

EH101 - MAIN ROTOR HEAD COMPONENTS EVALUATION OF THE DAMAGE TOLERANCE CAPABILITY

M. Biasini - Stress Engineer - Rotor Dept.
U. Mariani - Senior Stress Engineer - Fatigue Dept.
F. Oggioni - Senior Stress Engineer - Rotor Dept.

AGUSTA s.p.a.
C. Costa - Italy

Abstract

The EH101 is a multy purpose helicopter jointly designed and manufactured by Agusta and Westland. The civil certification was based on the safe life approach. Additional flaw tolerance evaluations for impact damages, environmental ageing and manufacturing discrepancies were carried out for the composite components.

A post Type Certificate activity of Damage Tolerance (DT) capabilities evaluation was agreed with the Authorities and this paper reports information on the proceedings related to the Agusta components of the Main Rotor Head, addressing details on the results currently achieved on the Main Rotor (M.R.) Hub, the M.R. Damper Hub Attachments, the M.R. Support Cone, the M.R. Inboard and Outboard Tension Links and the Elastomeric Bearings.

Main Rotor Head Components

The EH101, the three engines, multy purpose helicopter jointly designed and manufactured by Agusta and Westland was certified in November 1994 simultaneously by the Registro Aeronautico Italiano, the British Civil Aviation Authority and the U.S. Federal Aviation Administration.

The civil certification was based on the safe life approach. Flaw tolerance evaluations for impact damages, environmental ageing and manufacturing discrepancies were carried out for the composite components.

A post Type Certificate activity of Damage Tolerance (DT) capabilities evaluation was agreed with the Authorities and this paper reports information on the proceedings related to the Agusta components of the Main Rotor Head, addressing details on the results currently achieved on the Main Rotor (M.R.) Hub, the M.R. Damper Hub Attachments, the M.R. Support Cone, the M.R. Inboard and Outboard Tension Links and the Elastomeric Bearings.

According to the different critical sections, the material, the fatigue strength and the loading conditions, different approaches are used, taking advantage of the three options for flaw tolerance demonstration: fail safety, slow flaw growth and enhanced safe life.

The table hereafter provides an overview of the test plan carried out for D.T. evaluation compared to the basic test plan for safe life.

Component	N° of Tests for Safe Life Evaluation	N° of Tests for Damage Tolerance Evaluation
M. R. Hub	2 Full scale 10 Structural Elements	1 Full scale
M.R. Damper Hub Attachments	5 Full scale	2 Full scale
M.R. Support Cone	4 Full scale	4 Full scale
M.R. Inboard Tension Link	4 Full scale 30 Structural Elements	2 Full scale 10 Structural Elements
M.R. Outboard Tension Link	3 Full scale 20 Structural Elements	3 Full scale 12 Structural Elements
Elastomeric Bearings	6 Full scale	2 Full scale

The figure 1 shows the EH101 Main Rotor Head with the components verified for Damage Tolerance capabilities.

M.R. Hub

The M.R. Hub, figure 2, assures connection of the 5 blades and transfer the loads to the mast through a splined coupling. It is a hybrid metal-composite structure made by a titanium splined coupling and 10 small plus 2 large carbon fibre-epoxy loop windings enclosed by an external wrapped glass-epoxy box. The hub is a 125°C autoclave cured component.

Both composite and metallic parts were successfully evaluated for DT capabilities according to a full scale spectrum test with artificially simulated damages and local failures due to the previous safe life test.

No damage growth in the service life was proved by tests in composite parts, which were impacted at 50J with a spherical impactor $\phi=25$ mm, for Barely Visible Impact Damages (BVID), and with a 90° pyramid, as a sharp tool, for Clearly Visible Impact Damages (CVID), figure 3. In addition, relevant scratches and delaminations in the glass wrap due to amplified loading of safe life test proved a slow flaw growth in the start-stop cycles of the D.T. test, and no damage growth at flight loads, figure 4.

After the safe life test, tolerance to fretting in the titanium splined core was checked removing the solid lubricant and 10% of the Hub teeth in the splined coupling with the M.R. Mast and testing again at amplified Torque equal to safe life test, see figure 5.

The component could sustain the same loading cycles without failures.

The S/N curve for the fretting failure mode was computed using a two mean standard deviation reduction for the Enhanced Safe Life evaluation, instead of the standard three standard deviations used for pristine components, considering structural redundancy and the relevant flaws under test, figure 6.

Flaw tolerance of the Aluminium Upper and Lower Plates was checked removing 4 out of 15 bolts on both plates in the spline area and testing the Support Cone coupling area with relevant cracks and fretting due to the previous safe life tests, figure 7.

Also for this case the S/N curve was computed for the Enhanced Safe Life evaluation.

The residual fatigue life computed according to these data is used to establish in service inspection intervals.

The fatigue test proved some hours of fatigue life with the blade shear loads sustained by the composite arm only. This allows, from the structural point, the safe landing of the aircraft in case of a support cone failure.

Residual strength up to limit load was proved without failure or stiffness degradation.

M.R. Damper Hub Attachments

The M.R. Damper Hub Attachment is made by an upper and a lower Al-Alloy plate, bonded to the Hub and additionally fitted by three bolts, figure 8.

After the upper plate failure during the safe life test at amplified loads, the crack growth in the upper plate was monitored at maximum in flight loads proving relevant fatigue strength to propagation.

An artificial flaw was then made by a saw cut in the lower plate, in the section which has showed an additional failure mode in the safe life tests.

According to the favourable test evidences a significant 'enhanced safe life' evaluation can be computed for this item.

M.R. Support Cone

The M.R. Support Cone connects the Pitch Change Arm to the Rotor Hub. It is made by Titanium with a vulcanised Elastomeric Centering Bearing, which allows the pitch movement of the blade, figure 9. The Support Cone is connected to the Hub core via two Special Bolts and four Stud Bolts.

Different flaws are taken into account for the evaluation of the D.T. capability of this component, according to the different critical sections:

- the Stud Bolts failure, which is not critical for the item due to redundancy of the two Special Bolts
- fretting of the Special Bolts
- flaws in the lugs of the Special Bolts, simulating flaws that could be done during assembling and disassembling operations, figure 10. 'V' grooves were made on components tested at constant amplitude loading to determine the Wohler curve of the flawed specimen for the 'Enhanced Safe Life' calculations
- flaws in the cylindrical part of the Support Cone, for simulation of improper production or maintenance operations, figure 10.

M.R. Inboard and Outboard Tension Links

The M.R. Inboard Tension Link is a hybrid structure composed by with two carbon and glass-epoxy composite plates bonded and bolted to a titanium forged frame in the outer folding section. The M.R. Outboard Tension Link is a hybrid structure composed by a titanium forged frame with two glass-epoxy composite plates bonded to the upper and lowed metal frame plates.

Figure 11 shows the two components.

Flaw Tolerance of the composite plates to BVID, manufacturing discrepancies and environmental ageing were already proved for Civil Certification 1994.

Tolerance to CVID and large manufacturing discrepancies is evaluated by tests on full size components of both Inboard and Outboard Tension Links and by additional tests on composite lug structural elements, representative of the inner lug section of the Inboard Tension Link.

Titanium lug structural elements provide data for flaw tolerance evaluation of the Outboard Tension Link lug section.

The capability of the composite plate to provide a redundant loading path after local failure of the titanium lug was checked by full size test of the Outboard Tension Link, figure 12, proving relevant fail safety at maximum flight loads and residual static strength up to limit loads. Equivalent capability is expected by the outer lug section of the Inboard Tension Link.

Tolerance to fretting of the Inboard Root Bolts and the Outboard Main Rotor Blade Pins is evaluated in the D.T. full size tests using components already fatigue cycled during the safe life tests.

Elastomeric Bearings

Two types of Elastomeric Bearings, figure 13, are installed on the M.R. Head, providing the drag, pitch and flap hinges of articulation and transmitting the blade shear loads, Centering Bearing, and centrifugal force, Spherical Bearing, to the Hub. The Spherical Bearing transmits part of the blade shear loads due to its radial stiffness and it can provide a redundant loading path for the flight completion in case of failure of the Centering Bearing, as proved by test.

Additional tests are carried out to provide comprehensive data on the strength and stiffness degradation after fatigue damage, high temperature and contamination by potentially aggressive fluids, like hydraulic fluid and lubricating oil.

Tests are following three phases: accelerated fatigue damage at amplified loads, damage propagation monitoring with and without contamination, residual static test for strength and stiffness evaluation up to limit load.

Conclusions

Relevant Agusta components of the EH101 M.R. Head have already demonstrated significant flaw tolerance capabilities. Additional tests and analysis are carried out to provide a more comprehensive evaluation.

References

1. Candiani L., Mariani U., "Toward a damage tolerance evaluation of Helicopter composite components" Presented at : International Committee on Aeronautical Fatigue ICAF '95, Melbourne 1995
2. Guzzetti G. , Mariani U. , Oggioni F., "Certification of the EH-101 composite components: comprehensive approach" Presented at : American Helicopter Society 51st annual Forum, Forth Worth, Tx , May 9-11 1995

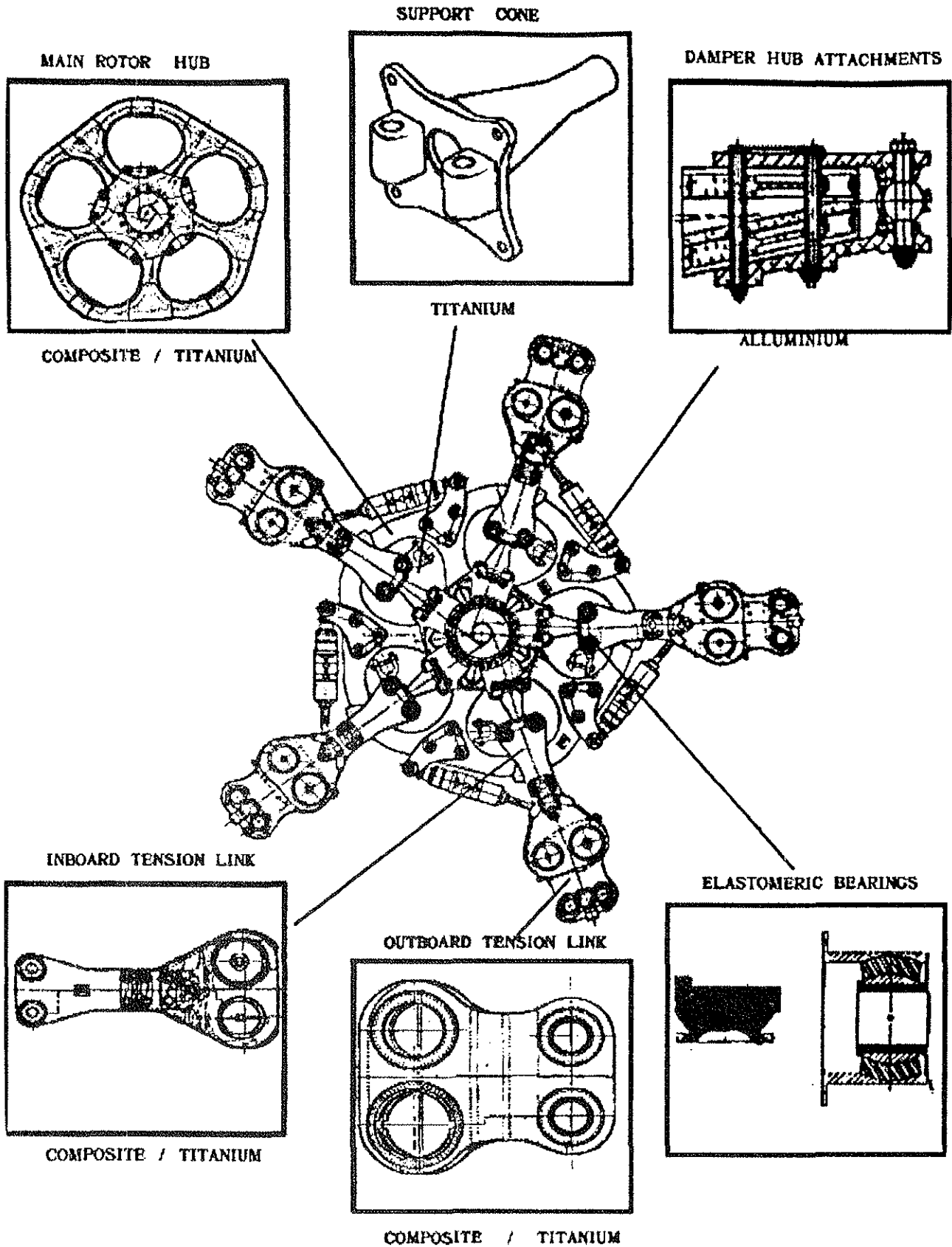


Figure 1 - EH101 Main Rotor Head - Components verified for Damage Tolerance capabilities.

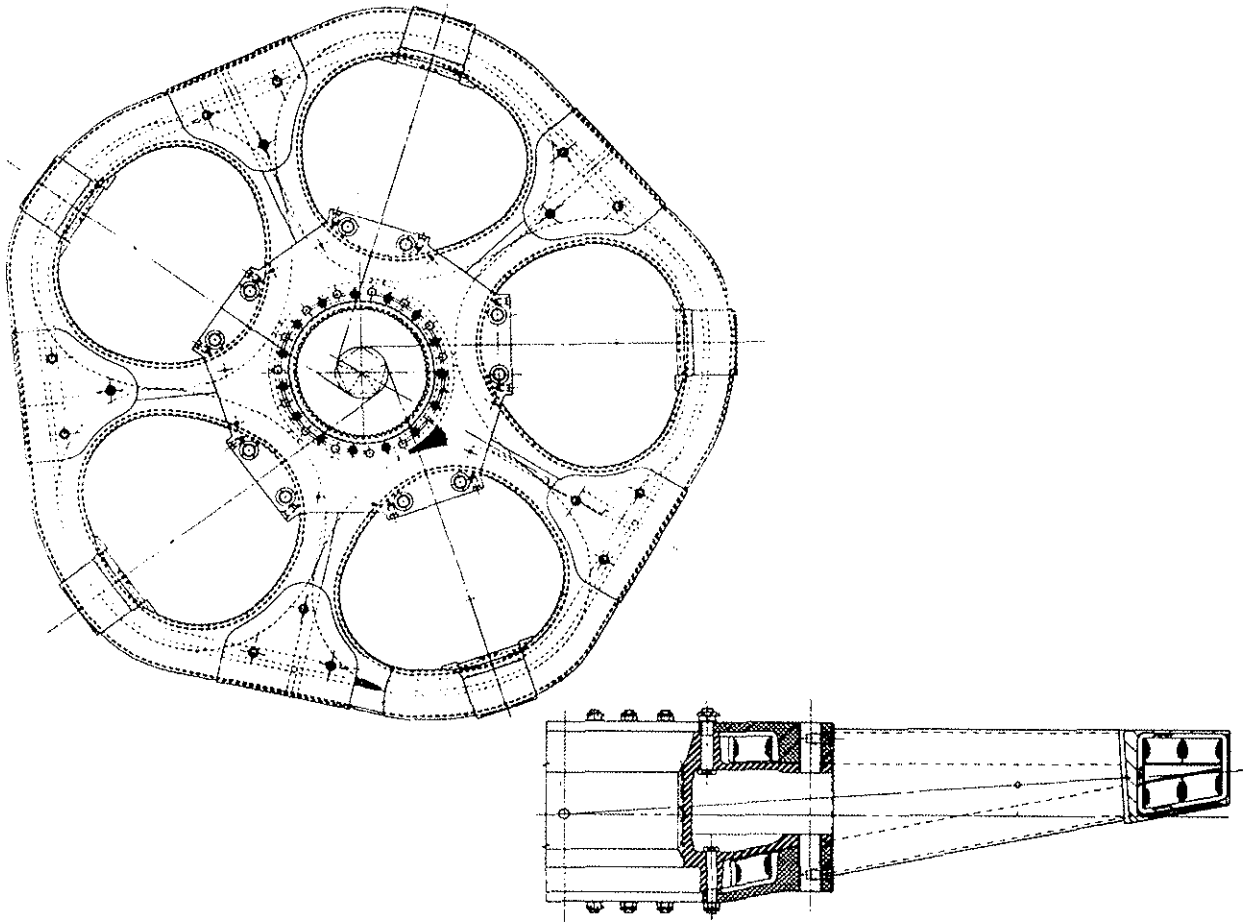


Figure 2 - Main Rotor Hub

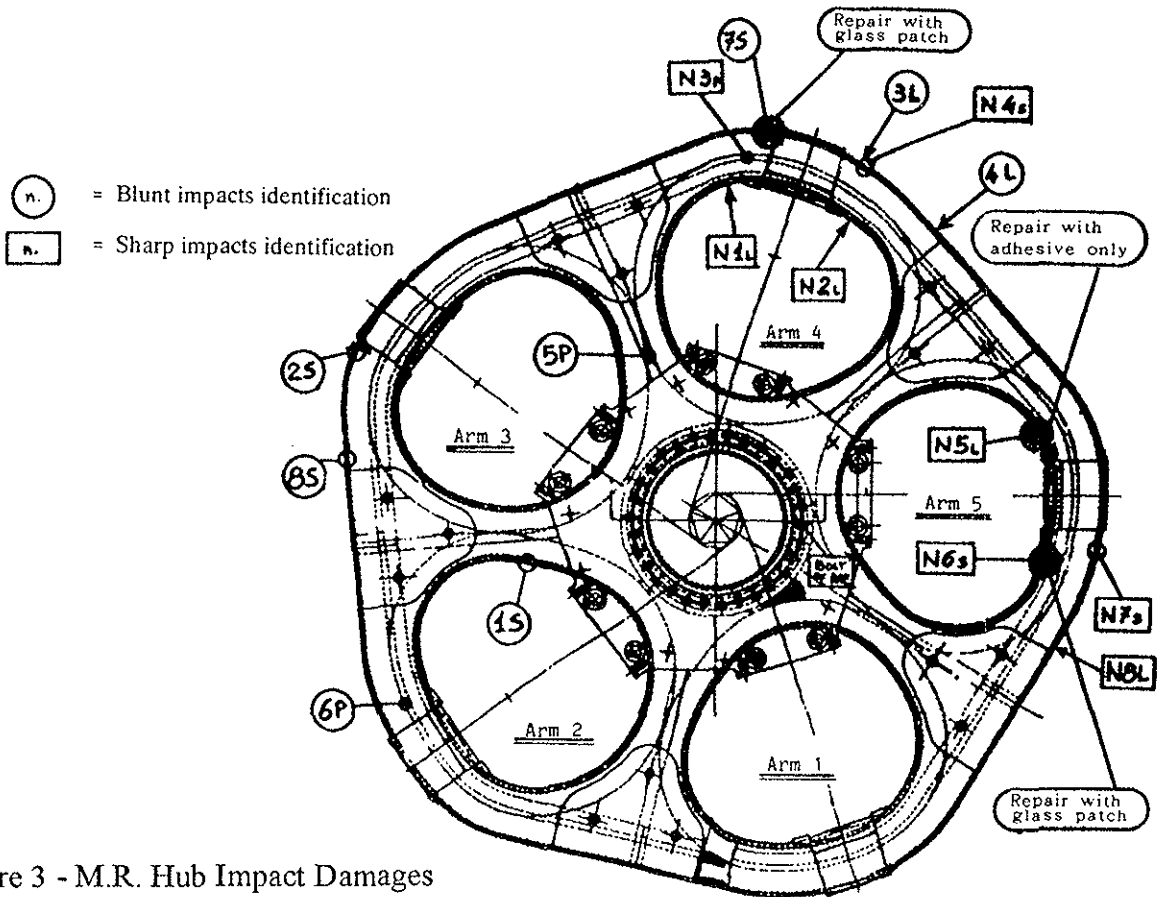
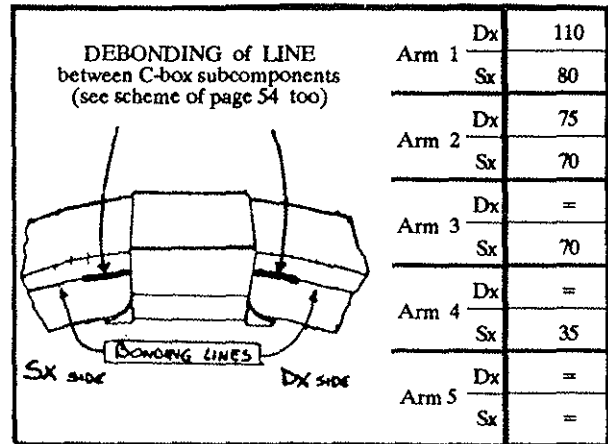
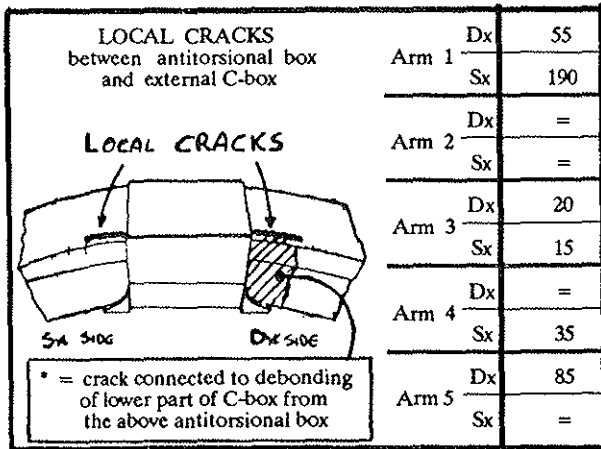


Figure 3 - M.R. Hub Impact Damages



(Dx = right side ; Sx = left side)

Type of DAMAGES - damages extension in mm

Figure 4 - M.R. Hub Damages after Safe Life Test

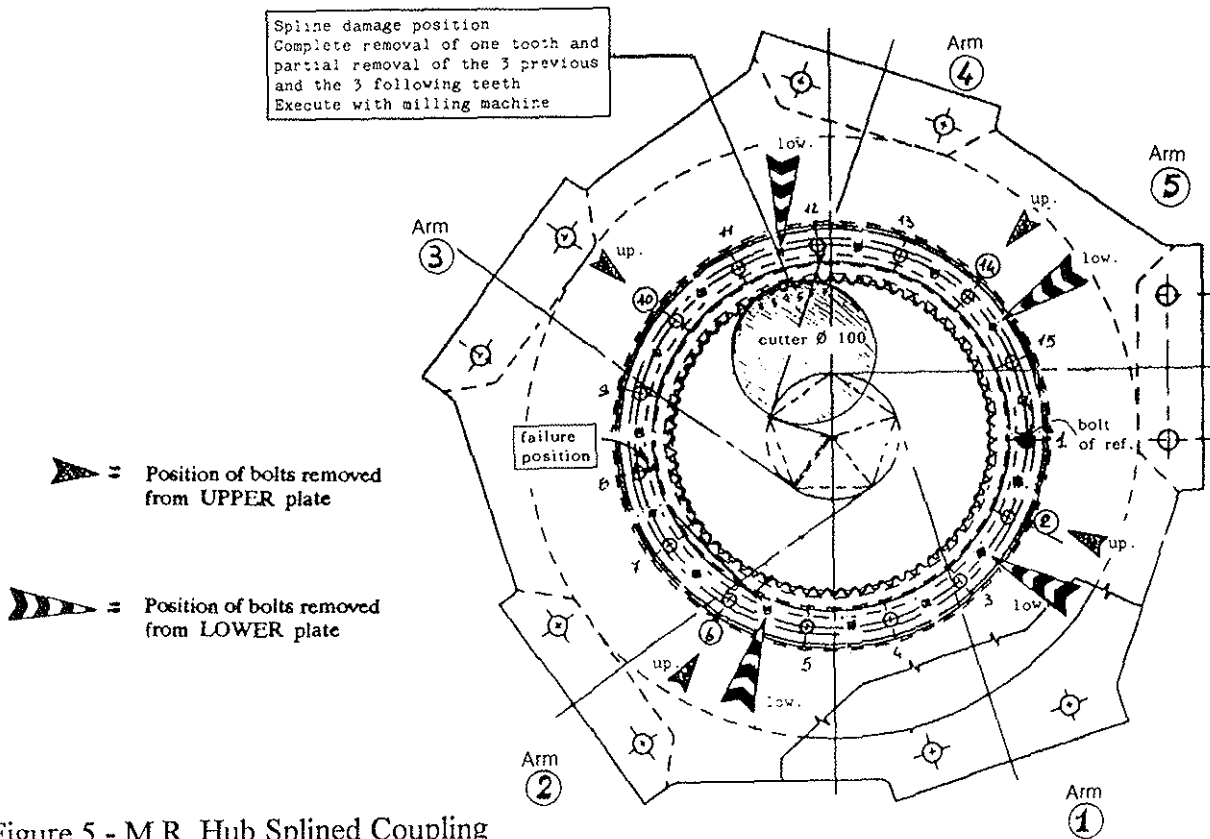


Figure 5 - M.R. Hub Splined Coupling

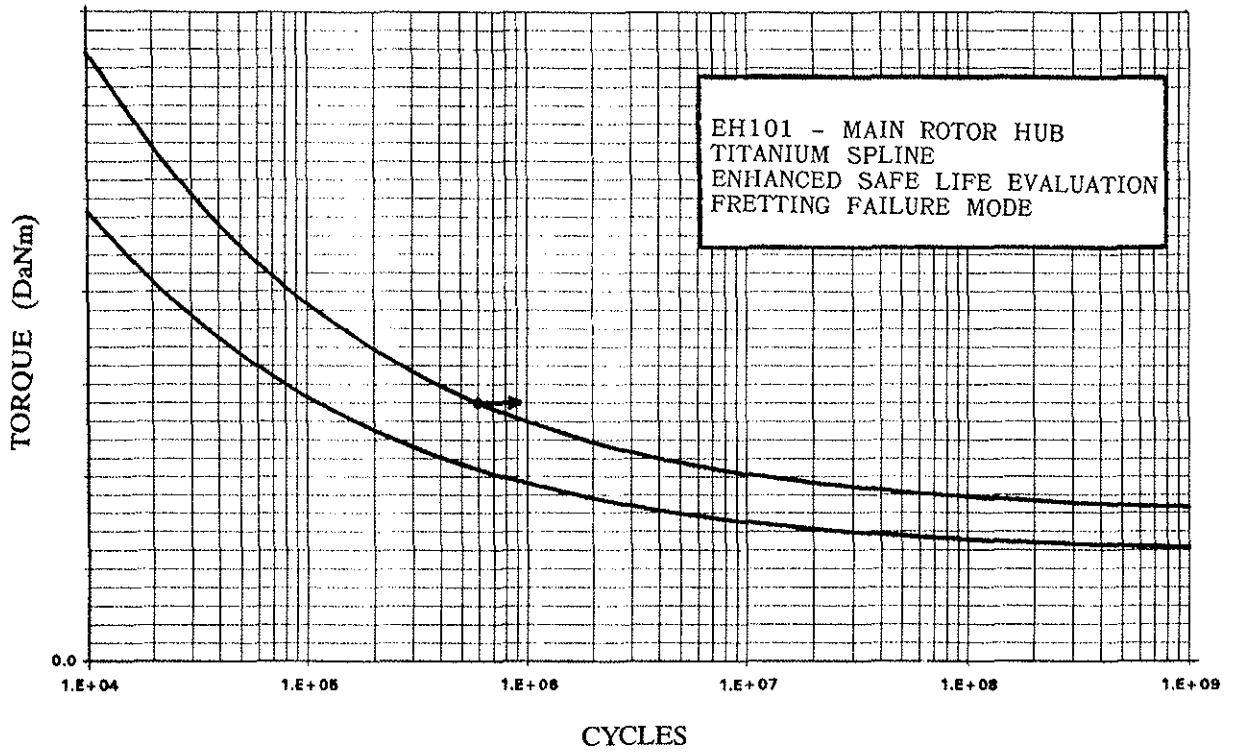


Figure 6 - M.R. Hub Splined Coupling - S/N Curves for Enhanced Safe Life Evaluations.

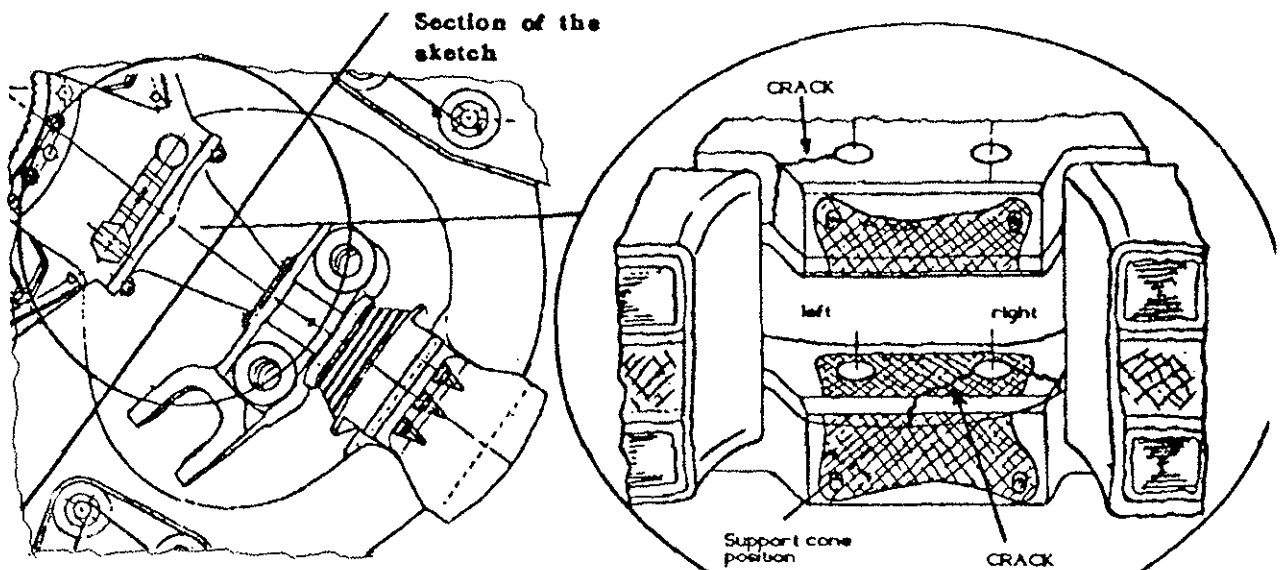


Figure 7 - M.R. Hub Flaws in Aluminium Plates and Titanium Core

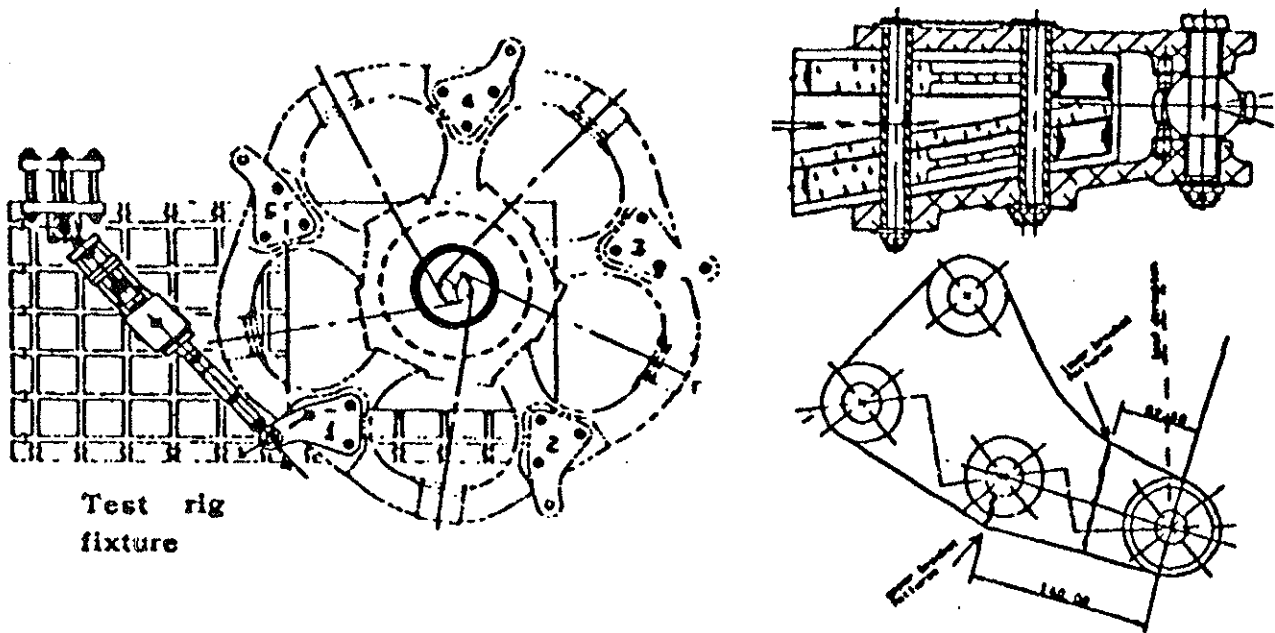


Figure 8 - M.R. Damper Hub Attachments

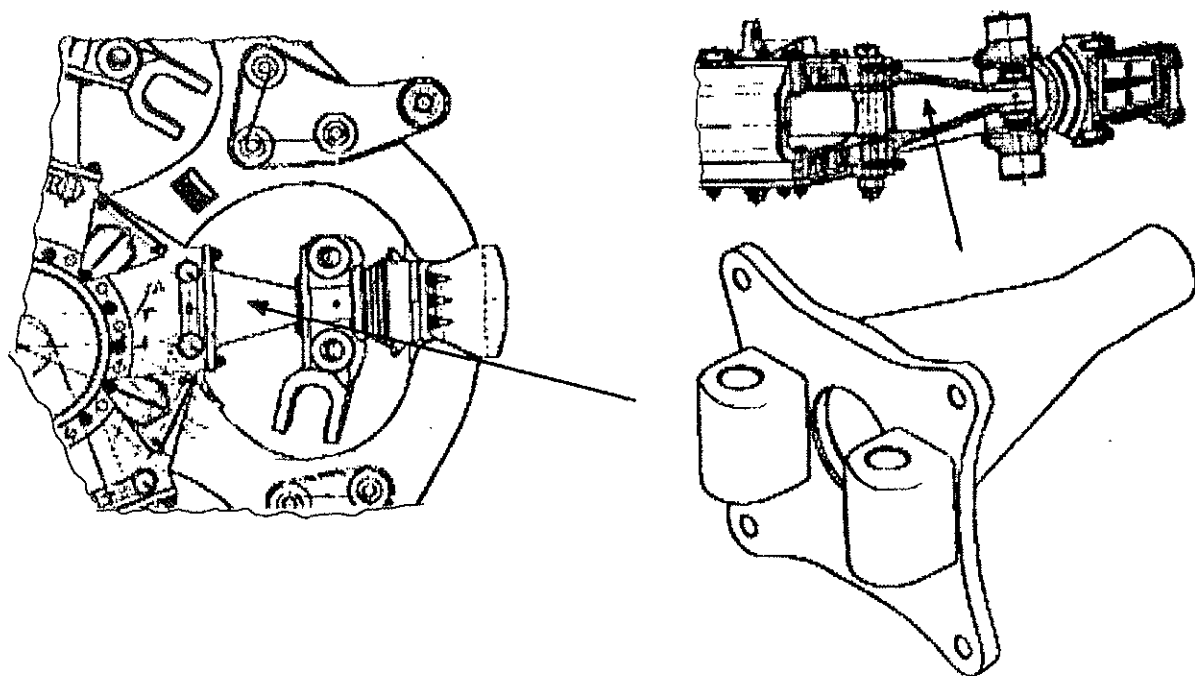


Figure 9 - M.R. Support Cone

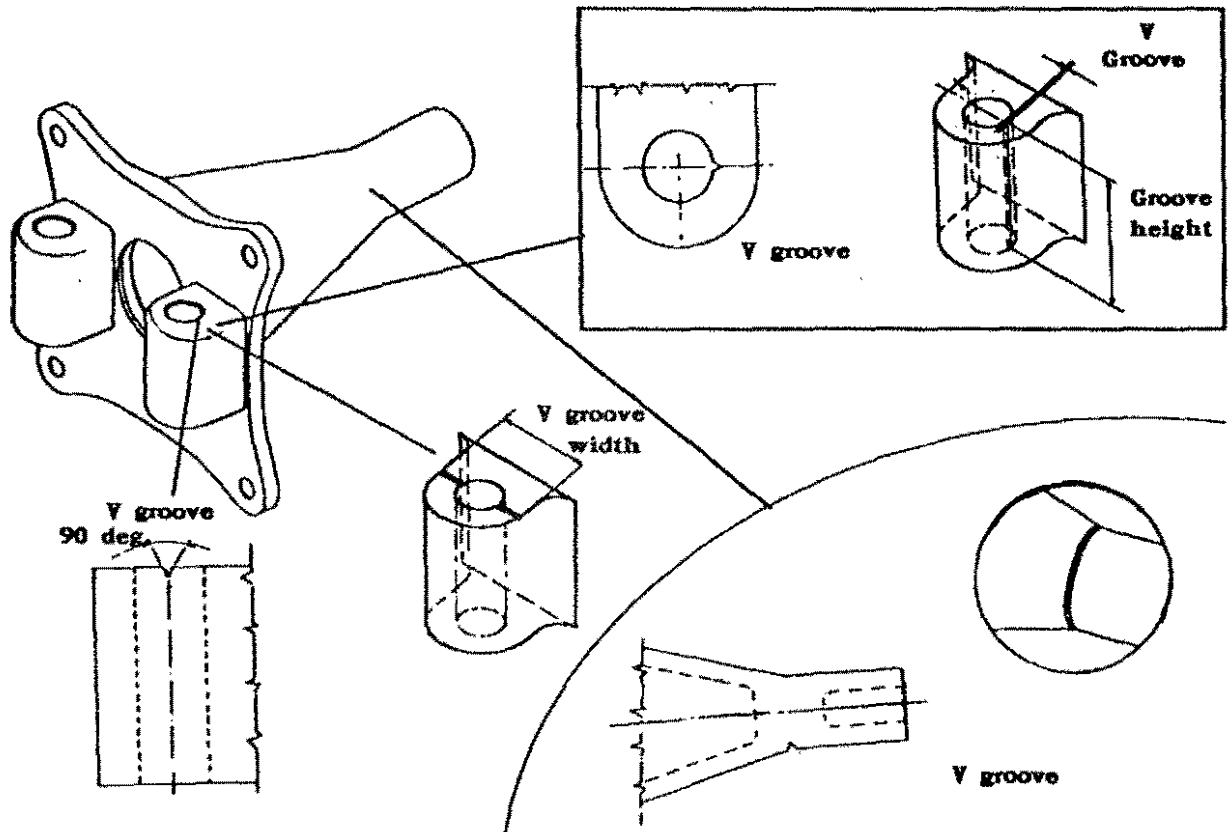


Figure 10 - M.R. Hub Support Cone - 'V' grooves of flawed components for fatigue tests

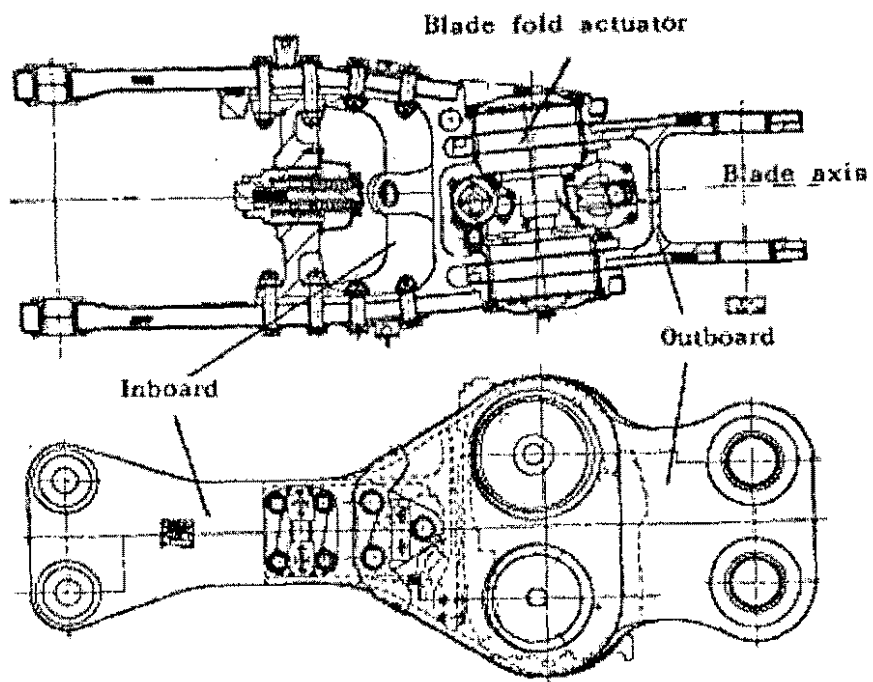


Figure 11 - M.R. Inboard and Outboard Tension Links

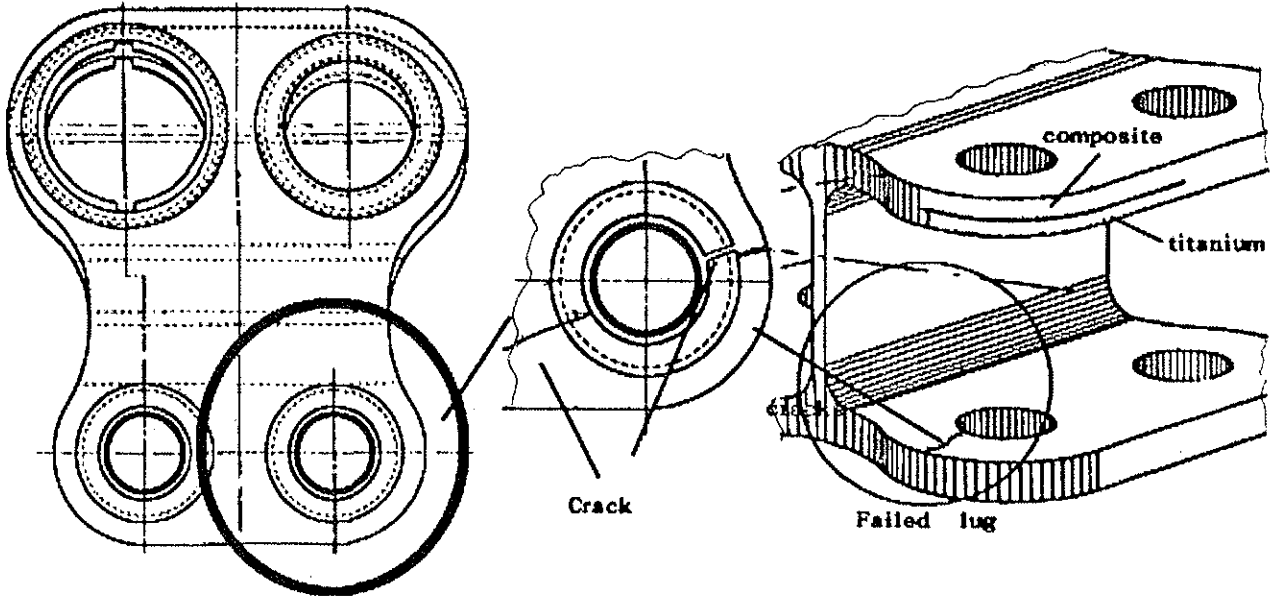


Figure 12 - M.R. Outboard Tension Link fatigue cracking of the titanium lug

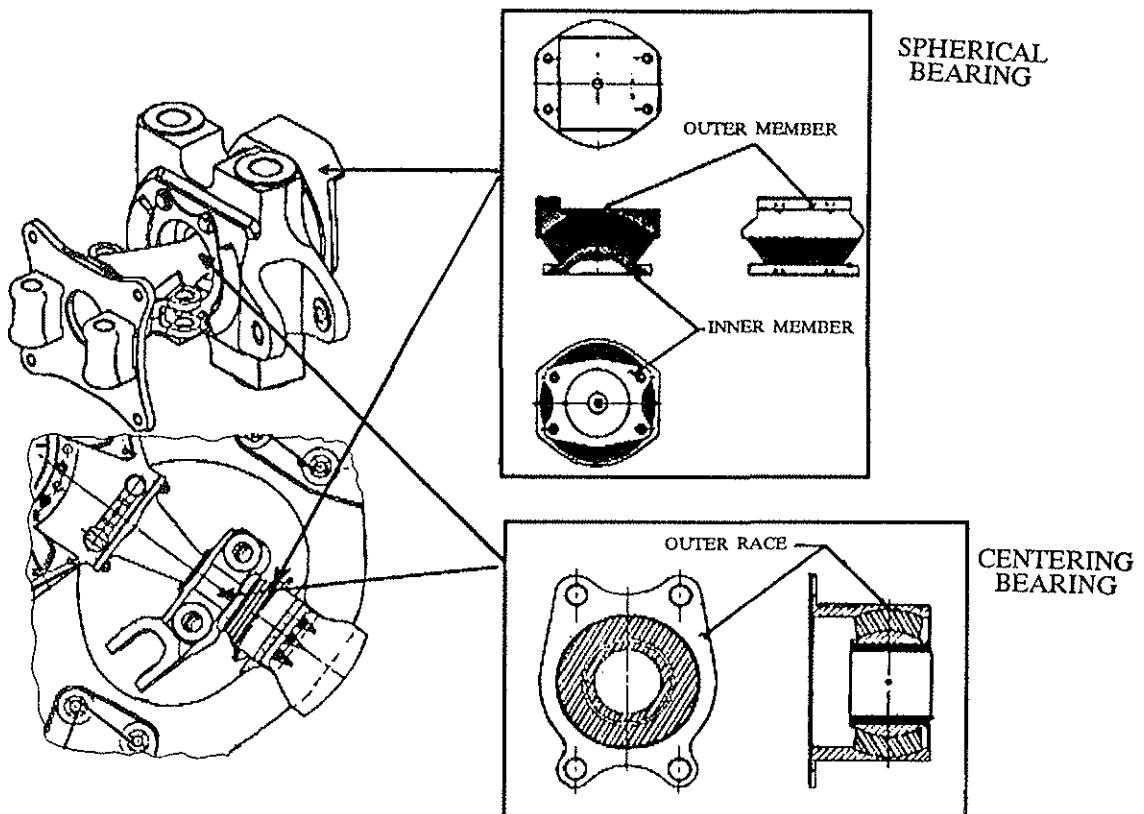


Figure 13 - M.R. Hub Centering and Spherical Bearings