DEPARTMENT OF DEFENCE
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DSTO

Workshop on Helicopter Health and Usage Monitoring Systems, Melbourne, Australia, February 1999 - Part 2

Graham F. Forsyth (Editor)

DSTO-GD-0197 (Part 2)

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Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Over the last 10 years, helicopter Health and Usage Monitoring Systems (HUMS) have moved from the research environment to being viable systems for fitment to civil and military helicopters. In the civil environment, the situation has reached the point where it has become a mandatory requirement for some classes of helicopters to have HUMS fitted. Military operators have lagged their civil counterparts in implementing HUMS, but that situation appears set to change with a rapid increase expected in their use in military helicopters.

A DSTO-sponsored Workshop was held in Melbourne, Australia, in February 1999 to discuss the current status of helicopter HUMS and any issues of direct relevance to military helicopter operations. This second part contains a list of those attending and a number of papers not received in time for publication before the event.

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Contents

1. Introduction

Helicopters have a higher rate of accidents due to technical causes than public transport fixed-wing aircraft, so it should come as no surprise that equipment capable of detailed monitoring of critical helicopter functions is now routinely fitted to medium and large-size helicopters used by civil operators. This equipment is usually referred to by the name "Health and Usage Monitoring Systems" (HUMS) although most of the HUMS in service concentrate mainly on assessing the health of the helicopter and have only rudimentary usage monitoring.

Military operators have been slower than civil operators to implement HUMS in their fleets. However, there are good reasons for this. Military helicopters, in general, are operated at a much lower rate of effort (ROE), expressed as flight hours per year, and are kept in service for a much longer period. Military operators also have less need to minimize training and test flying than civil operators since these types of flying may be regarded by the military as a legitimate function rather than as a deviation from the main purpose. These factors mean that, although current HUMS may show similar rates of return for both military and civil helicopters, when expressed as return per unit flying time, military operators have a lower rate of return than civil operators per unit of calender time.

This difference means that military operators are showing more interest in improving the usage monitoring component of these systems.

It is noticeable that the amount of time by which military operators lagged their civil counterparts in installing accident data recorders is much greater than that for the installation of HUMS.

The papers listed in the timetable, in a following section, were presented at a Workshop coordinated by the Airframes and Engines Division of DSTO Aeronautical and Maritime Research Laboratory in Melbourne, Australia, on February 16 and 17, 1999. Papers were presented by authors from HUMS manufacturers, research institutions, helicopter operators, and other organisations. Most of the papers presented at the Workshop have been included in a proceedings document, published as DSTO-GD-0197, in the format provided by their respective authors. Some papers, however, were not available for inclusion in that document at the time of its publication and they are included herein, along with an attendance list and the final timetable.

2. Acknowledgments

The Helicopter Health and Usage Monitoring System (HUMS) Workshop was arranged via a committee comprising:-

Graham Forsyth, as convenor,
Neil Kennedy, representing RAAF Williams,
Paul Marsden,
Graeme Messer,
Luther Krake, and
Bill Clark (who is on secondment from the US Navy)

Additionally, this committee needs to thank Christine Vavlitis for arranging the barbeque, Jim Nichols from Boeing for organising the video feed for those unable to fit in the conference room, staff from the AED office for attending to the registrations, arranging coffee and various odd jobs, Domenico Lombardo for directing and guiding the bus morning and evening, and almost every other staff member of the Propulsion area of AED for helping with the escorting of visitors.

3. Final Timetable

Time/Chair	Chair	Day 1 - Tuesday 16 February		
0830 - 0900		Registration		
0900 - 0915		**Official Welcome – Dr Bill Schofield, Director AMRL**		
0915 - 0955	Graham Forsyth	**John Gill** **Rick Muldoon**	BFGoodrich US Navy	Integrated Mechanical Diagnostics (IMD) HUMS *Page 7* ♦
0955 - 1020	Graham Forsyth	**David Horsley**	RAF AMDS, UK	Introduction of HUMS into the RAF ♦
1020 - 1035	Graham Forsyth	**Keith Mowbray**	Helitune, UK	"Modular Distributed HUMS – an Overview" *Page 17*
1035 - 1100		Morning Tea Break		
1100 - 1140	Dennis Helie (USA)	**Charles Trammel,** Gerald Vossler	Smiths Industries	"UK Ministry Of Defence Health and Usage Monitoring System (HUMS)" *Page 23*
1140 - 1210	Dennis Helie (USA)	**Pierre Feraud,** **Phillipe Lubrano**	Eurocopter, France	"Commitments of the Helicopter Manufacturer Regarding HUMS Activities" ♦
1210 - 1235	Dennis Helie (USA)	**J.W. Bird,** M.F. Mulligan, J.D. MacLeod, Capt D Little	IAR/NRC, Can(3) DND/ATESS Canada	"Developments in Non-intrusive Diagnostics for Engine Condition Monitoring" *Page 203*
1235 - 1335		Lunch		
1335 - 1440	LCDR G. Williams	***AMRL Technical Site Tours (AOSC, HTTF, SETH)***		
1440 - 1510	LCDR G. Williams	**Larry Dobrin**	Chadwick-Helmuth, USA	"Health Monitoring of Helicopters - Case Histories of Benefits" *Page 43*
1510 - 1540	LCDR G. Williams	**David Blunt,** Peter O'Neill, Brian Rebbechi	AMRL, RAN-NALMS, AMRL	"Vibration Monitoring Of Royal Australian Navy Helicopters" *Page 49*
1540 - 1605		*Afternoon Tea Break*		
1605 - 1635	Paul Howard (USA)	M.C. Havinga, **C.J. (Nelis) Botes**	AMS, South Africa	"Health and Usage Monitoring System for the Hawk Aircraft" *Page 217*
1635 - 1705	Paul Howard (USA)	**Charlie Crawford**	GTRI, USA	"HH-60G Mission Usage Spectrum Survey Methodology Overview" *Page 57*
1705 - 1730	Paul Howard (USA)	**Graham Forsyth**	AMRL	"An Econometric Model for HUMS Cost Benefit Studies" *Page 75*

Time/Chair		Day 2 – Wednesday 17 February		
0815 – 0830		Registration for Wednesday-only attendees		
0830 – 0850	James O'Farrell	**Brian Rebbechi** Albert Wong	AMRL	Machine Dynamics ◆
0850 – 0930		**Jarek Rosinski**	Design Unit - Gear Technology Centre, Newcastle, UK	Gear Noise and Vibration – Research at UK Gear Technology Centre ◆
0930 – 1000		**Robert Cant**	Vibro-Meter, UK	"ROTABS: Re-Writing the Manual on Rotor Track and Balance" ***Page 89***
1000 – 1030		**Yujin Gao,** R. B. Randall	Uni of NSW	"Detection of Bearing Faults in Helicopter Gearboxes" ***Page 99***
1030 – 1100		Morning Tea Break		
1100 – 1140	LTCOL O.E. Aberle	**John F. Reintjes**	NRL, USA	"LASERNET Machinery Monitoring Technology" ***Page 113***
1140 – 1210		**Paul Howard,** John F. Reintjes	Paul L. Howard Ent. NRL, USA	"A Straw Man for the Integration of Vibration and Oil Debris Technologies" ***Page 131***
1210 – 1225		**Grier McVea**	AMRL	Sensitivity of Oil Debris Monitor in S-70A-9 Intermediate GB. ◆
1225 – 1340		*Lunch – BBQ*		
1340 – 1410	CDR Chris Fealy	**C.J. (Nelis) Botes**	AMS, South Africa	"Health and Usage Monitoring System for the Denel Aviation Rooivalk Attack Helicopter" ◆
1410 – 1440		**Bill Hardman,** Andy Hess	NAWC AD, USA	"SH-60 Helicopter Integrated Diagnostic Systems (HIDS) Program Experience and Results of Seeded Fault Testing." ***Page 181***
1440 – 1455		**Ben Parmington**	AMRL	Lubrication Oil Debris Monitoring Program at AMRL ◆
1455 – 1510		**Domenico Lombardo**	AMRL	"Helicopter Structural Usage Monitoring Work at DSTO Airframes and Engines Division" ***Page 137***
1510 – 1540		**Alan Draper**	MOD PE, UK	"Fatigue Usage Monitoring in UK Military Helicopters" ***Page 153***
1540 – 1610		*Afternoon Tea Break*		

1610 - 1650	Graham Forsyth	**David J. White**	AeroStructures USA	"Structural Usage Monitoring Using the MaxLife System" *Page 167*♠
1650 - 1710		**Peter Frith**	AMRL	Engine Gas Path Condition Assessment ♦
1710 - 1720		*Closing Session*		
1900 - 1945		*Pre-dinner drinks - Observation Deck, Rialto on Collins*		
1945 - 2315		*Conference Dinner - Oriel Room, Rialto on Collins*		

Page Numbers quoted are those of the paper in the Proceedings published as DSTO-GD-0197.

♦ indicates that this paper or the presentation slides from this paper are included in this document.

♠ indicates a paper where some additional slides to those in DSTO-GD-0197 are included in this document.

The timetable was prepared on behalf of the HUMS Workshop committee by Graeme Messer.

4. Attendance List

The following table was prepared from registration details supplied by those persons present. It does not include a considerable number of AMRL and ADF staff who attended only part of the conference or who did not complete a registration form.

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Attendance List

* indicates a speaker,

^ currently on secondment to AMRL, from NAWCAD, Patuxent River.

\# Attended TTCP AER-TP3 meeting afterwards.

5. Papers Included in this Document

The following pages contain either the paper or a copy, as two slides per page, of the PowerPoint[1] Presentations of those papers not included in the original Proceedings. As well, one presentation is included where the paper was included in the original Proceedings and some additional slides are published for one presentation.

The presentations have been included in the order determined by the timetable of a previous section.

* Paper version in DSTO-GD-0197, PowerPoint slides here.

[1] PowerPoint is a registered trademark of Microsoft Inc for software generating presentation slides.

NAVAL AVIATION SYSTEMS TEAM

BFGoodrich Aerospace
Aircraft Integrated Systems

U. S. Navy / BFGoodrich Integrated Mechanical Diagnostics HUMS Overview & Status

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IMD HUMS

- *IMD HUMS is a Commercial Operations & Support Saving Initiative (COSSI) to improve helicopter operational readiness and flight safety while slashing maintenance-related costs.*

- *The U. S. Navy (USN) has partnered with BFGoodrich to field this military/commercial "dual use" HUMS.*

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IMD HUMS

- **Overview**
  - Program Status / Concept of Operations
  - System Functions
- **Major Airborne Components**
  - Primary LRUs
  - Sensors & IO
- **Selected Functionality**
  - Mechanical Diagnostics
  - Rotor Track and Balance
  - Exceedance Monitoring
  - Engine Monitoring
  - Structural Usage
  - Aircrew & Maintainer Interaction
- **Conclusion**

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IMD HUMS

Current Status

- **Critical Design Review - Complete June 98**
- **COTS Demo / Risk Mitigation Complete**
  - CH-53E & SH-60F
- **DT Commences - April 99**
  - CH-53E
  - SH-60B
- **OPEVAL - Oct 99**
  - 5 CH-53E (HMT-302) / 5 SH-60B (2@HSL-40, 3@ HSL-41)
- **Limited Rate Production Decision - Oct 99**
  - 6 CH-53Es / Lease for 200+ legacy H-60s
- **Full Rate Production Decision - March 00**
  - All H-53Es / CH-60 / SH-60R

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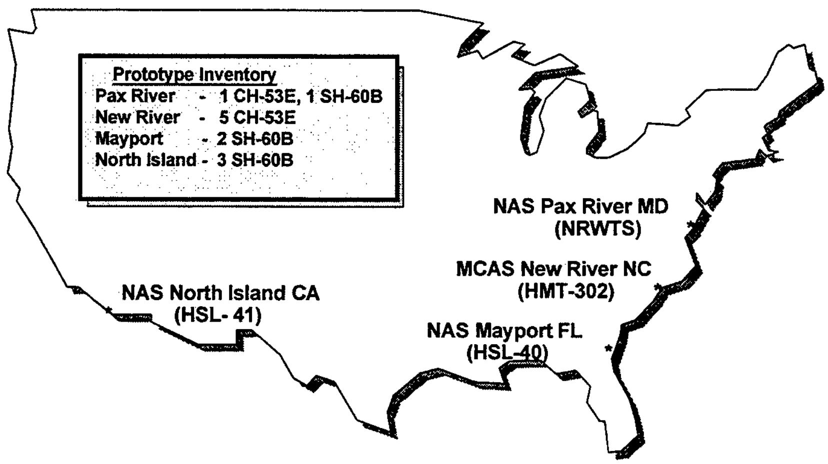
IMD HUMS
STAGE I Sites



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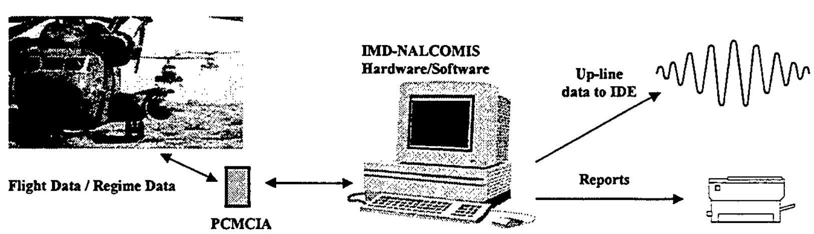
IMD HUMS
Concept of Operations



Pre-Flight Data /
Post Flight Debrief

BUNO & Crew Specific Info loaded in PCMCIA

Weight & Balance Data

Fuel Load

Weapons Load

Generate VIDS/MAFs/NAVFLIRs
Make Electronic Logbook Entries

Maintenance Management
Configuration Management

RTB Adjustments & Trending
Diagnostic Trending
Scheduled & Periodic Maint. Interval Adjustments

Life Limited Comp. Usage
Fatigue Life and Exceedance Tracking
Parts Tracking

Internal Users
Maintenance Control
QA
MO / MMCO
Supervisors / Technicians

External Users
IMA / NADEP / Depots
Wings / TYCOMs
NAVAIR
CFA / ISST
OEM

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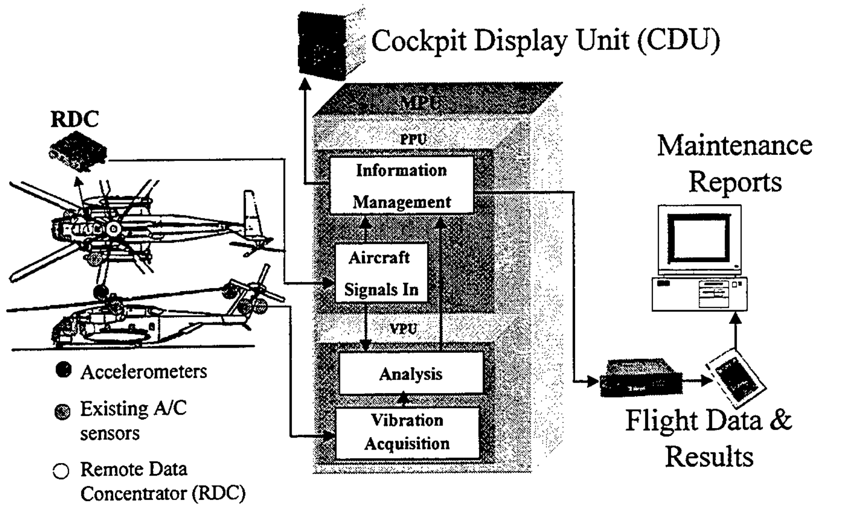
IMD HUMS Overview (System)



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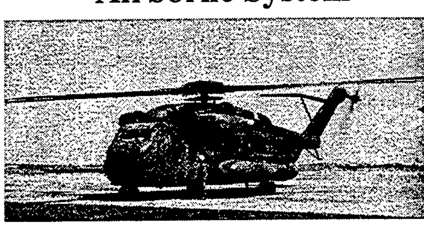
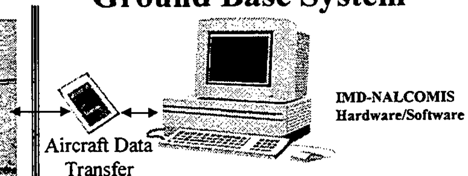
IMD HUMS Overview (Functions)

Airborne System



- Acquire & Process Data
- Provide Advisories (if desired)
- Automates Functional Check Flights
  - RT&B & Engine
- Provides Maintenance Info to Flight-line Troubleshooters & FCF Pilots

Ground Base System



- Pilot Debrief
- Provides diagnostics/prognostics
- Identifies maintenance actions
- NALCOMIS Interface:
  - Maintenance Management
  - Configuration Management
  - Serialized Parts Tracking
- Interactive RT&B
- Apply usage
  - Structural & Operational

Open System Architecture

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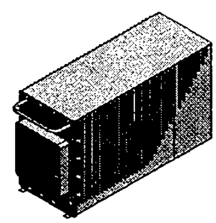
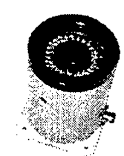
Major Airborne Components

Primary Airborne LRUs

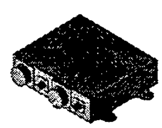


Main Processor Unit (MPU)



Optical Tracker

Data Transfer Unit (DTU)



Remote Data Concentrator (RDC)

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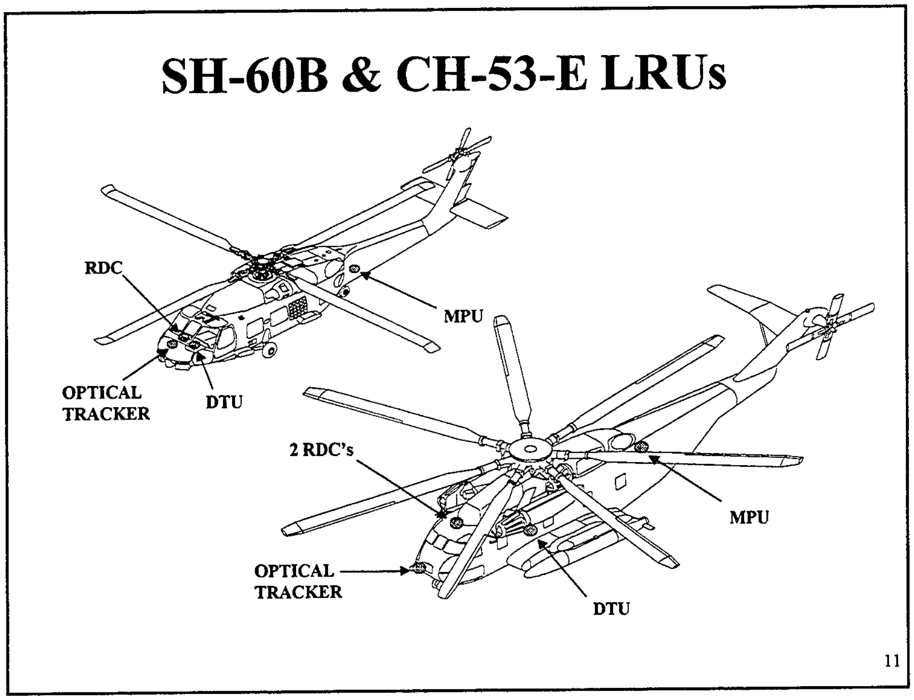

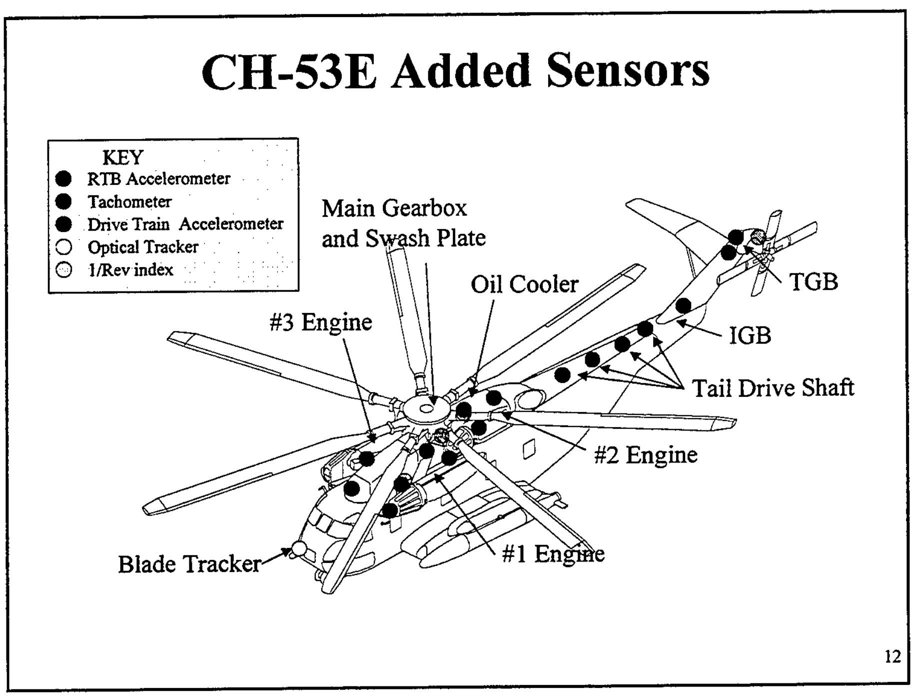

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Generic and Scaleable IO

Signal Type (Inputs unless noted)	H-60B		CH-53E	
	Used	Avail.	Used	Avail.
Discrete Inputs	35	48	63	96
Synchros	0	4	7	8
AC Signal	4	16	12	32
DC Signal	17	32	37	64
Accelerometers	34	36	44	46
Frequency	5	17	7	22
Index	7	8	6	9
MIL-STD-1553	1	1	1	1
RS-422/RS-485 I/O	0	3	1	3
ARINC-429 Inputs	0	13	0	12
Outputs	0	3	0	3
RS-232/RS-422 I/O	0	3	0	3
ARINC-717 (FDR) Out	0	1	0	1

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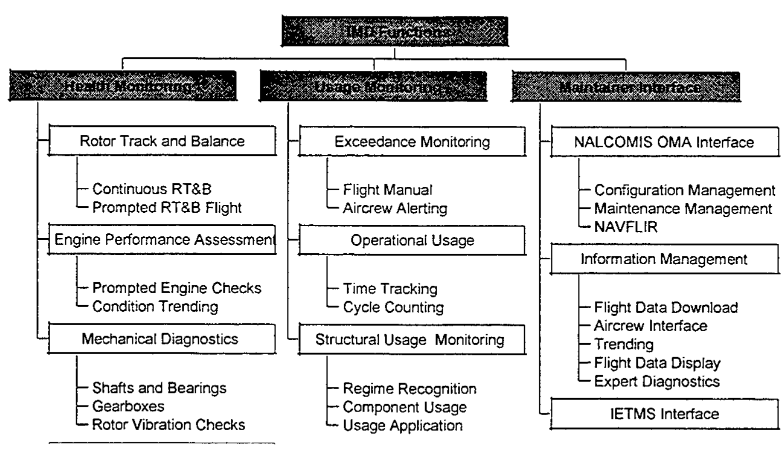
IMD HUMS Functionality



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Major Functions (Examples)

- Mechanical Diagnostics
- Rotor Track & Balance
- Exceedance Monitoring
- Engine Monitoring
- Structural Usage
- Routine Aircrew Interaction
- Routine Maintainer Interaction

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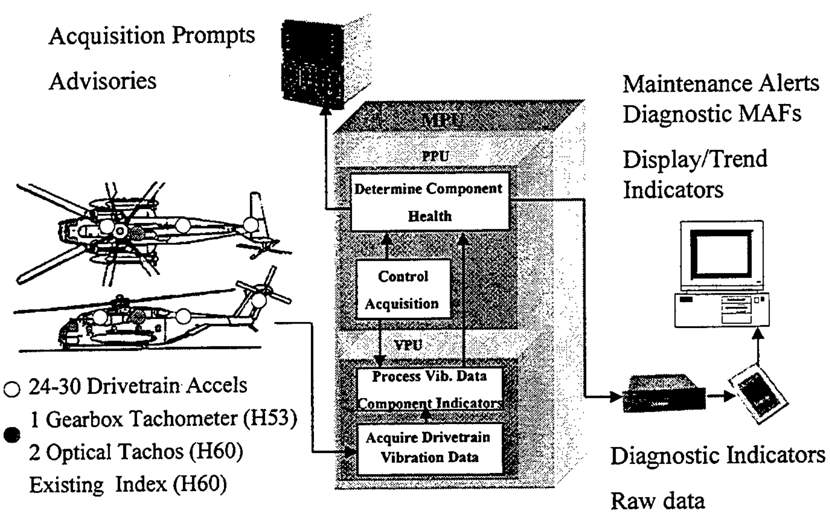
Mechanical Diagnostics Functional Flow



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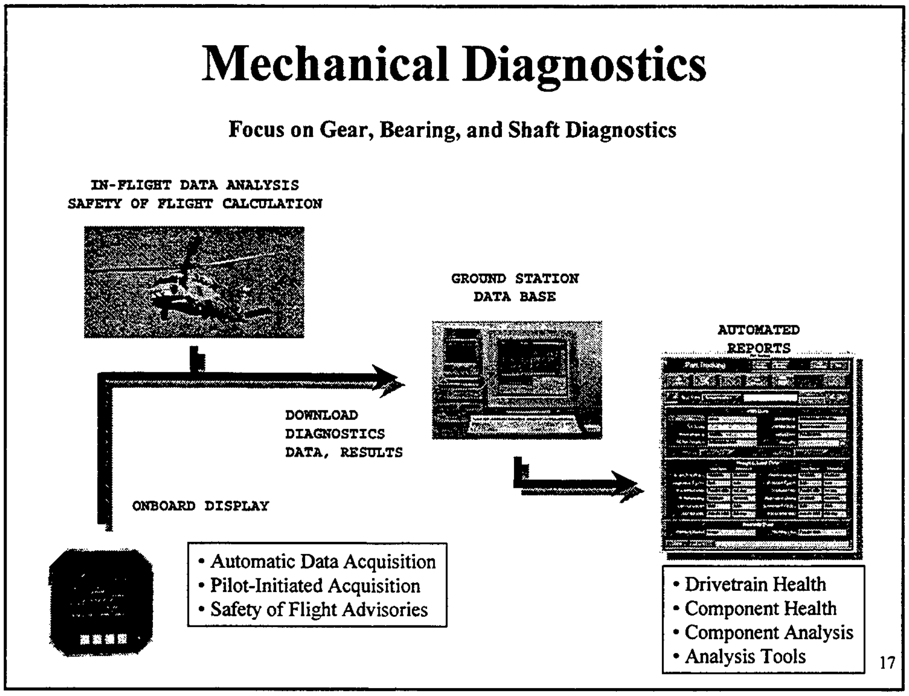

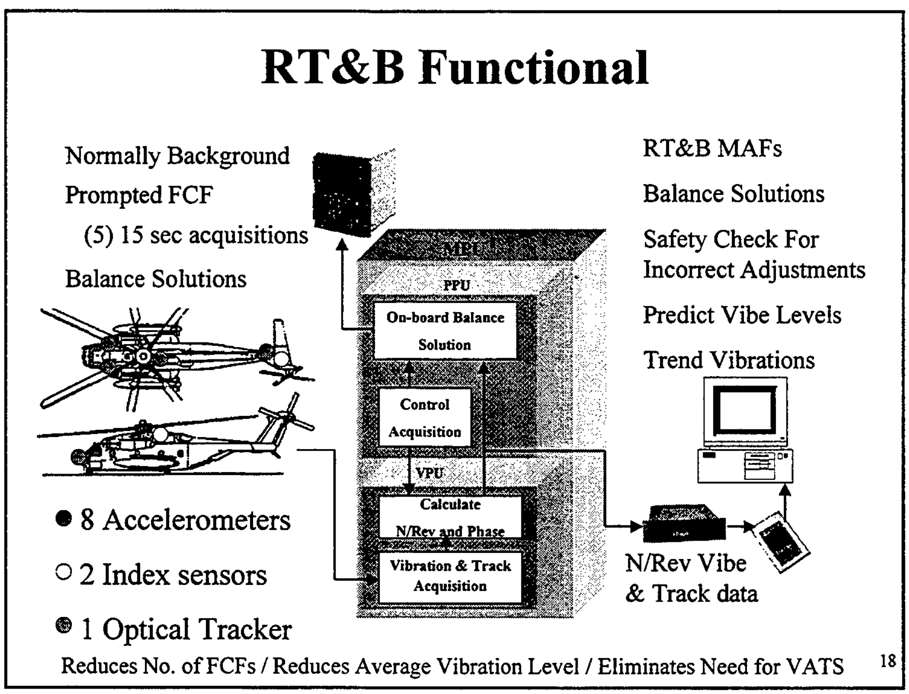

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Exceedance Monitoring Overview

- **Exceedance Monitoring Function**
  - Incorporates NATOPS/maintenance manual limits and time-related thresholds
  - Annunciated only if no other pilot indication is available and Pilot Action is required
  - Exceedance summaries available on OBS/GBS
- **Changes from Present Practices**
  - On-board Crew acknowledgement for certain exceedances (Configurable)
  - Crew review for all exceedances on GBS
  - Automatic MAF request generation if required

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Engine Monitoring Function

- **Engine Monitoring Function**
  - Usage
  - Limit Exceedance
  - Performance
- **Changes from Present Practices**
  - Automates Data Transfer from OBS to GBS
    - Cycle count, Run Time, Limit Exceedances
  - Automate Selected Power Checks
  - Monitors Vibration
  - Trends Engine Performance

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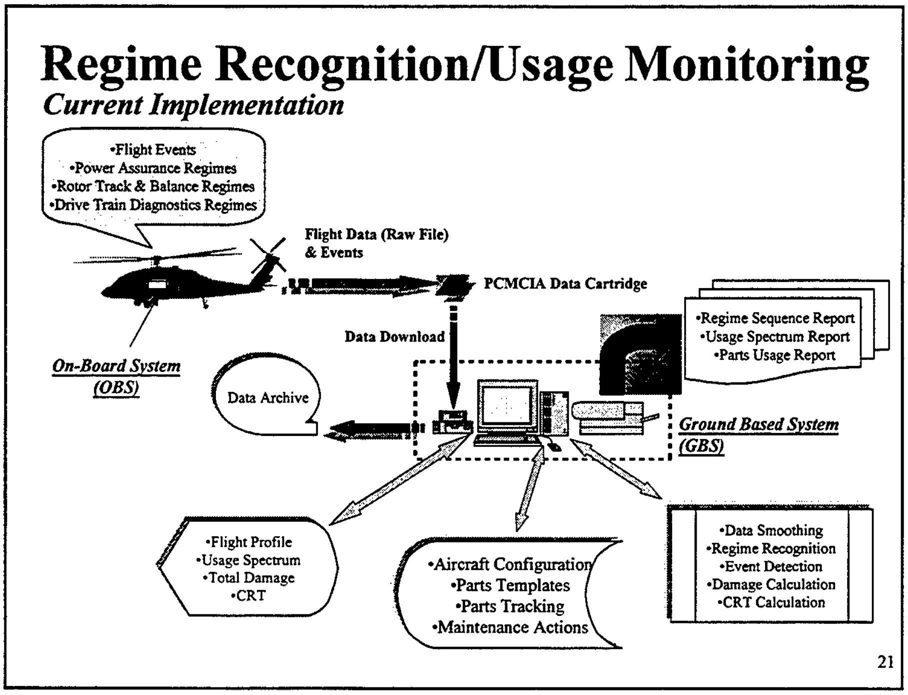

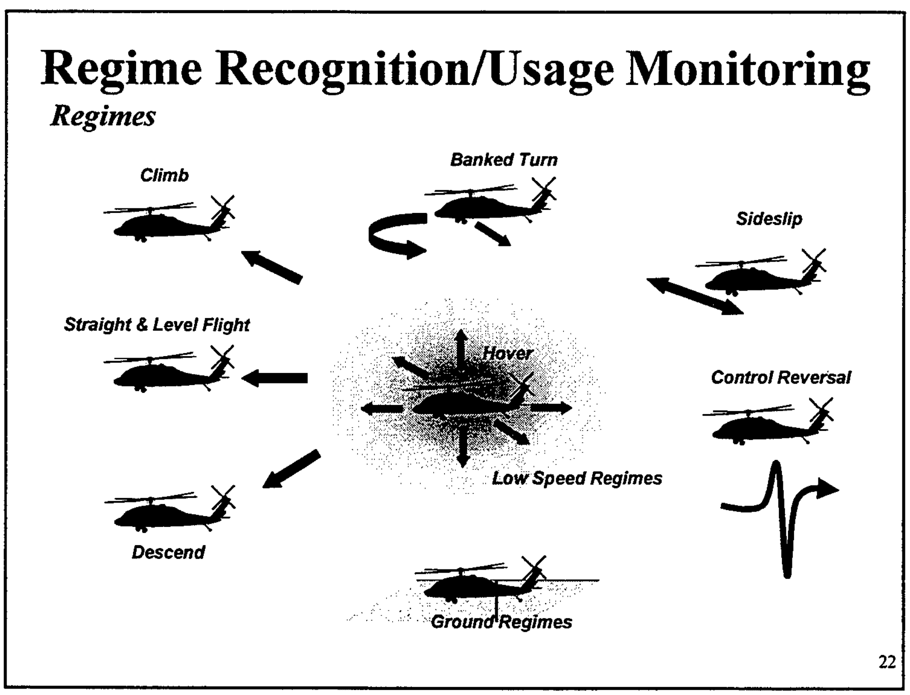

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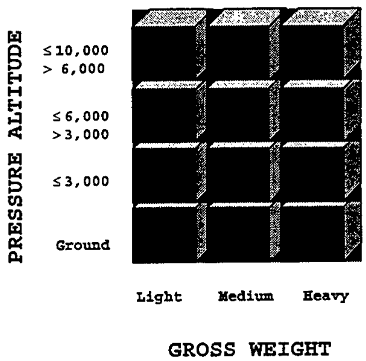
Regime Recognition/Usage Monitoring

Generic Approach

Flight load data are taken on the ground, at three altitudes and at three weights

Each gross weight-altitude combination makes up one part of the core set

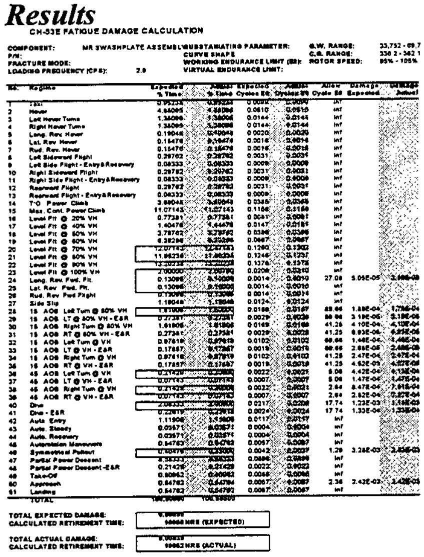


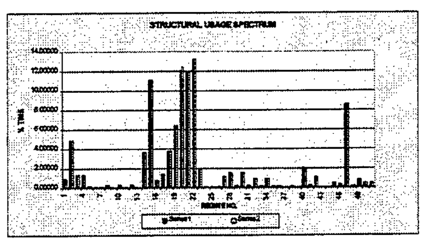
For example;

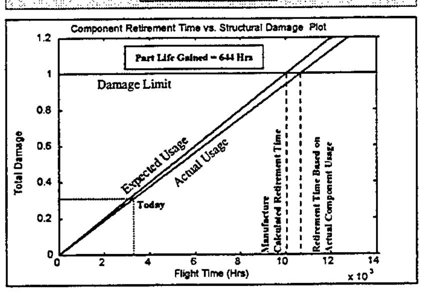
- One set of regimes for each gross weight - altitude combination (total of 12 core sets).
- Each core set can have the following subset options:
  - level flight, climbs, turns,
  - partial power descents, autorotations,
  - steady heading sideslips,
  - pull-ups, etc.
- Time in each regime relates directly to flight loads used to decrement finite life.
- Ambiguities resolved in conservative way -
  - favor most damaging regime in question

Regime Recognition/Usage Monitoring

Results







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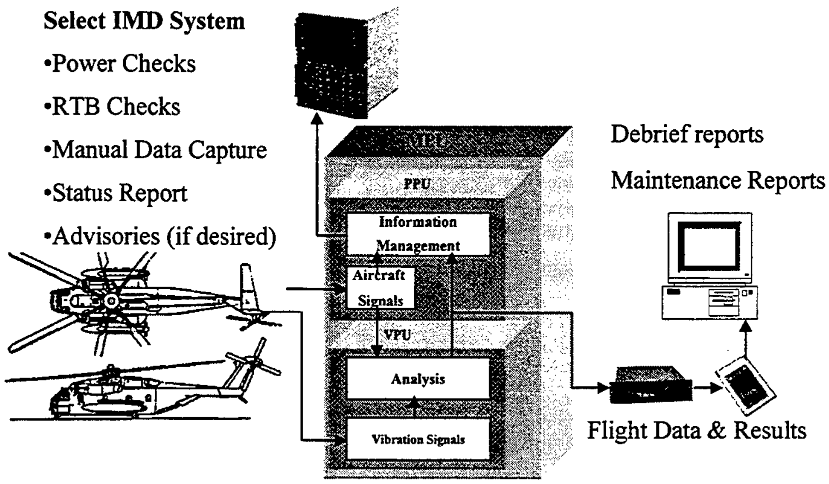
Routine Aircrew Interaction

Select IMD System
- •Power Checks
- •RTB Checks
- •Manual Data Capture
- •Status Report
- •Advisories (if desired)



Information Vice Data!!

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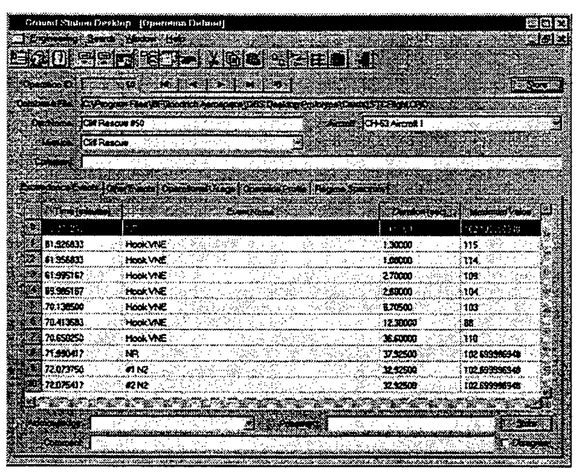
Routine Aircrew GSS Interaction

- **Aircrew Debrief**
- **Acknowledge and Comment**
- **Interface to NALCOMIS**
- **Card Initialization**



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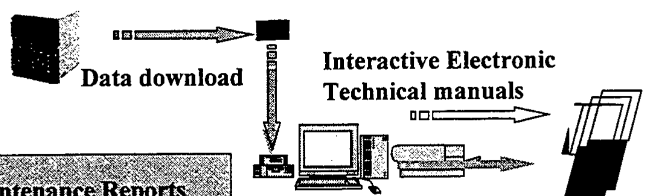
Routine Maintainer Interaction

Rotor Track and Balance on CDU

Flight-line Troubleshooting



NALCOMIS Maintenance Reports

- •Aircraft Daily Status Report
- •Work Center Work Load Report
- •Aircraft/Equipment Work Load Report
- •Aircraft Phase Inspection Report
- •Aircraft Material Status Report
- •Outstanding Requisition -
- - Aircraft Material Status Report
- •Material Control Register Report
- •Inspections by TEC Report
- •Scheduled Inspection Report
- •Phase Inspection MRC Report
- •Special/Conditional Inspection MRC Report

IMD Calculations
- **•Regime recognition**
- **•Usage Algorithms**
- **•Diagnostics**

Rotor track and balance
Troubleshooting
Interactive Diagnostics
Power assurance review
Results viewed on GUI window
Drill down to details

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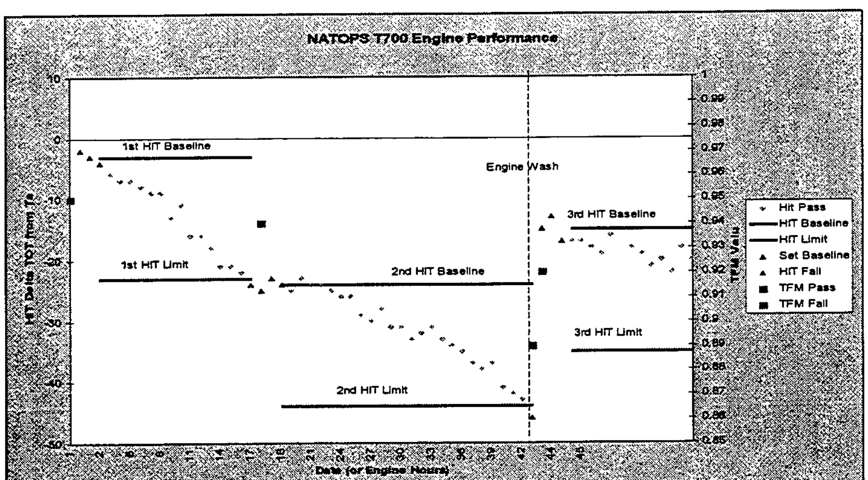
Example of Routine Maintainer GSS Interaction



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Fleet Implementation Issues

(A Sample)

- **Implementation planning**
  - Installations / Training / Support / Incremental Implementation of Functions
  - Use of Fleet Advisory Committee
- **Policy & procedure roadblocks - maintenance re-engineering**
  - Total asset visibility during all levels of maintenance
- **Logistics necessary for stage I & II**
  - "O" to Contractor "D"
  - NALCOMIS Optimized OMA installations & Training
  - Publication updates....
- **Anomaly adjudication process**
  - i.e. diagnostic alarms when traditional indicators show no problem
- **Supply for squadron IMD equipped aircraft**
- **Human Factors Engineering - user interface assessments**
- **Capturing benefits**
- **Dealing with IMD & Non-IMD equipped acft in one squadron**

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IMD HUMS FLEET BENEFITS

- **Open System Architecture - Scalable, Portable, & Upgradeable**
- **NALCOMIS Interface**
- **Maintenance Information Vice Engineering Data**
- **Improved ACFT Safety**
- **Improved Mishap Investigation - FDR/CVR**
- **Increased Availability & Reliability**
- **Reduction in Scheduled Maintenance**
- **Rapid Determination of ACFT Status**
- **Reduced O&S Costs**
- **Decreased MMH/FH**
- **Reduced Schedule Component Removal**
- **Component Life Based on Actual Mission Profile Data Vice Assumed**

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QUESTIONS

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The Royal Air Force

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ROYAL AIR FORCE

Flight Lieutenant

DAVE HORSLEY

B Eng C Eng MIEE RAF

HUMS &
GROUND SUPPORT SYSTEMS
TEAM LEADER

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SCOPE

- LOGISTICS SUPPORT SERVICES
- EXPECTATIONS
- PROJECTS
- INTRODUCTION STRATEGY

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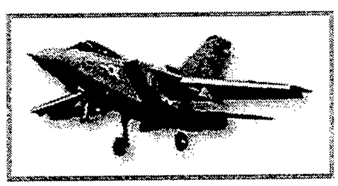
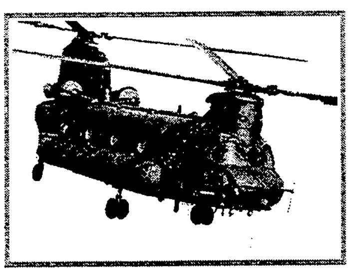
ENGINEERING CV

RMCS Cranfield University

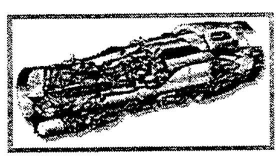
B Eng (Hons)
Electrical Systems



Tornado 2nd line



Chinook 1st line



Engines
3rd line

HUMS & GSS

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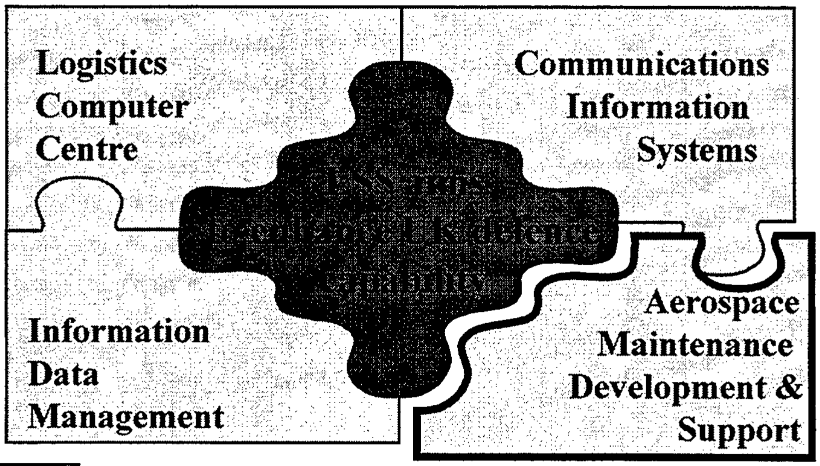
LOGISTICS SUPPORT SERVICES



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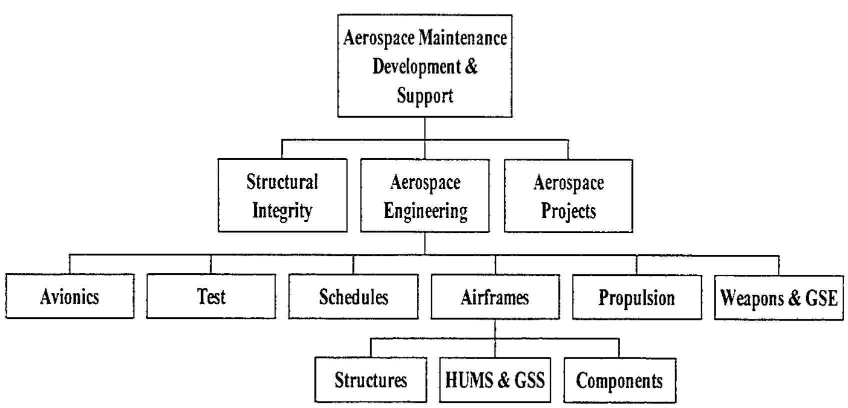
LOGISTICS SUPPORT SERVICES



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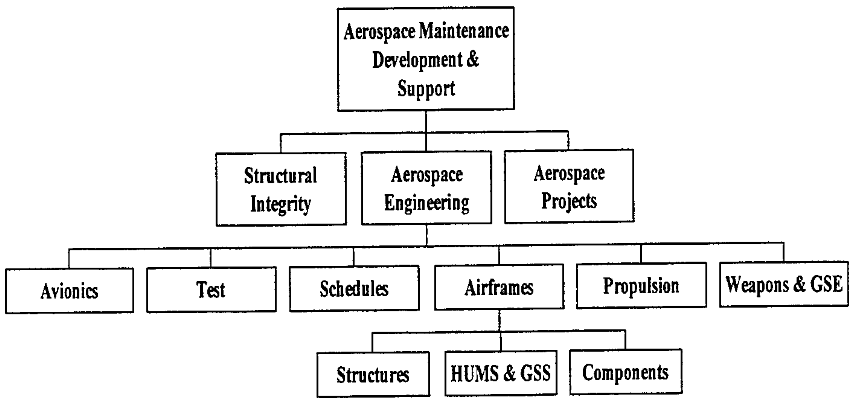
LOGISTICS SUPPORT SERVICES



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HUMS & GSS TEAM

MISSION

TO ASSIST IN THE EFFICIENT & EFFECTIVE INTRODUCTION TO THE RAF OF HUMS & GROUND SUPPORT SYSTEMS THAT IMPROVE MAINTENANCE DATA COLLECTION & REDUCE MAINTENANCE COSTS, THUS IMPROVING AIRWORTHINESS & MINIMISING THE COST OF OWNERSHIP

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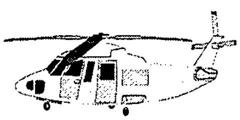
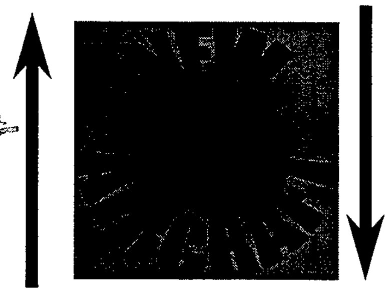
EXPECTATIONS

COST OF OWNERSHIP





AIRWORTHINESS

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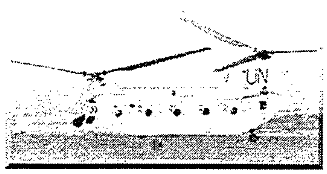
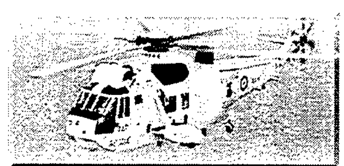
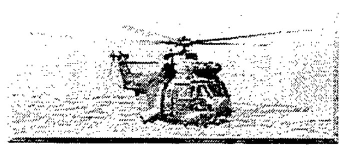
RAF HUMS PROJECTS

GHUMS







OEM HUMS

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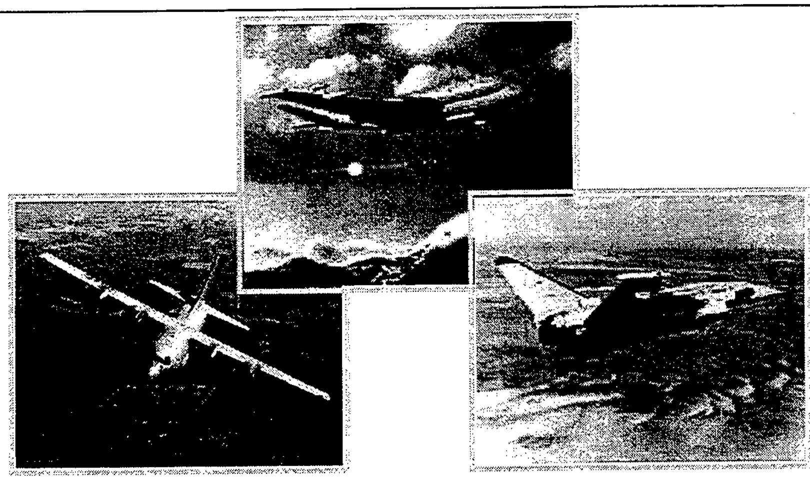
RAF HUMS PROJECTS



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INTRODUCTION STRATEGY

- AIRWORTHINESS
- DATA HANDLING
- OBSOLESENCE
- OEM ACCREDITATION

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AIRWORTHINESS

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AIRWORTHINESS

- INSTALLATION IS ENDORSED
- NOT FLIGHT SAFETY CRITICAL

CONFIDENCE

- ALERT CREWS IN-FLIGHT?
- REPAIR OR FLY?

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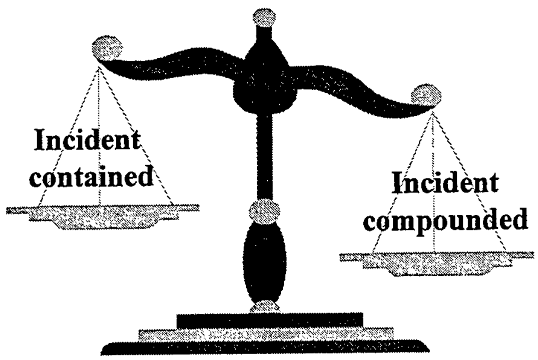
AIRWORTHINESS

'TO DISPLAY OR NOT DISPLAY?'



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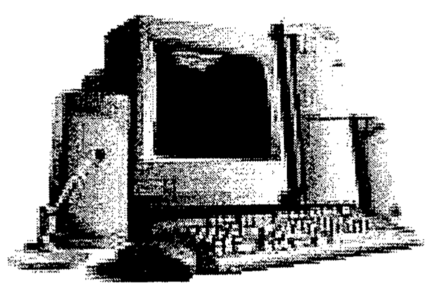
AIRWORTHINESS



GROUND SUPPORT SYSTEM

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AIRWORTHINESS

IN-FLIGHT ALERTS SUPPRESSED

PROCESSED DATA ADVISORY

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DATA HANDLING

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DATA HANDLING

LOTS OF DATA

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LOTS OF INFORMATION

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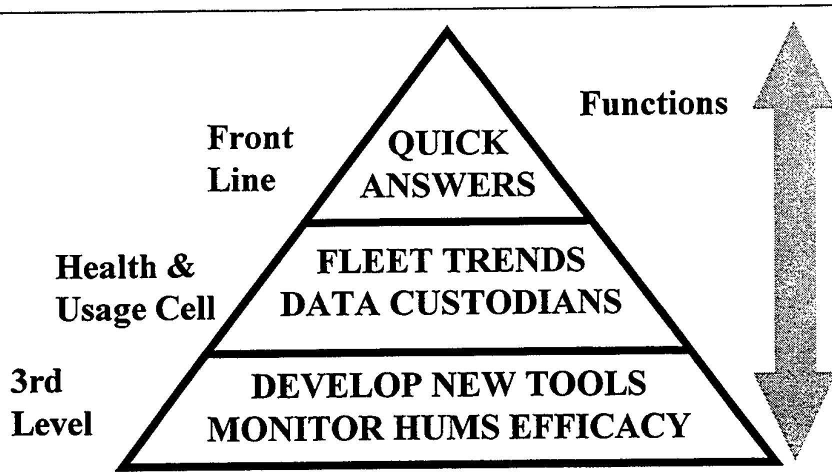
DATA HANDLING



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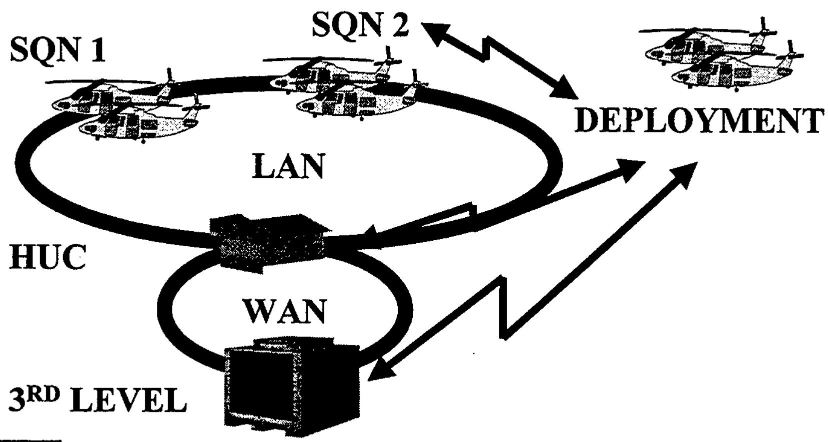
DATA HANDLING



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OBSOLESCENCE

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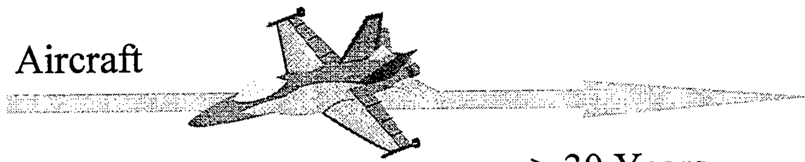
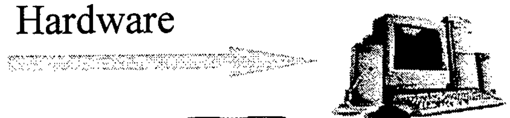
OBSOLESCENCE

Aircraft



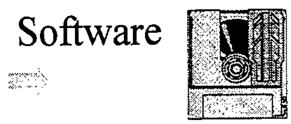
> 30 Years

Hardware



< 5 Years

Software



<< 18 Months

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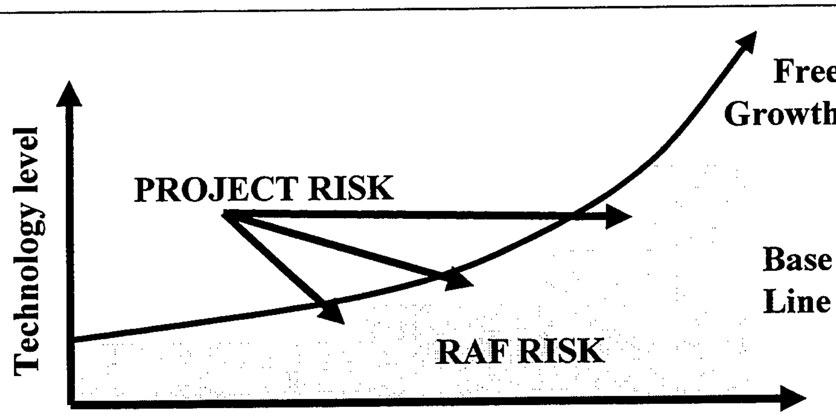
TAMING OBSOLESENCE



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Horsley - 12

OEM ACCREDITATION

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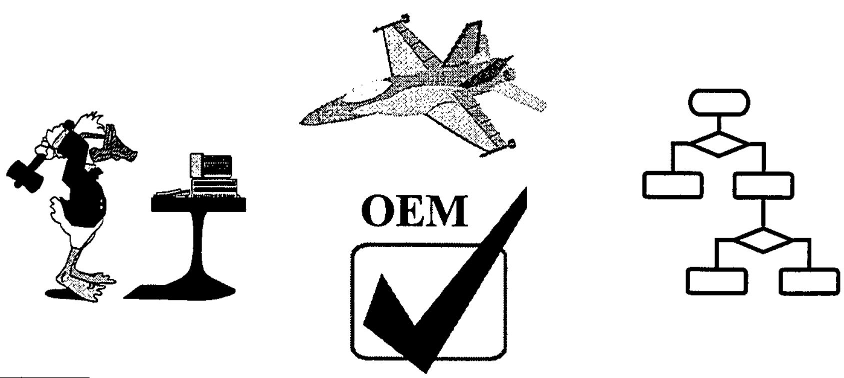
OEM ACCREDITATION

SYSTEM UPGRADES



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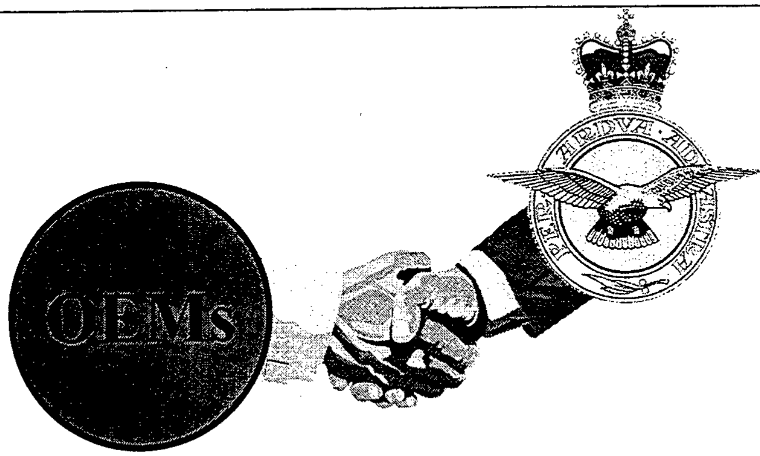
OEM ACCREDITATION



Aerospace Maintenance Development & Support - Airframe Section

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SUMMARY

Aerospace Maintenance Development & Support - Airframe Section

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Horsley - 14

SUMMARY

- HUMS IS COMING
- BENEFITS AND LIMITATIONS
- KEY IS DATA HANDLING
- HARNESS OBSOLESCENCE
- PARTNERSHIPS REQUIRED

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HUMS AND GSS TEAM

Questions?

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The Royal Air Force

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EUROCOPTER H.U.M.S

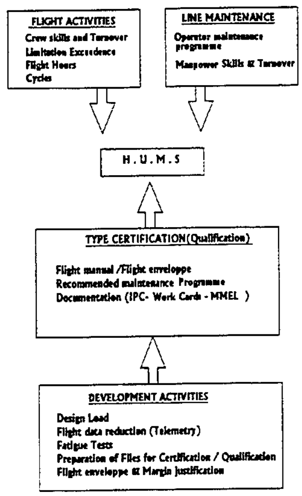
The Helicopter Manufacturer
commitments

EUROCOPTER HUMS

- Safety and Confidence scope
- HUMS design principles
- HUMS module configuration
- End user's needs
- Eurocopter experience
- Safety &Costs benefits

Lubrano/Feraud - 1

SAFETY & CONFIDENCE SCOPE



HUMS DESIGN PRINCIPLES (1)

- **Many possible simple functions**
  - Ex: Usage, Health (Vibration airframe+Eng.), RT&B
- **Equipement status**
  - Airborne Kit
  - Ground station computer (Flight Report / Maintenance reports)
  - Ground support equipment (System maintenance)

Lubrano/Feraud - 2

HUMS DESIGN PRINCIPLES (2)

- **System Approach**

- Early integration analysis
- Specifications to be done for each function related to HW & SW
- Modular concept design
- Module development

HUMS MODULE CONFIGURATION (1)

- **Module 1: Usage Functions**
  - **Basic a/c parameters**

- Flight hours counting
- Cycle counting
- Exceedance of limitation
- Power assurance check
- CD rom documentation link (Work cards / MSR)

Lubrano/Feraud - 3

HUMS MODULE CONFIGURATION (2)

- **Module 2: Engine vibration health**
  - An important part of the H/C
    - ➔ Engine manufacturer approval
  - PAC in accordance with MM of the Engine Supplier
  - Functions developed in accordance with the engine Manufacturer experience & its design criteria

- **Module 3: H/C Vibrations**
  - Vibration Status of H/C and its monitored components
  - On board Rotors Track & Balance
  - Link with CD rom documentation

HUMS MODULE CONFIGURATION (3)

- **Module 4: Transmissions(Health)**
  - Drive Shafts (Unbalance / Bearings)
  - Gearboxes
  - Link with CD rom documentation

- **CV/FDR Module**
  - Existing sensors
  - Additional equipment

Lubrano/Feraud - 4

END USER'S NEEDS (1)

- **Basic EC customization**
  - 7000 flying helicopters for more than 1500 customers
  - ↗ 1500 different customized configurations
  - Yearly flying rate: 2 000 000 hours
- **Actual & contractual Use of the Helicopter**
  - Civil / Military
  - Airworthiness & Operational regulations
    - FAA, JAA, CAA, DGAC, OffShore
  - Specific flight envelope & profile (ex: Logging)
  - Yearly Rate

END USER 'S NEEDS (2)

- **User 's Environment**

- Air & Ground manpower
- Airworthiness organization
- Maintenance facilities (level/PBH)
- Computerized stores & spares management
- Mission preparation systems/fleet management
- Communication network
- Computer policy

END USER 'S NEEDS (3)

- **HUMS Documentation**
- Part of the helicopter documentation
    - HUMS basic complement and enhanced user guide for efficient trouble shouting.
- Available in paper or electronic format.

- **HUMS Training**
- On line maintenance
- GSC&GSE operator
- HUMS administrator

END USER'S NEEDS (4)

- **HUMS Support**

- Controlled service introduction and assistance (HUMS in relation with all a/c aspects)
- Technical assistance (on the job or on call basis)
- Optimum spares avalaibility
- HW & SW cots obsolescence survey
- Continous operational conditions
- Easy & reliable upgrades
- Customized support contract
- Annual user 's conference

EUROCOPTER EXPERIENCE (1)

- **Early involvement in design & support**
- **Super Puma & Cougar:**
  - 80 systems fitted
  - Over 100,000 hours flown
- **Upgrades in continuous progress**
- **Available products for all EC helicopters version**

EUROCOPTER EXPERIENCE (2)

- **Safety Enhancement & Cost reduction**
  - You get « both » with HUMS
  - Cost benefit must be calculated with accurate assumptions
  - A certified helicopter is safe
    - ➔It is safer with HUMS

EUROCOPTER EXPERIENCE (3)

- **COOPERATION**
- H/C manufacturer / Equipment vendor / Users have to win together
- These 3 actors will be actively pushed forward by airworthiness authorities (JAA-CAA), and by new operational requirements.
- Each party has an added value to be identified in order make sure that the job is not done twice.

EUROCOPTER EXPERIENCE (4)

- **Former difficulties**
  - HUMS understanding
  - False Alarm rate
  - Usage data provides "more accuracy"
  - Hardware reliability
  - Software configuration management
- **Current Status**
  - HUMS is running stable
  - Defect reports are managed through our Support centers
  - Improvement of H/C work cards (Trouble shooting+Maint.)
  - Safety cases have proven HUMS added value

Lubrano/Feraud - 8

EUROCOPTER EXPERIENCE (5)

- **HUMS Community**
  - Annual EuroHUMS Conference
  - Working group has defined field of benefits
  - CAA HUMS task force
  - Insurance companies briefing by EC periodically
- **EC HUMS support centers**
  - Specific services have been put in place
    - Hot line, On job training, Tech assist 24h
  - Networks (EC/ End Users - Base to Base)

SAFETY & COST BENEFITS (1)

- **Detected fault cases**

- MGB gear failure
- Tail rotor fitting crack
- Engine / MGB drive shaft unbalance
- MGB bearing advanced wear
- Maintenance error on tail drive shaft

- ➔ **Safety has been increased**

SAFETY & COST BENEFITS (2)

- Former accident status
  - Accident origins are approximately:
    - Pilots: 80%
    - Maintenance: 15%
    - Tech. Issues: 5%
- Each field of accident has the possibility to be reduced by the use of HUMS.

SAFETY & COST BENEFITS (3)

- **Use of HUMS Database**
- Being updated every day
- Pilots & Mechanics behavior and turnover
- H/C historical exceedance data (a/c and LRU)

Lubrano/Feraud - 10

SAFETY AND COST BENEFITS (4)

- **Achieved Cost Reduction**

- Technical Flight reduction
- Ground tests reduction
- Lighter scheduled inspection
- Better vibration status of the Helicopters
  - Crew / Passengers / Equipments
- Customized maintenance for limitation exceedence
- ↘ Cost of overhaul for monitored components
- TBO extension
- ↘ Unscheduled maintenance by 20%

Conclusion

- Since 1993, Eurocopter has tried to offer the best alternative to its customers based on their growing operational requirements

- We have taken into account all economical and technical aspects related to the products offered to our customers. So far, the ROI has been confirmed by users as follow:

- **Heavy helicopters**
  - Civil: 4 to 5 years / Military: 7 to 10 years
- **Medium/Light Helicopters**
  - Civil: Less than 3 years / Military: 3 to 5 years.

DSTO

MACHINE DYNAMICS

Brian Rebbechi and Albert Wong

AMRL

Helicopter HUMS Workshop

AMRL Fishermens Bend Melbourne, Australia

16th - 17th February 1999

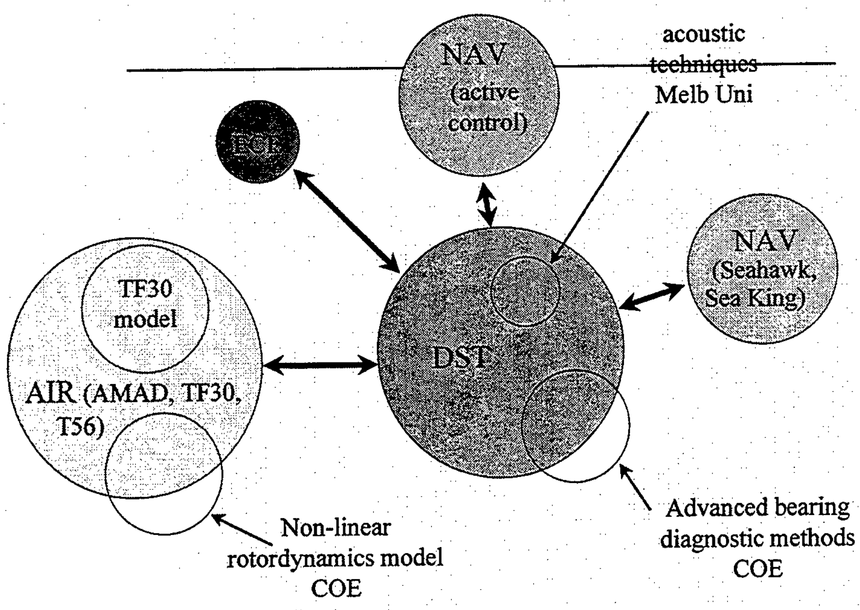
DSTO

Machine Dynamics Tasks

Task	Title	Task Manager
DST98/164	Advanced Transmission Diagnostics ▪ Algorithm development ▪ Psycho-acoustics (ISVR) ▪ Bearing fault detection (COE) ▪ Smart bearing ▪ Acoustic detection (Melb Uni)	Albert Wong
AIR97/090	Propulsion System Vibration Analysis – RAAF ▪ AMAD ▪ TF30	Brian Rebbechi
NAV98/094	Vibration Monitoring of Navy Helicopters ▪ Hardwiring of Seahawk and Sea King fleets	David Blunt
NAV98/267	Active Vibration Control of Propulsion Systems ▪ Concept demonstrator	Brian Rebbechi
COM98/245	Eurocopter Seeded Fault Analyses – Commercial ▪ Consultancy	Albert Wong

Rebbechi - 1

DSTO



DSTO

AD- Hoc Investigations

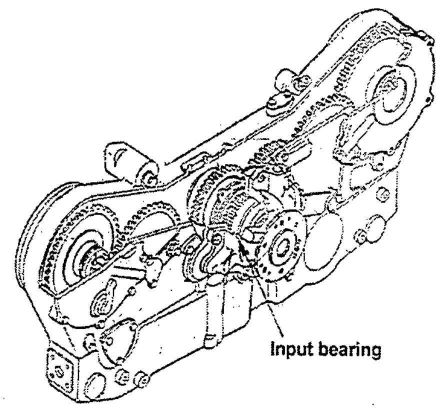
F/A-18 AMAD Gearbox

T56 Turbine Blades

Rebbechi - 2

DSTO

F/A- 18 AMAD GEARBOX



1. Failures of the input bearing have resulted in two in-flight fires.

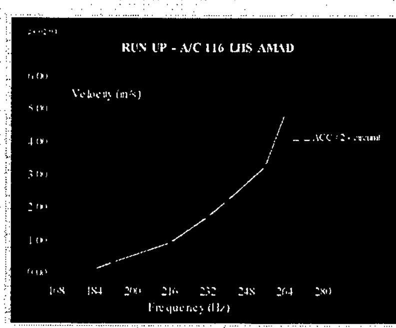
2. The second fire caused substantial airframe damage which required overeats repair.

DSTO

Initial Assessment of Problem

1. Very high vibration levels, largely as a result of unblanace due to shaft clearances and proximity of drivetrain to critical speed

2. Alleviation of problem by assessing all aircraft, and developing a procedure to reduce vibration by shaft rotation



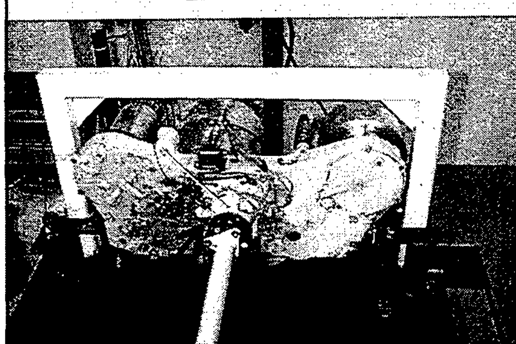
DSTO

Dynamic Load Measurement

Dynamic bearing load measurement using strain gages confirmed estimates o high bearing load. Measured values in excess of 500 lbf (Design 130 lbf) which will have life of less than 400 hrs at 100% power

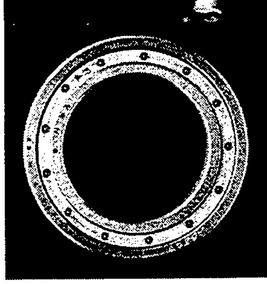
DSTO

F/A 18 AMAD Gearbox Test Rig



Design changes introduced from June 2000 to June 2002 (Bigger input bearing)

AIM: To fail bearing under service conditions. ~500lbf radial unbalance load applied.



Gearbox vibration, bearing cage speed and wear debris are monitored.

Test data from rig will complement existing vibration monitoring of the fleet.

Rebbechi - 4

DSTO

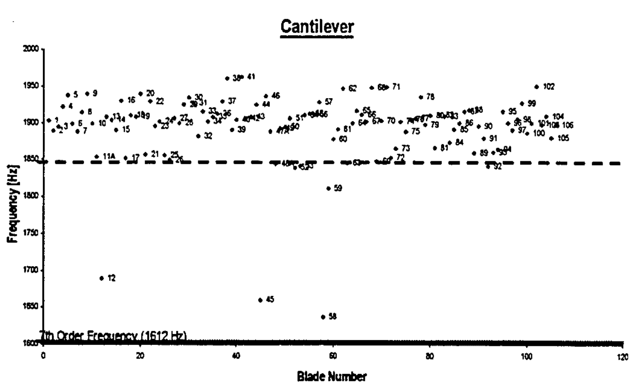
T56-A-7B Turbine Blades

- Investigating possible natural frequency excitation leading to failure
- Frequency screening of new blades
- QANTAS will take over screening

DSTO

T56-A-7B Turbine Blades

Frequency screening of new blades



Rebbechi - 5

DSTO

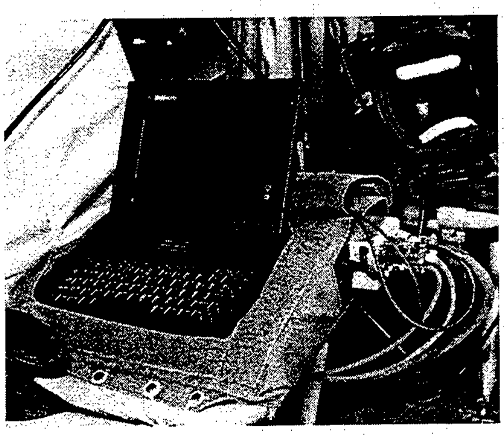
RAN Hard Wiring for Sea King and Seahawk

Chadwick - Helmuth Track and Balance

AMRL diagnostics of main, intermediate and Tail rotor

DSTO

Ruggedised Portable PC System



- Fieldworks FW7500 PC (75MHz 486)
- Custom built signal conditioning card (6 accelerometer + 2 tacho channels)
- Anti-aliasing filter card
- A-to-D converter card
- Connector interface

Rebbechi - 6

DSTO

RAAF Aircraft Diagnostics

DSTO

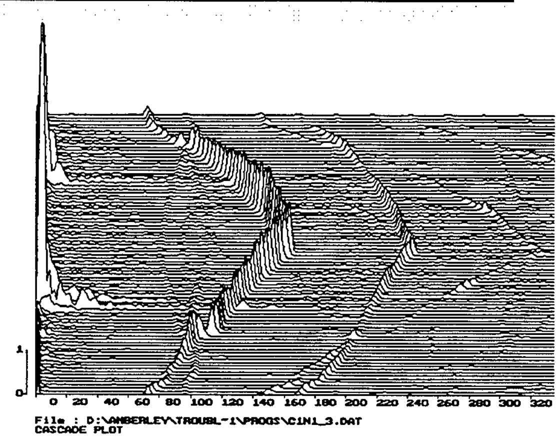
TF30 Vibration analysis system

Multi channel data acquisition

- realises $200k fuel saving per year

Advanced Diagnostics

- Nyquist and bode using engine tachos
- Cascade analysis



Rebbechi - 7

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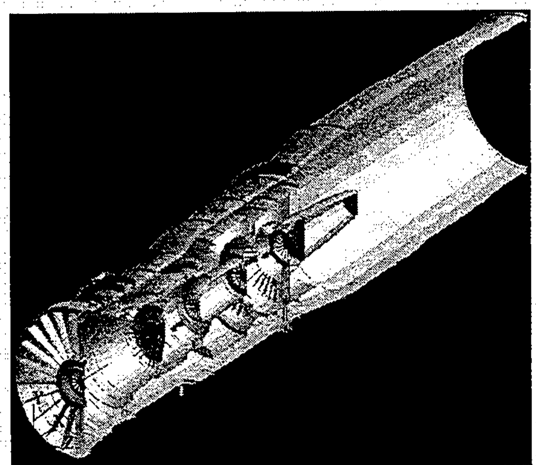
3D finite element model

Have constructed 3D FE rotordynamics model

Used to simulate structural faults and refine fault predictions



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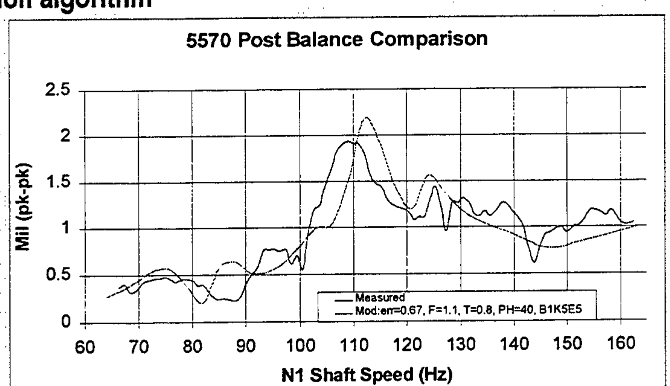
Rotor-dynamic modelling

- From a measured run-up curve give prediction of unbalance distribution and structural fault degradation
- Uses Finite Element mathematical model of TF30 and optimisation algorithm



Rebbechi - 8

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Background R&D

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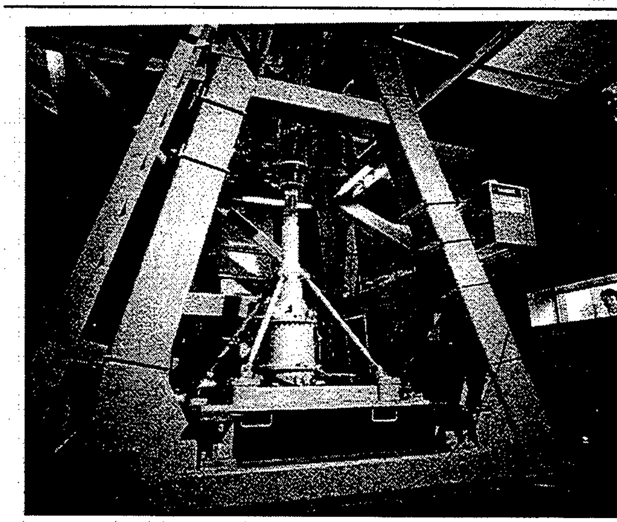
Helicopter Transmission Test Facility



Rebbechi - 9

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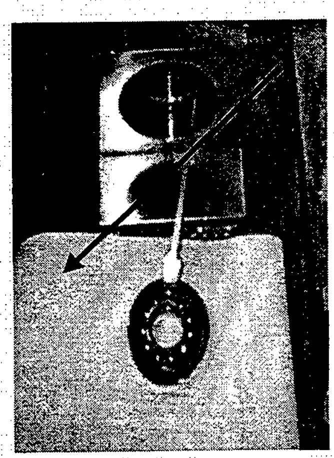
Planet Separation Techniques

DSTO

SMART BEARINGS



- PVDF Piezoelectric film (between bearing outer race and housing) senses vibration
- Will ultimately trigger alarm once vibration amplitude exceeds threshold

Rebbechi - 10

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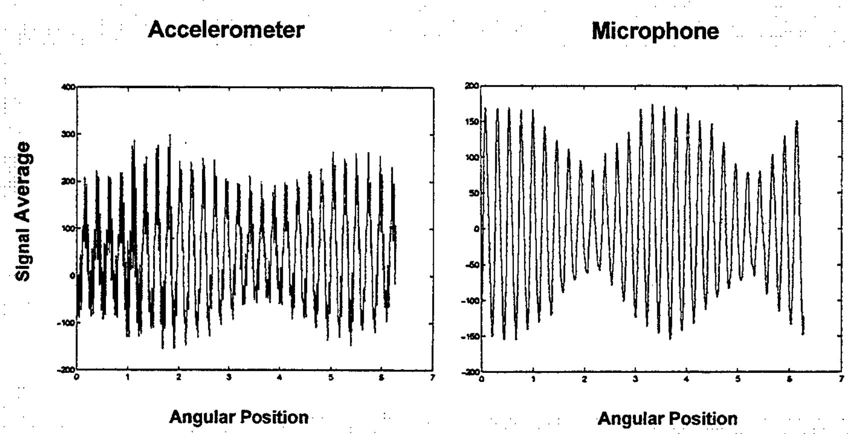
Time Signal of Synchronous Average



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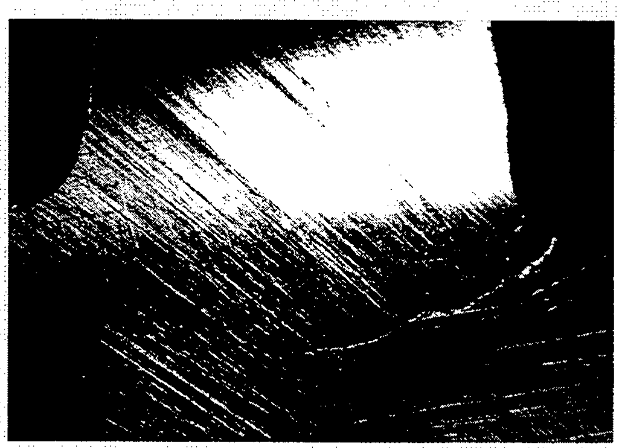
Tooth Crack



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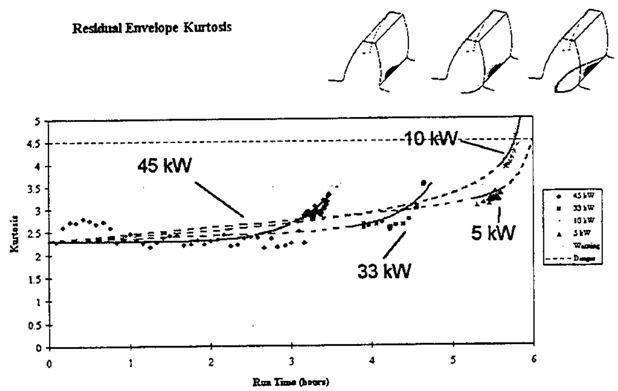
Kurtosis vs run time



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Future Directions

Primary role is to Support ADF

R&D Development of diagnostic techniques

International collaboration USN, UK

Rebbechi - 12

J. Rosinski
Design Unit
Gear Technology Centre
Newcastle University (UK)

Gear Noise and Vibration Research at National Gear Technology Centre

ORGANISATION & FACILITIES

Self-funding research, development and design group in the field of mechanical power transmission, working for industry and government.

Founded: 1970
Staffing: 19 full time staff: 10 Engineers, 7 Technicians, 2 Secretaries.

WORKSHOPS

Well equipped mechanical and electronics workshops for the manufacture of test rigs and instrumentation.

LABORATORIES

- Gear Noise and Vibration Laboratory with 8 MW back to back test facility.
- Gearbox Test Laboratory for parallel axis and worm gearboxes.
- Gear Fatigue Test Laboratory with 8 test back-to-back rigs of 75mm and 160 mm centres and up to 1.6MW power. Metallurgical & Materials Laboratories including facilities for X-ray diffraction, atomic force microscopy etc.
- National Gear Metrology Laboratory - the UK national standards laboratory for gear metrology.

Rosinski - 2

EXPERTISE

- •Gear, gearbox and transmission system design and development, particularly for low noise and high strength
- •Gears system dynamic analysis (experimental and theoretical)
- •Special measurement and data analysis systems for mechanical drives
- •Gear material surface and bending fatigue strength, metallurgy and heat treatment
- •Gear noise and vibration measurement and analysis
- •Gear manufacture and metrology
- •Gear Stress analysis including full 3-D FE based elastic mesh analysis
- •Failure investigation and analysis and on-site load, stress and vibration analysis of mechanical systems

AREAS OF WORK

The Design Unit has experience of design, analysis and troubleshooting in mechanical transmission systems for:

- **•marine propulsion, including naval gearboxes**
- **•industrial drives including mining, quarrying, steel plant and chemical plant applications**
- **•rail traction drives, AC and DC, EMU's, locomotives and light rail**
- **•automotive gearboxes for cars, off-road vehicles, buses, HGV's and heavy quarry equipment**
- **•control and servo drives for machine tools, printing machinery and materials handling.**

RESEARCH

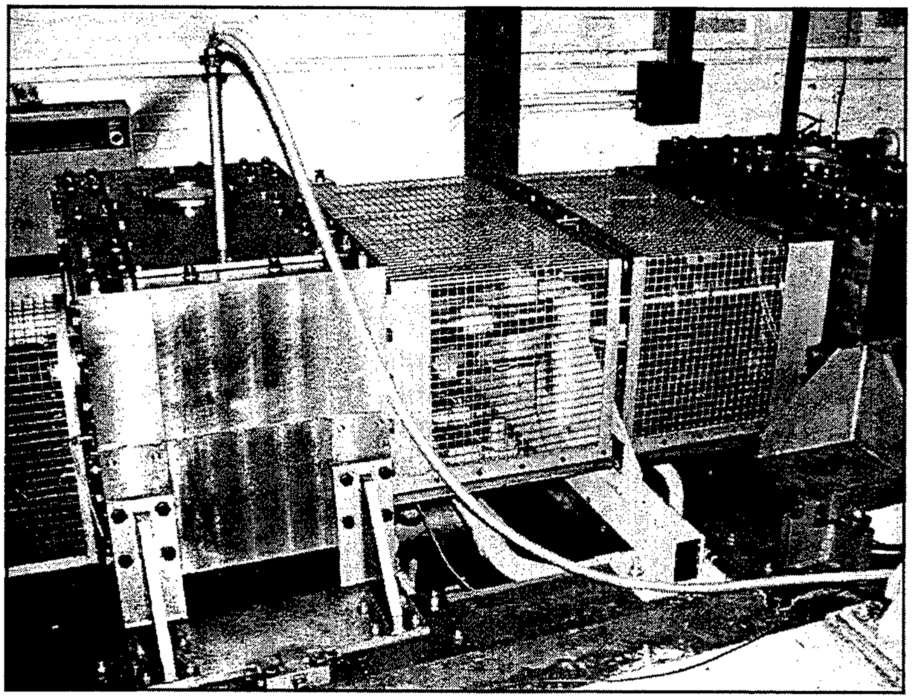
The Design Unit is engaged in fundamental research in the following areas of gear technology:

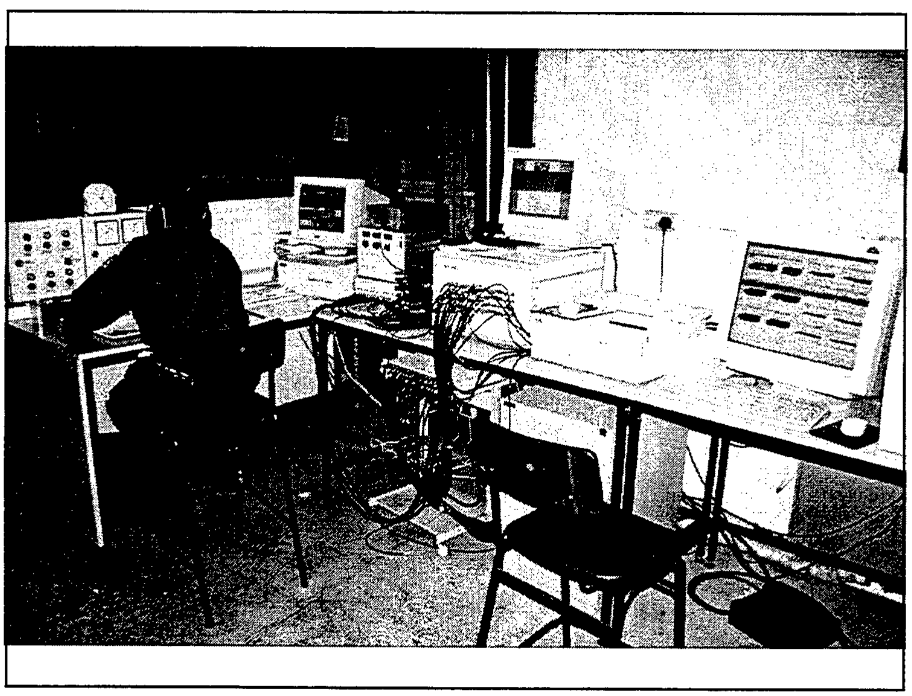
- gear stress analysis
- gear noise and vibration
- gear material fatigue strength enhancement
- gear system dynamics
- gear grinding
- gear metrology

SERVICE FOR INDUSTRY

A dedicated team of engineers provide rapid on-site technical assistance in solving industrial problems. Work is typically undertaken not only in the UK but anywhere in the World.

Rosinski - 4





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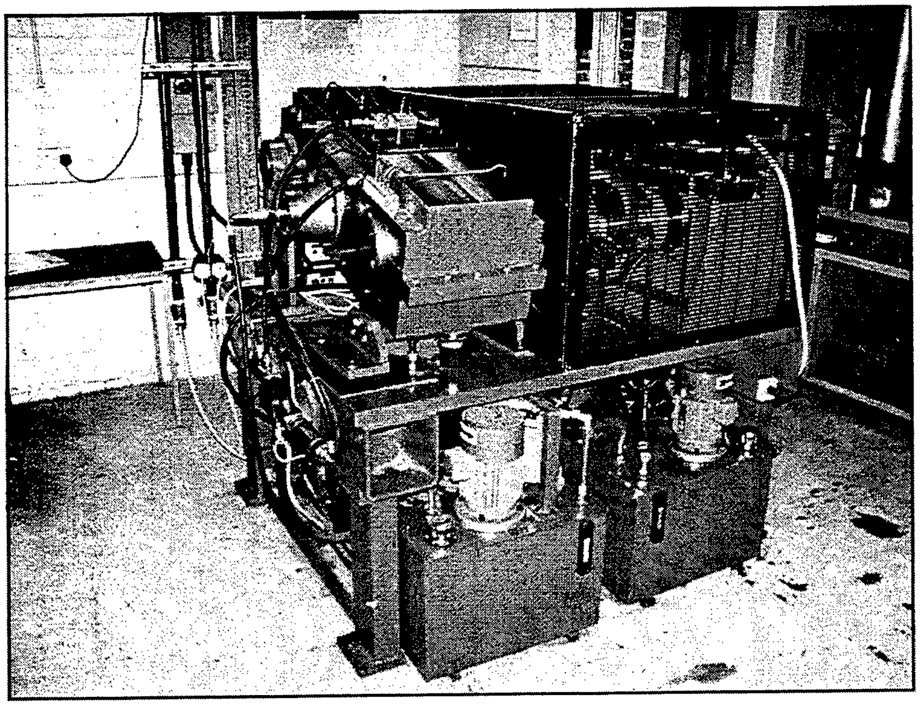
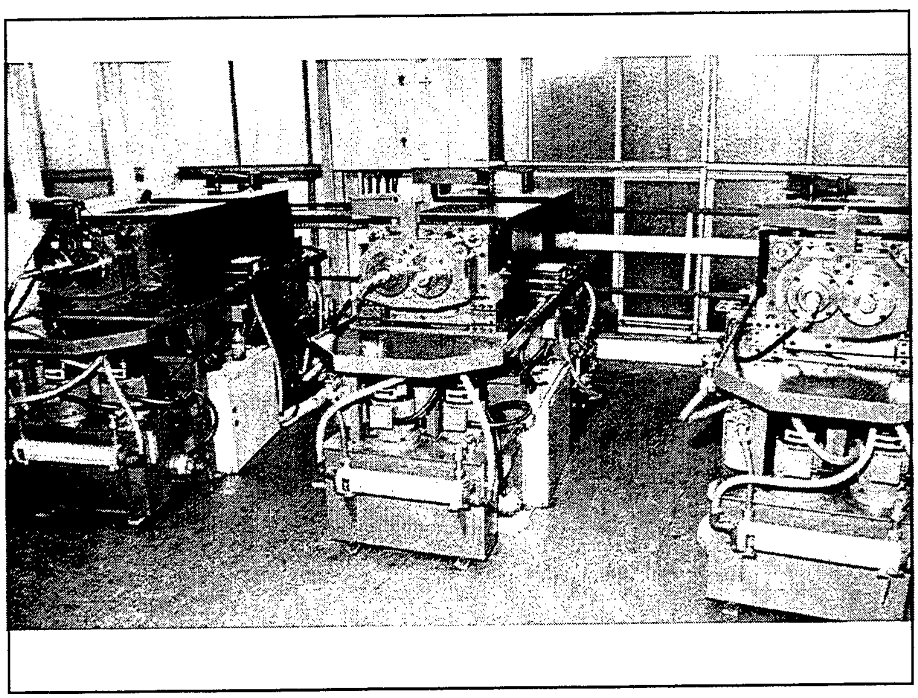
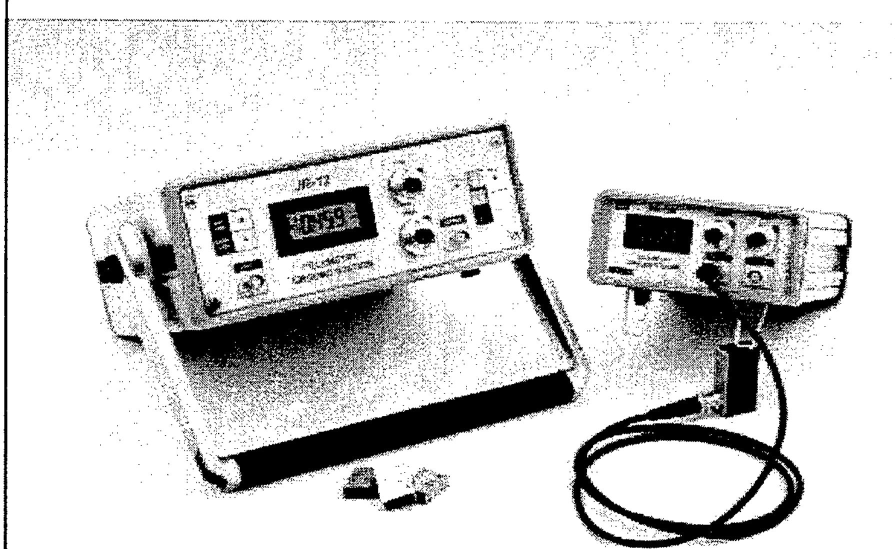


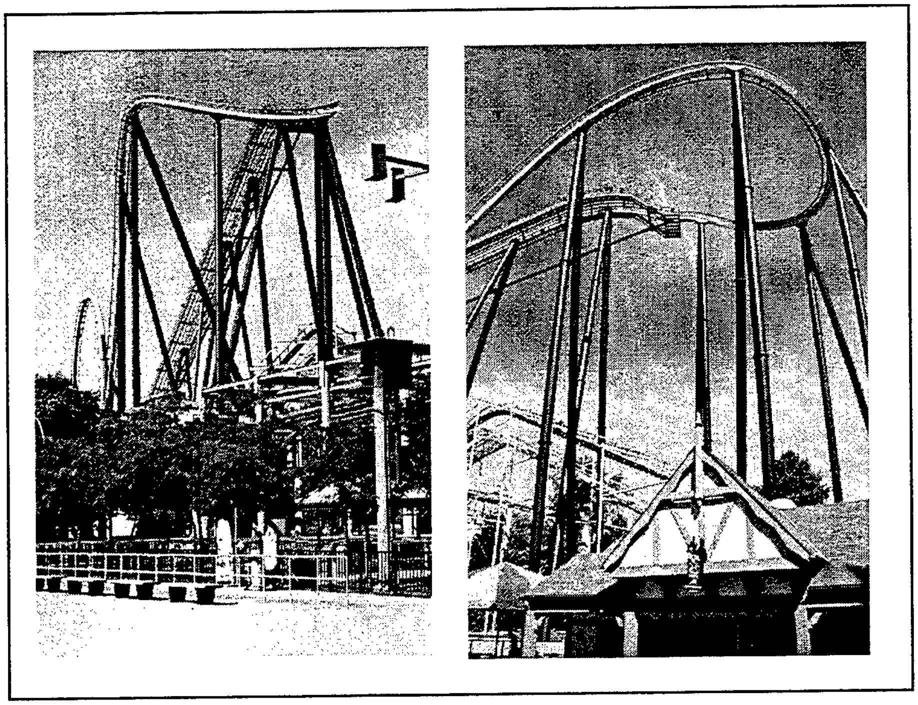


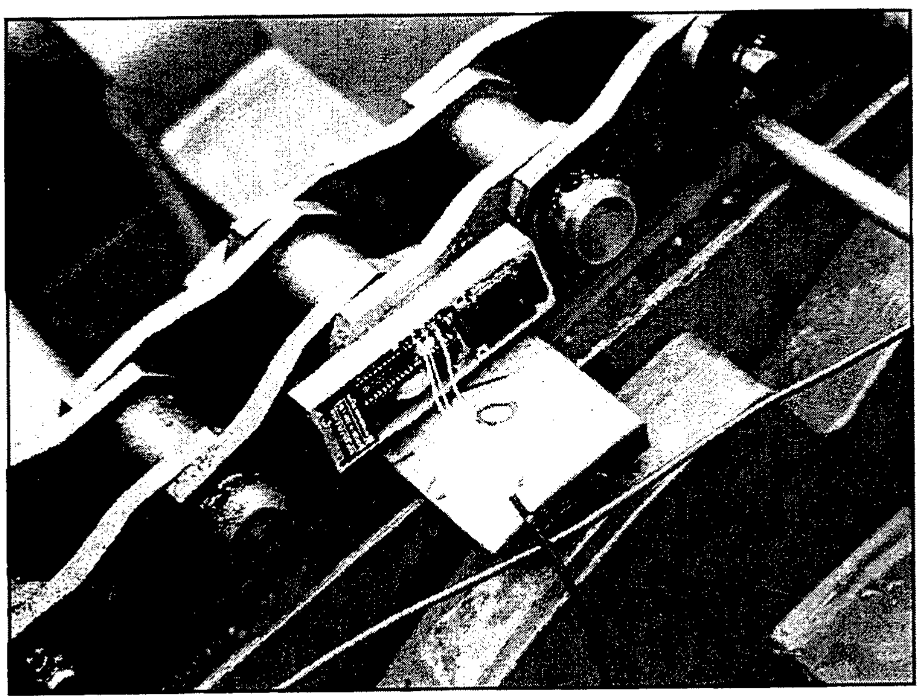
Rosinski - 6

SPECIAL INSTRUMENTATION

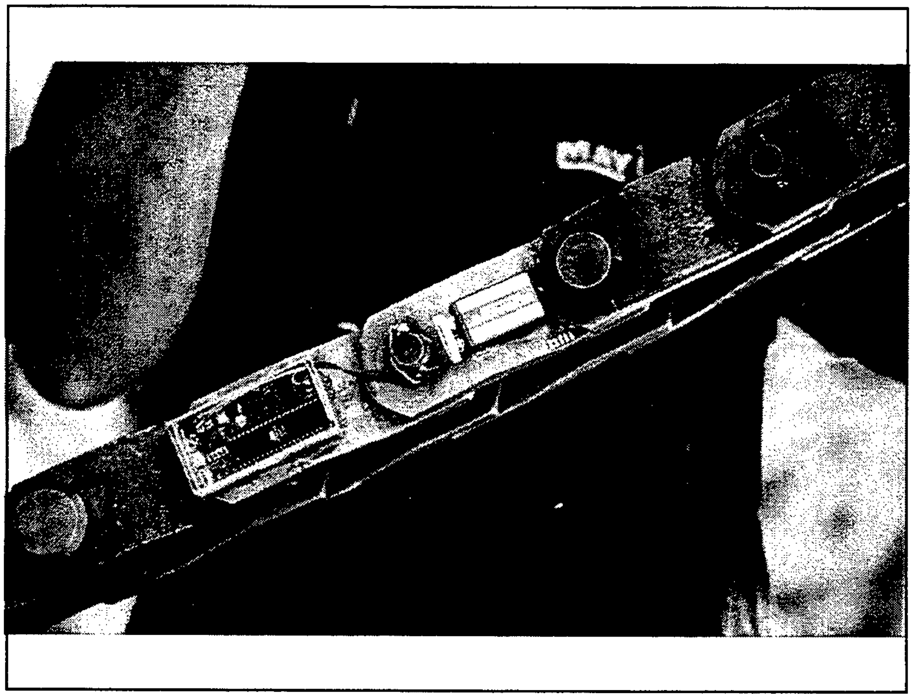
- Telemetry Systems
- Miniature Slip Ring Instrumentation
- Unattended Data Loggers
- Electronic Gear Alignment Instrumentation
- Portable Gear Inspection Instruments
- Miniature Strain Gauge Amplifiers
- Dedicated Computer Based DSP - Built Inside Gear Elements

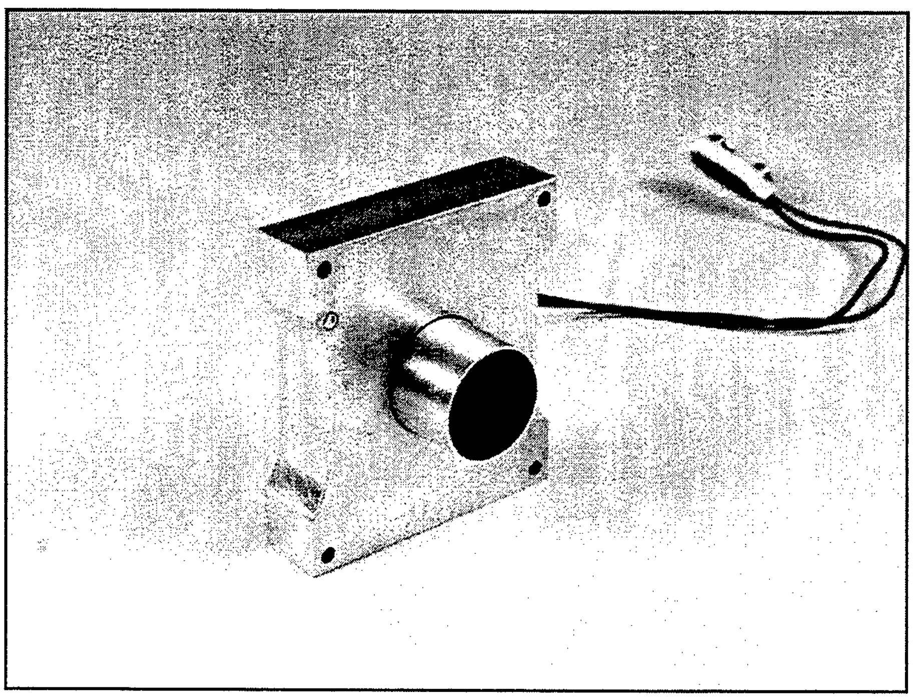






Rosinski - 8





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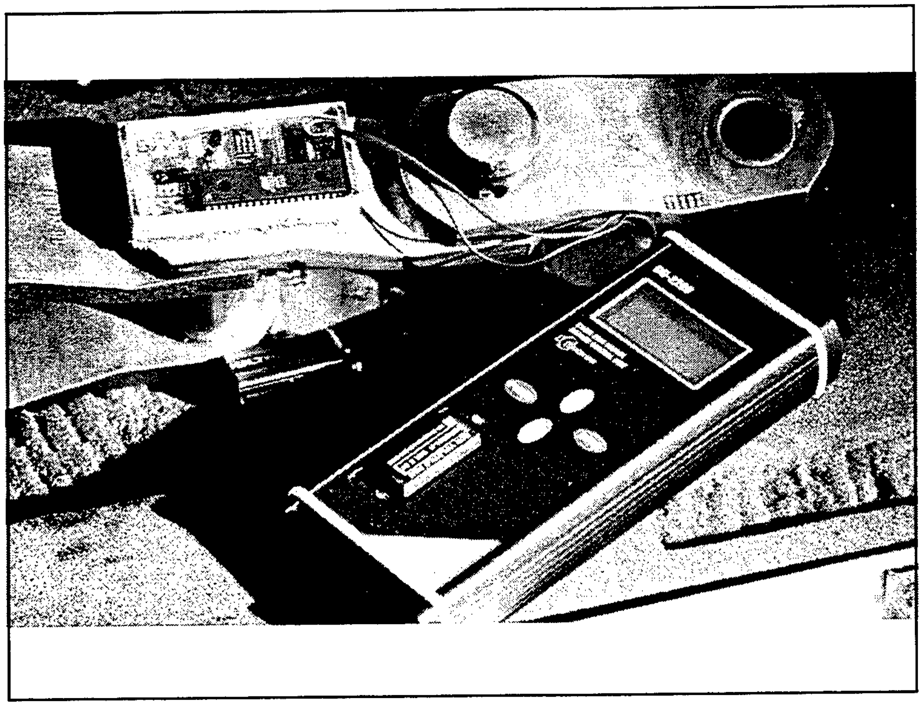

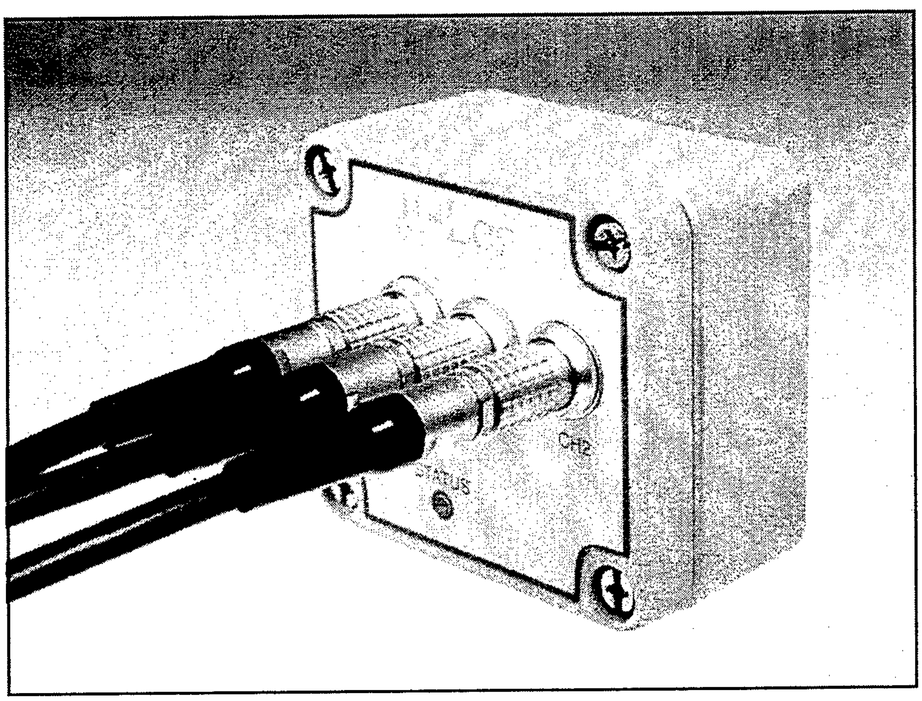

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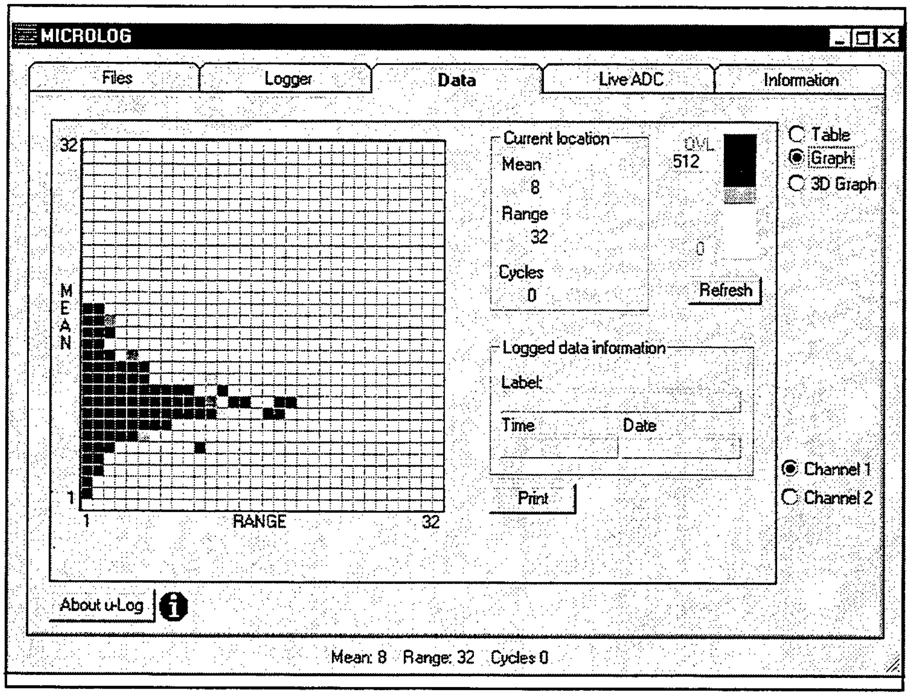
MICROLOG
Files
Logger
Data
Live ADC
Information
32
M
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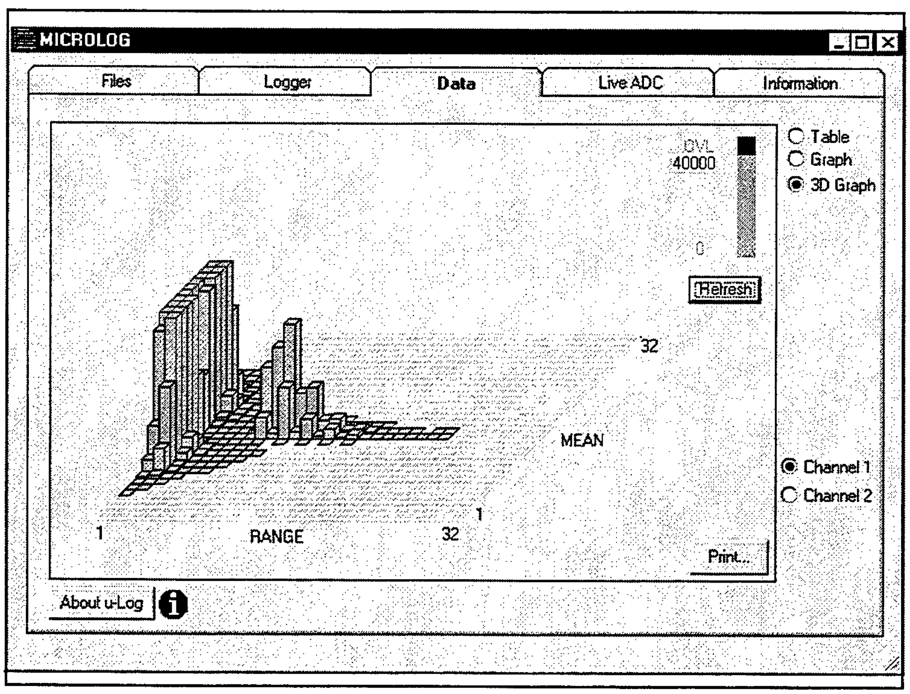
A
N
1
1
RANGE
32
Current location
Mean
8
Range
32
Cycles
0
OVL
512
0
Refresh
Logged data information
Label:
Time
Date
Print
Table
Graph
3D Graph
Channel 1
Channel 2
About u-Log
Mean: 8 Range: 32 Cycles 0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Files
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1
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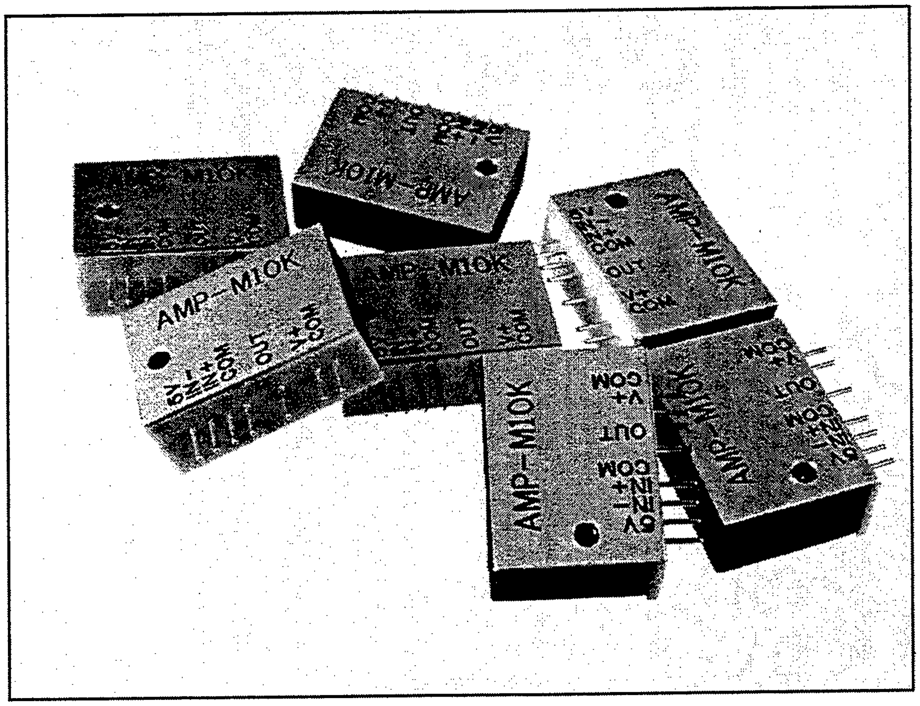
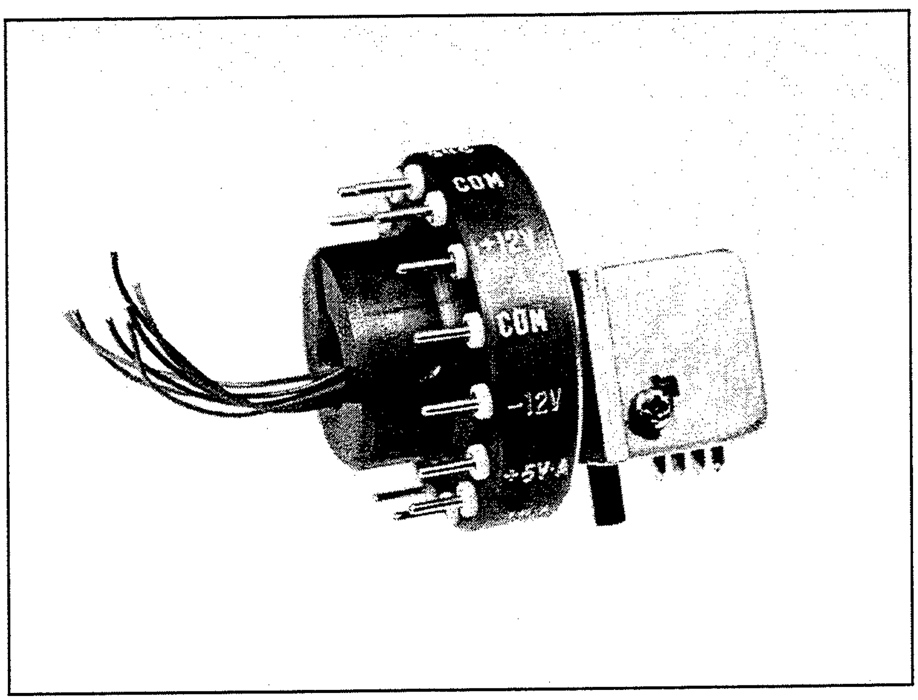
32
Channel 1
Channel 2
Print...
About u-Log

Rosinski - 11





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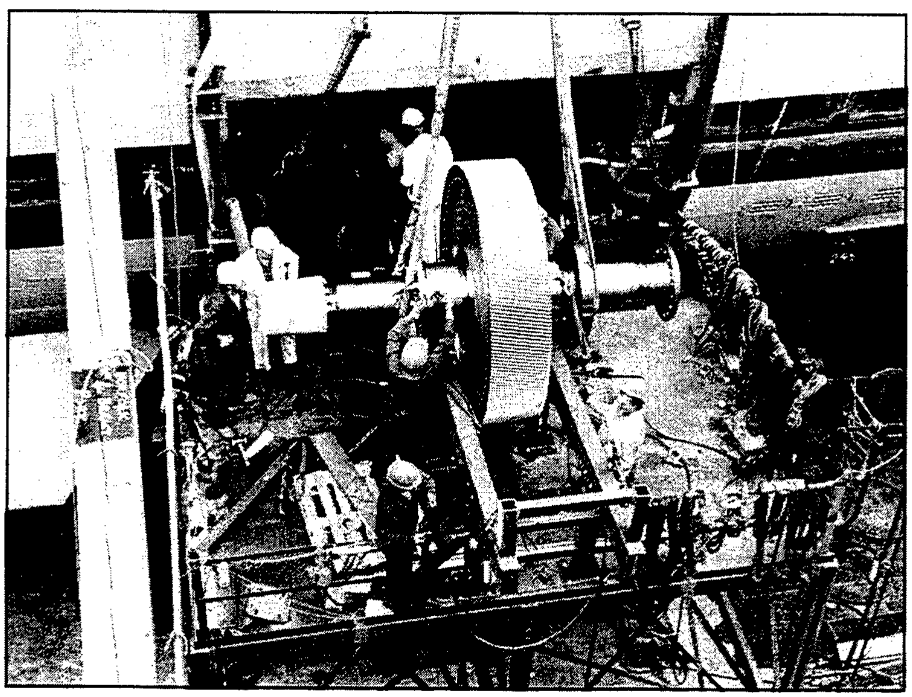
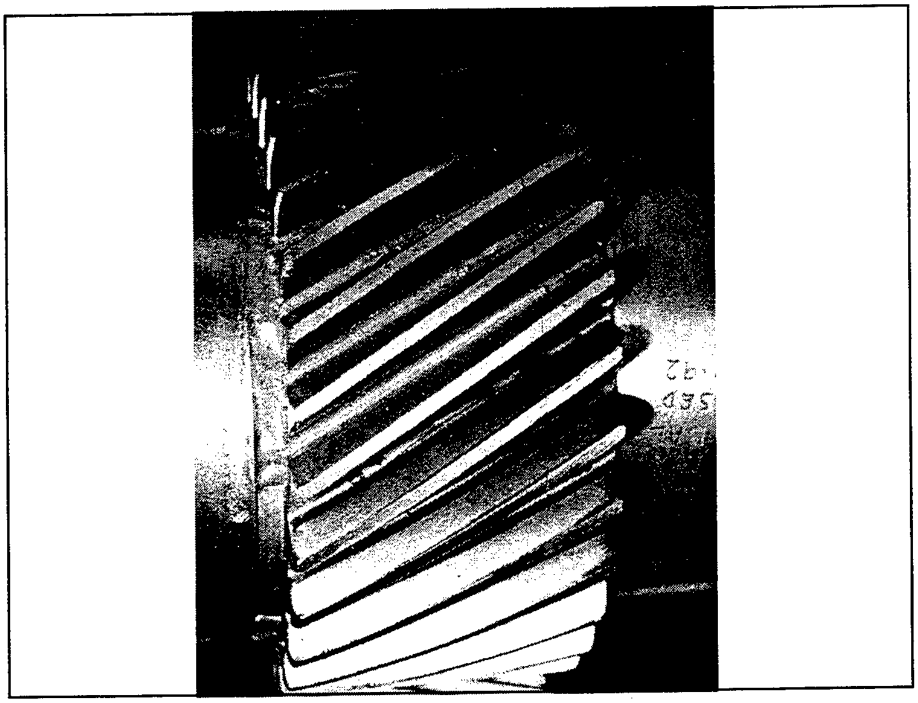
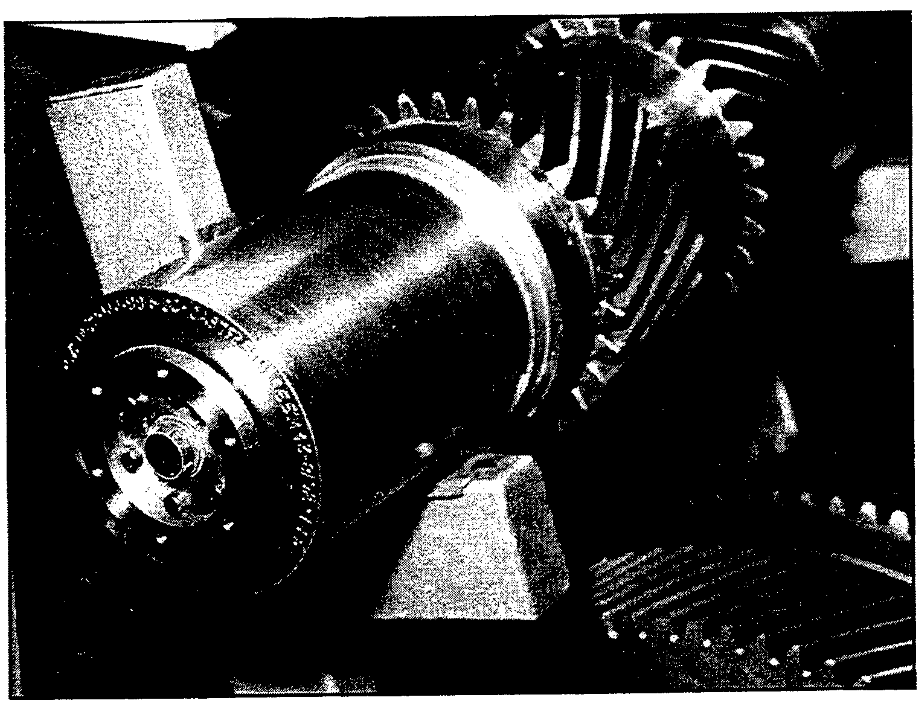
IN - SERVICE GEAR ALIGNMENT



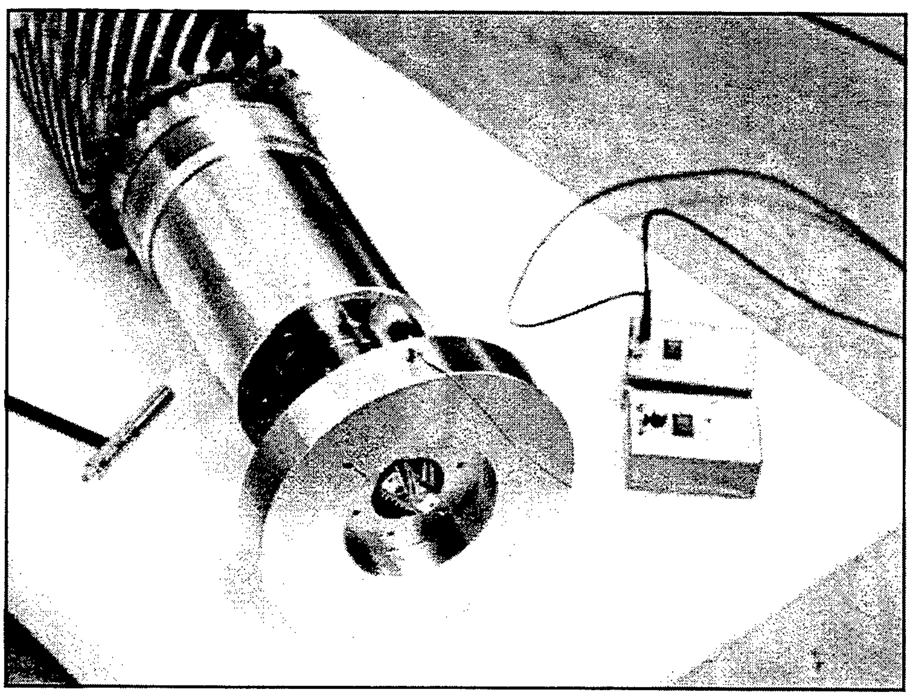
Rosinski - 13





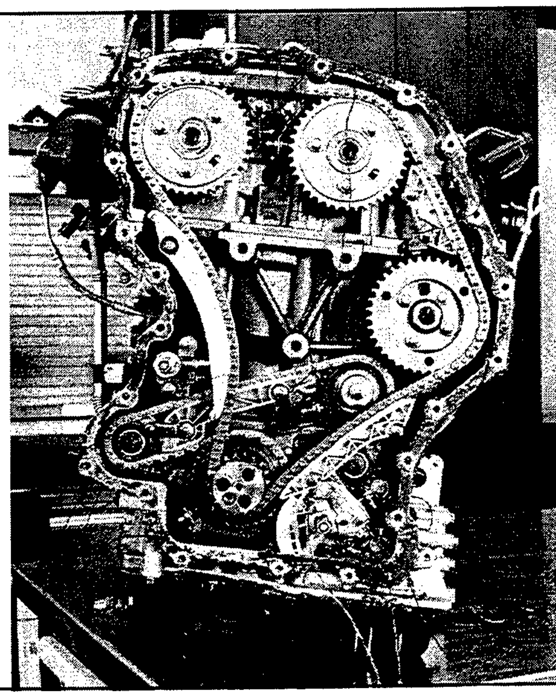
Rosinski - 14

GEAR DYNAMICS

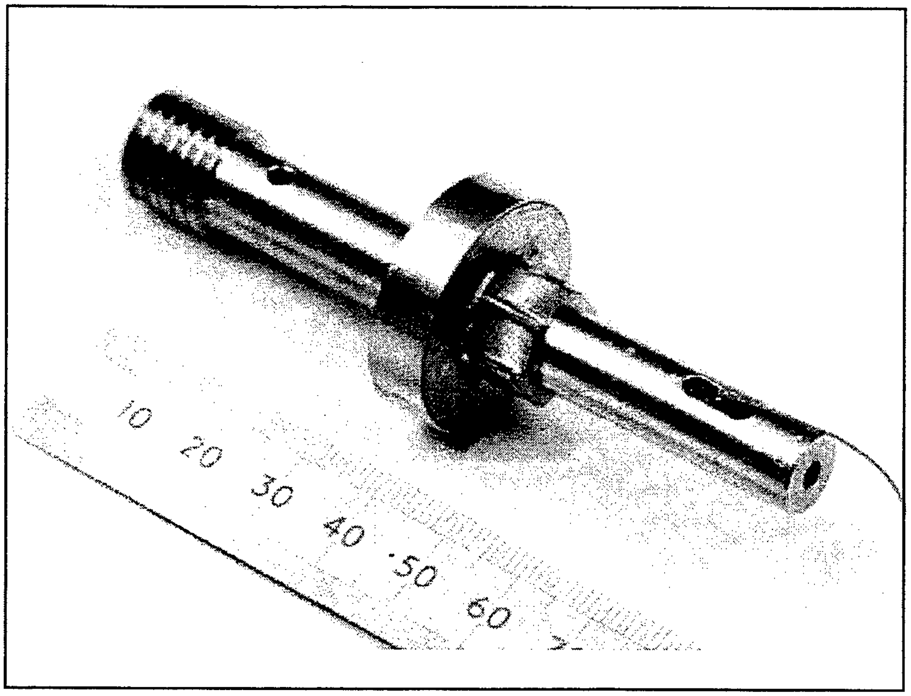


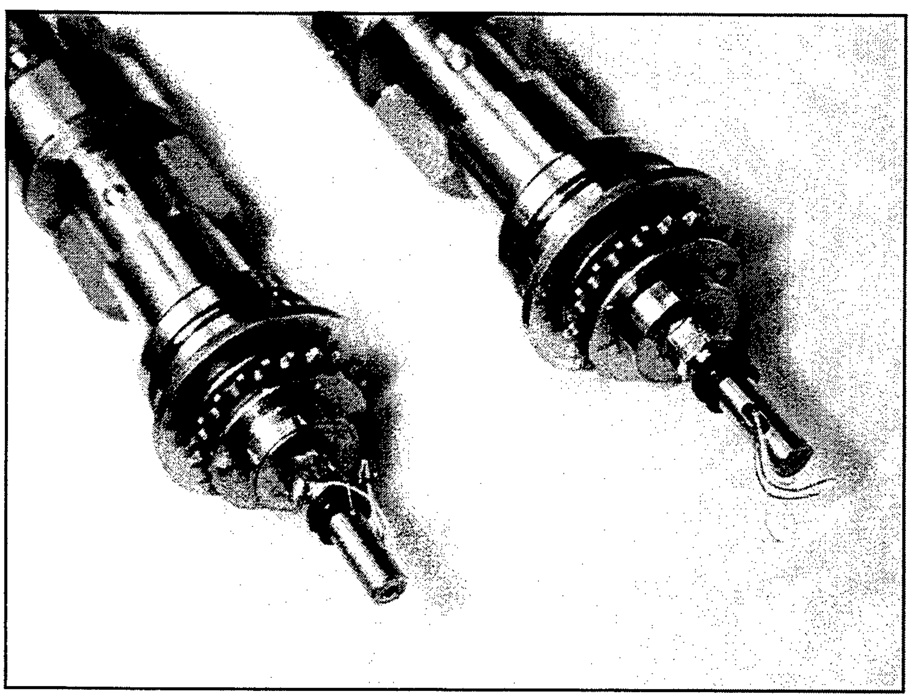
Rosinski - 15

TROUBLESHOOTING TRANSMISSION SYSTEMS

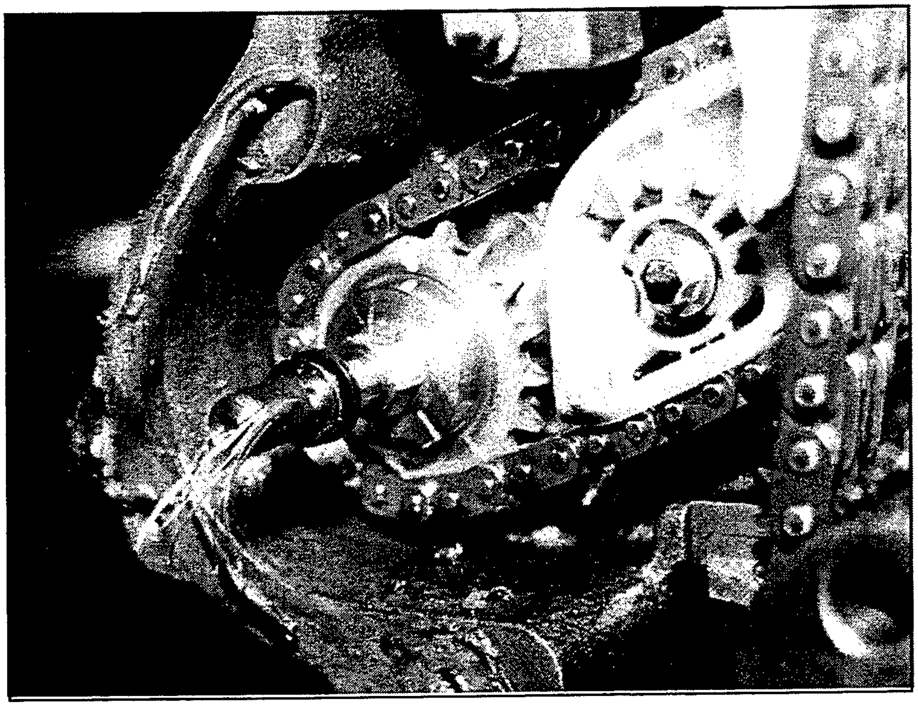


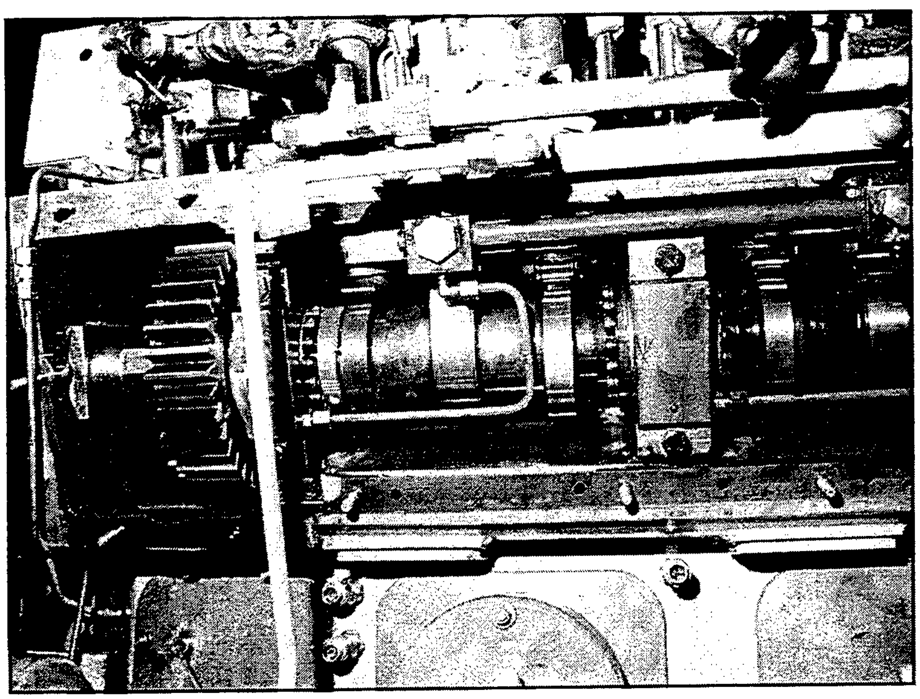
Rosinski - 16



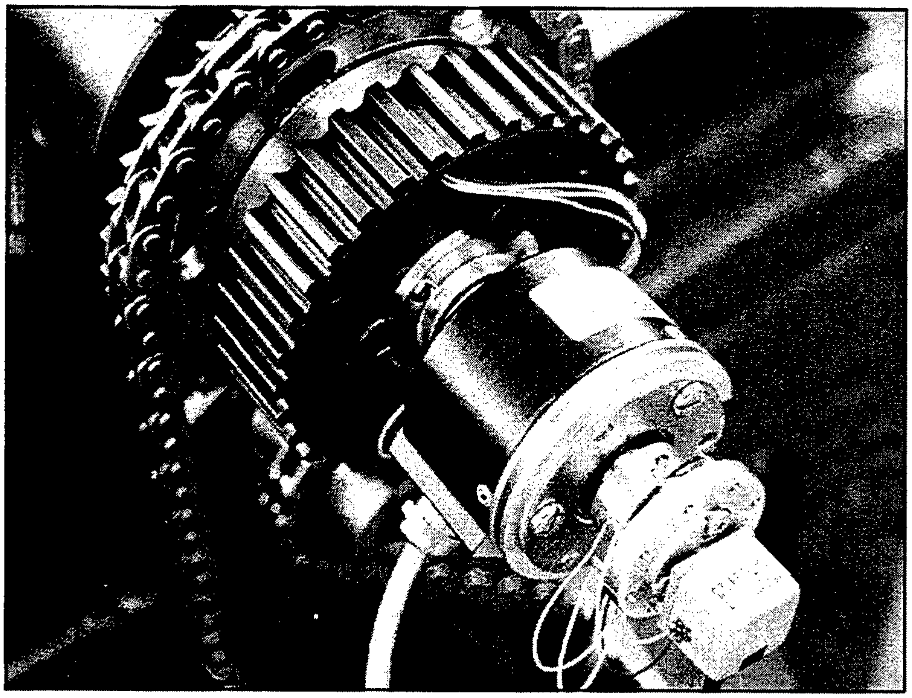


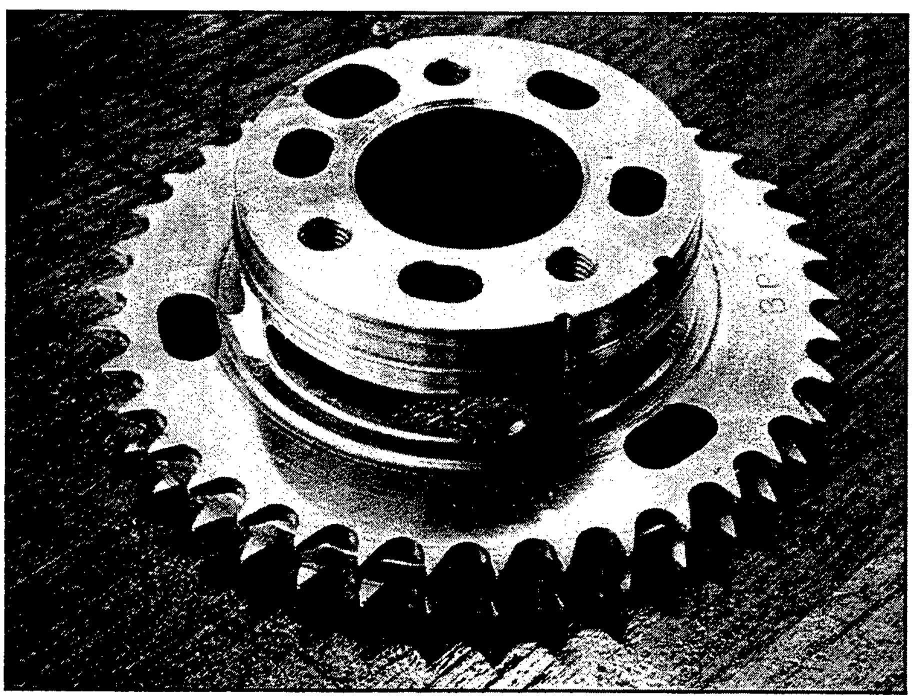
Rosinski - 17



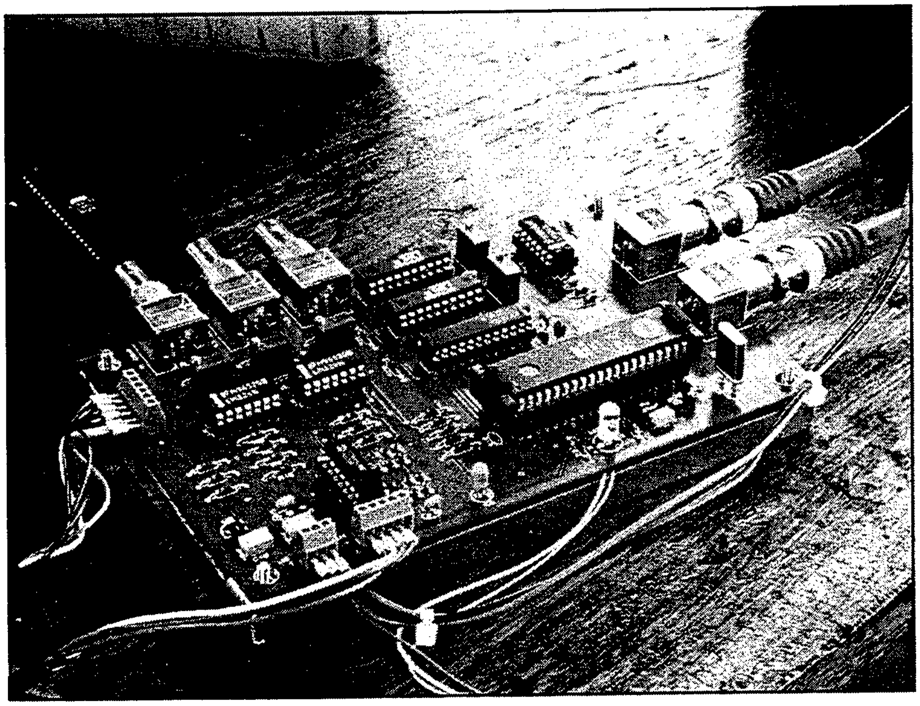


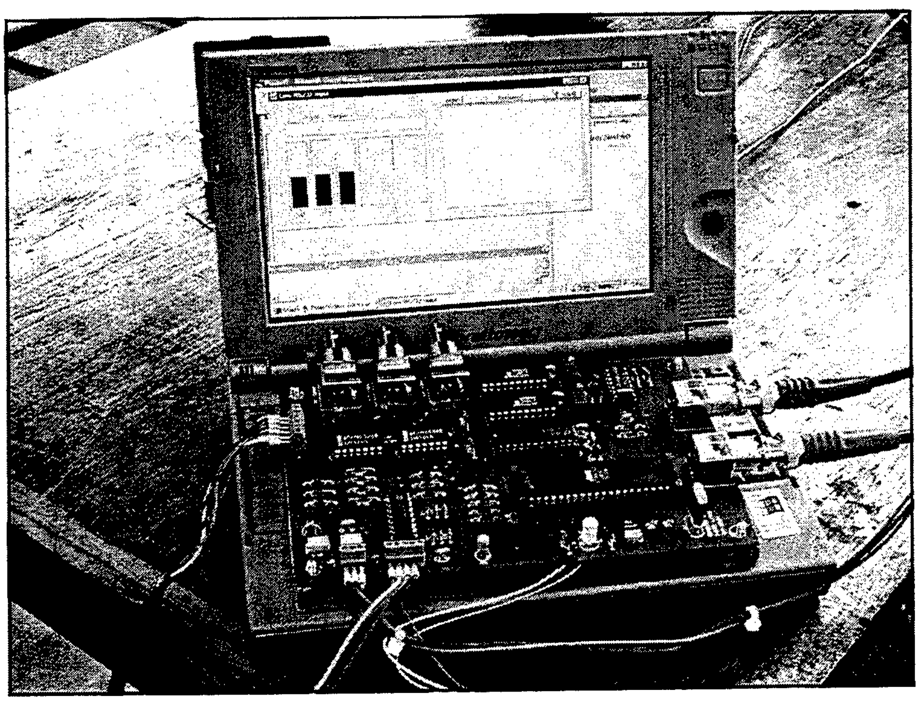
Rosinski - 18



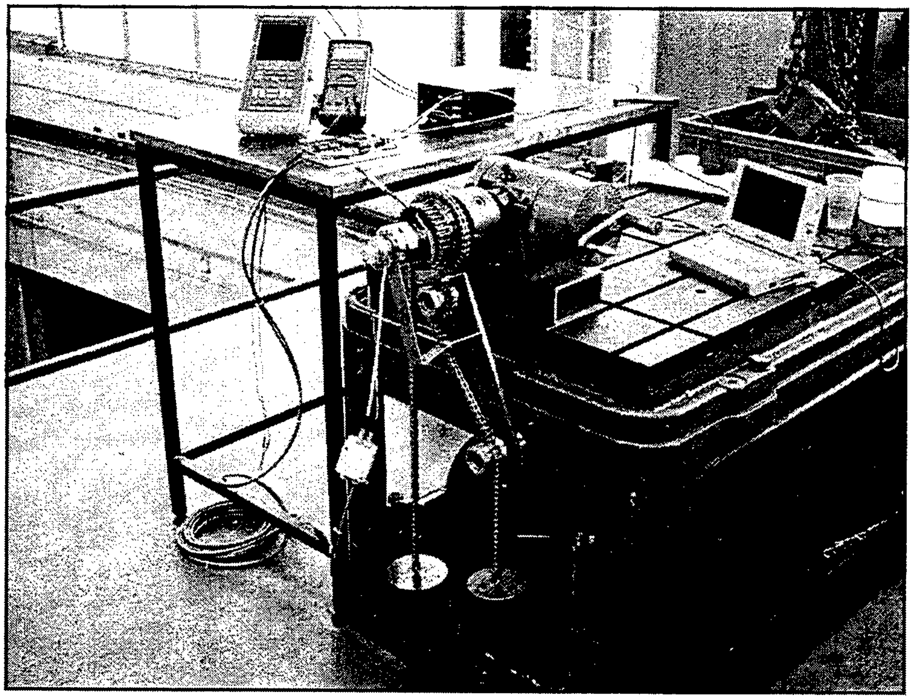


Rosinski - 19



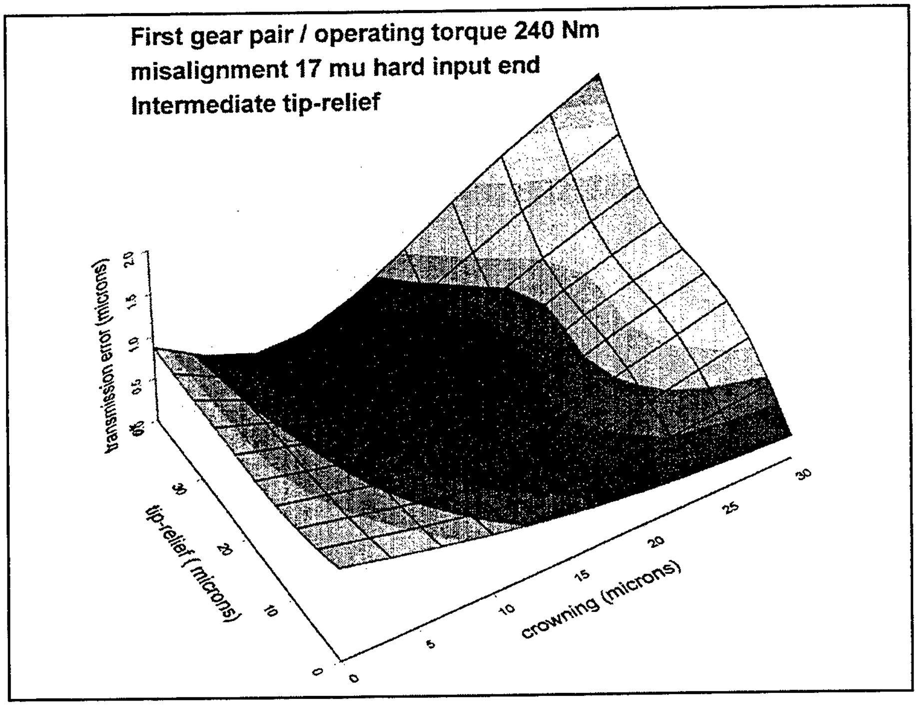


Rosinski - 20



3-D GEAR MODELLING

Rosinski - 21


First gear pair / operating torque 240 Nm
misalignment 17 mu hard input end
Intermediate tip-relief
transmission error (microns)
tip-relief (microns)
crowning (microns)
0
5
10
15
20
25
30

Rosinski - 22

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

RESEARCH INTO SENSITIVITY OF ELECTRIC CHIP DETECTORS (ECDs), AS INSTALLED IN ADF BLACK HAWK HELICOPTERS

SPLASH LUBRICATED ENVIRONMENT IN AN INTERMEDIATE GEARBOX

"A NON-PLANAR BRIDGE" →

Presenter:

Grier McVea

Airframes and Engines Division — DSTO

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Current operational mode of Electric Chip Detectors (ECDs) for Helicopter IGB

- ECD Warning Light activates in cockpit
- Land, check and remove material from ECD
- Replace ECD, ground run 1 hour
- If there is an increased amount of metal particles

  Gearbox is removed and sent to OEM for overhaul

Airframes and Engines Division — DSTO

McVea - 1

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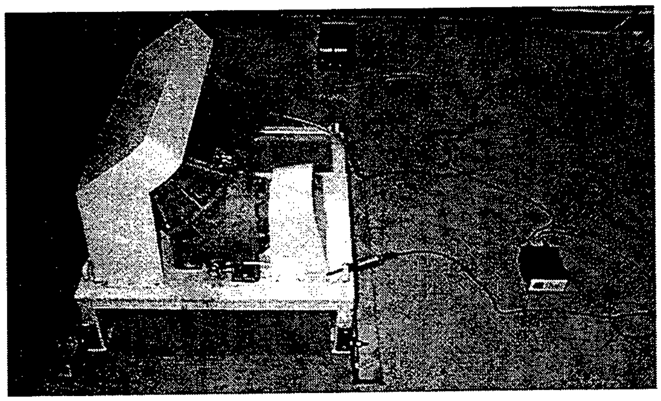
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Black Hawk Intermediate Gearbox Rig

Work described here was done, using a Black Hawk IGB coupled to an electric motor and operated at the same speed (rpm) as in the helicopter.



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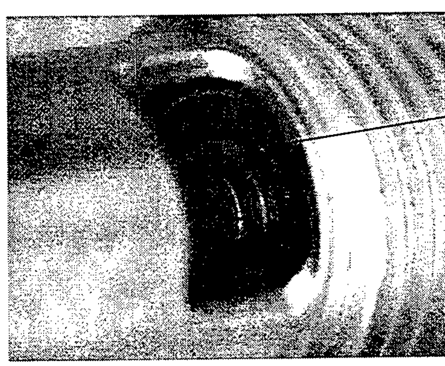
RADIAL ELECTRIC CHIP DETECTOR IN IGB



2 mm GAP

Magnetic area for collection of wear debris

Wear debris is distributed across the gap, to close the electric bridge and activate the cockpit light

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McVea - 2

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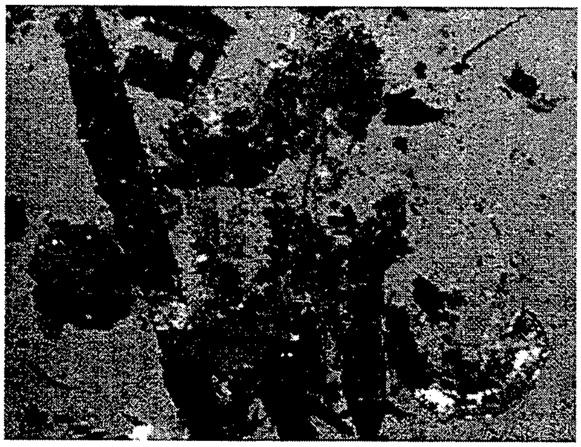
Splash lubricated gearboxes are highly contaminated with debris (difficult to remove)



Debris shown was still in the IGB oil, after 15 flushes with new filtered clean oil.

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IRON PARTICLES USED FOR SEEDING IGB

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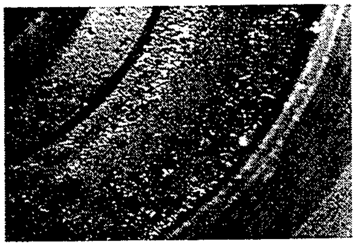
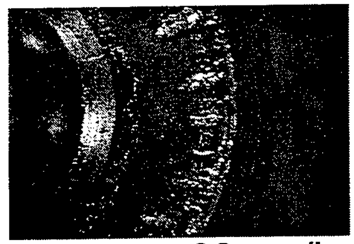


1 hour, 30 mg/L



2 hours, 60 mg/L

3 hour, 120 mg/L

ECD magnetic chip collections in the running IGB rig, with NO warning light activation.

Indicates very low sensitivity of the radial ECD.

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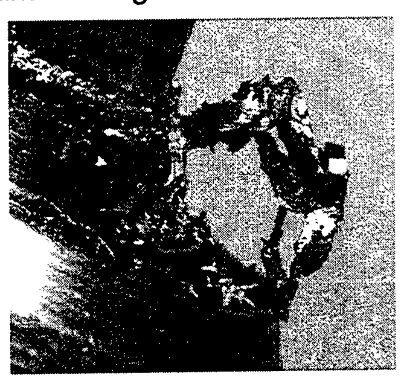
Gearbox component failure was finally recorded when the oil system was over-dosed with huge quantities (250mg/L) of simulated wear debris (iron filings).

Bridge was made with a non-planar arrangement of debris



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ECD particle collection adjacent to radial gap

Metal deposits on magnet not contributing to bridging

gap

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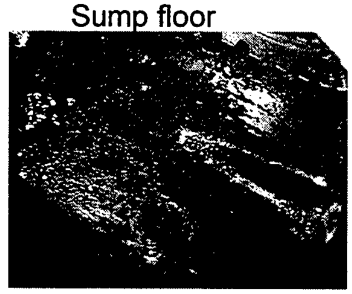
PARTICLE SETTLING INSIDE IGB SUMP

Iron particle deposits directly below ECD position

Sump floor



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McVea - 5

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Current operational mode of Radial Electric Chip Detectors (ECDs) for IGB Health

Conclusion:

- Current **Radial ECDs** located in IGBs appear to be **very insensitive** to wear debris accumulation within the gearbox
- Stronger magnets would provide earlier warning

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Planned further Black Hawk IGB Work

To study effects on ECD capture efficiencies with

- increased oil temperatures
- introduced vibration

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McVea - 6

HEALTH AND USAGE MONITORING SYSTEM FOR THE ROOIVALK COMBAT SUPPORT HELICOPTER

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South Africa

Abstract

The Health and Usage Monitoring System (HUMS) developed for the Denel Aviation Rooivalk CSH forms an integral part of the System Status Monitoring (SSM) capability of the aircraft. It provides an on-board capability to monitor and report *basic aircraft* health, usage on critical components, status, performance and limits exceedances to both the air and ground crews.

The HUMS comprises of the following elements:

a) Two Health Monitoring Units (HMUs) which include the Master Warning electronics;

b) Vibration Monitoring Unit (VMU);

c) Refuel/Defuel Unit (RDU);

d) Crash Recorder Unit (CRU) (optional);

e) Mission Planning and Ground Support Station;

f) Set-up and Diagnostics Station.

This is an excellent example of a fully integrated HUMS with all the associated benefits of minimising the number of Line Replaceable Units (LRUs) on-board the aircraft.

1. Introduction

The Health and Usage Monitoring System (HUMS) on-board the Denel Aviation Rooivalk CSH forms a integral part of the System Status Monitoring (SSM) capability dedicated to monitoring the basic aircraft system by means of a large number of sensors distributed throughout various parts of the aircraft.

The HUMS provides the Rooivalk CSH with an on-board capability to monitor and report *basic aircraft* health, usage on critical components, status, performance, limits exceedances and exceptions, to both the air and ground crews via the Integrated Management System (IMS).

The *basic aircraft* is defined to include the airframe, airborne avionics systems, powerplant and transmission systems.

The relationship between the SSM, IMS, HUMS and *basic aircraft* is best described as shown in figure 1.

The objectives of the SSM is to:

a) Provide the aircrew with the information necessary to ensure a high degree of confidence that the aircraft is fit for flight and airworthy at any point in time.

b) Inform the aircrew in the event of system failure, either through malfunctioning or battle damage, with information necessary to:

c) Make the correct mission related decisions;

d) Make the correct decisions related to optimised management of the remaining aircraft capabilities.

e) Provide the aircraft support system with the correct information to enable effective maintenance and support of the aircraft, both in the long and short term. This includes operational support.

f) Provide the accident investigation team, in the event of an accident, with information necessary to make the correct deductions concerning the cause of the incident.

The information required on the *basic aircraft* to meet the above objective, is acquired via the HUMS and distributed to the relevant on-board and off-board systems via the IMS. This is used to provide information for in-flight indication, but restricted to events likely to cause a mission failure. All information necessary to maintain the aircraft in a flight serviceable condition, that is health, usage and fault history, is recorded by the on-board system.

After a flight, a limited set of recorded data is available to the maintenance crew via the Multi-Function Displays (MFDs) in the cockpit. This data set is limited to information about the aircraft's fitness to fly and information to assist the maintenance crew in maintaining the aircraft. All recorded on-board data is available for downloading, via a Data Transfer Unit (DTU) to the logistic information system for further analysis.

2. Rooivalk HUMS System Design

The major sub-systems comprising the on-board equipment of the HUMS are:

a) Two Health Monitoring Units (HMUs) which include the Master Warning electronics;

b) Vibration Monitoring Unit (VMU);

c) Refuel/Defuel Unit (RDU); and

d) Crash Recorder Unit (CRU) (optional).

The off-board equipment consist of the following:

a) Mission Planning and Ground Support Station;

b) Set-up and Diagnostics Station.

The HUMS system architecture and interfaces are shown in figure 2.

The HUMS architecture reflects a combination of historical events as well as specific requirements relevant to the role of an attack helicopter.

In terms of the history, the previous architecture on the ADM Rooivalk CSH implements the current HUMS functionality in 14 separate LRUs distributed all over the aircraft. The subsequent development phase required a substantial mass reduction of the aircraft, which led to the large-scale integration of separate LRUs into the current HUMS.

Due to the fact that this is a HUMS for an attack helicopter with a glass cockpit design and the fact that the Master Warning Unit (MWU) resides inside the HMU, dual redundancy was required for the HMU in terms of the basic aircraft status reporting. This increases the probability of supplying information to the aircrew on which a decision can be based to complete the mission, even in the event of some battle damage being incurred.

Another unique characteristic of this HUMS architecture is the fact that the Refuel/Defuel Unit (RDU) was contracted as a part of the HUMS. Although somewhat of historical nature, the most significant reason for this is the fact that the HUMS performs the fuel management and leakage detection functions.

In summary the HUMS can be regarded as an Air Vehicle Management System, which performs the following major functions:

a) Basic aircraft status monitoring;

b) Basic aircraft health and usage monitoring;

c) Basic aircraft sub-system control and management;

The HUMS monitors the following aircraft systems:

- Engines;
- Engine Air Intake System;
- Automatic Flight Control System;
- Air/Ground System;
- Air Data System;
- Airframe;
- Transmission and drive train elements;
- Rotor System;
- Fuel System;
- Fire Detection System;
- Lighting System;
- Hydraulic System;
- Electrical Power Generation Systems;
- Environmental Control System.

3. HUMS Equipment Breakdown

3.1 Health Monitoring Unit (HMU)

3.1.1 HMU Functionality

The two HMUs perform the Health and Usage monitoring function of the basic aircraft. The HMUs form a dual-redundant set for flight-critical parameters and is the interface between the Helicopter Mission Computers (HMCs) and external sources. The HMUs perform signal conditioning, digital encoding, processing, analysing and conveying of data to the avionics bus. In the case of the fuel system they perform the fuel management function, with the exception of the refuel/defuel function.

The HMUs are physically identical units up to pin level, while the software identify each HMU as either HMU1 or HMU2 by the individual looming connections.

The master warning capability is physically located within the HMU and is totally independent from the other functions performed by the HMUs. Each master warning unit within its respective HMU contains its own power supply and is backed up by the HMU power supply. Warnings are provided via the aircraft annunciator panel.

The HMU performs the following major functions:

a) Data acquisition, conversion and validation of basic aircraft sensor data;

b) HUMS data processing and analysis (models);

c) Mode, time and regime handing;

d) Built in test, error handling and event handling;

e) Sub-system excitation and control, e.g. Fuel management and Environmental control;

f) Data reduction, storage and management;

g) Data reporting to various sub-systems;

h) Independent master warning function that couples basic aircraft warning and alarms to the annunciator panels;

i) On-board set-up and testing.

A HMU hardware functional block diagram is shown in figure 3.

3.1.2 HMU Characteristics

The HMU hardware was fully designed, developed and manufactured by AMS. The on-board processing of the basic aircraft data was implemented by AMS as defined in the models supplied by Denel Aviation. This required close co-operation with Denel Aviation in order to ensure that the basic aircraft interfaces are implemented to meet these requirements. The HMU utilises a convection cooled ¾ ATR packaging with a power capacity of 120 Watts. The 10 slot backplane provides a IEEE 1296 MultiBus II interface between the MIL-STD-1389D (SEM-E) processor and I/O modules. The hardware characteristics can be summarised as follows:

3.1.2.1 HMU Processor Module (1x)

- Intel 80960 32-bit RISC processor (25 MHz).
- 2 Mbyte Static RAM.
- 2 Mbyte Flash Memory.

- IEEE 1296 compatible MultiBus II interface.
- Two independently programmable serial ports (RS422 & RS232).
- Facilitates the onboard processing of all data acquired from the aircraft systems as defined in the C-language based HMU960 CSCI.

3.1.2.2 1553B Processor Module (1x)

- Intel 80960 32-bit RISC processor (25 MHz).
- 2 Mbyte Static RAM.
- 2 Mbyte Flash Memory.
- IEEE 1296 compatible MultiBus II interface.
- Two independently programmable serial ports (RS422 & RS232).
- Dual redundant MIL-STD-1553B bus interface as Bus Controller, Remote Terminal or Bus Monitor.
- Facilitates the onboard processing required for data reporting on the 1553B databus as defined in the C-language based I/O960 CSCI.

3.1.2.3 General I/O Module (1x)

- Provide 96 multi-level discrete inputs between 0 and 28V, programmable in steps of 150mV of which 48 is opto-isolated.
- Provide 16 discrete outputs capable to sink/source up to 25V at 100mA continuous of which 8 is opto-isolated.
- This module functions as a slave MultiBus II interface.

3.1.2.4 Dedicated I/O Module (1x)

- Accepts up to 192 multi-level discrete signals from the aircraft and converts the 28V signals to TTL compatible signal.
- Inputs are programmable between 0 and 28V in steps of 150mV capable of either sink or source current.
- Provide 8 discrete outputs with full short circuit protection.
- This module functions as a slave MultiBus II interface.

3.1.2.5 Comms and Tacho Module (1x)

- Intel 80386 32-bit processor (16 MHz).
- 4 Mbyte Flash Memory.
- Serial communication includes 3x RS232 ports, 3x RS485 ports, 1x RS485/RS422 SDLC port, 2x ARINC 429 inputs, 1x ARINC 429 output and 1x Harvard BI-Phase port.
- Accepts up to 32 multi-level discrete signals from the aircraft and converts the 28V signals to TTL compatible signal.
- IEEE 1296 compatible MultiBus II interface.
- 6x Tacho inputs (0-20kHz and 0-5kHz).
- Facilitates the onboard processing required for data reporting on the 1553B databus as defined in the C-language based I/O960 CSCI.

3.1.2.6 General Analogue Module (3x)

- Provides all sensor excitations and stimulus.
- Provides 12 bit resolution ADC and DAC with associated filtering to monitor all analogue signals.
- Analogue signals catered for are 10x differential input DC voltages, 3x differential input AC voltages, 1x differential input AC current, 2x differential input DC currents, 6x resistive temperature sensor inputs, 2x potentiometer inputs and 12x excitations.
- This module functions as a slave MultiBus II interface.

3.1.2.7 Master Warning Module (1x)

- Operates independently from other HMU modules and is powered from a separate power source.

- BIT circuitry reported back to the HMU.
- Provides the interface between aircraft sensors and the annunciator panels to indicate the following:
  - Engine fire
  - Pilot initiated reset
  - Engine low pressure
  - Power loss/faults in engines
  - Low fuel quantities
  - Low/High NR
  - Rotor-brake status
  - Low gearbox oil pressures
  - Shutoff valve status
  - Main gearbox fire
  - Delta between NG1/NG2 out of limits
  - Low cross-feed pressures between fuel tanks
  - AFCS not functional

3.2 Vibration Monitoring Unit (VMU)

3.2.1 VMU Functionality

The Vibration Monitoring Unit performs vibration related health analysis on the engines and drive-train elements of the aircraft and acquires vibration and track information in order to perform rotor track and balance.

The mission of the VMU is to improve aircraft safety by early detection of component degradation before secondary damage or catastrophic failure and to supply intelligent diagnostic information, which can be used as a maintenance tool to give an indication of defective components without removing the components for inspection. This is accomplished by analysing the vibration response of the different components using dedicated vibration sensors and the accompanying acquisition and analysis hardware and software.

The system initiates the execution of the appropriate algorithms in accordance with specific ground and flight regimes in order to minimise interaction with the aircrew.

The emphasis of the system design is to provide an early alarm of any vibration related abnormalities which may endanger the aircrew or aircraft life.

The VMU makes provision to monitor the following systems:

a) Rotor System
   - Main rotor system.
   - Tail rotor system

b) Engines 1 & 2

c) Transmission System
   - Coupling gearboxes 1 & 2
   - Main gearbox
   - Intermediate gearbox
   - Tail rotor gearbox
   - Oil cooler fans

d) Drive Shafts
   - Tail rotor drive shafts, couplings and hanger bearings
   - Drive shafts between MGB and CGB
   - Drive shafts between engine and the CGB.

The VMU performs the following major functions:

a) Data acquisition, conditioning, validation and signal processing;

b) Vibration analysis on the aircraft gearboxes, critical bearings, engines, critical shafts, main and tail rotors;

c) Acquisition and analysis scheduling according to the current flight regime or commands via the HMU;

d) Data storage and management;

e) Exceedance detection and reporting;

f) Built in test;

g) Communication with the HMU and SDS over serial channels.

Botes - 5

A VMU hardware functional block diagram is shown in figure 4.

3.2.2 VMU Characteristics

The VMU hardware was fully designed and developed by AMS. The software development was performed by AMS in co-operation with UK based MJA Dynamics (MJAD), who supplied all the vibration diagnostic algorithms. These algorithms were defined by MJAD for implementation by AMS, while the acquisition software was an AMS development. This required close co-operation AMS, MJAD and Denel Aviation to ensure that all the detail geometrical data of the drive train were reflected in the detail algorithm implementation. The VMU utilises a convection-cooled ½ ATR packaging with a power capacity of 45 Watts. The 5 slot backplane provides the MultiBus II interface between the MIL-STD-1389D (SEM-E) processor and I/O modules. The hardware characteristics can be summarised as follows:

3.2.2.1 VMU Processor Module (1x)

- Intel 80960 32-bit RISC processor (25 MHz).
- 2 Mbyte Static RAM.
- 2 Mbyte Flash Memory.
- IEEE 1296 compatible MultiBus II interface.
- Two independently programmable serial ports (RS422 & RS232).
- Facilitates the acquisition process control and onboard diagnostic calculation of all data acquired from the drive train elements as defined in the C-language based Control and Diagnostic CSCI.
- This CSCI calculates all the dimensionless 12x Gear indices, 7x Bearing indices, Engine indices, Shaft indices, Main RTB indices and Tail balance indices.

3.2.2.2 Vibration Acquisition Module (1x)

- DSP based (TMS320C31) floating point processor.
- Two simultaneous acquisition channels, each with 15 multiplexed inputs, 30 accelerometer interfaces in total.
- Provide for a total of 8 tacho signal interfaces, 6 magnetic type inputs and 2 TTL compatible inputs.
- Provide for a tracker interface via RS485.
- Provide accelerometer excitation constant current source of 4.6mA at 28Vdc for each channel.
- Software selectable Gain Amplifiers, High Pass Filters and Internal Clock, 8th order elliptical Anti-alias filter, 12bit Analogue to Digital Converter and 24bit resolution Period Counter with 16.5MHz clock frequency.
- 2 Mbyte Dynamic Memory used for storage of acquired data.
- Facilitates the acquisition process and pre-processing to determine the signal and power averages required by the diagnostic algorithms as defined in the C and Assembler language based Acquisition CSCI.

3.3 Refuel/Defuel Unit (RDU)

3.3.1 RDU Functionality

The RDU automates the process of pressure refuelling and de-fuelling and provides fuel quantity measurement and tank leakage information on a continuous basis to both HMUs.

The front face of the unit forms the man-machine interface when performing the refuel/defuel function. The RDU performs the following major functions:

a) Automatic control of the pressure refuel/defuel process on-board the aircraft;

Botes - 6

b) Prime fuel measurement system on-board the aircraft; and

c) Internal tank leakage detection and associated tank inhibition.

3.3.2 RDU Characteristics

AMS and Denel Aviation jointly specified the RDU and the development was sub-contracted to INTERTECHNIQUE in France. Due to the limited applicability of the RDU to HUMS in general, no further detail is supplied in this paper.

3.4 Crash Recorder Unit (CRU)

3.4.1 CRU Functionality

The CRU records all data for accident/incident investigations and is connected to both HMU1 and HMU2 via a Harvard bi-phase link. The primary source of data is from HMU1 and in the event of HMU1 failure HMU2 will take over the function. The CRU implementation was designed to be EUROCAE ED55/56A compliant while the actual fit is provided as a customer option.

3.4.2 CRU Characteristics

The CRU for the Rooivalk CSH is regarded as on off-the-shelf item with no development work required. Currently the BASE SCR500 CVFDR is proposed as a customer option. Up to 25 hours of flight data and 2 hours of voice data (4x channels) can be stored.

3.5 Off-board HUMS Sub-systems

3.5.1 Set-up and Diagnostic Station (SDS)

This function is implemented on a portable PC with a serial interface (RS232) to the unit under test. It is used to up-load configuration data to the relevant HUMS on-board equipment. It is also used to perform limited testing of the on-board equipment to enable confirmation of failed equipment. Software revision upgrades is also facilitated via the SDS without opening the onboard equipment. From an OEM/Operator point of view, the SDS is used as an aircraft installation tool to verify sub-system functionality as installed on the aircraft.

3.5.2 Mission Planning and Ground Support Station (MGSS)

The Mission Planning and Ground Support System is a computerised facility that will be deployed with the Rooivalk CSH to allow the flight crew to perform on-line and off-line mission planning and debriefing, and the maintenance support crew to perform, configure and document aircraft logistic analysis and support actions. The MGSS System primarily consists of the following major components:

- MGSS computer hardware platform.
- Ground Data Transfer Unit (GDTU).
- Mission Planning and Debriefing software application Module (MPDM).
- Data Transfer/Translator software application Module (DTTM), which will be a library part of the MPDM (possible a DL).
- Maintenance Data software applications Module (MDM).

For the purposes of this paper, only the MDM will be discussed further as this is relevant to the HUMS implementation.

3.5.2.1 Maintenance Data Module (MDM)

The MDM shall be a tool in aid of the maintenance support crew that will facilitate th eplanning, transfer, debrief, analysis and processing of maintenance (logistic) information of the aircraft in order to provide maintenance management support for the complete Rooivalk CSH.

The MDM shall have the following capabilities:

- Provide the ground support crew with the capability to ensure that all aircraft at squadron or aircraft "deployed" within a flight/element are maintained and supported at all times.

- Provide the support crew with the capability to accurately diagnose aircraft system level faults, usage, health and performance, and to prognose possible failures from the data acquired by means of the aircraft on-board system. This entails:
- Processing and Analysis of the captured on-board data suing the HUMS Expert Analysis and Fault Diagnostics (FD) modules.
- Diagnostic decision support to diagnose and isolate system level faults using the FD module and Reference Information (Refinfo) module.

The MDM consists of the following main modules:

- SLIS Module
- RefInfo Module
- Fault Diagnostics (FD) Module
- HUMS Export Analysis Module
- System Utilities Module

The SLIS Module forms the primary Integrated Logistics Support Information System in the SAAF and supports force logistic application operations.

The RefInfo Module is responsible for the creation, modification, management and publishing of technical documents for both paper and interactive delivery.

The Fault Diagnostics Module is responsible for providing a decision support system that utilises logistic (SLIS) and system data to assist maintenance personnel to achieve efficient fault diagnosis.

The HUMS Expert Analysis Module is responsible for providing a processing and analysis function to generate performance information from the Rooivalk on-board HUMS systems. For example:

- Fault Isolation and Model Inversion Analysis
- Go/No-Go Analysis
- Health Analysis
- Failure/Condition Analysis
- Event Analysis
- Usage Analysis
- Trend Analysis

The System Utilities Module is responsible for performing certain system and database, administration functions such as System Access Control, File Management, Import/Export of data, Audit Trails and Ad Hoc User Defined Reporting and Queries, etc.

The MGSS is currently still under development with Denel Aviation as the prime contractor to ensure integration of the Mission Planning and Maintenance Support functions.

4. Conclusion.

The HUMS as developed for the Rooivalk CSH is an excellent example of a fully integrated HUMS. This stems from the fact that the HUMS was designed in as part of the basic aircraft as well as the avionics, rather than an add-on system. The benefits are that duplication of functionality is minimised with the obvious associated reduction in the number of LRUs onboard the aircraft. This in turn has a mass reduction advantage and over and above the expected HUMS benefits, provides a life-cycle cost reduction benefit. This architecture also provides the flexibility to adapt the HUMS information available to the aircrew to the requirements of each specific customer.

By maximising the amount of parameters recorded by the HUMS, the future growth path is provided to include future enhancements by software upgrades, thus avoiding costly hardware upgrades.

5. Acknowledgement

AMS would like to acknowledge the support of Denel Aviation with regards to the HUMS development. Further acknowledgement also to INTERTECHNIQUE on the RDU development and MJA Dynamics as the VMU algorithm supplier, who distinguished themselves as excellent partners in the development programme.

6. List of References

1. Air Vehicle System Development Specification, Document Number 08A0000TB0001, Issue E.
2. Prime Item Development Specification for the XH-2 Aircraft Health Monitor System, Document Number 08C4800TB0001, Issue 1.
3. Prime Item Development Specification for the Mission Planning and Ground Support Station, Document Number 08C1500TB0003, Issue A.

List of Abbreviations

AMS	:	Analysis Management & Systems (Pty) Ltd
AP	:	Annunciator Panel
ATR	:	Air Transport Racking
AIU	:	Aircraft Identification Unit
ADM	:	Advanced Development Model
CRU	:	Crash Recorder Unit
CGB	:	Central Gearbox
DECU	:	Digital Engine Control Unit
DTD	:	Data Transfer Device
DTU	:	Data Transfer Unit
ECS	:	Environmental Control System
EDU	:	Engine Data Unit
IMS	:	Integrated Management System
I/O	:	Input / Output
HMC	:	Helicopter Mission Computers
HUMS	:	Health and Usage Monitoring System
LRU	:	Line Replaceable Unit
MFD	:	Multi-Function Displays
MMI	:	Man Machine Interface
MWU	:	Master Wing Unit
MGB	:	Main Gearbox
PDS	:	Portable Data Store
RDU	:	Refuel/Defuel Unit
SDS	:	Set-up and Diagnostic Station
SSM	:	System Status Monitoring
VMU	:	Vibration Monitoring Unit

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List of Figures

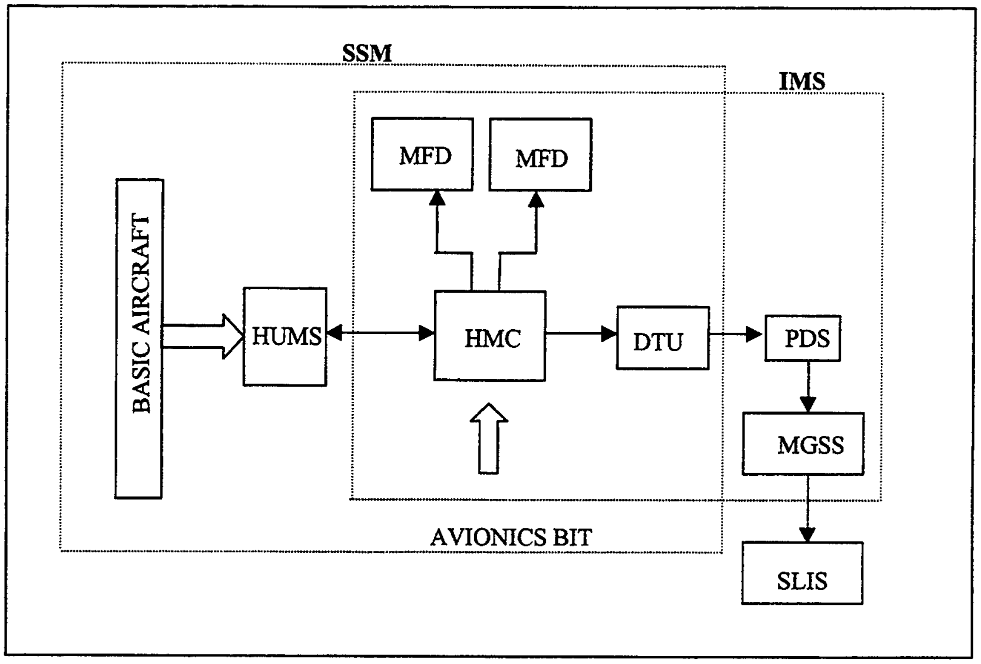

Figure 1 : SSM, IMS and HUMS Context diagram

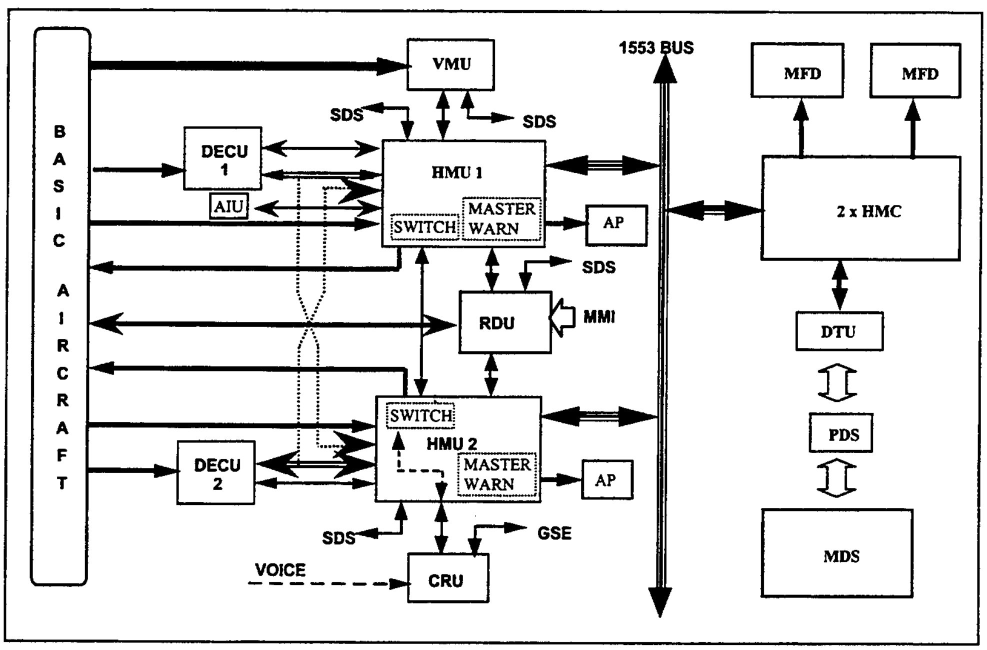

Figure 2 : Rooivalk HUMS Architecture

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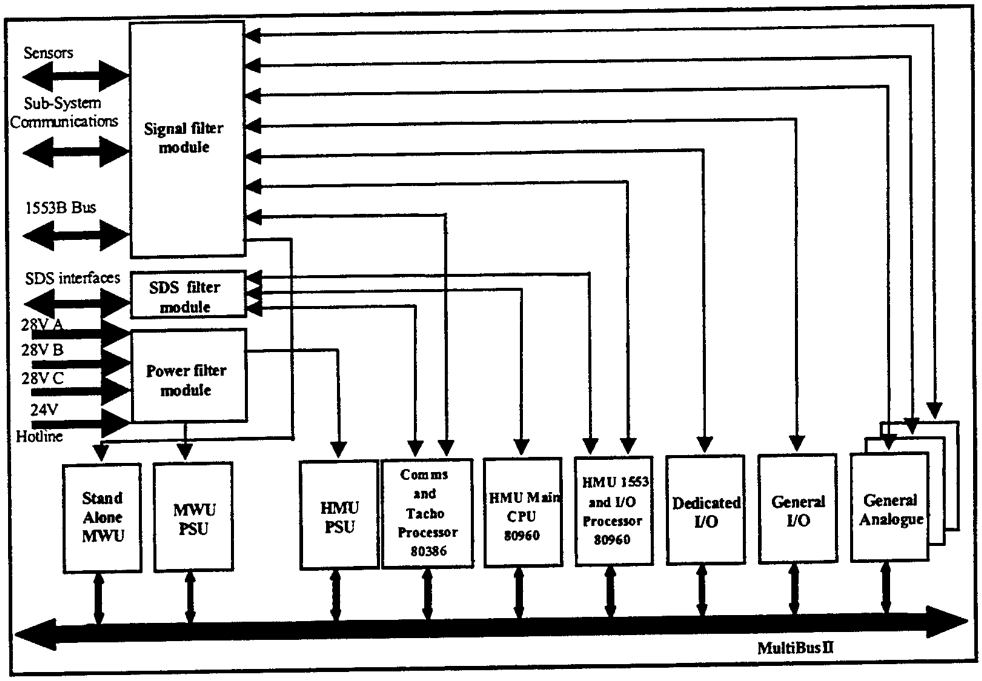

Figure 3 : HMU Hardware Functional Block Diagram

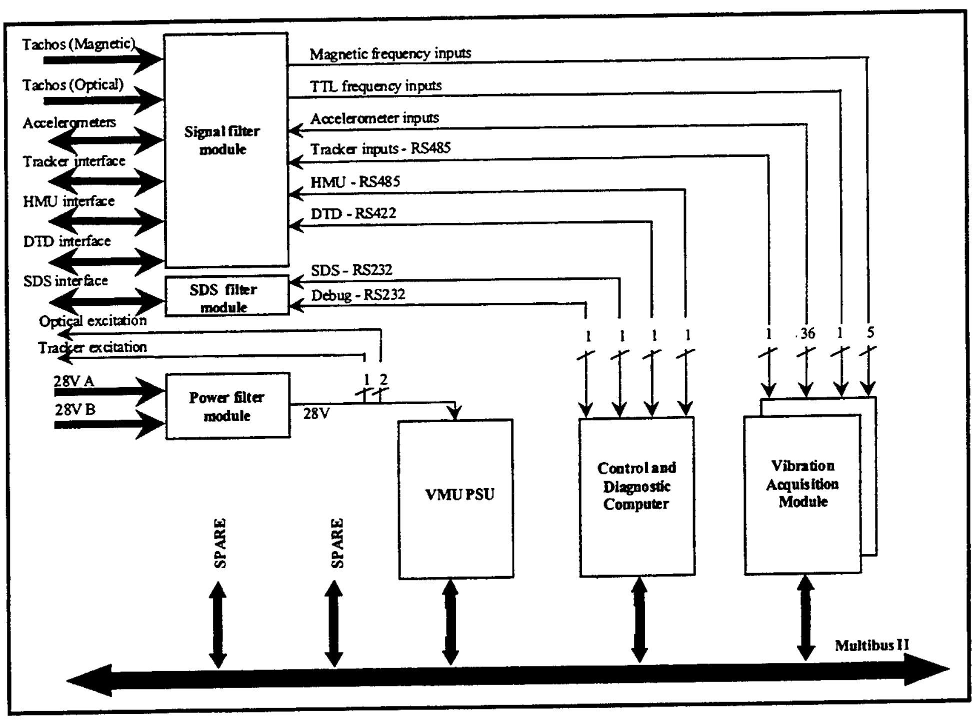

Figure 4 : VMU Hardware Functional Block Diagram

Botes - 12

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LUBRICATION OIL DEBRIS MONITORING PROGRAM AT AMRL

Presenter

Ben Parmington

Airframes and Engines Division DSTO

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

LUBRICATION OIL DEBRIS MONITORING PROGRAM AT AMRL

OBJECTIVE OF THE PROGRAM

- **Enhance AMRL's understanding of the operation and performance of existing and new generation oil debris monitors,**

IN ORDER TO

- **better position AMRL to provide advice to the Australian Defence Force on the performance of monitors used on existing aircraft and of new generation monitors that are becoming available.**

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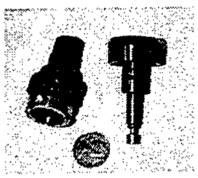
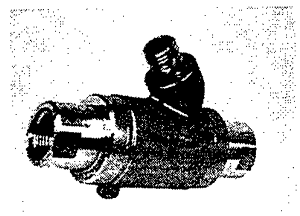
Tedeco
standard magnetic plug

Tedeco
electric chip detector

GasTOPS
inductive type





Courtesy of Aerospace Engineering

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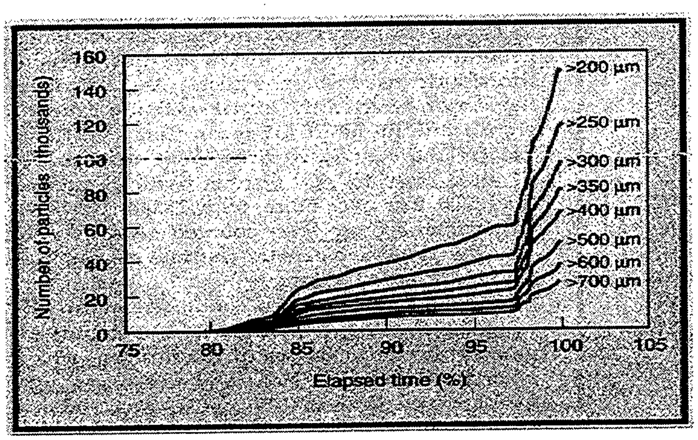
Output from GasTOPS inductive monitor



Courtesy of Aerospace Engineering

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Manufacturers/Developers of Advanced Inductive type In-line oil Debris monitors

GasTops Ltd of Canada:	Full flow monitor capable of detecting Magnetic and non Magnetic metal particles
Tedeco US:	Full flow monitor detects only magnetic particles
Thompson Power UK :	Full flow monitor detects only magnetic particles
Smiths Industries UK:	Detects both magnetic and non magnetic metallic particles
Wells Krautkamer/ Manor Technology:	Detects both magnetic and non magnetic metallic particles.

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LUBRICATION OIL DEBRIS MONITORING PROGRAM AT AMRL

WHAT WE WANT TO KNOW

- **REGISTRATION EFFICIENCY = number particles registered versus number of particles passed**
- **STATISTICAL DISTRIBUTION OF THE REGISTRATION EFFICIENCY**
  - **for range of particle sizes**
  - **at different oil temperatures**
  - **at different oil flow rates**
- **RESPONSE OF THE SENSOR TO DISTRIBUTION OF WEAR PARTICLES IN THE FLOW**
  - **particles widely dispersed**
  - **cloud of particles densely packed**
- **PERFORMANCE OF SENSOR AS AN EARLY WARNING MONITORING DEVICE**
- **ELECTRONIC INTEGRITY AT ELEVATED TEMPERATURES**

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LUBRICATION OIL DEBRIS MONITORING PROGRAM AT AMRL

WHAT IS REQUIRED OF THE RIG

- HEATING CAPABILITY OF OIL TO 200 DEGREES CENTIGRADE
- VARIABLE OIL TEMPERATURE CONTROL
- VARIABLE OIL FLOW RATE UP TO 100 L PER MINUTE
- AUTOMATED SEQUENTIAL INJECTION OF WEAR DEBRIS
- REMOTE OPERATION OF THE RIG
- WEAR DEBRIS RECOVERY FOR EVALUATION OF REGISTRATION EFFICIENCY
- PROVISION OF AERATION OF THE OIL

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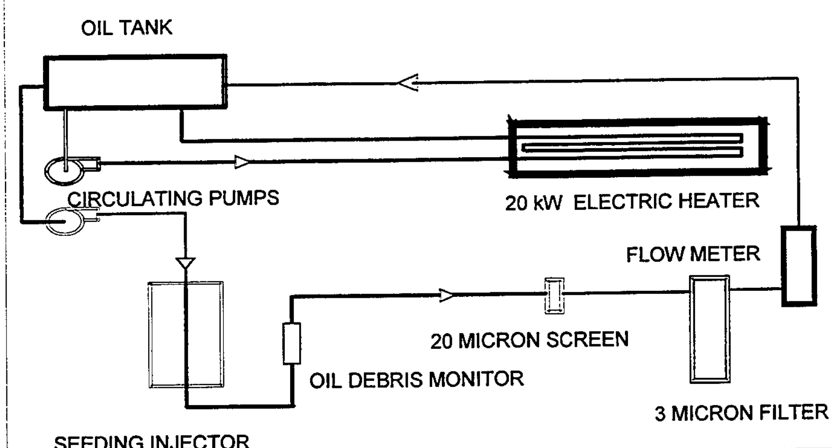
SCHEMATIC OF OF OIL DEBRIS MONITORING TEST RIG



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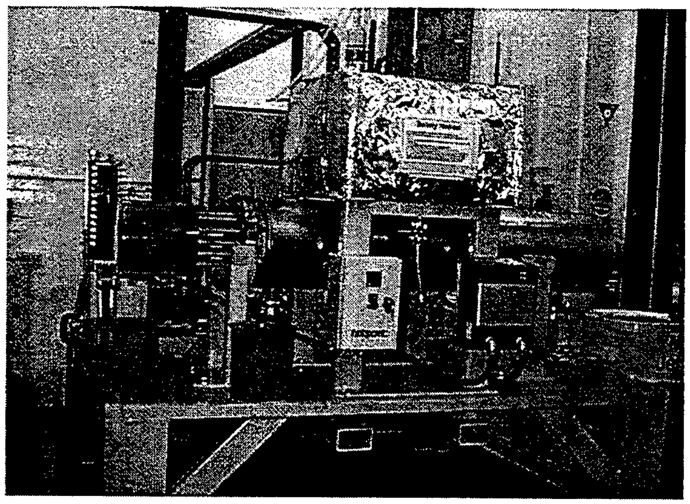

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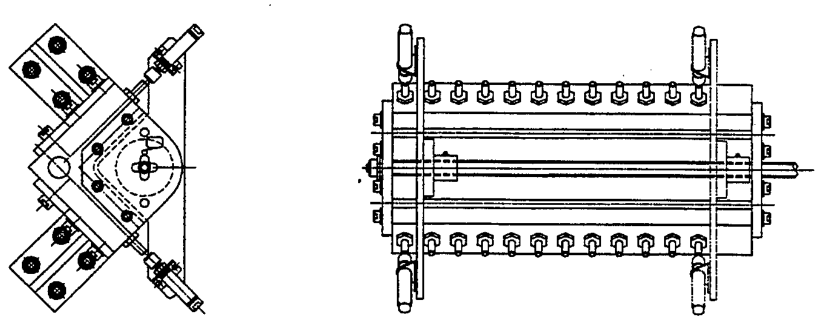

INJECTOR MANIFOLD

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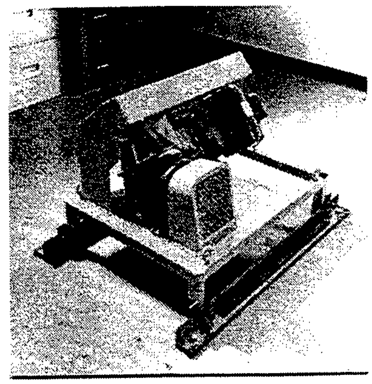
<u>Wet sump gearbox</u>

- Rig capable of duplicating oil churning rates

Cannot duplicate the effect of:

- Power input
- Gearbox running temperatures
- Gearbox vibration



S-70A-9 BLACK HAWK INTERMEDIATE GEARBOX RIG

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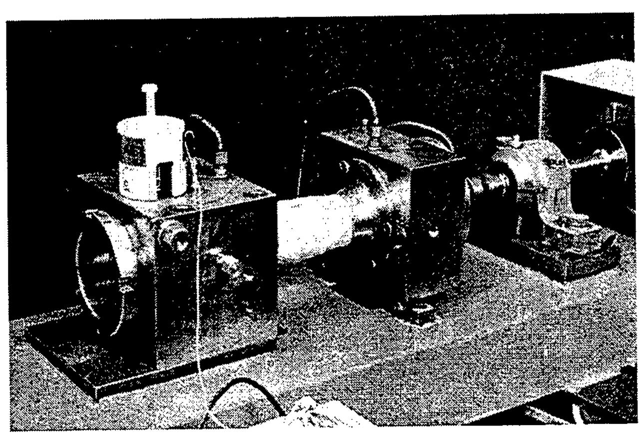
Rig for Generating Bearing Debris Material



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LUBRICATION OIL DEBRIS MONITORING PROGRAM AT AMRL

STATUS

- **Tests on the Black Hawk (S-70A-9) Main Rotor Gearbox sensor and GasTOPS MetalSCAN ready to start within the next fortnight.**

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ANY QUESTIONS ?

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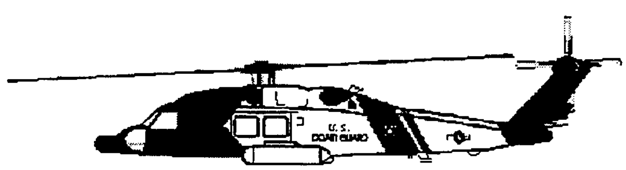
Aerostructures, Inc.

Helicopter Usage Monitoring Using the MaxLife System

DSTO Helicopter HUMS Workshop -- February 1999

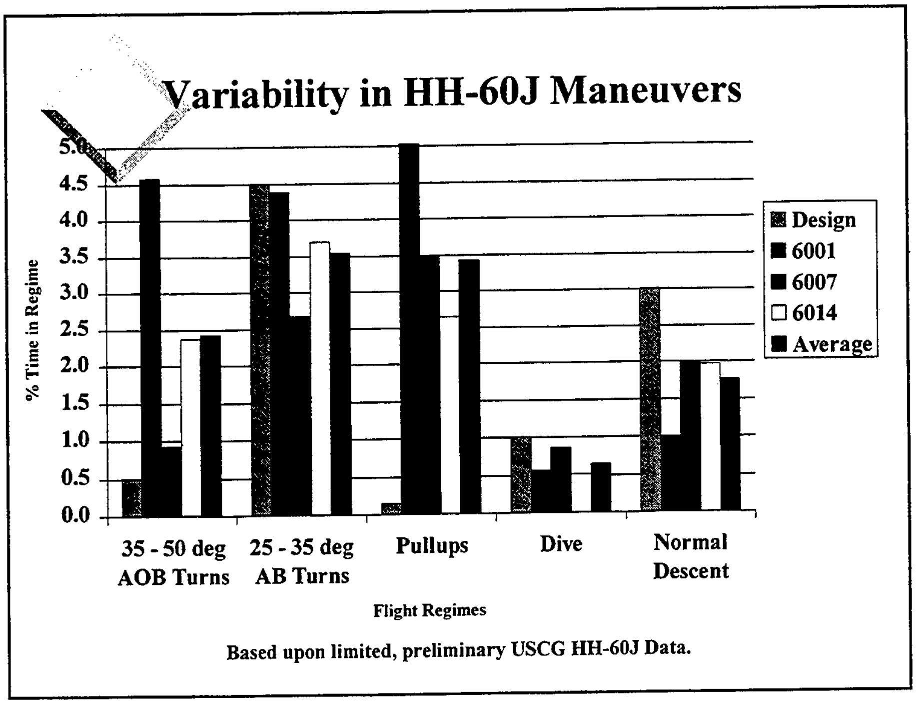
United States Coast Guard HH-60J STRUCTURAL USAGE MONITORING EVALUATION

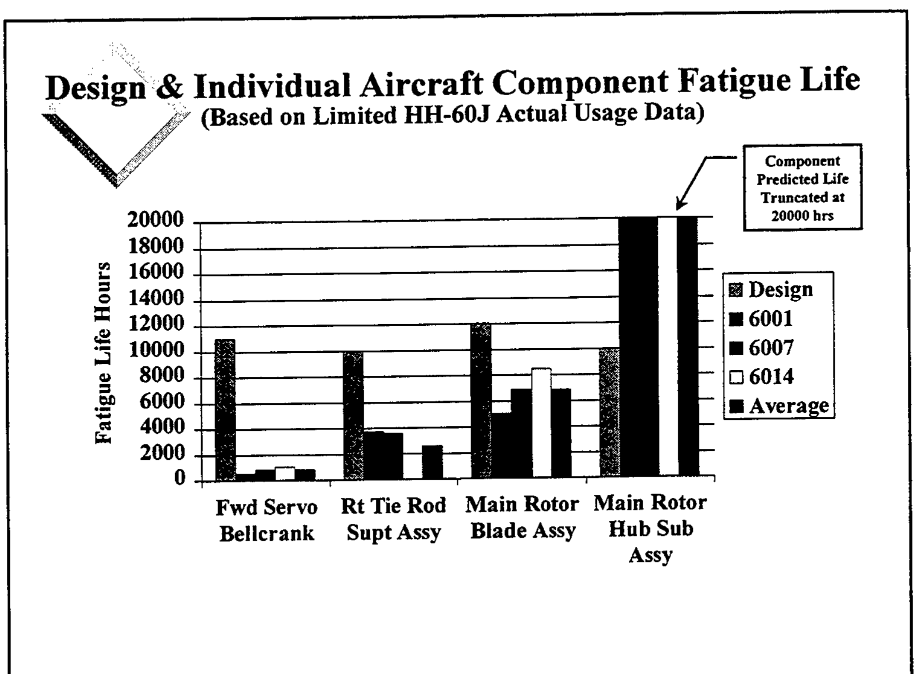


TEAM HAWK MEETING

February 17, 1999

David White (Extra Slides) - 1





David White (Extra Slides) - 2

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Helicopter HUMS Workshop

Engine Gas Path Condition Assessment

by

Dr Peter Frith

Head, Engine Performance
Airframes and Engines Division
Aeronautical & Maritime Research Laboratory
Tel: 61 3 9626 7695
Fax: 61 3 9626 7083
E-mail: Peter.Frith@dsto.defence.gov.au

Melbourne, Australia
February 16-17, 1999

DSTO

OUTLINE

- DSTO gas path condition assessment activities
- HUMS related T700 engine activities
- Power Performance Index (PPI)
- T700 model based power check
- T700 MATLAB-Simulink twin engine model
- Summary

DSTO

Major Gas Path Condition Assessment Projects

- TF30 engines in F111
  - Engine Diagnostic and Acceptance System (EDAS)
    (for engine test cells)
  - Interactive Fault Diagnosis Isolation System (IFDIS)
    (for flight line troubleshooting)
- F404 engines in F/A-18
  - Automated Diagnostic and Acceptance Test System (ADATS)
    (for engine test cells)
- T700 engines in Black Hawk, Seahawk and Seasprite
  - Model-based power check
    (for future HUMS)
  - Model-based diagnostics
    (for future HUMS)

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Main Technical Activities

- Facilitate implementation of automated engine diagnostic, test acceptance and data acquisition systems
- Acquire and classify engine data into fault-signature data-bases
- Develop and validate advanced adaptive component based thermodynamic engine models
- Investigate and develop the use of neural and fuzzy logic techniques to identify fault signatures against the observed measurement and model uncertainty

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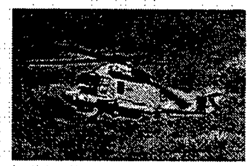
ADF Helicopters with T700 turboshaft engines





Black Hawk Seahawk Seasprite

T700

DSTO

HUMS Related T700 Engine activities.

- On-going assessment of current HIT and power checks
- Assessment of Power Performance Index (PPI) for US Navy HIDS
  (a TTCP AER-TP-7 collaborative activity)
- Development of model-based power check
  (a TTCP AER-TP-7 collaborative activity)
- Development of MATLAB-Simulink twin engine model
- Development of model-based diagnostics

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Assessment of GE Power Performance Index (PPI)

- PPI uses a simple TGT versus TQ reference curve
  - represents minimum acceptable performance

RESULTS

- Restricted to sea- level and low to medium power levels
- Developed new version applicable to 14000 feet
- Established best capture window
  - endurance / range cruise
  - 12 second window

Produces useful end of flight condition indicator

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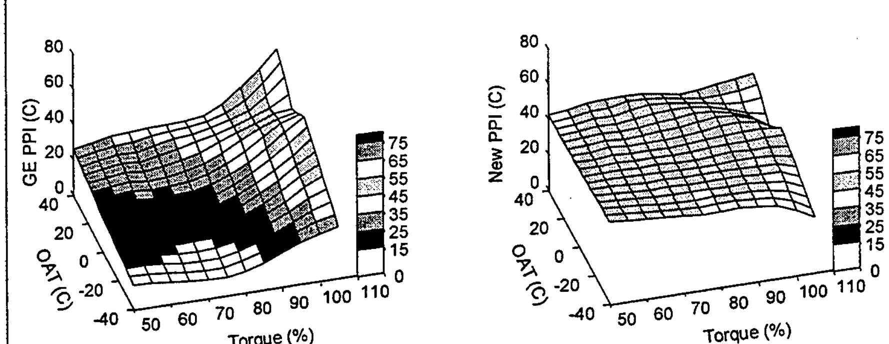
New PPI in HIDS SH-60 HUMS



PPI MARGINS AT 2000 FEET FOR T700-401C CYCLE DATA

Sensitive to OAT correction

Frith - 4

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T700 Model-Based Power Check

Aim: to predict the power available from twin engine helicopter installations when the two engines operate with varying levels of component degradation (i.e. significantly different to specification performance)

Roles: Maintenance - Engine Removal
Operational - Mission Planning

Model : Based on NASA T700 dynamic model (Fortran)

Developed open-loop single engine degradation version

Validated against specification and test data

Results: Good match to specification and US Navy test data across power range

Dual engine power can be generated from steady-state single engine results

Provides Dual Engine Power Check and Mission Planning Capability

DSTO

Single Engine Open-Loop Degradation Model

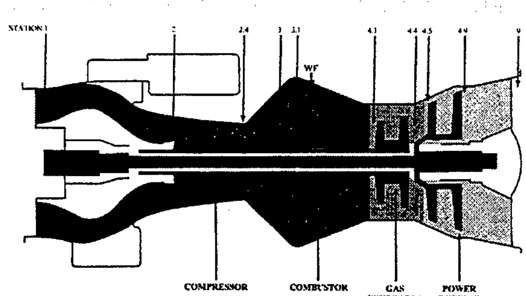
FIDELITY vs SIMPLICITY

COMPONENT EFFECTS:

- Intake
- Scavenge/Anti-ice/Starting Bleeds
- Compressor
- Compressor/Customer Bleeds
- Combustor
- Gas Generator Turbine
- Power Turbine
- Exhaust

TWO PARTS:

- Engine to Engine Variations
- Component Degradation



Fidelity of T700 Degradation model is okay for Power Check

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Data-Bases for Model Validation

OEM Models: GE T700 Specification Models
- -701A, -401, -401C

Operational : AUS Army Manual HIT and Power Checks

TTCP: US Navy HIDS Patuxent Flight Trials
US Navy Trenton Test Cell Data
- -700, -401, -401C
- fleet rejected engines

Overhaul: Pacific Turbine Test Cell Data
- -701A modules and engines
- pre and post maintenance tests

Future: Fault implant test program
- -701A engine available

Benefit from Fault Implant Test Program

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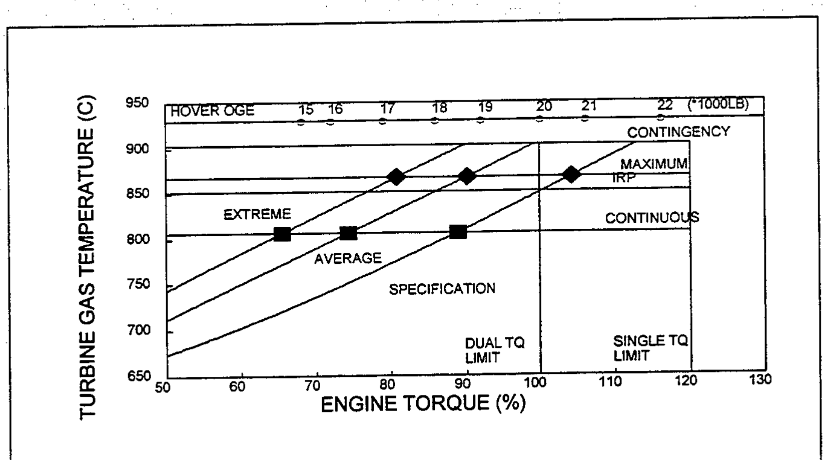
Maximum Power Available - Two Engine
{4000 ft and 35C}



Developing version to be run in Excel

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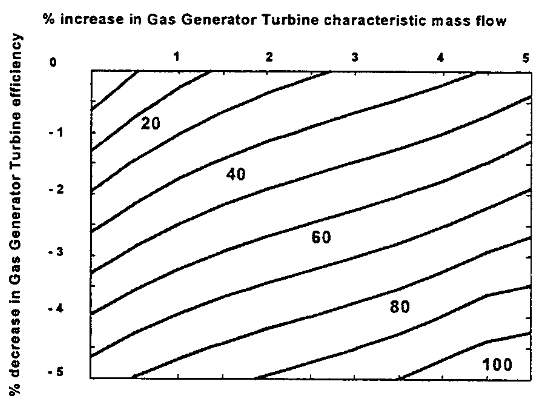
Effect of Varying Gas Generator Turbine Degradation



Increase in TGT (C) values for HIT check at 60% Torque.

Engine Runs Hotter

Use to Relate HIT values to Power Check

DSTO

MATLAB - Simulink Twin Engine Model

Aim: to develop enhanced T700 modelling tool
- true twin engine transient model
- readily interfaced with modern software tools

Simulink: improvement over Fortran model / interactive simulation
visual display of engine model / construct by 'drag-an drop
interface with signal processing, fuzzy logic, real-time workshop toolboxes

New Capabilities: diagnosis from transient flight data
engine related accident investigations
retrofitting FADEC

What next? Validate against HIDS SH-60 flight test data

Okay for what-if studies - further validation for diagnostics

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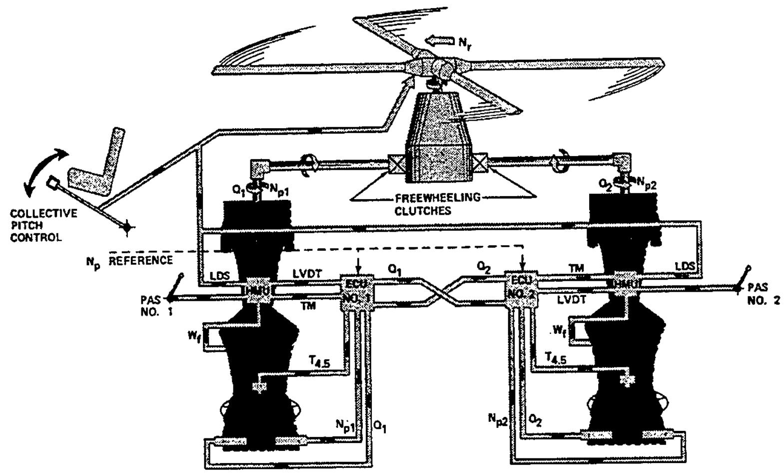
T700 Twin Engine Installation



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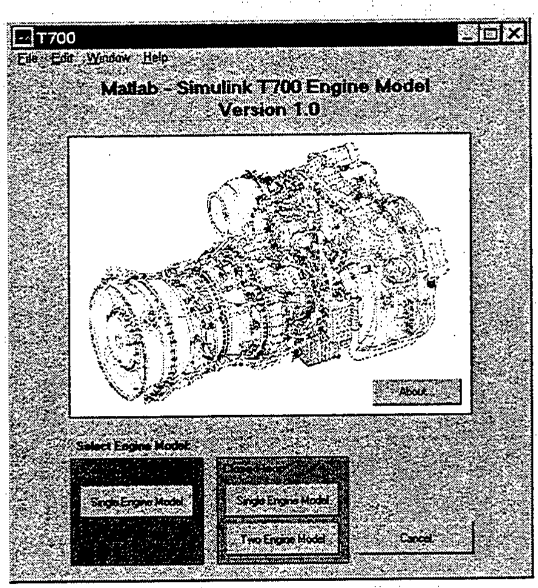
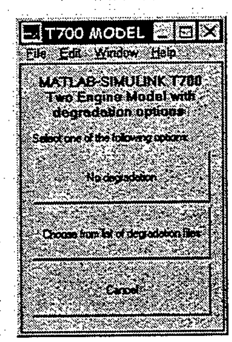


Title Interface



...and Degradation Interface

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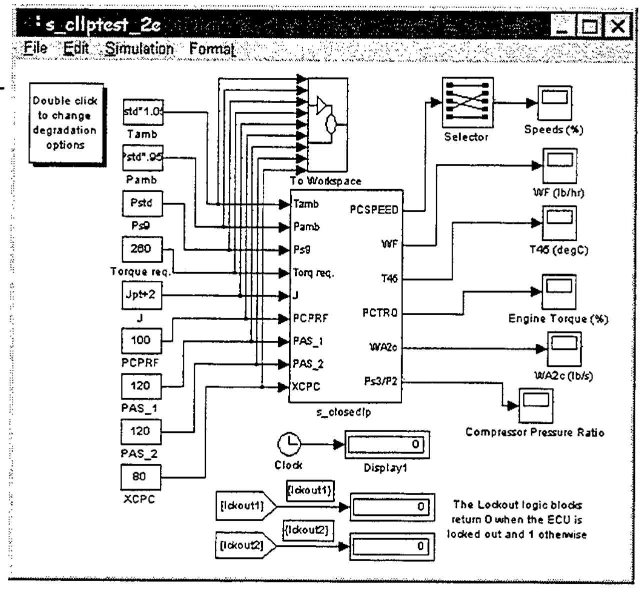
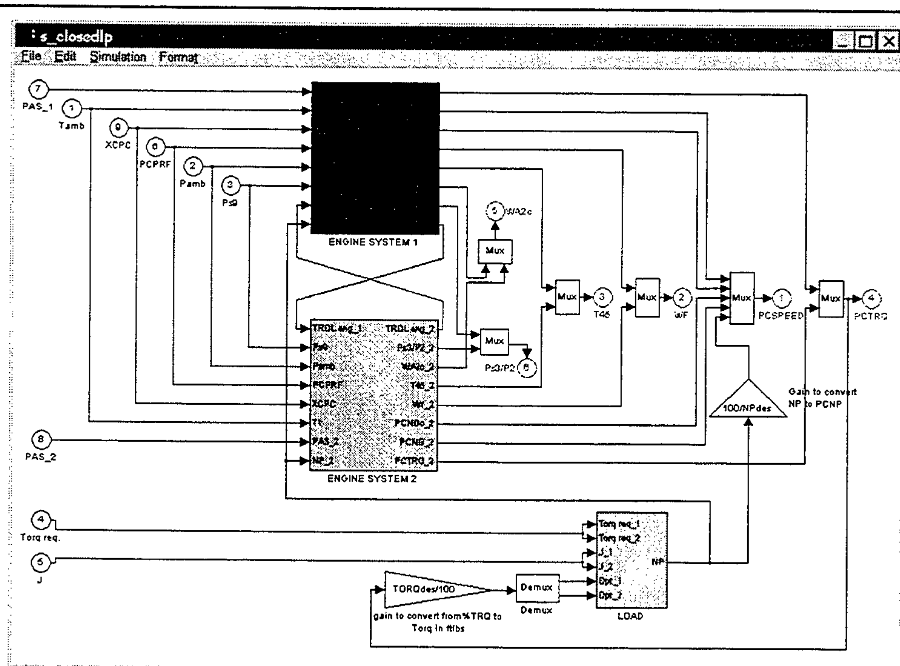
Display of the model





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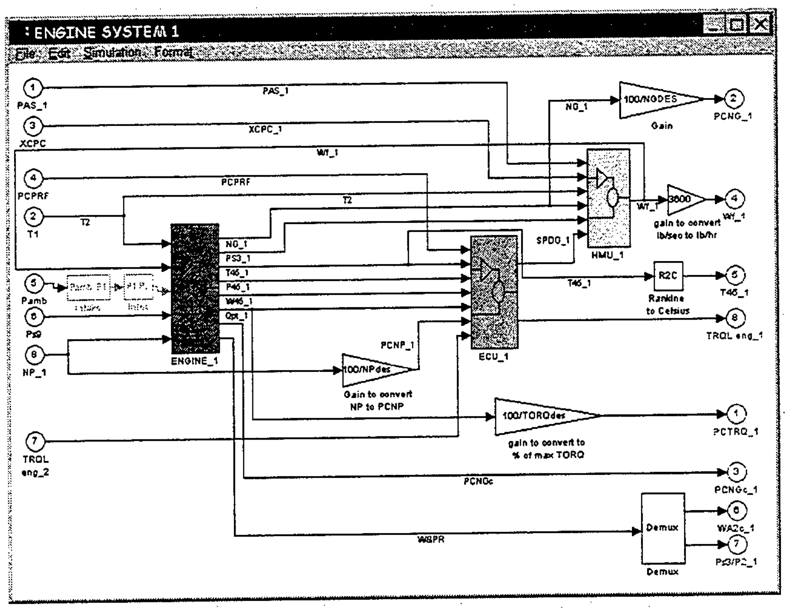

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Cold End Degradation (E2)

Torque (% of max design) vs Time (s)

Torque Demand

Torque (Engine 1)

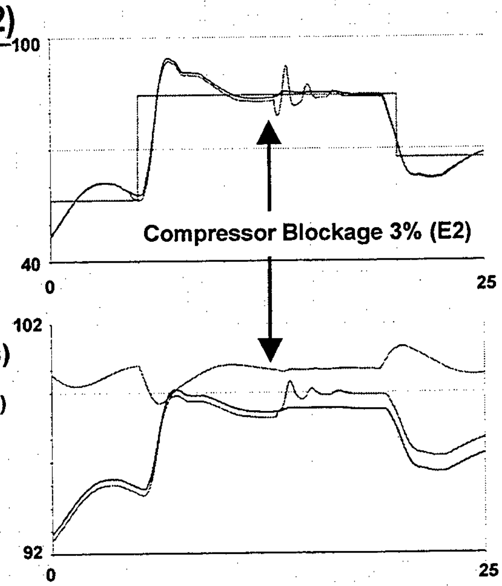
Torque (Engine 2)

Engine Speeds (%) vs Time (s)

Power Turbine Speed (Both Engines)

Gas Generator Speed (Engine 1)

Gas Generator Speed (Engine 2)



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Hot End Degradation (E1)

Torque (% of max design) vs Time (s)

Torque Demand

Torque (Engine 1)

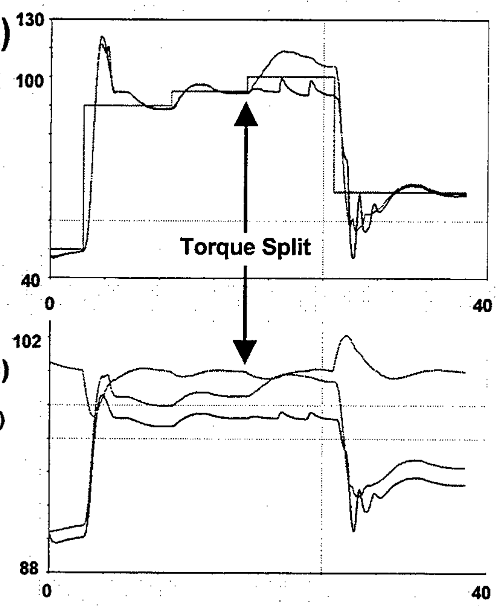
Torque (Engine 2)

Engine Speeds (%) vs Time (s)

Power Turbine Speed (Both Engines)

Gas Generator Speed (Engine 1)

Gas Generator Speed (Engine 2)



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Summary

- Power Performance Indicator provides extended HIT check
  - end of flight condition indicator - trendable
- Power Check requires model-based approach
- Developed T700 component degradation model
  - validated against specification and test data
  - provides dual engine power check / mission planning capability
- Developed enhanced T700 modelling capability - Simulink model
  - true twin engine transient model
- Currently developing a model-based diagnostic capability

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19. ABSTRACT

Over the last 10 years, helicopter Health and Usage Monitoring Systems (HUMS) have moved from the research environment to being viable systems for fitment to civil and military helicopters. In the civil environment, the situation has reached the point where it has become a mandatory requirement for some classes of helicopters to have HUMS fitted. Military operators have lagged their civil counterparts in implementing HUMS, but that situation appears set to change with a rapid increase expected in their use in military helicopters.

A DSTO-sponsored Workshop was held in Melbourne, Australia, in February 1999 to discuss the current status of helicopter HUMS and any issues of direct relevance to military helicopter operations. This second part contains a list of those attending and a number of papers not received in time for publication before the event.