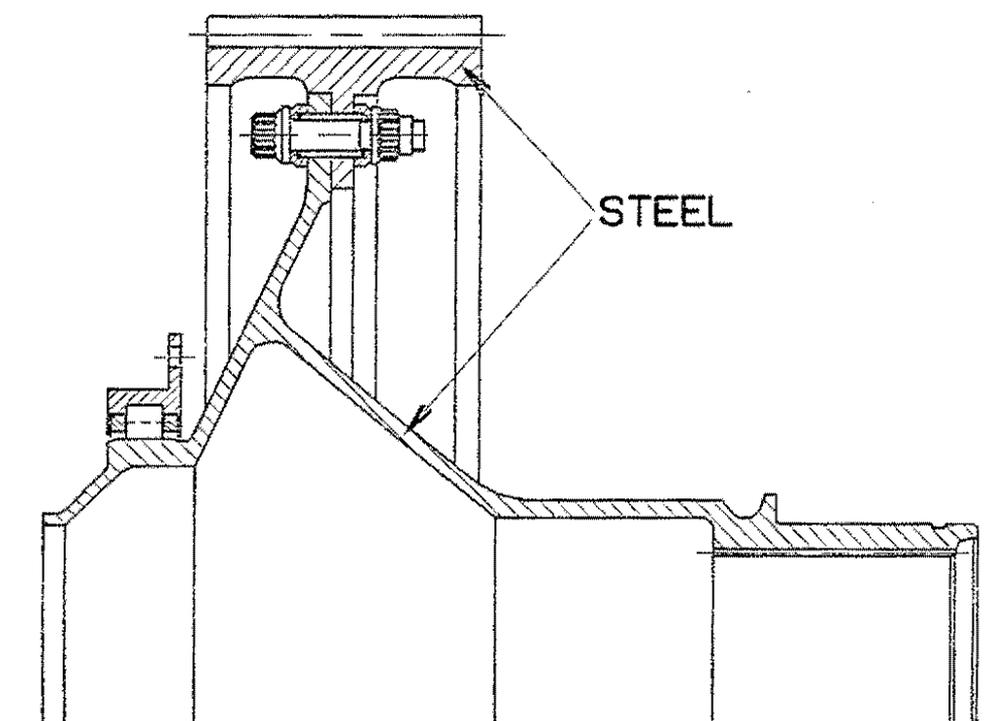


Deformation

Finite element model of the collector shaft.

This finite element model is used to analyze the deformation characteristics of the collector shaft.

INTEGRATION

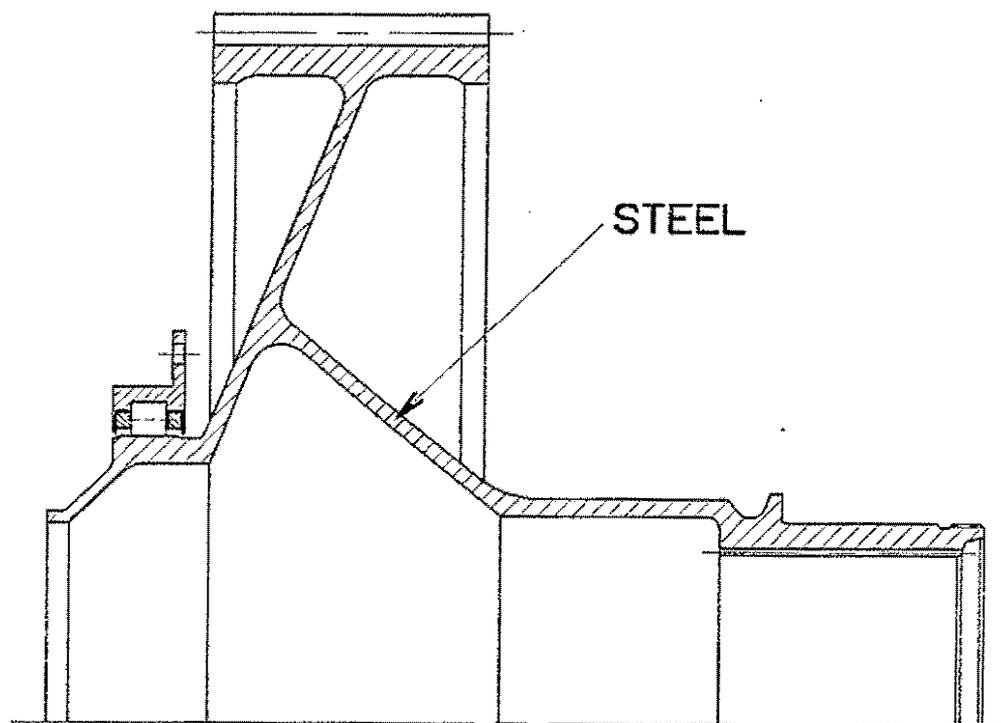


COLLECTOR SHAFT (BOLTED)

- STEEL COMPONENTS

By choosing case-hardening steel for the shaft section, it is possible to integrate the roller raceway and dispense with the bearing inner ring and its attachments.

EASE OF MANUFACTURE COSTS



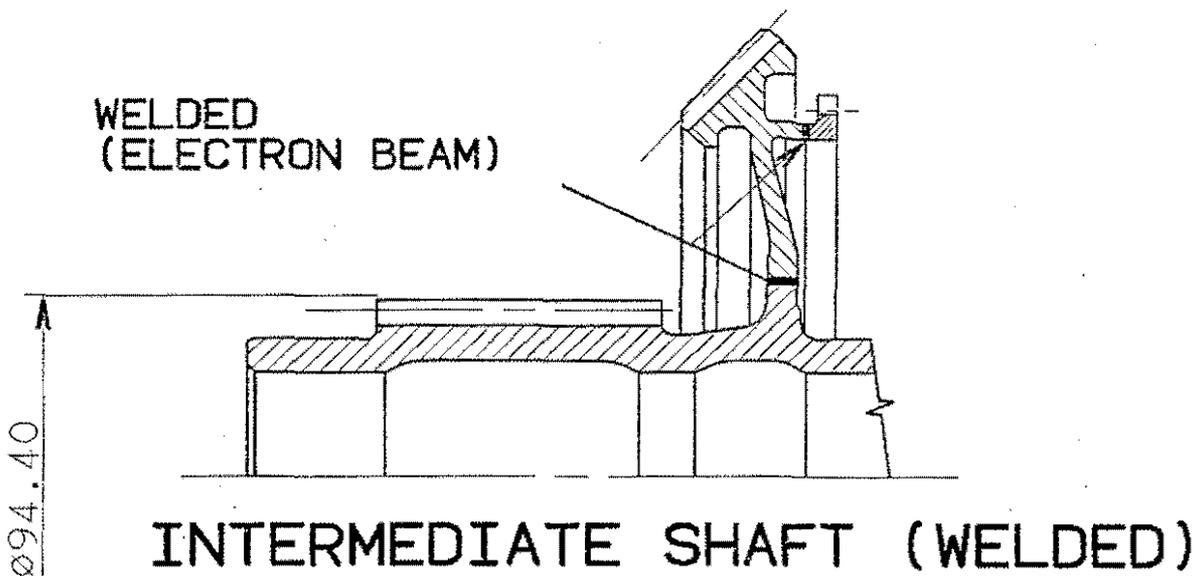
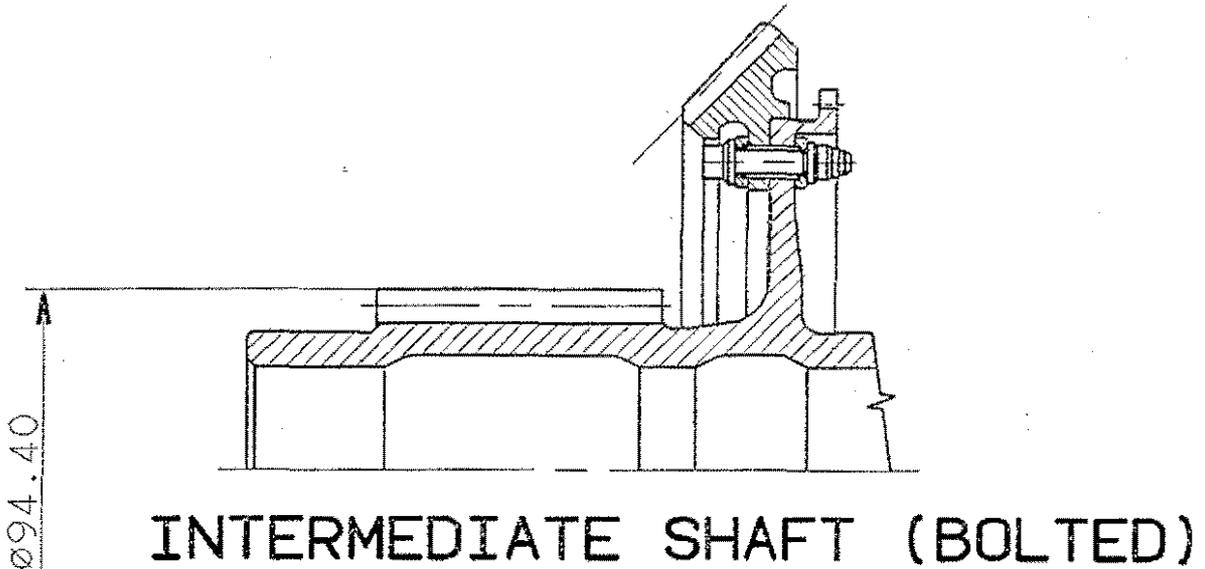
ONE-PIECE COLLECTOR SHAFT

- STEEL COMPONENT

The development goal is to make the shaft part and gear section out of an integral piece of case-hardening steel, this being the optimum solution to the requirements of weight and costs.

In addition to stress considerations, the requirements of carburizing and tempering must be taken into account.

EASE OF MANUFACTURE COSTS



These pictures show the possibilities of weight-saving allowed by consistent use of electron beam welds.

(Note: component separation is unavoidable due to the manufacturing procedure for Hypoid bevel gears).

4. BEARINGS

Some methods for optimizing function and reducing weight of bearings in the construction of helicopter gearboxes are listed below:

4.1 Integrated raceways

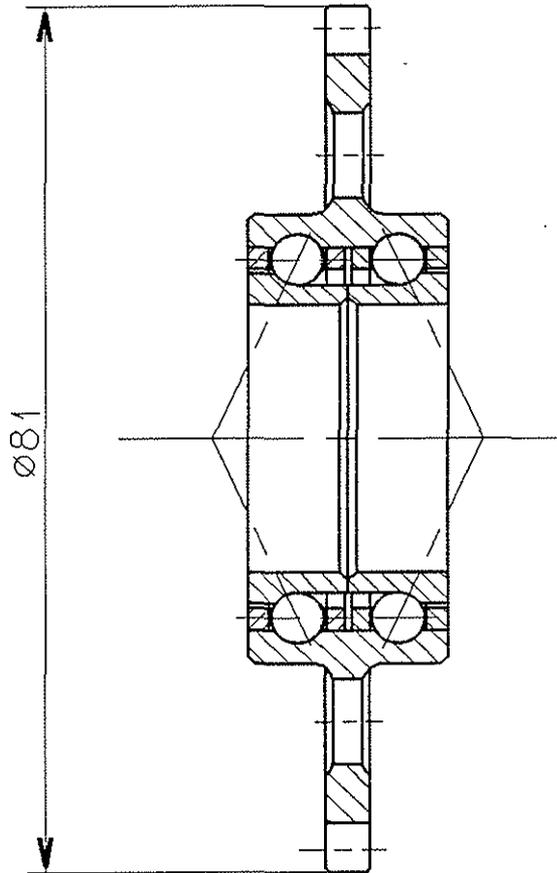
Where it is possible to design integrated raceways, this represents the state-of-the-art for cylinder roller bearings in the aircraft industry. Some integrated raceways for ball bearings have also been introduced.

Integrated raceways offer the following weight saving advantages:

- Removal of one or even both bearing rings
- Reduction in the number of parts
- No additional bolts and fixing elements

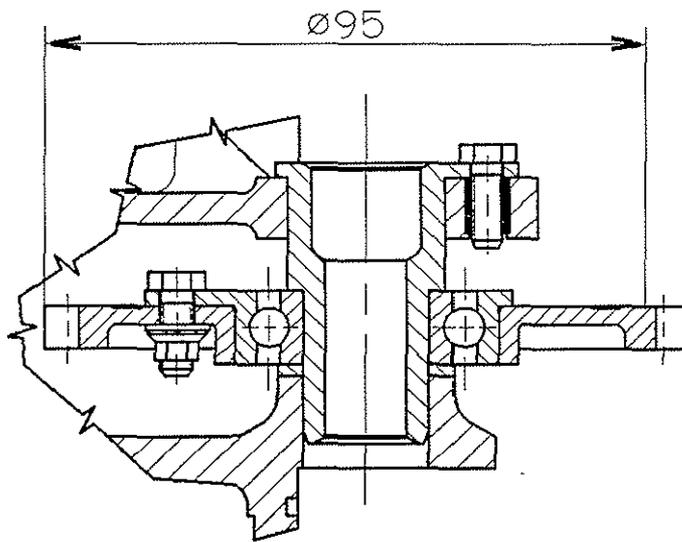
Additionally, the cost and breakage risk of the functional unit is reduced

INTEGRATION



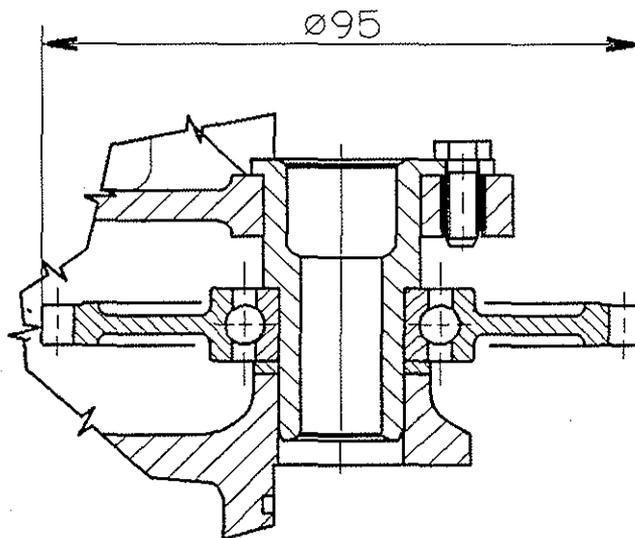
IDLER GEAR

- INTEGRATED BEARING RACEWAY



CONVENTIONAL IDLER GEAR

- FLANGE BEARING
- BOLTING / CENTERING DIAMETER



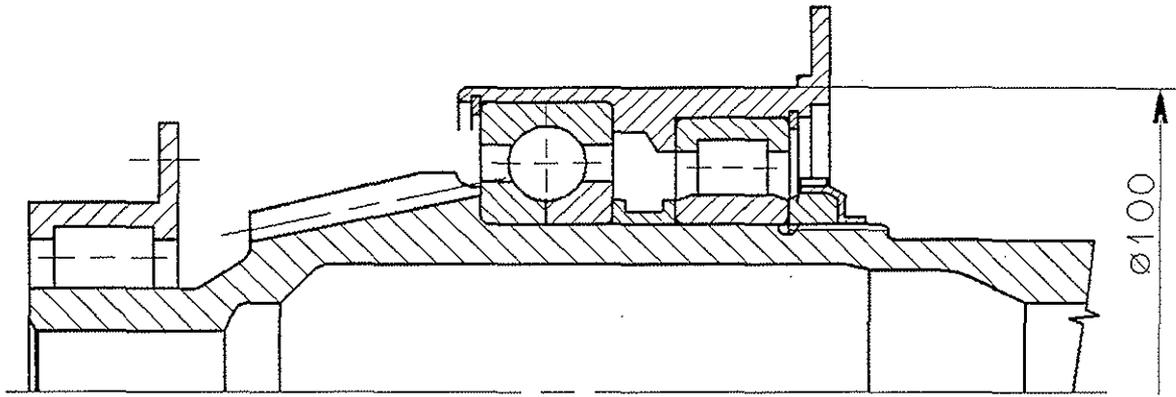
IDLER GEAR WITH INTEGRATED BEARING RACEWAY

4.2 Combined bearings

The term combined bearings is used to describe arrangements whereby several functions are integrated in only a few components. This involves bearings which can absorb axial forces using a ball or 4-point bearing and can also cope with radial forces using a cylindrical roller bearing. The various raceways are manufactured in one component, meaning that additional spacer rings, torsional fixings, fixtures and bearing bushes can be dispensed with. One exception is the bearing inner rings of 4-point bearings which must always be separated for assembly reasons, so an additional bearing inner ring half is always necessary.

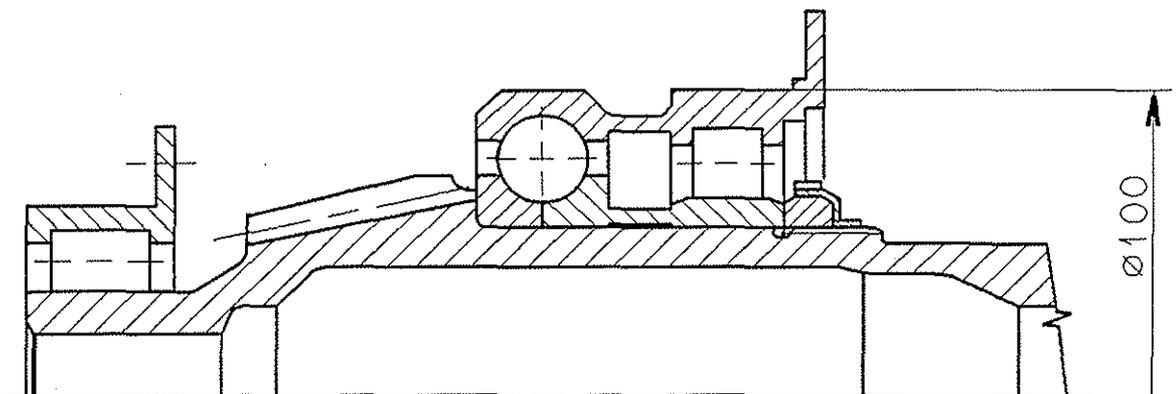
In addition to saving weight, combined bearings offer the following advantages:

- fewer parts
- logistics/stores
- easier to assemble
- less close-tolerance work



CONVENTIONAL BEARING CONFIGURATION

- LARGE NUMBER OF INDIVIDUAL PARTS
- UNFAVOURABLE WEIGHT RATIO



COMBINED BEARINGS

- FEW INDIVIDUAL PARTS
- WEIGHT REDUCTION

4.3 Cage materials

Plastic cages are already being used in large quantities in the engineering industry for roller bearings. Plastic cages have only been used in restricted quantities in aircraft transmissions.

The main reasons for this are:

- operating conditions
- no experience of use
- thermal loadings
- lubricants (MIL-L-23699)

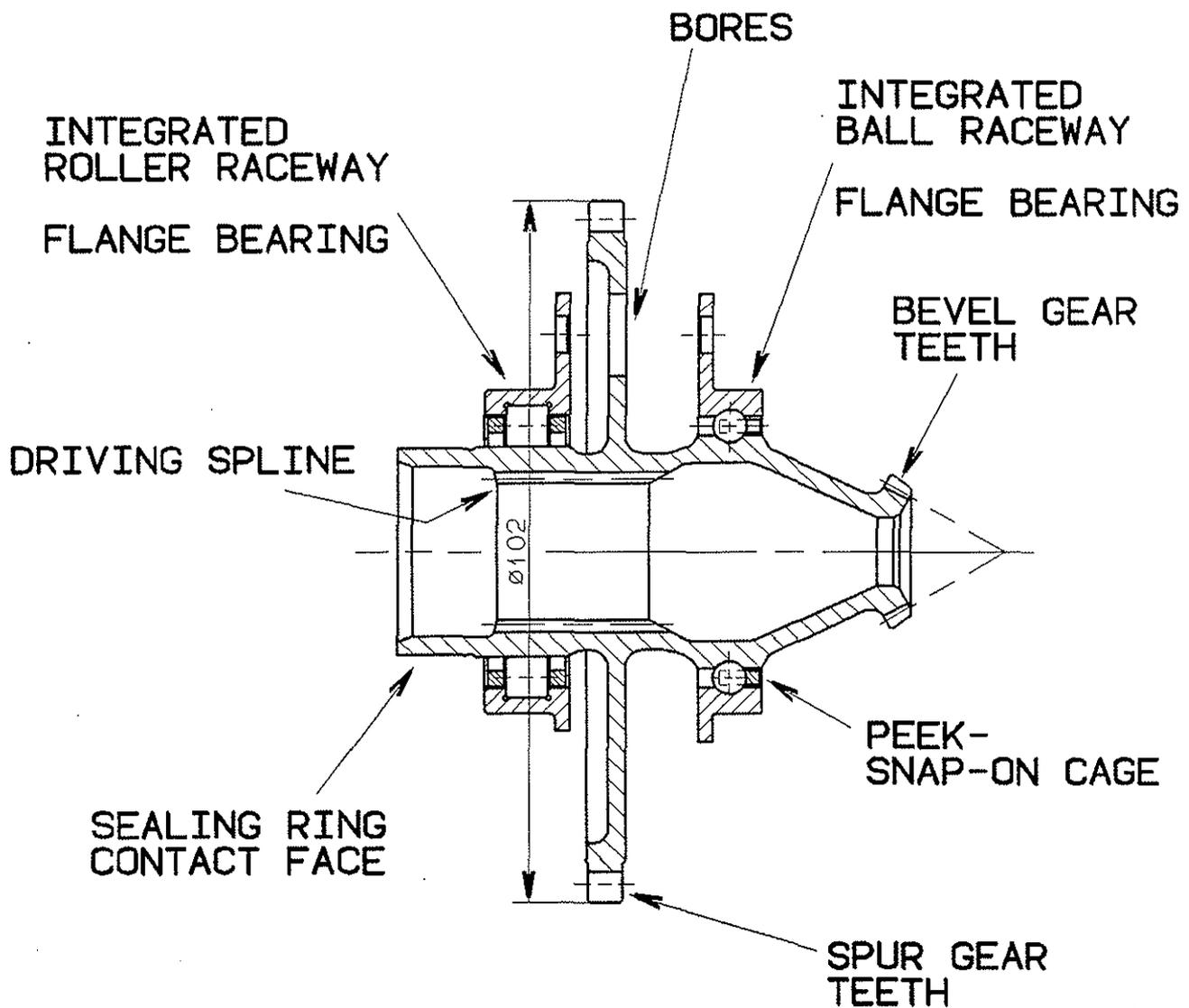
When the standard lubricant to MIL-L-23699 (synthetic oil) is used, the only cage material which can be used is polyether-etherketon (PEEK).

PEEK offers sufficient chemical and thermal resistance to MIL-L-23699 lubricants.

The advantages of PEEK cages are:

- considerably less weight than steel or brass cages
- high flexibility
- good shock absorbing and low friction characteristics
- low heat build-up
- also suitable for high continuous temperatures
- good emergency operation properties
- noise characteristics

LOW WEIGHT DESIGN ON HELICOPTER TRANSMISSIONS



MAXIMUM ADAPTION OF SHAFT CONTOUR
TO STRESS DISTRIBUTION

5. CONCLUSION

This paper presented examples of the main components (housings, shafts and bearings) showing what weight-saving potential is available when various analysis methods are used.

This not only takes account of economic but also ecological considerations:

- Careful handling of resources
- Minimization of material use
- Reduction of energy costs for material preparation
- Reduced energy requirement during operating period
- Better noise characteristics

Consistent weight reduction therefore is not an end in itself, but an elementary design challenge for today and the future.