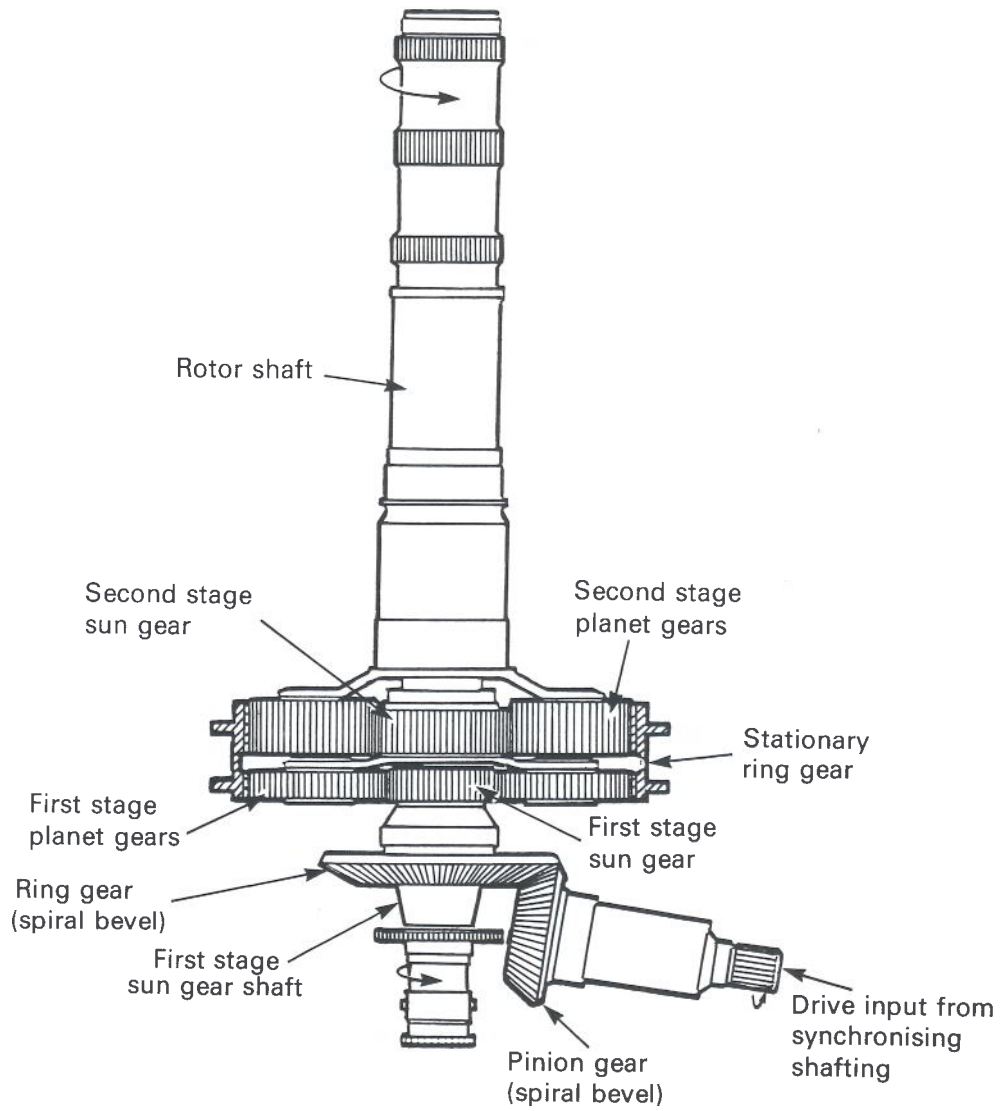
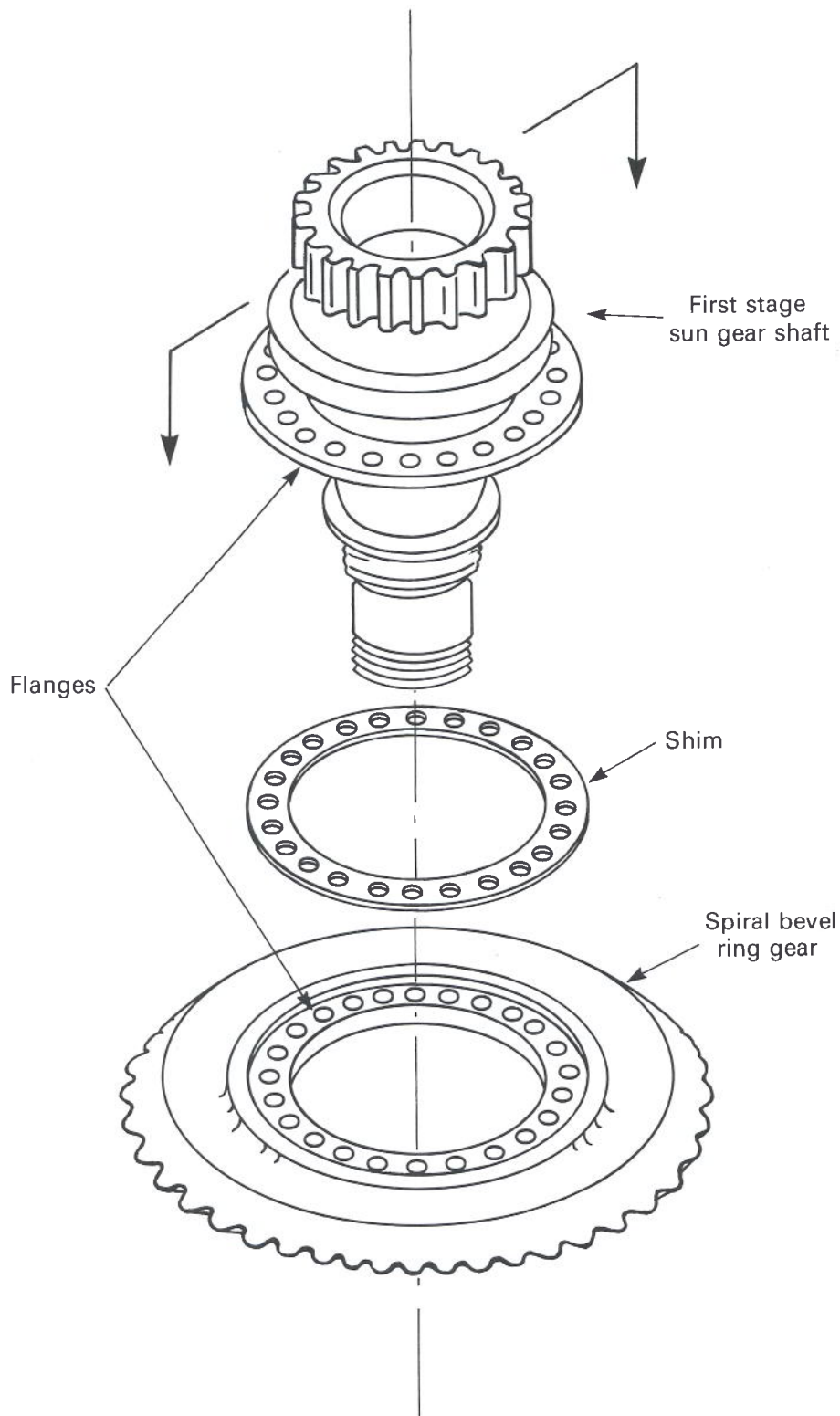


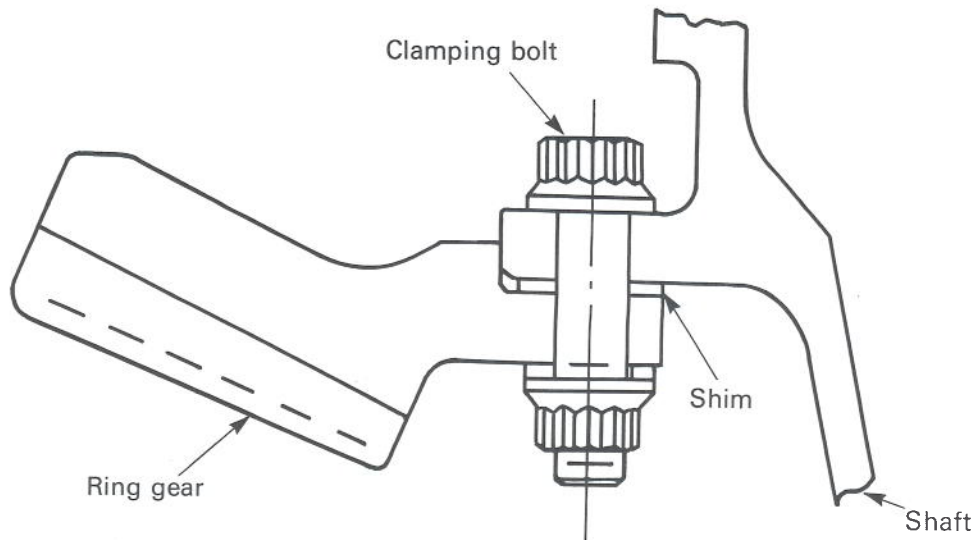
BV234 Main Drive System Component Layout



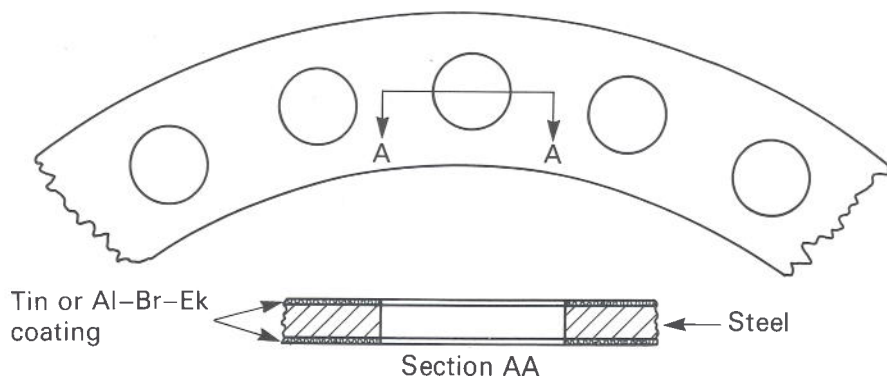
BV234 Forward Transmission Gear Train



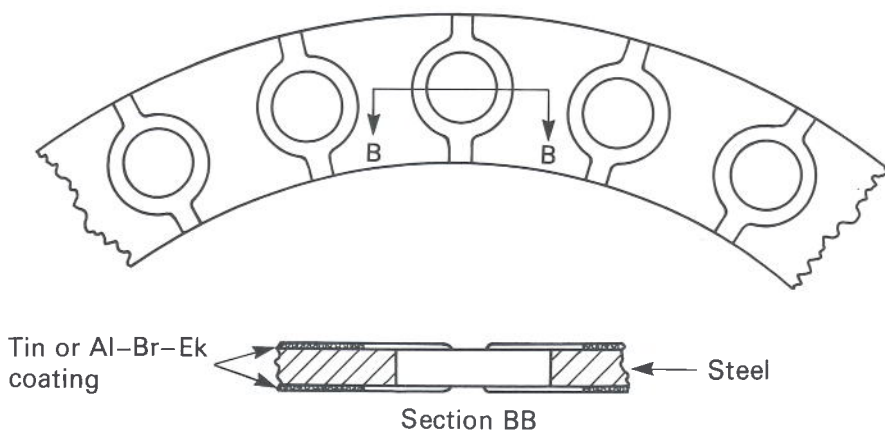
Exploded Diagram of Assembly of Spiral Bevel Ring Gear onto First Stage Sun Gear Shaft (24 Clamping bolts not shown)



Cross Section Through Joint of Ring Gear to Sun Gear Shaft



Solid Shim (as used with -6 Standard Ring Gear)



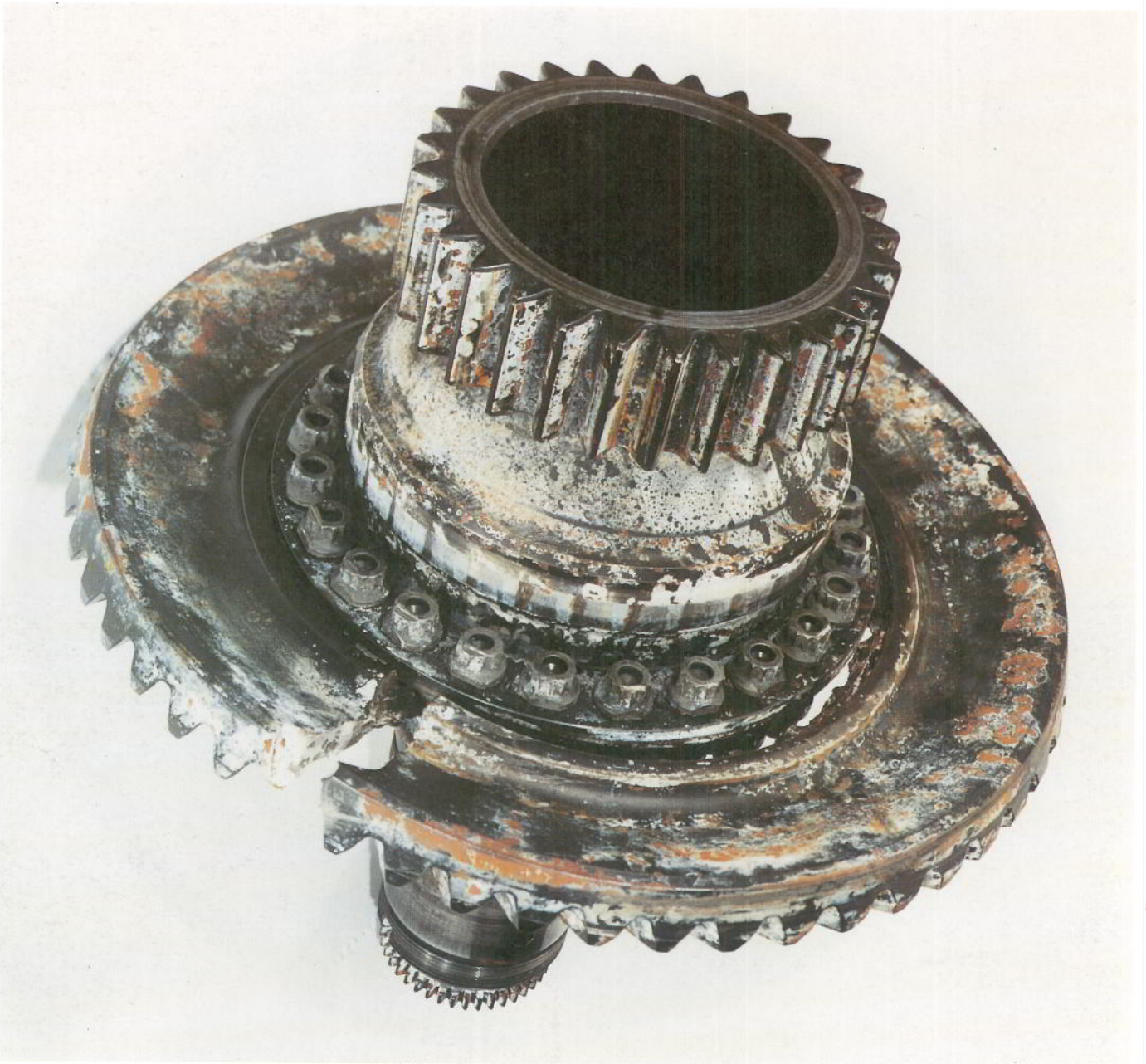
Scalloped Shim (as used with -5 Standard Ring Gear)

Views of Segments of types of Shim fitted between the Flanges of the Sun Gear Shaft and the Spiral Bevel Ring Gear



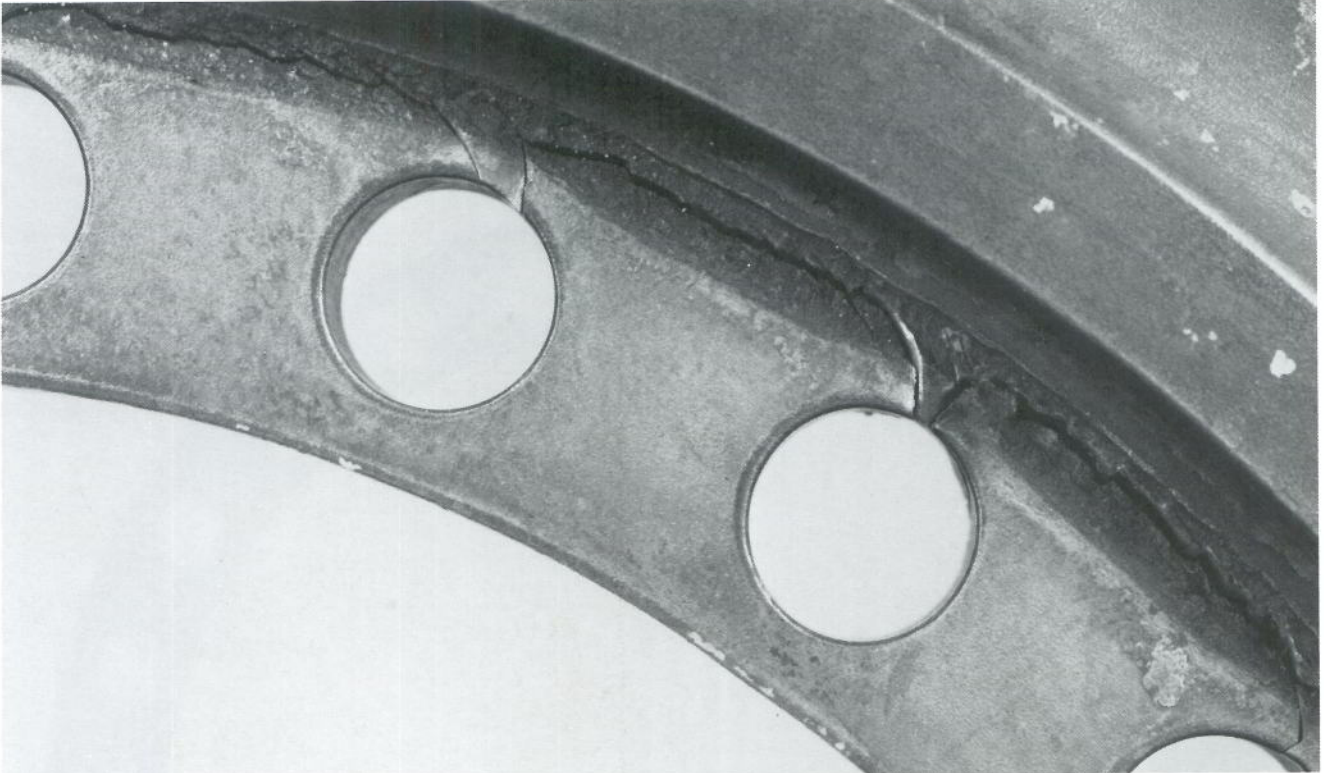
(Photograph taken after removal from transmission for clarity)

View of Spiral Ring Gear on Sun Gear Shaft as first seen



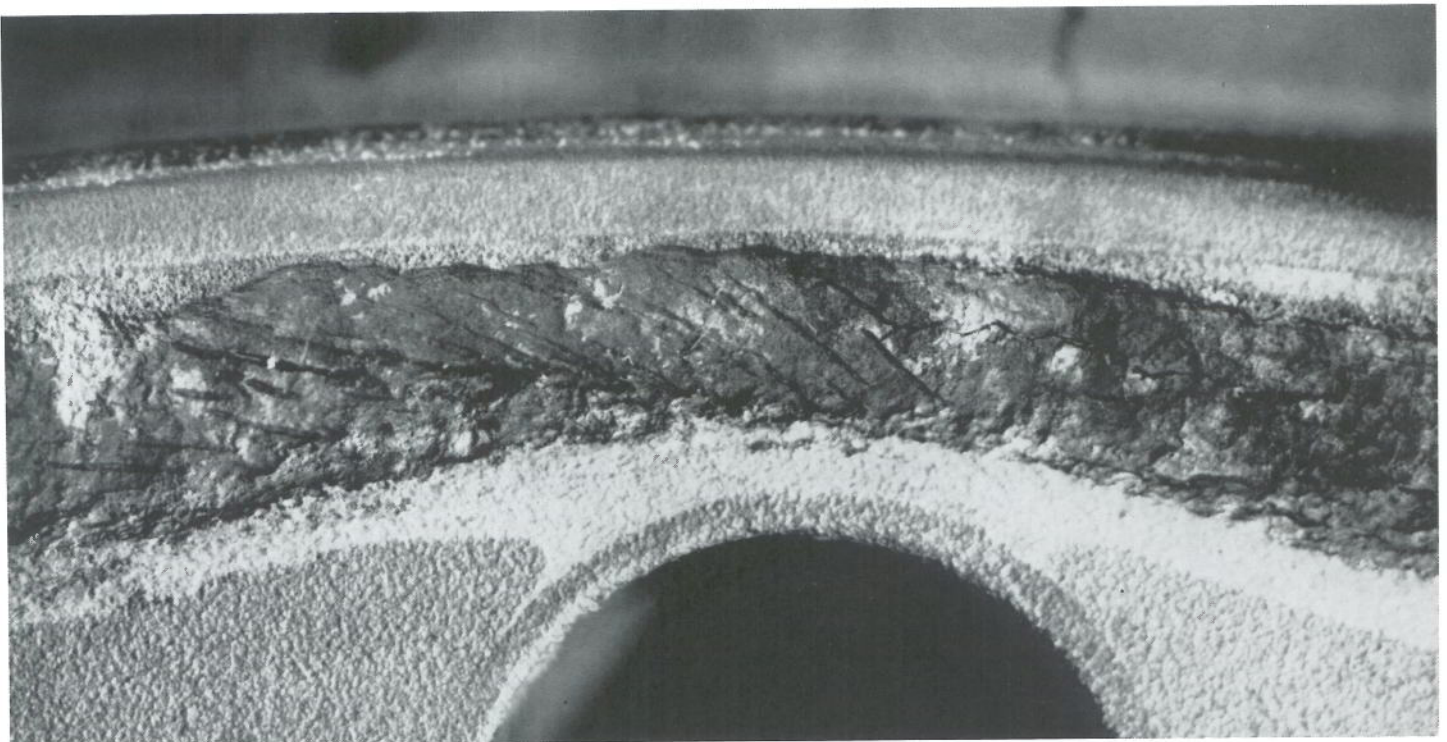
Note:- a) Radial severance of gear rim at lower left.
b) Gap between rim and shaft flange at lower right.

Spiral Bevel Ring Gear on Shaft before disassembly



(1) Sector of the mating face of the attachment flange of the accident gear showing the groove in the flange face and the main circumferential crack.

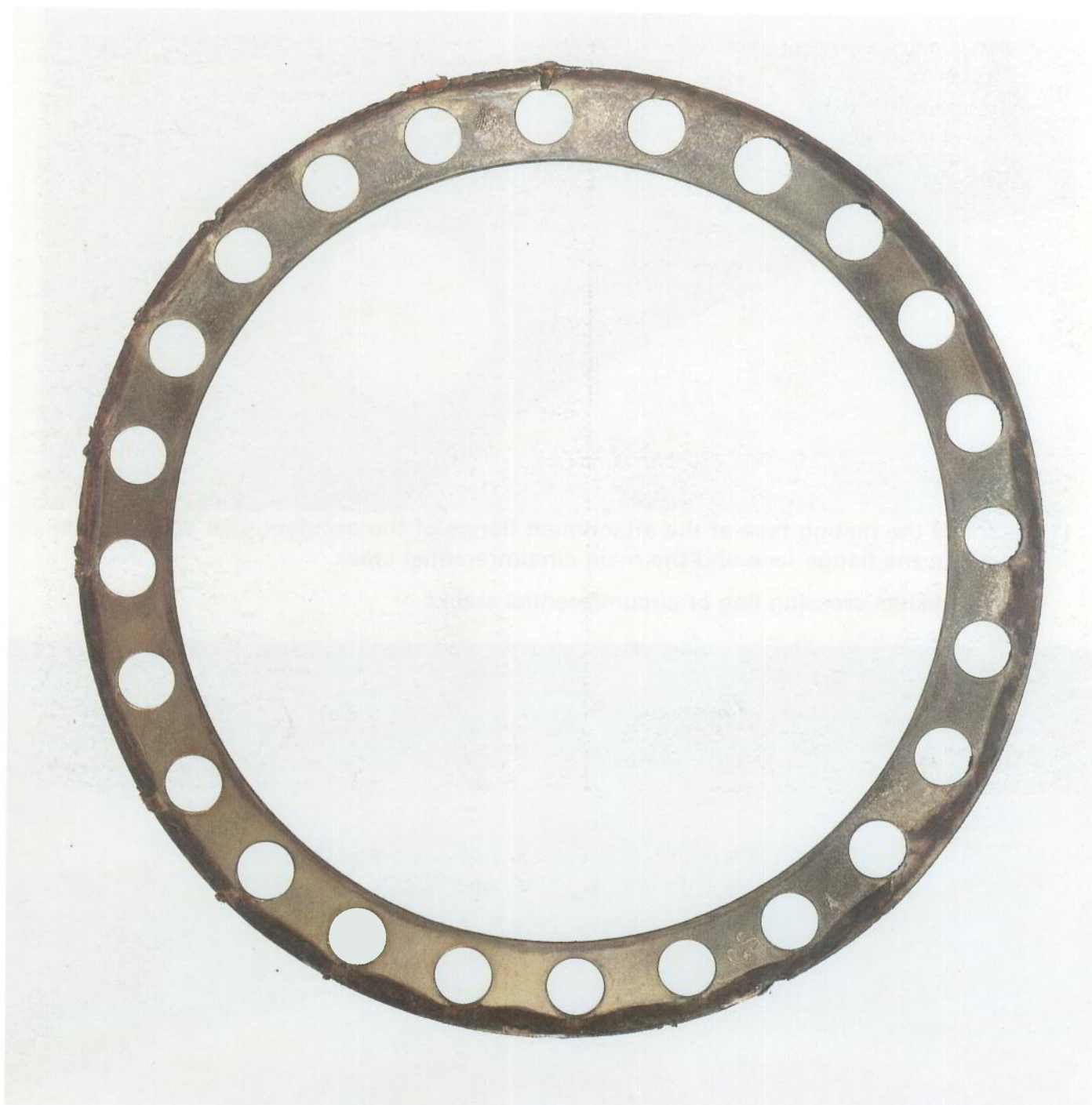
Note cracklets crossing line of circumferential cracks



(2) Sector of the mating face of the flange of another forward transmission ring gear, showing similar groove formation.

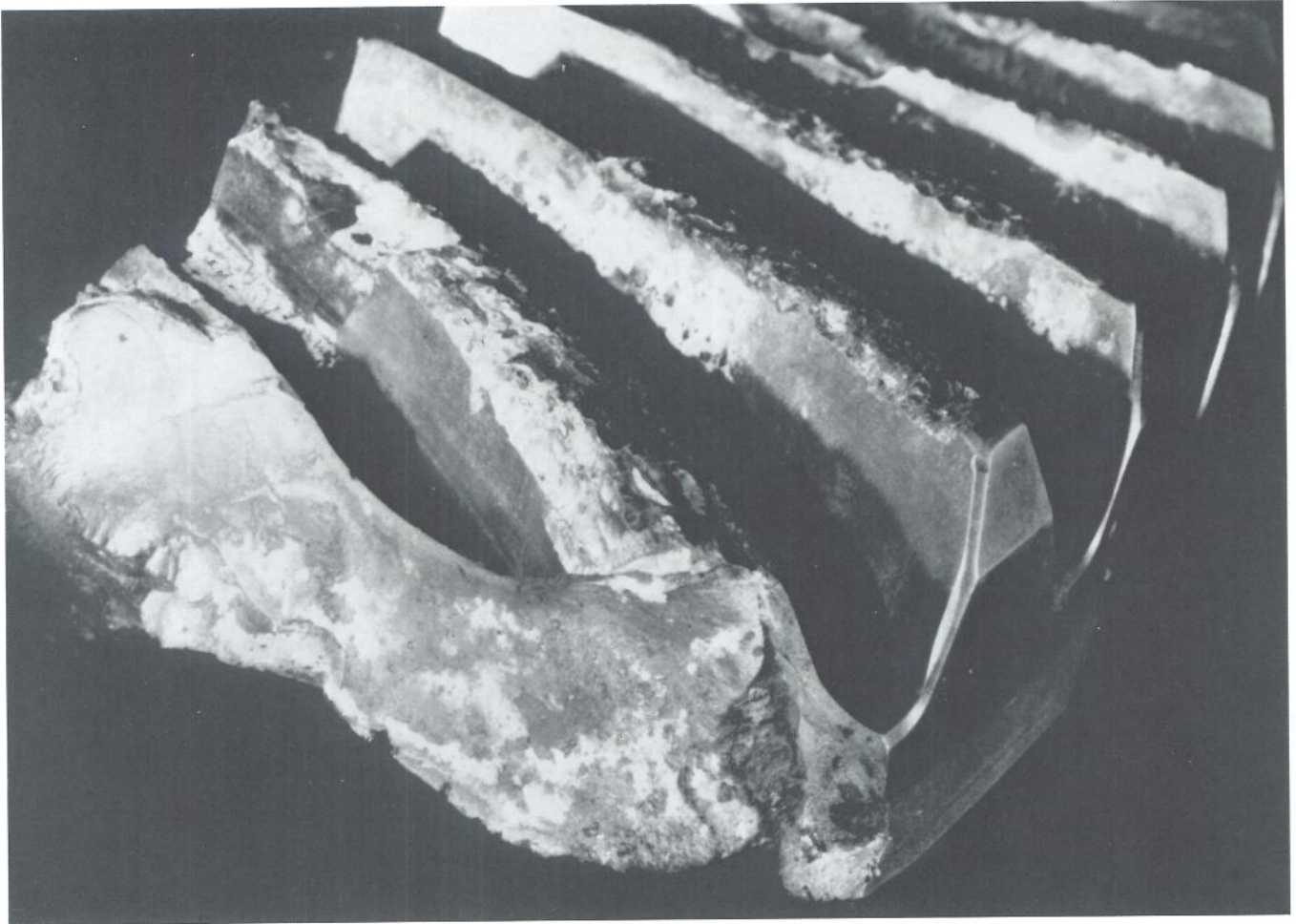
This figure shows more clearly the characteristic angular change in the orientation of the cracklets in the groove between and passing attachment bolt holes.

Crack Formation within Grooves on Gear Flange



View of shim showing face which was in contact with the gear flange.
Dark anulus near outer rim shows area in which sticky deposit was formed

Shim

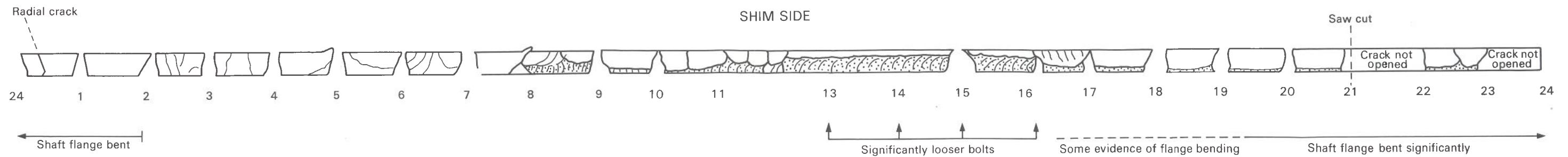


Note more severe damage to crown of first gear tooth after fracture compared to that on subsequent teeth.

Radial Fracture of Gear Rim

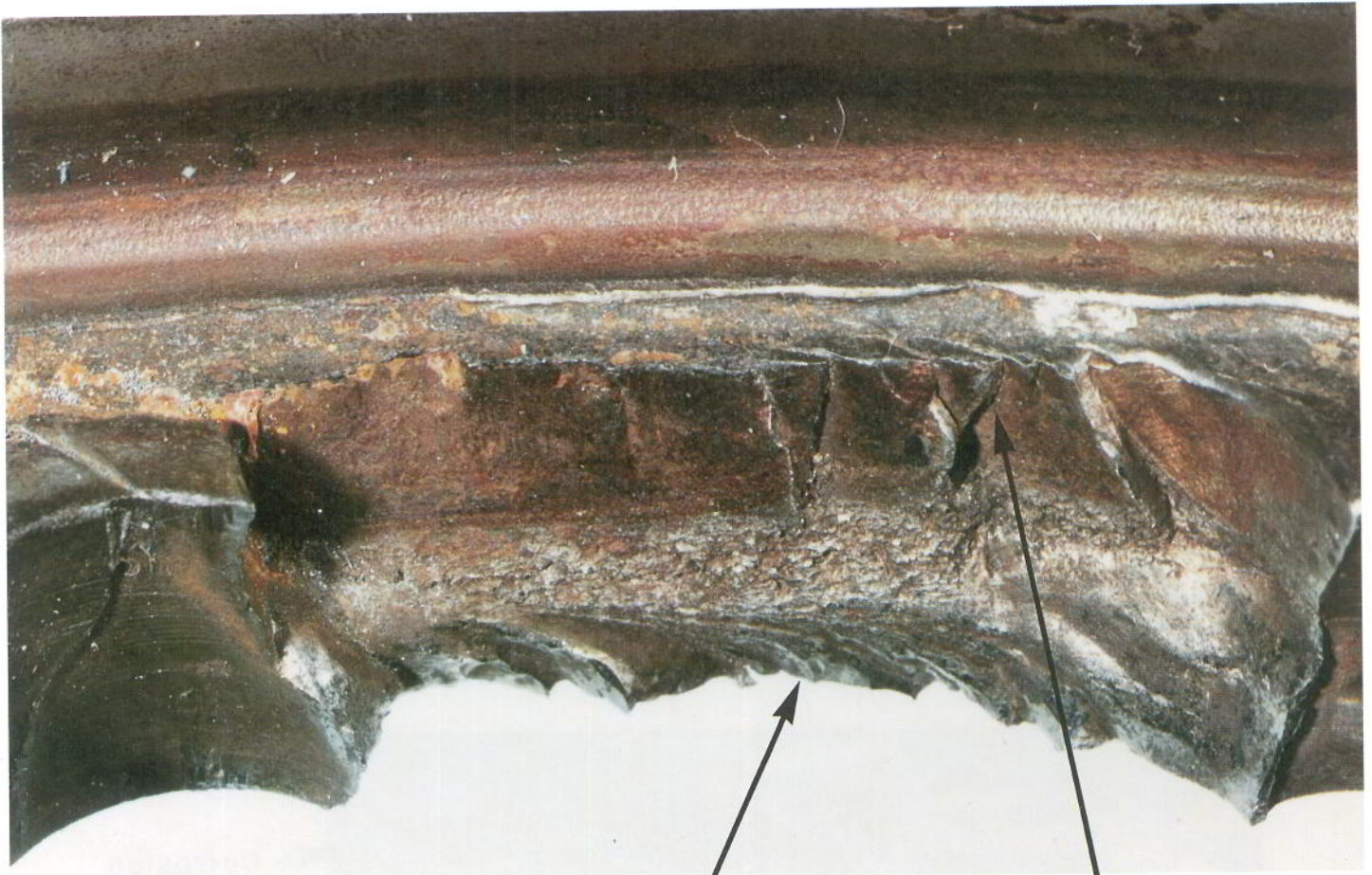
All fracture surfaces shown are stable fatigue crack growth except area's shaded:-

- Fast fracture during opening of cracks at RAE
- Fast tearing during final break-up of the transmission



Features of circumferential crack

Peripheral View of the Crack Faces in the Flange looking inwards towards Shaft Centre



Area of fast cyclic tearing.

Area of fatigue with cracklets crossing main fracture.

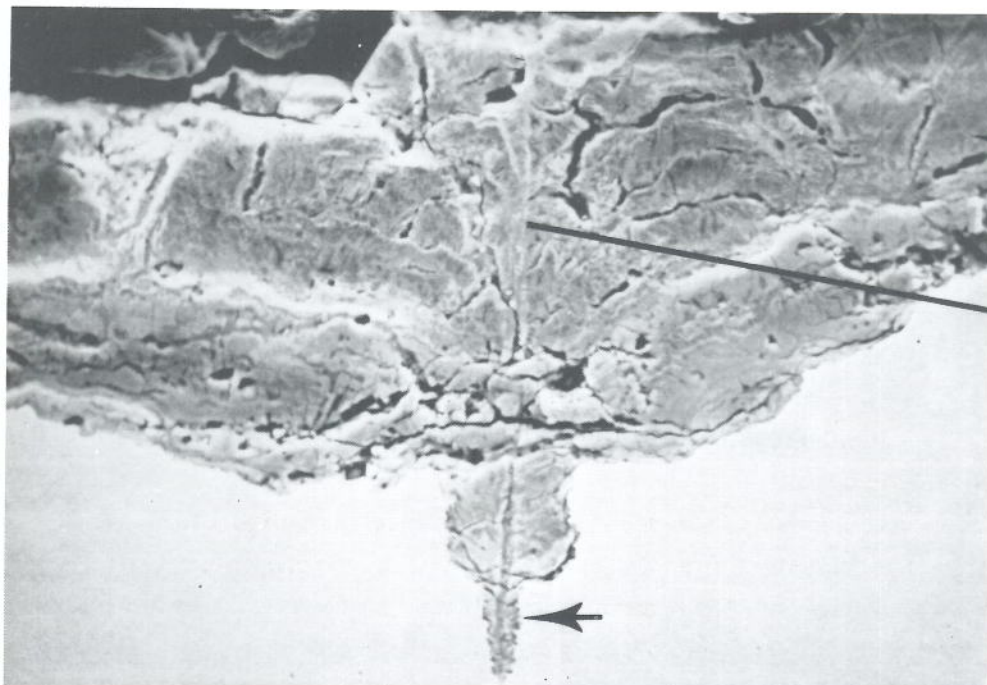
Portion of Circumferential Fracture Face between Holes 9 and 10



Corrosion product

a

X 200



Corrosion product

Ghost mark

b

X 300

Sections through gear flange showing growth of fatigue cracks from the bottom of 'V'-notches and 'ghost' cracks in the corrosion product in the base of the groove.

Micro sections of Gear Flange

Extract from CAP 491. Review of helicopter airworthiness

"Condition Monitoring

Condition or Health Monitoring is not a new technique. It has been practised for many years for jet engine maintenance, where "on condition" overhaul has replaced engine removal after specified periods time between overhauls (T.B.O). Indeed a Report on Condition Monitoring of machines, published by the Department of Industry in 1979, outlined the significance of the procedure to general industry, which had been under consideration by a Dol committee since 1970.

As this report states "Condition monitoring is concerned with extracting information from machines to indicate their condition, and to enable them to be operated and maintained with safety and economy".

Practice in the engine field however allows for a mixture of pilot-displayed monitors (warning lights indicating excess magnetic debris from metallic particles generated improperly from gears or bearings/ unusual vibration "noises") and ground detected abnormalities (unusual metallic particles in oil samples, or visual examination of internal condition by "Borosscopes"). All this is predicated by a philosophy which accepts that engine failure will not be catastrophic (as the remaining engines, if one fails in flight will enable flight to continue), but that the total system cost will increase if an engine is removed for overhaul before it is necessary.

What the Panel would wish to propose is a philosophy based on the argument that where full redundancy is not possible in the design of helicopters warning of likely failure (at some reasonable period ahead in time, maybe only an hour or two) could provide the equivalent overall safety level.

Because we viewed this possibility as important we sought the help of Rolls Royce who are already skilled in these matters, and they kindly made available to us a senior engineer, Mr C Elliott, whose report on Condition Monitoring was considered in detail by the Committee and is available to those concerned with developments in this area. We are grateful for this assistance.

In general terms we wish to see the potential techniques of Condition Monitoring exploited more fully. We are well aware that a monitoring system which is not reliable may be worse than no system, since spurious warnings will lead to warnings being ignored. But we believe that the long term potential of the modern reliable micro-

electronics and the parallel development of micro-transducers will lead to devices whose reliability and performance can bring great benefit.

We make the following brief comments on the various known systems:

(a) chip detectors: some helicopters already have warning lights on their central warning (annunciator) panels illuminated by excessive chip collections on magnetic plugs in gearboxes. The information is qualitative and plugs are often removed for examination for quantitative assessment of debris. Proper location of plugs requires demonstration during development. Newer developments allow for some degree of discrimination on particle size, as between small and large debris.

(b) vibration monitoring, the principles of which are well established is at a very early stage but offers much hope for the future. We would hope to see airborne equipment with computerised analysis to simplify the display of information to the crew.

(c) thermal detection or imaging in flight might be useful. It is already in use during testing.

(d) oil sampling by spectrographic or similar methods to detect metallic particles is regularly used by maintenance crews on the ground. Samples have to be sent to laboratories for analyses. We see no reason why special portable equipment to detect a limited number of materials (perhaps only iron) should not be developed for airline use. It is not inconceivable that continuous airborne sampling may be evolved.

(e) telemetry (of information between aircraft and a ground station) is already being used by airlines. It may have potential on helicopters to remove some responsibility for monitoring critical elements from the pilot to a ground specialist.

(f) a new development is a "Usage Monitor" to be carried in the helicopter and to monitor, via an airborne computer, actual engine, rotor and transmission parameters, enabling assumed use to be compared with reality. This must represent a major step forward.

We wish to see research and development in these areas encouraged; it is a fruitful field for engineering ingenuity and research workers in universities and industry, and while equally applicable in the military and civil helicopter field, has applications throughout general industry.

Thus we make the following recommendations:

RECOMMENDATION 11 The CAA should set up a working party between experts in the Airworthiness Division, Ministry of Defence and selected specialists from universities and industry to draw up proposals or requirements for parameters to be measured and for new or improved condition monitoring devices or systems, to be widely publicised.

RECOMMENDATION 12 The CAA should draw the attention of the Science and Engineering Research Council to the benefits to be obtained by industry as a whole from supporting work in condition monitoring.

RECOMMENDATION 13 The CAA should draw the attention of a Learned Society (for example the Royal Aeronautical Society) to the need to stimulate developments in condition monitoring by the promotion of discussion or conferences."

List of abbreviations used in this report

AAIB	Air Accidents Investigation Branch
ADELTA	Automatically Deployable Emergency Location Transmitter
ARB	Airworthiness Requirements Board
Al-Br-Ek	Aluminium Bronze Ekonal
CAA	Civil Aviation Authority
CVR	Cockpit Voice Recorder
FAA	Federal Aviation Administration
HARP	Helicopter Airworthiness Review Panel
SAR	Search and Rescue
SB	Service Bulletin
SOAP	Spectrographic Oil Analysis Programme

Application for Review

In conducting this investigation the provisions of Regulation 11(1) of the Civil Aviation (Investigation of Accidents) Regulations 1983, were complied with and representations made by Boeing Helicopter Company were considered before the report was completed.

Following the submission of the report to the Secretary of State in January 1988, Boeing Helicopter Company asked that the findings should be reviewed by a Review Board.

In accordance with the Regulations, the Lord President of the Court of Session in Scotland appointed a Review Board under Sheriff P G B McNeill QC, assisted by Professor P Hancock and Mr K V Kellaway (Assessors).

CIVIL AVIATION (INVESTIGATION OF ACCIDENTS) REGULATIONS 1983

REVIEW OF REPORT ON THE ACCIDENT TO BOEING BV 234 LR CHINOOK HELICOPTER,
G-BWFC, 2.5 NAUTICAL MILES EAST OF SUMBURGH AIRPORT, SHETLAND, SCOTLAND ON
6 NOVEMBER 1986

R E P O R T

before

Sheriff P G B McNeill QC (Chairman)

and

Professor P Hancock

and

Mr K V Kellaway

(Assessors)

APPEARANCES

Mr T Dawson, QC (Instructed by the Crown Agent)
appeared as Counsel on behalf of
the Review Board

Mr N Morrison, QC (Instructed by Solicitor to the Secretary of
State) appeared for D F King, Esq, Principal
Inspector of Accidents, and Air Accidents
Investigation Branch

Mr M S Jones, Advocate (Instructed by Simpson & Marwick WS) for
Boeing Helicopter Company

Mr J A Cameron, QC (Instructed by McGrigor Donald, Solicitors,
Glasgow) for British International Helicopters

Mr R Webb, QC (Instructed by W J Burness WS)
of English Bar, and after for British Airways PLC
14 August 1988 Mr B Logan,
Solicitor

Mr P Martin, Solicitor, (Instructed by Frere Cholmeley, Solicitors,
London, at preliminary London) for Coltax Aerospace Limited
hearing only

Mr D A Y Menzies, Advocate (Instructed by Tods Murray, WS) for Civil
Aviation Authority

Mr C N McEachran, QC (Instructed by Balfour & Manson, Solicitors)
for Chinook Disaster Legal Group consisting of
Captain P Vaid, Mr E Morrans and the personal
representatives of 41 passengers

D Stevenson, Solicitor (Instructed by Robin Thompson & Partners) for
the personal representatives of Donald
Richardson and others

Mr J Watson, Clerk

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List of Documents

Note by Air Accidents Investigation Branch

Front Sheet relating to productions 3/4

Service Bulletin 234-63-1014

Service Bulletin 234-63-1015

Report by Material and Structures Department, Royal Aircraft Establishment, Farnborough

Front Sheet relating to productions 7/16

Copy Process/Operation Card

Copy Worksheets and documentation in respect of gear reworking and shotpeening

Copy Worksheets

Copy Extract from Service Bulletin 234-63-1014

Copy Design Authorisation dated 19 January 1984 and relative papers

Letter dated 8 April 1987 and enclosures

Letter dated 8 December 1987

Letter

Copy Presto Black BST4 literature and Material Safety Data Sheets

Copy Instant 44/40 Gun Blue literature and Material Safety Data Sheets

Front Sheet relating to productions 18/28

Copy Inspection Reports dated 22 January 1986 and 17 February 1986

Inspection Report dated 22 January 1986

Worksheets M3501

Copy Certificate dated 16 January 1986

Copy Certificate dated 7 January 1986

Test Sheet dated 13 February 1986

Certificate dated 13 February 1986

Worksheets M3601

Copy Preliminary Defect Report dated 7 January 1986

Bolt Torque Diagram

Copy Forward Transmission Component History Printout

Extracts from Maintenance Manual

Front Sheet relating to productions 30/36

Extracts from Maintenance Manual

SOAP Guidance Sheets and Fuzz Buster Plug Wipe Programme Sheet

Copy SOAP result sheets

Copy SOAP/Wipe Report and Action Sheets

Copy Graphical Plots of SOAP results

Letter dated 26 January 1987 and copy Oil Uplift Record

Copy Page from Maintenance Manual

Book of photographs marked A, B, C1, C2, D, E, G, H1 and H2

Table of bolt torque comparisons

Diagram of decay of bolt torques

Table of bolt torque comparisons

Graph of Contaminant Levels in SOAP

Chart of Raw Rate of Change of Contaminant Levels in SOAP samples (averaged from one sample point to the next)

Chart of Rate of Change of Contaminant Levels in SOAP samples (averaged from one sample point to the next but one)

Chart of Rate of Change of Contaminant Levels in SOAP samples (averaged from one sample point to the mean of the next two)

Graph of Contaminant Levels in SOAP samples (plot of what would have been recorded with sampling points nearest to 35 hour intervals)

Chart of Raw Rate of change of Contaminant Levels in SOAP samples (averaged from one sample point to the next taking samples nearest 35 hour intervals)

Graph of Contaminant Levels in SOAP samples (Plot obtained by interpolation of data points to estimate levels at 35 hour intervals)

Chart of Raw Rate of Change of Contaminant Levels in SOAP samples (averaged from one sample point to the next using interpolated 35 hour interval Levels)

Chart of Rate of Change of Contaminant Levels in SOAP samples (averages over two sample points of interpolated 35 hour samples)

Chart of Raw Rate of Change of Contaminant Levels in SOAP samples (averages over three sample points of interpolated 35 hour samples)

Two sheets of Torque Levels (measured during removal of bolts in attachment flange of forward spiral bevel gear M5197)

Table of failed bevel gear wheel bolt torques

Graph of calibration of torque wrench

Graph of measured groove depths in service and test wheels

Chart of experimental rates of wear in wet and dry atmospheres

Diagram of fatigue curves for 0.7C steel

Diagram: forward transmission sun gear shaft

Analyses of gear M5019 flange and of groove therein

Analyses of crashed gear flange and of groove therein

File of SOAP records - G-BWFC

File of SOAP records - G-BISN

File of SOAP records - G-BISR

File of SOAP records - G-BISP

Inspection Report dated 8 April 1986

Worksheets - transmission A7-1581

Delivery Note

Certificate of Conformity dated 4 April 1986

9 debris record cards

SOAP/WIPE reports and relative documents

Book of photographs marked F3, F15, F28, F30, F32, F33, F34, F39, F40, F41 and F42

Book of photographs marked F10, F12, F17, F18, F19, F22, F43, F44, F45 and F51

Book of photographs marked A, B and C

Book of photographs marked A, B and C

Figure 6 - Diagram: Forward Transmission Bolted Joint

Figure 24 - Diagram: Forward Sun Gear Shaft

Figure 46 - Corroded Region Adjacent to polished area A, on gear M5019

Figure 47 - Analysis of polished area A, adjacent to hole 24 in gear M5019

Figure 49 - Analysis of debris removed from shim surface

Table of bolt torque comparisons

Figure 16 - Peripheral view of the crack faces in the flange looking inwards

Documentation in respect of transmission A7-1625, first visit to workshop April 1986

Documentation in respect of transmission A7-1625, second visit to workshop April 1986

Documentation in respect of transmission A7-1625, visit to workshop May-June 1986

Documentation in respect of transmission A7-1625, visit to workshop November 1986

Service Bulletin 234-63-1010 - 20 August 1984 (Revision 2 26 September 1985)

Service Bulletin 234-63-1014 - 1 August 1985

Alert Notice Change to SB 234-63-1010 - 20/8/84 (Revision 2 26/9/85)

Service Bulletin 234-63-1015 - 1 August 1985

Service Bulletin 234-63-1016 - 1 August 1985

Service Bulletin 234-63-1022 - 6 May 1986

Maintenance Manual Part 1 page 14 - 04-05-01 18 September 1986

Maintenance Manual Part 1 page 15 - 04-05-01 18 September 1986

Letter Boeing Vertol to FAA January 24, 1985 (3 pages)

FAA Compliance Certificate, January 4, 1985

Engineering Test Lab Report - 12/10/84 (3 pages)

Engineering Materials Laboratory Report - January 17, 1985 (3 pages)

Photocopy Shim 150 hour coating test (EMLR84-180E)

EMLR84-180B photographs of components with comments

EMLR84-180B photographs of components with comments
EMLR84-180B photographs of components with comments
Aft Transmission 150 hour bench test results
Telex Boeing Vertol to BAH and others (9 pages)
Diagram - rework of forward transmission first stage sun gear SB234-63-1014
Diagram - rework of forward transmission spiral bevel ring gear SB234-63-1014
Telex Boeing Vertol to BAH and others - aft transmission (9 pages)
Diagram - rework of aft transmission sun gear SB234-63-1015
Drawing - rework of aft transmission spiral bevel ring gear SB234-63-1015
Drawing - rework of sun gear support assembly SB234-1015
Letter Boeing Vertol to FAA - 9th October 1984 (2 pages)
FAA Certificate of Complainece - 2 October 1984
Letter Boeing Vertol 234 to RB Page, Civil Aviation Authority, 4 February 1985
Letter Boeing Vertol to FAA, March 14, 1985 (2 pages)
Telex RB Page (CAA) to Boeing Vertol, 3 June 1985
Letter Boeing Vertol to RB Page (CAA), 2 April 1985
Service history of -5 and -6 gears (enclosure 5-8-7575-CAA-214)
Boeing 234 bolted joint gear statistics
Boeing 234 - forward transmission - North Sea summary
Boeing 234 - forward transmission - ring gear summary
Boeing 234 - forward transmission - sun gear summary
Boeing 234 - aft transmission - North Sea summary
Boeing 234 - aft transmission - ring gear summary
Boeing 234 - aft transmission - sun gear summary
Boeing 234 - drive system substantiation summary forward and aft bolted joint service experience
Forward/aft joint summary (6 pages)

Torque check - failed gear - 10 November 1986

History Sheet - A7-1625

Operator flight hour summary - 234 aircraft, 30 November 1986

Preliminary review of BIH transmission overhaul repair records - 24 November 1986

History sheet forward transmission, 8 January 1986 - A7-1581 (page 1)

History sheet - A7-1581 (page 26)

Engineering Test Lab Report, 5 December 1986

Measured torque

Engineering Test Lab Report, 1/9/87

Measured torque - sun, bevel joint

Engineering Test Lab Report - 1/5/87

Forward transmission A7-1639 bolt torque at 300 hours

Engineering Test Lab Report - 5/6/87 (2 pages)

Engineering Test Lab Report - 6/5/87 (2 pages)

Transmission Test Lab worksheet - A7-1639

Transmission Test Lab worksheet - A7-1639

Telex RB Page (CAA) to Boeing Vertol - 3/4/85

Telex FAA to Boeing Vertol, March 12, 1985

Letter Boeing Vertol to FAA, March 14, 1985

Letter Boeing Vertol to RB Page (CAA), April 2, 1985

Copy telex FAA to CAA, April 9, 1985

Telex 27100, T J Green (Boeing Vertol) to RB Page (CAA) (2 pages)

Boeing Vertol internal office memo - 21 May 1985

British Airways Helicopters internal memo - 2 May 1985

Handwritten sheet - TWX received 2/6/87 (2 pages)

Data pertaining to forward transmission A7-1625, 15/5/86 to 6/11/86 (from EIH sketch - Shim from gear M5109 (1333 hours flight time))

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 601

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 602

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 603

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 604

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 605

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 606

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 607

Graph - Fe and Cu concentration

Maintenance Manual - Spectrometric Oil Analysis - inspection check - page 608

Memo SOAP analysis summary - J Paschal

Telex 22 May 1984, BAH to Boeing Vertol

BAH Ltd - SOAP and QDM programme memo - P O'Hara (undated) (pre-September 1985)

SOAP data - exhibit E (2 pages)

BAH Ltd 1 forward and aft transmission (SOAP only) (sheet 1)

BAH Ltd SOAP copper - sheet 2B

BAH Ltd Chip Wipe Programme - forward and aft transmissions only (2 sheets)

BAH Ltd SOAP (Ferrous) sheet 2A

BIH SOAP data - Caleb Brett (2 pages)

SOAP results graph - A7-1625

SOAP graph prepared by J Paschal - Boeing

BIH Chip Wipe counts - G-BWFC

BAH Ltd Technical Log Special Instruction - 20th July 1981

BAH Ltd Technical Log Special Instruction - 19th April 1985

BAH Ltd - Fuzz Buster Plug Wipe Programme
BV234 SOAP/Wipe Report (Hangar) - BAH Ltd -
SOAP data - A7-1580 (2 pages)
SOAP data - A7-1581
Chip Wipe counts - A7-1600
SOAP data - A7-1600 (2 pages)
Chip wipe counts - A7-1600
Graph plot of SOAP counts - A7-1600 sheet - A7-1600 forward transmission
debris count
SOAP data - A7-1602
SOAP data - A7-1610
SOAP data - A7-1625 (2 pages)
Chip Wipe count - A7-1625
Chip Wipe count - A7-1625
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Chip Wipe count - A7-1625
Chip Wipe count - A7-1625
Chip Wipe count - A7-1625
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Chip Wipe count - A7-1625
Chip Wipe count - A7-1625
Graph plot SOAP A7-1625
A7-1625 forward transmission debris count
BAH Ltd - history sheet - A7-1625 (34 sheets)
Certificate of Conformity - BAH Ltd - 13/2/86
BAH Ltd - history sheet - A7-1625 - 13/2/86 (6 sheets)
BAH Ltd - history sheet - A7-1625 - 24/4/86 (6 shets)
BAH Ltd - history sheet - A7-1625 - 16/4/86 (18 sheets)
BAH Ltd Preliminary Defect Report - 7/1/86

SOAP data A9/1519 (2 pages)
Chip Wipe counts - A9-1519
SOAP data - A9-1521
SOAP data - A9-1533
SOAP data - A9-1550
Chip Wipe counts - A9-1550
Chip Wipe counts - A9-1550
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Chip Wipe counts - A9-1550
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Chip Wipe counts - A9-1550
Chip Wipe counts - A9-1550
SOAP data - A9-1562
SOAP data - A9-1569 (2 pages)
Chip Wipe counts - A9-1569
Chip Wipe counts - A9-1569
BAH Ltd - internal memo - 1/5/86
BAH Ltd - Defect Report - 30/4/86
BAH Soap Report - 29/4/86
Workshop Repair Report - A7-1581
Inspection Report H100346X - A7-1581 (28/5/86)
Telex T J Green (Boeing) to P O'Hara (BAH) - 2/6/86
BAH Ltd internal memorandum from P O'Hara - 2/5/86
Fax T J Green (Boeing) to BAH - 17/4/86
BAH workshop repair record A7-1581 - 21/8/86
BAH Ltd - history sheet form M3522 Issue 2 - A7-1581 (pages 1 to 9, 11 to 13, 17 and 18)
History of ring gear in A7-1581

Graph plot, iron count of A7-1625/1600/1631/1662

Graph plot, iron count of A7-1625/1600/1631/1662

300 hour test photographs and figures

Lab test photographs and figures on gear 1289 hours S/NM5 123 (aft transmission)

Lab test photographs and figures on gear 1333 hours S/NM5019 (forward transmission)

Copy page 236 - "Fretting Corrosion"

Copy page 108 - "Fretting Corrosion"

Copy page 126 - "Fretting Corrosion"

Copy page 134 - "Corrosion and Corrosion Control"

Copy page 189 - "Fretting Corrosion"

Copy page 236 - "ASLE Transactions - Fretting of Steel and Selected Treatments"

Copy page 237 - ditto

Copy page 238 - ditto

Copy page 239 - "ASLE Transactions - Fretting of Steel and Selected Treatments"

Copy page 240 - ditto

Copy page 241 - ditto

Copy page 242 - ditto

Federal Aviation Administration Maintenance Review Board Report

Telex 29 April 1983 - Boeing to Helikopter Service and BAH (2 pages)

Shell International Trading Company to Spectrometric Analysis document (16 pages including tables and appendices)

Boeing memo 21st March 1984 (2 pages)

Fax BAH to Boeing Vertol - 10/6/86 (2 pages)

Letter 28/2/85 - Spectro to BIH

Memo 25/7/83 BIH - Principal Performance Engineer to Quality Manager

Letter 13/10/83 - BIH to Boeing

Boeing handwritten chart - A7-1625 SOAP values
Spectro SOAP plot - A7/1631
Spectro SOAP data - A7/1631
Spectro SOAP Plot - A7-1662
Spectro SOPA data - A7-1662
Boeing SOAP plot for A7-1581
Boeing SOAP plot for A7-1662
Boeing SOAP Plot for A7-1631
Fwd/Aft gear box bolted joint check - A9-1562
Fwd/Aft gear box bolted joint check - A9-1569
Fwd/Aft gear box bolted joint check - A9-1521
Fwd/Aft XMSN - SB ring gear joint summary (4 pages)
BAH history sheet, forward gear box bolted joint check A7-1662
Notes 1 J Paschal - 11/12/86
BAH wipe programme (4 pages)
BV234 WIPE counts - G-BISR (A7-1580/A9-1533) (6 pages)
BV234 WIPE counts - G-BISN (A7-1659/A9-1521) (6 pages)
Health monitoring BV - components being monitored (5 pages)
BAH history sheets 27/11/86 - A9-1519 (52 pages)
BAH history sheets 26/9/86 - A9-1519 (40 pages)
BAH history sheets 30/8/85 - A9-1519 (51 pages)
BV-MELR86-832 Rev.A. 30th July 1987 (9 pages)
BV photographs 300 hour salt spray test (photographs A to L)
Telex 15/2/83 - Boeing to BAH
Letter 5/3/83 - BIH to CAA
Telex 5/9/88 (?) - BAH to Boeing
Telex 21/9/83 - Boeing to Lycoming
Telex 6/6/84 - Boeing to Helikopter Service and Others (6 pages)

Telex 6/8/84 - Boeing to BAH (3 pages)

Telex 28/12/84 - Helikopter Service to Boeing

Telex 11/1/85 - Boeing to Helikopter Service

BAH Preliminary Defect Report - 13/43/85 - A7-1625

BAH memo 25/7/86 to Boeing (3 pages)

Telex 13/10/86 - BAH to Boeing (2 pages)

Telex 7/11/86 - BIH to Boeing

Fax 11/11/86 - BAH to Boeing (2 pages)

BV fax 20/11/86 - Green to Ayoub

BV fax 25/11/86 to BIH

Telex 26/11/86 - BIH to Boeing

Telex 3/12/86 - Boeing to BIH

BIH fax 13/1/87 to BV (4 pages)

Letter 22/1/88 - Boeing to AIB (4 pages)

Telex 18/1/88 - Boeing to AIB

Letter 20/11/87 - Boeing to AIB

Letter February 1987 to AIB to Boeing

Telex 23/12/87 - BIH to Boeing

Telex 17/12/87 - Boeing to BIH

Telex 30/12/86 - BIH to Boeing

Letter 29/12/86 - Boeing to BIH

Notes 12/4/86 - J Paschal

Notes 29/1/87 - J Paschal

Telex 17/12/87 - Boeing to Coltax

Curriculum vitae - J J De Luccia (7 pages)

Spectro brochure

Board chart - BIH SOAP plot

Board chart - BIH SOAP data

Board chart - Helikopter Service SOAP data

Board chart - Helikopter Service SOAP plot

Board chart - SOAP Fe plots for modified forward transmissions

Board chart - A7-1625 SOAP plot

Board chart - breakaway torque values for modified transmissions

Break away bolt torque values

Forward/Aft gearbox bolted joint check

History sheet forward gearbox bolted joint check (Gearbox A7-1631)

Sun bevel gear bolted joint connection A7-1639 bolt torques at completion of 300 hour test

Engineering test labs accomplishment/failure report - forward transmission A7-1639

A7-1662 forward transmission nut torques in-situ and break-away

Gearbox A9-1521 forward/aft bolted joint check

Gearbox A9-1550 forward/aft bolted joint check

Gearbox A9-1562 forward/aft bolted joint check

A9-1600 aft transmission nut torques in-situ and break-away

Diagram of spike and crack distribution on flange of S/B ring gear - S/N M5019

Diagram of spike and crack distribution on flange of S/B ring gear - S/N M5215

Diagram of spike and crack distribution on flange of S/B ring gear - S/N M5153

Spectro laboratory brochure

Spectro SOAP data - A9-1600

Spectro SOAP plot - A9-1600

Spectro SOAP data - A9-1598

Spectro SOAP plot - A9-1598

BIH SOAP plot - A7-1625 from TSD reports

Inspection Report H102819 for A7-1625 - 4/7/86

BAH Unit Overhaul Sheets for A7-1625 (3 pages)
Certificate of Conformity for A7-1625 dated 29/4/86
BAH memorandum O'Hara to Green - 10/6/86
SOAP print out
Series of fourteen viewgraphs
Maintenance history for transmission A7 - 1580
Maintenance history for transmission A7 - 1581
Maintenance history for transmission A7 - 1600
Maintenance history for transmission A7 - 1602
Maintenance history for transmission A7 - 1610
Maintenance history for transmission A7 - 1625
Maintenance history for transmission A9 - 1519
Maintenance history for transmission A9 - 1521
Maintenance history for transmission A9 - 1550
Maintenance history for transmission A9 - 1562
Maintenance history for transmission A9 - 1569
SOAP data for transmission A7 - 1580
SOAP data for transmission A7 - 1581
SOAP data for transmission A7 - 1600
SOAP data for transmission A7 - 1602
SOAP data for transmission A7 - 1610
SOAP data for transmission A7 - 1625
SOAP data for transmission A9 - 1519
SOAP data for transmission A9 - 1521
SOAP data for transmission A9 - 1550
SOAP data for transmission A9 - 1562
SOAP data for transmission A9 - 1569
SOAP narrative for transmission A7-1625

SOAP narrative for A7-1600

SOAP narrative for A9-1533

SOAP data for transmission A9-1553

Maintenance history for transmission A9-1533

BAH internal memorandum dated 1st May 1986 from J Morgan

BAH preliminary defect report dated 3rd June 1986

FAX from Bob Dawson of Boeing Vertol to Ian Skipper dated 9th May 1986

BIH replacement note, fax and sub-contract advice note accompanying A9-1533 on return to Boeing

FAX from Bob Dawson of Boeing dated 10th June 1986 to Ian Skipper and Skipper's reply of 16th June 1986 both regarding A9-1533

FAX from Pat O'Hara to Boeing Vertol dated 10th June 1986 re A9-1533

Boeing Vertol's report on A9-1533 dated 9th October 1986

Photographs of A9-1533

Copy telex from Boeing to BIH dated 29th April 1983 (Boeing here confirm that originally they were of the view that 100 hours was sufficiently frequent for SOAP sampling)

Letter from Ian Skipper to CAA dated 26th July 1985

Roy Mitchell's letter of 1st April 1986 to the Civil Aviation Authority

John Benyon of CAA's letter to Ian Skipper to BAH dated 7th May 1986.

British Airways Helicopters Limited's Technical Log Special Instruction H.1814

British Airways Helicopters Limited's Technical Log Special Instructions number H.1676

Graph of A7 - 1625 from May until failure

Chart showing the aircraft to which the aft transmissions were fitted.

Chart showing the aircraft to which the forward transmissions were fitted.

FAX from Boeing to BAH dated 20th May 1986

Telex from Caleb Brett Limited to BAH dated 1st August 1986 giving analysis of the debris found in A7-1625 a few days earlier

"Diary" showing the days when A9-1533 was not flying

"Diary" showing the days when A7-1625 was not flying

"Diary" showing the days when A7-1600 was not flying

"Diary" showing the days when A7-1581 was not flying

British Airways internal document modification number 234/63.23.005 regarding the implementation of Boeing service bulletin 234-63-1014

Coltax Aerospace Limited approxed Certificate Release Note dated 16th January 1986

Details of strip torques assessed after 6th November 1986 for A7-1581, A7-1625, A7-1662 and A9-1600

Set of graphs with BIH Alert levels for A7-1625 and A7-1600

Set of graphs with Boeing Alert levels for A7-1625 and A7-1600

Set of graphs showing trench for A7-1625 and A7-1600

Comparison of BIH and Boeing thresholds

1 Preliminary

1.1 Accident

On 6 November 1986 at 1131 hours, on a flight from the Brent oilfield in the East Shetland Basin to Sumburgh Airport, Shetland, Scotland, a Boeing Vertol 234 LR (BV 234) helicopter, G-BWFC (hereinafter referred to as "the helicopter") crashed into the sea about 2.5 nautical miles east of Sumburgh. The helicopter broke up and sank. The co-pilot and cabin attendant and 43 passengers were killed; but the captain and one passenger survived. The helicopter had been manufactured by Boeing Helicopter Company (formerly Boeing Vertol) in 1981; and at the time of the accident, it was owned and operated by British International Helicopters. (Before September 1986, the owners of the helicopter had been British Airways Helicopters.)

1.2 Investigation

The Chief Inspector of Accidents ordered Mr D F King, a Principal Inspector of Accidents, to carry out an investigation into the accident. Mr King carried out the investigation. The Inspector served a notice under Regulation 11 on inter alia Boeing Helicopter Company.

Boeing Helicopter Company thereafter served on the Inspector representations in respect of the proposed analysis of facts and conclusions of the Inspector. Thereafter, on 8 March 1988, Boeing Helicopter Company gave written notice under Regulation 12(1) that they wished findings (ii), (vi) and (xiii) and the cause to be reviewed by a review board. On 25 April 1988 Sheriff P G B McNeill QC was appointed by the Lord President of the Court of Session, in terms of regulation 13(1) to be the Chairman of the Review Board, along with Professor P Hancock and Mr K V Kellaway as assessors.

1.3 Proceedings of Review Board

Preliminary hearings took place on Monday 6 June 1988, and Tuesday 28 June 1988; and directions were given for the preparation and conduct of the Review.

At the meeting on 6 June, the following parties - apart from Boeing Helicopter Company and the Inspector who made the report - were granted leave to appear at the review under Regulation 14(2):

Air Accidents Investigation Branch, Department of Transport

British International Helicopters

British Airways plc

Coltax Aerospace Limited

The Civil Aviation Authority

Chinook Disaster Legal Group (being Captain P Vaid, Mr E Morrans and the personal representatives of 41 deceased passengers)

Representatives of Donald Richardson and others.

The Board refused leave to appear at the review to the Manufacturing Science and Finance Union in respect that they were not directly affected by the review in terms of Regulation 14(2).

We also refused the motion of Boeing Helicopter Company to allow consideration in this review of findings not specified in the notice of review.

Between the preliminary meeting and the hearing of the review, the position of Coltax Aerospace altered and they were not represented after the preliminary meeting.

On 30 June 1988, the members of the Review Board visited the Royal Aircraft Establishment at Farnborough in order to see the wreckage of the helicopter laid out in a hangar.

The Review Board sat in a court room in Parliament House, Edinburgh to hear evidence and submissions on 2, 3, 4, 5, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 22, 23, 24 and 25 August and in the Crown Office, Edinburgh on 16 December 1988. In terms of Regulation 13(4), the Review Board decided that the preliminary meeting and the hearing should be public - apart from the adjourned hearing of 16 December.

On the first day of the hearing of the review, the grounds on which Boeing Helicopter Company had originally challenged the Inspector's Report had remained unchanged: that is to say, they challenged findings (ii), (vi) and (xiii) and the cause. Other grounds of challenge (as will be noted in more detail later) were sought to be raised by Boeing Helicopter Company. The three findings and the cause covered three separate procedures which were briefly (1) the proper application of a surface conditioning treatment known as "Presto Black", (2) the torquing of the spiral bevel ring gear attachment bolts on the transmission to the specified level, and (3) the proper interpretation of the results from the system of element analysis of the oil from the transmission, known as spectographic oil analysis programme (hereinafter referred to as "SOAP").

On 2 August 1988, that position was modified: counsel for Boeing Helicopter Company intimated that his clients were departing from that part of their notice of review relating to Presto Black and which affected Coltax Aerospace Limited. This position had been intimated in advance by letter to Coltax Aerospace Limited and to the Crown Agent dated 28 July 1988. At the hearing, counsel for Boeing Helicopter Company intimated that Coltax Aerospace Limited would not be represented any further at the hearing of the Review Board. The Board took the view that the amendment of the notice of review was unnecessary, and we permitted the review to continue on the view that the concession by Boeing Helicopter Company would be

dealt with in our report "upon completion of the review" when we would confirm or reject the findings and the cause in whole or in part: Regulation 14(8).

Oral evidence was given by

Mr Allan W Twilling, Senior Accident Investigator, Boeing Helicopter Company

Mr Patrick Joseph O'Hara, Senior Technical Engineer, British International Helicopters

Dr John J de Luccia, Adjunct Professor in Department of Materials and Metallurgical Engineering, Evening College, Drexel University

Mr Joseph C Paschal, Manager Systems Design, Boeing Helicopter Company

Mr Carl Albrecht, Chief of Structures Technology, Boeing Helicopter Company

Mr Sol Binder, Chief of Dynamic Systems Department, Boeing Helicopter Company

Mr Michael Peter Anderson, Solicitor, Edinburgh

Mr David Frederick King, Principal Inspector of Accidents, AAIB

The proceedings were recorded in shorthand, and the 21 volumes of extended shorthand notes relate to the 21 days of the proceedings. Occasionally, in our report, we have referred to specific passages of the evidence in detail and have done so by reference to the volume and page number and, where appropriate, the letter on a particular page of these volumes.

2 Facts

2.1 Narrative

Certain matters concerning the crash of the helicopter which are dealt with in the Inspector's Report did not impinge upon the matters raised at the review, and accordingly we have not dealt with them in our report: these matters of factual information include the history of the flight, injuries to persons, personal information, aircraft information, and flight recorders.

However, other matters which have also been dealt with in the Inspector's Report, did impinge upon the review. In order to make this report complete in itself without reference to other documents, such as the Inspector's Report, and rather than to paraphrase what is said in the Inspector's Report, we have, where appropriate, quoted parts of the Inspector's Report. This approach has been adopted merely for the purposes of narrative. In almost all cases, the matters which have been thus excerpted were not in dispute at the review; but in so far as there was any dispute, that matter is dealt with later in our report.

It is common ground that the crash of the aircraft was caused by the failure of the spiral bevel ring gear, and in particular by the substantial fracturing of the attachment flange of that gear. There were two transmissions, one for each set of rotors. It was the forward transmission which failed: the layout of the main drive system, including the forward transmission, is illustrated in Figure 1.

"The forward transmission is driven from the combining transmission via the synchronising shafting which runs at a nominal 6,912 rpm. It angles the drive through 81° and reduces the speed to 225 rpm which is 100% rotor rpm in three stages within the transmission. The first stage uses a spiral bevel set (input pinion and ring gear) to angle the drive and reduce the speed. The other two stages are speed reducing only using planetary gear systems. The spiral bevel ring gear is attached to the first stage sun gear shaft by a bolted joint. Flanges on the two components are clamped together by 24 bolts and between the flange faces is a shim. This is used to improve the working characteristics of the joint and position the gear axially on the shaft for correct meshing with the input pinion. The shim is made of steel with a thin coating of anti-fretting material on both faces.

"The joint is designed to transmit the drive from the gear to the shaft by friction through the shim. The primary function of the bolts, therefore, is to generate pressure between the mating surfaces. The greater the clamping force so produced, the greater will be the torque transmission capability of the joint."

The forward transmission gear train is illustrated in Figure 2; and the assembly of the spiral bevel ring gear is illustrated by the exploded diagram, Figure 3.

After its recovery from the sea, "the transmission casing was cut away to allow the first stage sun gear shaft and spiral bevel ring gear to be removed as an assembly. Besides the radial crack, the ring gear had a circumferential failure around the outer radius of its flange which appeared to exist round at least 60% of the circumference." Figure 4 shows the radial crack at the bottom of the picture and the 60% circumferential failure.

"The helicopter suffered a catastrophic failure of the forward transmission which in turn led to de-synchronisation of the twin rotors such that the forward rotor and aft rotor blades collided. As a result, the aft pylon, complete with the aft transmission and rotor system, detached from the fuselage. The aircraft struck the sea in a tail down attitude with considerable force, broke up and sank".

In about 1980, when the BV 234 type of helicopter was introduced into civilian service, the bolted joint between the sun gear shaft and the spiral bevel ring gear had been modified several times and had reached the stage in its modifications that the bolts were 3/8" in diameter. The shim between the two flanges was scalloped as formerly but had a new coating of aluminium-bronze-ekonals (Al-Br-Ek): Figure 5. The torque prescribed by Boeing Helicopter Company was 650 - 700 in.lb. This modification has been referred to as the -5 standard. For a short time after 1982, Boeing Helicopter Company issued an instruction to apply a binding agent called "Loctite" to the bolt threads at overhaul with the intention of increasing the security of the clamping bolt nuts but after about two years, this instruction was discontinued.

The -5 joint was found to give problems in terms of loosening of the bolts and therefore "in order to improve the joint, and so reduce the frequency of inspection, the manufacturers introduced a modification, by Service Bulletin 234-63-1014 for the forward transmission and -1015 for the aft transmission, in which the clamping force was increased by introducing larger diameter bolts which were installed at a higher torque. This in turn had necessitated a return to the solid type shim to avoid bearing overload of the Al-Br-Ek coating" (Figure 6).

"The ring gear joint was at this modification standard (referred to as -6) at the time of the accident to G-BWFC." This modification introduced bolts of 7/16" diameter and an increased torque of 1065-1215 in.lb.

The modification to -6 of an individual transmission - which was to be carried out by the operator - was to be implemented by reference to the SB (Service Bulletin) 1014. In terms of that, the operator would make larger bolt-holes in the flanges but still 24 in number; larger bolts, nuts and washers were to be used with a modified unscaloped shim. "The SB was approved for embodiment by the FAA, with the stipulation that the torque of the clamping bolts in one forward and one aft transmission were to be checked at 500 flying hours and two of each at 1,000 hours in a similar way to that detailed in SB A234-63-1010.... Additionally, one forward and one aft transmission was to be stripped and the condition of the bolted

joint examined after 1,500 running hours. The CAA also approved the modification but required that two examples of each transmission be torque checked at 500 running hours. The manufacturer recommended compliance with the SB as soon as practicable after the parts became available."

SOAP also has a definite but limited use in monitoring the health of a unit such as the transmission. And the description of SOAP in the Inspector's report was accepted by Mr O'Hara who was a witness called by Boeing Helicopter Company.

"SOAP is a technique used for health monitoring of lubricated mechanisms. The philosophy adopted is that, as components wear within the mechanism, the minute particles produced by the wear processes become suspended in the oil. Thus, by determining the proportion of selected elements in the oil, usually measured in parts per million, it is possible to get an indication of the extent to which components containing particular elements are wearing.

"The quantity of any element that can be expected to be present in suspension will be, in some way, proportional to the amount of that element which is in a location where wear can take place and the relative proportions, normal concentrations and acceptable rates of change of concentration of each monitored element have to be established from experience of a particular mechanism. Thus, the normal and acceptable SOAP signature of a particular monitored mechanism is determined as the total use accumulates. During this learning process, any abnormal signatures which are noted have to be related to failures or abnormal wear discovered as a result of physical examination of the mechanism. In this way the dossier of failure and impending failure of signatures can be accumulated. In some cases where particular elements are present in unique or a limited number of locations within the mechanism, it may be possible to deduce the part which is wearing; but confirmation should be established by physical examination. Account must also be taken of the way in which the addition of fresh oil will dilute the concentrations of the elements.

"The technique, while useful in the monitoring of known wear problems, has limitations in the case of multiple failures, where several signatures may be overlaid, and the diagnosis of novel failures which produce a hitherto unseen signature. It is also recognised that the technique is unsuited to the detection of fatigue in components, since, unless the fatigue creates a marked increase of wear rates due to increased flexibility of the affected part, the fracture process itself will be unlikely to produce sufficient wear particles to create a significant change in the overall signature of the mechanism."

The modification of the spiral bevel ring gears from -5 to -6 as were used in the forward transmissions of these helicopters, resulted in wear and corrosion which gave rise to conditions in which fatigue could initiate in the bolted joint flange.

2.2 History of the Failed Transmission, A7-1625

The transmission which failed had the serial number, A7-1625; and contained the spiral bevel ring gear, serial number M5197. The transmission had previously been installed in the helicopter BV234 G-BISP, which was also operated by BIH.

On 1 August 1985, Boeing Helicopter Company issued their Service Bulletin 1014 which provided for the modification of the spiral bevel ring gear bolted joint of the forward transmission from -5 to -6. The accomplishment category of the Bulletin being:- "It is recommended that this change be accomplished as soon as practicable after the parts are available".

On 18 October 1985, the transmission was removed for scheduled overhaul at 4,019 hours. The Bulletin 1014 was incorporated at this time. (Although the accomplishment paperwork incorrectly inferred -5 torque values (650-700 in.lb.) had been applied, for reasons stated later, the Board found that the final torque applied to nuts was of the -6 values, namely, 1065 - 1215 in.lb.) On 15 February, the transmission was installed in another BIH helicopter, BV234 G-BISR. On 5 April, the rotor shaft of that helicopter was replaced; and on 8 April, the transmission was installed in the helicopter, G-BWFC (which was the craft which subsequently crashed).

On 16 April, because of a reduction in oil pressure and the discovery of particles of metal in an oil filter, the transmission was again removed from G-BWFC. At this time, the transmission had done about 70 hours since modification, and an in situ torque check on the bolts was effected. On 15 May, the transmission was again fitted to G-BWFC. From then on until the failure of the aircraft on 6 November, the operators carried out sampling and analysis of the oil in accordance with their own and the manufacturer's specifications. (For reasons stated later the Board find that the operators carried out the manufacturer's SOAP programme in accordance with the Boeing Helicopter Company maintenance manual 63-25-50 dated 31 December 1982 and later amended.)

On 8 September, Mr O'Hara recommended that the transmission be removed at the end of the week, (which would have been 12 September). This would be a "precautionary" removal to investigate the cause of iron content in the SOAP samples: but his recommendation was not accepted and he continued the SOAP programme which indicated a reduction in the iron content. On 12 September, because of the iron count, Mr O'Hara instructed a plan for a transmission change "in the near future"; and on 4 November, when the SOAP count was 24 ppm for iron, he requested that a forward transmission be standing by "for this weekend". On 4 November, the final SOAP readings were taken and on 5 November, they were reported. Then the iron and copper were both again dropping. On 6 November at about 1131 hours, the accident took place.

Decision of Review Board

The Board agrees with the submissions which were set forth by Mr Cameron for BIH, and which were adopted by the other parties that the proceedings of the Review Board are not an enquiry at large, nor even an enquiry into the accident, but merely a review of only three of the findings and the cause in the Inspector's report. The procedure is a means of redress, before publication of the report, whereby Boeing Helicopter Company who allege that their reputation is adversely affected by reason of the grounds specified in their notice of review can seek to have these matters reviewed by a Review Board. That is the meaning of Regulations 12(1) and (2).

If these grounds in the notice of review are irrelevant or are unfounded in fact, there can be no ground for saying that the reputation of Boeing Helicopter Company is adversely affected. In our view, the grounds of challenge contained in the notice of review, in so far as material, are unfounded in fact for the reasons narrated in this report.

There were originally three topics raised in the notice of review: torque, SOAP and Presto Black; but since Presto Black has now been departed from by Boeing Helicopter Company, only the other two topics remain. The way in which the grounds of challenge in the notice of review have been drafted has resulted in these topics being straddled over the findings and the cause: thus ground 1, which relates to finding (ii), refers to both torque and SOAP; ground 2, which relates to finding (vi), refers to torque only; ground 3, which relates to finding (xiii), refers to SOAP only and ground 4, which relates to the cause, refers to both torque and SOAP. It is clear that parts of findings (ii) and (vi) and the cause are not in dispute. For those reasons, we have dealt with each of the challenged findings and the corresponding ground of challenge in turn.

Although Mr Jones for Boeing Helicopter Company did not expressly ask us to confirm finding (ii), for the sake of completeness, we propose to deal with that finding as well. (Later we propose to consider each of the challenges.)

3.1.1 Finding (ii)

There was no challenge of the second part of finding (ii), namely "Its Certificates of Airworthiness and Maintenance were valid at the time of the accident.". In the absence of challenge and in the state of the evidence of Mr King when examined by Mr Jones at 18.2099, we would be disposed to confirm that part of finding (ii) in any event. However, the documentary evidence - the history sheets relating to the transmission A7-1625 (11/19 of process) and the certificate of release (11/18) - indicated that the paperwork of BIH in the inspection report and the history sheets relating to A7-1625 was not good. Nevertheless the inspection report which incorporates a certificate of release to service certifies in substance that the Service Bulletin 234-63-1014 was carried out (see also 18.1977A). In the state of the evidence before us, it

cannot be said that the Certificate of Airworthiness would be invalid merely because the paperwork was defective. In this regard, Mr King said, "It is always put to us by the CAA that that is a matter of interpretation of the law and has to be part of some legal process to draw the conclusion. But a certificate of release is a required document for such a component as this to be re-installed back in the aeroplane, it is a fundamental piece of maintenance paperwork. But if this were to be in some way invalidated, I don't think it is proper to say that the Certificate of Airworthiness is then invalidated" (18.1977E - 1978B). This evidence was not challenged and there was no contrary evidence; and accordingly we have no reason to reject it or to qualify our confirmation of this second part of finding (ii).

The first part of finding (ii) is in the following terms "The helicopter had been maintained in accordance with an approved maintenance schedule". In our view, the phrase "maintenance schedule" includes both the question of torque and SOAP.

In relation to torque, the question before the Review Board was whether the spiral bevel ring gear whose flange was bolted to the sun gear shaft had had its nuts torqued to the values of the -5 modification (650 - 700 in.lb.) rather than to the -6 value (1016 - 1215 in.lb.). The matter was clarified to some extent by the observation of Mr Jones for Boeing Helicopter Company that in the whole circumstances, there was not any basis for a view that any intermediate torque levels were applied: it was either clearly one or the other (19.2148C - D). In any event, on the evidence, we take the view that the nuts were torqued to -6 levels, not -5 levels. Our reasons for coming to this view are succinctly set forth in the evidence of Mr King (17.1864).

The first piece of evidence to which Mr King referred was the paperwork of BIH. It is true that in changing the assembly from -5 to -6, BIH used typewritten pro forma sheets which were appropriate to a -5 configuration, but in some cases the fitter (or whosoever) adapted these forms by altering them. As a result, these forms (which comprise the history sheets) included reference to additional components which were only appropriate to the -6 modification; and at one stage the history sheet for A7-1625 refers to "SPIRAL BEVEL S/N M 5197" alongside the words "REWORK I.A.W. BV SB (that is, "in accordance with Boeing Vertol" - the former name of Boeing Helicopter Company - "service bulletin") 234-63-1014" (Mr Twilling at 3.80 B-C). Further, the inspection report which relates to the same transmission, namely A7-1625, certifies that the Service Bulletin 234-63-1014 was complied with. We accepted this notwithstanding our observations on the paper work on which the certificate is based.

The AAIB also relied on the statements from BIH and on the circumstances of the gear. At the early stages of the investigation including the period when the failed gear was being disassembled in the presence of representatives of Boeing Helicopter Company and BIH among others, the question of the torques was not seriously in issue. Nevertheless, the AAIB made enquiry of those concerned with assembling the transmission to find

out at what torque they had put the nuts. These persons were Mr Redhead, Mr McAskill (who gave evidence at the Fatal Accident Inquiry) and the fitter who actually applied the torques. Reliance was also put on the fact that the fitter and the inspector had appended their stamps to the various steps in the disassembly and re-assembly of the gear, as disclosed by the history sheets (11/19).

These three witnesses were not called by Boeing Helicopter Company to speak on the matters on which they might be expected to have knowledge: that is to say, the fitter on whether the transmission A7-1625 was torqued to -6 or to -5; Mr Redhead on what damage was to be seen on the transmission A7-1581; and Mr McAskill on the reasons for not acceding to Mr O'Hara's recommendation to arrange the withdrawal of the transmission. These are all matters which Boeing Helicopter Company specifically rely upon in their notice of review; and which are discussed later in this report.

Where a party does not lead evidence in a case - and by the same token, in respect of one aspect of a case - that party cannot complain if "the most unfavourable inferences" are drawn from the other evidence in the case. Principle and authority indicate that the absence of such witnesses should tell against the party failing to call the witness; and Boeing Helicopter Company being the challengers of the Inspector's Report have the burden of proving that challenge: Ross v Associated Portland Cement Manufacturers [1964] 1 WLR 768; O'Donnell v Murdoch McKenzie & Co Ltd 1967 SC (HL) 63. But, Mr Redhead was not only on the list of witnesses for Boeing Helicopter Company, but had been precognosced on the very subject of the gear A7-1581 by their solicitor, Mr Anderson, who gave evidence to the Board on this point. In addition, an important matter of evidence, namely, the conflict as to what Mr Redhead or the fitter said to the AAIB, would also have been a matter within the knowledge of Mr Redhead: he had been precognosced by Mr Anderson on this point also.

A further legal question arose as to whether the witness Mr King who narrated these matters could competently refer to not merely hearsay, but hearsay of hearsay in respect that it was not he but members of his staff who took statements from these persons in BIH. In the present statutory procedure which governs this Review Board, there is no requirement that the rules of evidence appropriate to a civil or criminal litigation should be adopted in their entirety. There are other proceedings - such as planning inquiries - in which the rules relating to hearsay are considerably relaxed. Also, in some aspects, at least, of the present proceedings, consideration of hearsay is a necessary part of the process of arriving at a decision. In our view, the present situation is one of those aspects; and what the Inspector has done is clearly a proper way for him to proceed - by delegating to members of the AAIB staff the various parts of the investigation which are then co-ordinated by the Inspector who wrote the report. When the report comes under scrutiny in a Review Board, to see whether the findings of the inspector should be confirmed or rejected, we are of the view that that information which was properly before the Inspector does not cease to be material to which we can have regard.

The second circumstances on which the Inspector relied tending to the view that the assembly was torqued to the -6 level was the position of the flats on the nuts. The nuts in the -6 configuration, unlike those in the -5 configuration, had in their heads 2 flat sides parallel to each other which required to be positioned with one of the flats facing the journal or to the inboard of the assembly. On disassembly of the failed gear, the nuts were in their correct position; and Mr King deduced from that that the fitter had in front of him the service bulletin 1014 or the correct information from it. As indicated above, we see no reason to reject the information that came from BIH as to the assembly of the gear (17.1970 - 1972C, 1880D). Although it appeared that the name of the fitter was given by Mr Redhead (20.2435) this does not advance the matter on behalf of Boeing Helicopter Company; and it has to be taken in the context of the fact that Boeing Helicopter Company made nothing of the torque values at the time as indicated by Mr King.

The third reason put forward by Mr King was the in situ tests (18.2011B-C; 17.1852, and 1863). There should be an in situ test of the transmission: if the in situ test was at 400 in.lb, the joint was to be regarded as adequate and the transmission could be reintroduced into service. (The former level for the -5 configuration was 350 in.lb. as specified in Boeing Helicopter Company's Service bulletin, 234-63-1010, para 3.B.8). It was common ground that the failed transmission had been tested in this way between 16 April and 16 May at 70 hours (18.2011B-C) and on 5 October at 555 hours (15.6 and 17.1863 and 1852). Mr Binder, chief of Dynamic Systems and Structures of Boeing Helicopter Company in Philadelphia, gave evidence that originally they fixed a figure of 350 for the -5 modification. He said "We didn't want to put the burden on the operator of pulling gearboxes that were properly torqued up so we had run this test and looked at the scatter and established the 350 value as being just below that scatter value that we had observed as being an acceptable level for this in situ check" (15.1654C-D). When the change from -5 to -6 took place, larger bolts were used and Mr Binder agreed that the change from 350 to 400 was approximately directly proportional to the change in diameter of the bolt (15.1654E). He also said "We felt although the transmission wouldn't be acceptable below the 400 level there was no imminent danger at that particular level" (15.1655D). Mr Twilling, the senior accident investigator with Boeing Helicopter Company, said that the in situ checks would not have disclosed that the bolts had been wrongly torqued - if they were still at the torque value they had been torqued to (4.135C-D). This is because the torque values of the in situ checks are below the requirements of the original assembly torque values for either -5 or -6. On disassembly of the failed gear, it was found that all of the torque values - apart from two - were above the 400 value of the in situ test; and the failure of two bolts to come up to that standard was an admitted exception to the rule. Thus, even after the accident, according to the standards laid down by Boeing Helicopter Company, the transmission would have passed their test for bolt torque to enable the unit to remain in service.

The fourth item of evidence tending to the view that the failed gear had at assembly been torqued to the -6 figure arises from the comparison of the torques of gears and the local damage. The evidence of Mr King was that the assembly torque values would go down. Mr Albrecht, the Chief of Structures Technology with responsibility for stress engineering with Boeing Helicopter Company in Philadelphia, said at first that the trauma of the accident would make the torques even greater, but in cross-examination he said "I said that there were some cases where that is entirely possible, it could go lower in some areas and higher in some areas" (14.1429F - 1430A); but Mr Albrecht had done no tests to support his theory that it was an extremely remote possibility that the torque values would decrease. We found the evidence of Mr Albrecht on these matters unconvincing. And Mr Binder did say that even although the transmission would not be acceptable below 400 in.lb there was no imminent danger at that level.

On consideration of the chart which showed the breakaway torques of several forward and aft gears set against the band of proper torque levels for -5 and -6 configurations (Figure 7), it appears that there is a distinction between forward and aft gears in that with service, the torque values of the aft gears appear to go up whereas the torque values of the forward gears go down. We think it appropriate to disregard (as did Mr King) all the aft gears and to consider only available test results from the forward gears which had been in service, all of which showed a drop in torque values. The only gear that did not show reduced values was the gear which underwent a salt test rather than operational service (see Mr King at 18.2019). In this regard, Mr Albrecht said that if the gears A7-1581 and A7-1662 had in fact been torqued to the -6 values, the chart indicated a drop in torque values after service.

In his cross-examination of Mr King, Mr Jones introduced for his consideration other factors which might cause the torque to go up rather than down. These were changes in lubrication, corrosion, the impact of the rotor blades, damage to the bolts, damage to the washers (and groove width) and the use of Loctite on the bolts - despite the fact that Loctite was, according to Mr Twilling, rescinded about September 1983 (3.53E and 65E). Most of these matters were not put to the witnesses for Boeing Helicopter Company and although not all had been considered by Mr King in arriving at his decision, he regarded them as being insignificant and not to cause him to doubt his original view: we accepted this view of Mr King.

The fifth element in Mr King's consideration that the bolts were torqued to the -6 configuration was the width of the groove which developed in the various gear flanges. Mr King said that he regarded the groove width as a very significant indicator of the local clamp up (17.1865) and he correlated bolt torque or local clamp up to changes in groove width. We accept Mr King in this regard and look upon his evidence as important, namely that a high torque is associated with a narrow and deep groove (18.2032C) and a low torque is associated with a wide and shallow groove. In particular, he examined the failed gear from transmission A7-1625, and compared that groove with A7-1581 which was accepted to be of

-6 configuration correctly torqued and A7-1600 which was not disputed to be -6 configuration and correctly torqued. Mr King looked at the groove in the A7-1662 gear and indicated that it was marginally broader than the groove in the gear M5019 which was on transmission A7-1600 - except at the location of bolts 4 and 14, which had very low torque values. He accepted the theoretical position of Dr De Luccia, who was the expert in metallurgy led on behalf of Boeing Helicopter Company when he indicated that where the clamping was very loose, there was the effect of washing of the corrosive elements so that deep grooves did not occur in the areas of low torque.

The effect of Mr King's evidence, which we accepted, is that all -6 gears had a similar groove and that the gear from transmission A7-1625 was in that pattern also. In relation to lower torque, at one extremity the two loose bolts indicated a washing effect with a broad shallow groove, whereas the groove more local to the bolts was more pronounced. The gears from A7-1600 and A7-1625 were part of the same family, and fell within the bounds of scatter of the results in respect of the difference in the life of the gears to the point of failure. This is dealt with by Mr King at 17.1938-1939, 18.2042-2044. In cross examination by Mr Morrison, Mr King said scatter ratios of the order of 5:1 are commonplace under fatigue conditions. (18.2043C).

Mr Albrecht was asked if he had done tests on -5 gears but had done none to support his hypothesis. If the failed gear A7-1625 was unique, it was only unique because someone other than Boeing Helicopter Company made it unique. Mr King says it was not unique.

Mr Binder (at 15.1565) dealt with the gear A7-1581 and concluded that there would be evidence after 105 hours. In our view, this is speculative: there is no evidence before us to show that corrosion is a linear problem and it is quite possible that there could be an initial incubation period when little evidence of corrosion would be observed.

The sixth and last consideration of Mr King was the disassembly torques on other transmissions as indicated in Figure 7. The inference to be drawn from these is twofold: that they come down during service and that all A7 torques come down even more with trauma. This is not just the evidence of Mr King. Mr Albrecht indicated that he thought the unopposed tightening torques would go up because of the greater frictional force on the bolts, but he also said that these values could go up or down due to distortion. We regard the frictional forces as the smaller of the two effects. We are of this view because the unopposed tightening levels were generally only about 100 in.lb. higher than the opposed untightening values, and this increase would be indicative of the additional frictional forces. However, the average dropped several 100 in.lb. from the initial torque levels.

It was contended by Mr Jones that this was unsound in respect that it was deduced from a small sample of gears. In our view this criticism would be of value if there was disagreement, but here all the A7 values go down in service: not one goes up.

In any event, it would not assist Boeing Helicopter Company to establish that the failed gear had been torqued at -5 configuration because, as we have seen, the evidence of Mr Binder was that the transmission was safe at 400 in.lb.: there was no imminent danger at that level (15.1653 - 1655). According to Mr Binder, an in situ check at 400 in.lb. would not have given any indication of what the actual torque was (15.1655E - 1656B). It follows therefore that there was no causal mechanism of failure related to torque.

Accordingly, we are of the view that the helicopter had been maintained in accordance with an approved maintenance schedule in so far as that schedule related to the torquing of the nuts.

As we have indicated, we regard as part of the "maintenance schedule", the spectrometric oil analysis programme, (otherwise referred to as spectrographic oil analysis programme), but herein referred to as SOAP. We have two preliminary matters to deal with. In our view, we are only concerned with those aspects of SOAP which are challenged by Boeing Helicopter Company in their Notice of Review at page 2. The second matter relates to the ambit of SOAP. Whereas the words in the ground (at page 2) might appear to limit SOAP strictly to the bare oil analysis and consideration of results in isolation, the Board are of the view - which is supported by evidence (eg Mr Paschal, the Manager, Drive and Systems Design, for Boeing Helicopter Company in Philadelphia, at 12.1196C) - that SOAP must be used in conjunction with other health monitoring activities, such as filter and magnetic plug debris analysis (chip wipe).

From the information which is based on the evidence of Mr O'Hara, a senior technical engineer in the Technical Services Department of BIH and the section of Boeing Helicopter Company maintenance manual 63-25-50 as well as the documentation of BIH, the Board are of the view that the programme of BIH was, in all particulars - except iron - not less, but more stringent than the programme set forth in the maintenance manual 63-25-50. This can, to a large extent, be demonstrated by the charts contained in "comparison of thresholds". This shows the thresholds for aluminium, chromium, copper, iron, magnesium, silicon and silver in both the maintenance manual 63-25-50 of Boeing Helicopter Company and the technical log of BIH. In our view, Mr O'Hara was not shaken in his evidence; and there was no contrary evidence in respect of the observance of SOAP, and there was no contrary final submission on behalf of Boeing Helicopter Company on that point. Indeed, it was put to Mr Paschal that the assertion in the notice of review, namely that "specifically to the information, knowledge and belief of the Manufacturer, the operator may have allowed levels of contaminants (as may have been diagnosed by SOAP as performed by the operator) to exceed the approved critical rate(s) on several occasions prior to the accident" was inaccurate. In reply, he said, "On the basis of testimony, that we have looked at today, that doesn't appear to be accurate" (13.1307); and Mr Paschal was presenting the argument for Boeing Helicopter Company so far as SOAP was concerned (12.1207).

We accepted the evidence of Mr O'Hara - chiefly in cross-examination by Mr Cameron for BIH - in relation to the day-to-day operation of SOAP in relation to the transmission A7-1625 and also to the effect that the operator used the SOAP programme according to the manual of Boeing Helicopter Company. This was the evidence of Mr O'Hara; and Mr Paschal, the SOAP expert of Boeing Helicopter Company, was of the same view: "All I am asking is if anything BIH did along the way with 1625 breached what was said in this manual? - Along the way, up to the point of recommendation, no" (12.1200A - B).

In his final submissions on behalf of Boeing Helicopter Company, Mr Jones did not suggest otherwise: indeed, he limited himself only to part of paragraph 1 of the notice of review, which relates to finding (ii), namely the failure of BIH to remove the transmission A7-1625 from service. Accordingly, we think that it is unnecessary to rehearse the evidence on the monitoring of the transmission in detail. (Boeing Helicopter Company had in their SOAP manual provided for the installation of a baseline with a sampling period of 175 hours. BIH did not use the baseline as suggested by British Helicopter Company, but used zero as their baseline because it was more conservative. There was no evidence that Boeing Helicopter Company demurred at this change in the baseline (10.831B). In any event, we do not regard this difference in the two programmes as being significant.)

At about the time when Mr O'Hara considered withdrawal of the transmission (at about 461 hours) the iron reading had risen over the previous 59 hours but had fallen thereafter (10.890 - 892). It had been suggested by Boeing Helicopter Company that in operating the SOAP programme it was necessary to consider the movement of copper and iron together: in our view that is not what the maintenance manual envisages and this was the evidence of Mr Paschal (13.1254). The readings of contaminants which were seen in relation to the gear only reached box B of the SOAP programme: they never reached box C. (Both boxes are referred to in maintenance manual 63-25-50.) Accordingly, there was no obligation on the operator to withdraw the transmission from service. Nevertheless, we feel it important to consider the evidence in relation to this aspect of the review because much time was spent on it during the hearing.

It was suggested that if BIH had removed the transmission before the accident, the accident would not have happened. In our view, the retention of the transmission in the helicopter is a causa sine qua non of the accident and does not assist in attempting to discover the causa causans of the accident which is the purpose of accident investigation (Regulation 4). On 8 September 1986, because of the SOAP count on the transmission A7-1625, Mr O'Hara on the hangar report made the following recommendation "2. Plan to change the FWD TX (that is, "forward transmission") A7-1625 week commencing (which should properly be "week ending") 12/9/86". On that hangar report in relation to the box for SOAP count were the words "See attached report". Presumably the attached report is the computer representation of SOAP results also dated 8 September

where all the elements are listed. On that document Mr O'Hara has starred these readings and circled aluminium, copper and iron. The star leads to a note at the bottom of the page which is in the following terms: "Recommend that this transmission be changed week ending 12/9/86". At that stage, there was no recommendation that the craft be immediately grounded and the transmission be immediately removed.

On 12 September 1986, in the context of an iron count of 17 Mr O'Hara made the following recommendation "3. Plan for a TX (that is "transmission") change in the near future".

On 4 November 1986, when the SOAP count was 24 for iron, Mr O'Hara's recommendation was "3. Please have a FWD TX standing by for this weekend". Again, there was no recommendation for an immediate withdrawal of the transmission: indeed, Mr O'Hara said that this last instruction was merely an element in forward planning. He had no reason to recommend the immediate withdrawal of the transmission, "because I didn't think the transmission was about to fail", and there was nothing in the manual of Boeing Helicopter Company which required withdrawal of the transmission. What was being looked for was whether the new -6 configuration was achieving its purpose, namely, to create adequate clamping of the joint; and all the evidence indicated that it was. As has been indicated earlier in relation to torque values, two in situ torque checks before the accident were within the recommended values of Boeing Helicopter Company whereby the transmission was to be regarded as fit for service; and the torque values found on the gear after the accident were also within these recommended values. Even if an operator had removed the transmission from the aircraft, there was no mandatory rule in the manual of Boeing Helicopter Company that the joint should be opened up and inspected.

Mr O'Hara appreciated that the SOAP values were erratic, but his aim all along had been to find out what these values indicated by way of damage: "Well, if these figures do not cause you to think that there may be anything happening in the bolted joint assembly in A7-1625, and if when you compared 1625 with 1533, there was some coincidence, why did you consider that there was anything about 1625 that you thought would require the sort of action you recommended? - Because it was my job to make sure that we didn't have any secondary damage. From past experience, we have found if we had caught a bearing in the early stages we would have spent perhaps £5,000 overhauling the transmission, whereas if we left it for a month or two, we could end up with spending £30,000 overhauling the transmission. And so I felt it as my job at the early stages of any wear problem to highlight it, and then the decision was to be made by someone else whether they pulled the transmission or not. Mine was just a recommendation saying, 'This is what I see, this is what I feel, it is up to you'". Mr O'Hara had seen what, at that time, he considered normal wear on the transmission A9-1533 after 1,200 or 1,300 hours and had no reason to think that the failed gear would be any different from A9-1533. There had been no loss of torque in that transmission. And the transmission A9-1533 had been sent back by BIH to Boeing Helicopter Company in or about June 1986 for investigation. From time to time

thereafter, Mr O'Hara telephoned Boeing Helicopter Company about what was happening in relation to the gear: he was told it was being investigated. In November, after the accident, Mr O'Hara noticed a similarity of wear patterns on the failed gear (A7-1625) and the gear in the hands of Boeing Helicopter Company (A9-1533) and asked for their report. In the middle of November 1986, Boeing Helicopter Company sent BIH a copy of their report on A9-1533 which was dated 9 October 1986. The report did not contain any recommendations from Boeing Helicopter Company to BIH in relation to that gear.

During the life of the transmission A7-1625, Mr O'Hara had been in touch with Boeing Helicopter Company. Their Mr Ayoub had concluded that it was a cage wear problem. And Mr O'Hara concurrently carried out health monitoring procedures other than SOAP.

The decision of the management of BIH whether or not to withdraw the transmission from service was beyond the requirements of the SOAP programme; and did not bear on the reputation of Boeing Helicopter Company. There was a design flaw here, and according to Dr de Luccia, the expert witness called on behalf of Boeing Helicopter Company, the gear was bound to fail ultimately (8.653). And it must tell against the case of Boeing Helicopter Company, that they did not call as witnesses the very persons in BIH who would have told the Review Board what the reasons of BIH were for not following out Mr O'Hara's recommendations.

Accordingly, the Review Board for these reasons confirmed finding (ii) in its entirety. Regulation 14(8), under which the Review Board makes its report to the Secretary of State, refers to those findings and conclusions of the Inspector "which were the subject of the review". We thought it appropriate as part of the reasons for "confirming or rejecting in whole or in part" the findings and conclusions and in the interests of completeness to indicate our view of the challenges which Boeing Helicopter Company made to the findings "by reason of which its reputation is likely to be adversely affected". We deal with the items in the challenges seriatim.

3.1.2 Notice of Review, para 1

Our view of the challenges contained in the notice of review is as follows:

1. The operator, its servants, agents and/or contractors did not fail properly to rework certain components to the standard laid down in the manufacturer's SB 234-6-1014, being the modification (to -6 status) concerning the ring gear and sun gear shaft of the forward transmission.

2. The whole of paragraph 2 has not been established, in respect that Boeing Helicopter Company have departed from their challenge in so far as it related to Presto Black.

3. The operator's implementation of a spectrographic oil analysis programme (SOAP) does not imply misleadingly that the operator's actions were in accordance with the manufacturer's programme: the operator's programme was more stringent in its limits but indicated higher sampling intervals which were agreed by Boeing Helicopter Company and CAA.

4. It is correct that the manufacturer's programme unequivocally sets out the frequency and standard of checks required, the critical rates as to contaminants in the oil that must not be exceeded and defines the mandatory action required if such critical rates should be exceeded.

5. It is true that the implementation of the programme requires a defined level of correlation/plotting by graphs of information.

6. As performed by the operator, these standards were achieved.

7. There was no recommendation from the operator's management.

8. There was a recommendation that the transmission be removed from service at a later date by reason of SOAP results but these levels began to go down.

9. The recommendation was not followed by the management of the operator. It was asserted on behalf of Boeing Helicopter Company that the best engineering advice was to withdraw the transmission; and the decision to withdraw or not to withdraw the transmission from service was a matter of judgment. Mr Paschal could not say if the decision was justified (12.1207D). Mr O'Hara was not an engineering manager: he was giving his recommendation to management; but none of these engineering managers were called as witnesses by Boeing Helicopter Company - even although at the Fatal Accident Inquiry in May 1987, at which Mr Jones and Mr Anderson, respectively counsel and solicitor for Boeing Helicopter Company, were present, Mr McAskill deponed that it had been he who had made the decision to overrule Mr O'Hara. In any event that decision did not affect the reputation of Boeing Helicopter Company.

3.2.1 Finding (vi)

In relation to finding (vi), the second sentence, "The manufacturer's Service Bulletin detailing the modification had received engineering approval from the FAA and was approved for embodiment into UK registered aircraft by the CAA" is purely factual and is not disputed. Accordingly we will confirm that part of finding (vi).

The first sentence in finding (vi), namely, "Spiral bevel ring gears within some BV 234 transmissions, including G-BWFC, had been modified to eliminate a loss of torque which was occurring on the bolts clamping the ring gear to the sun gear shaft" is on the face of it correct, but it appears from the notice of review that the contention of Boeing Helicopter Company is that the bolts were insufficiently torqued. In the view of the Review Board, it is not

proved that the gear was insufficiently torqued; and Boeing Helicopter Company have not been able to prove that the bolts were torqued to the -5 values. Further, we do not accept that low torque values would have given a more serious corrosion degradation: as we have found above, increased torque resulted in narrower but deeper grooves. Dr De Luccia, the expert for Boeing Helicopter Company, would not accept the statement in the notice of review, "that if bolts were insufficiently torqued there may have resulted additional motion and wear which may have created conditions conducive to the initiation of the corrosion process" (8.667F - 668C); and there is no-one else on whom Boeing Helicopter Company could rely for this assertion. Dr De Luccia had to assume that the gears A7-1625 and A7-1600 were torqued at different values but there was no supporting evidence of that. The only evidence of that is what Mr Cunningham (who was not a witness in the present proceedings - although on the witness list of Boeing Helicopter Company) said to Dr De Luccia; but the other evidence is to the effect that the torque values were the same for both gears. If it were to be contended that the gear A7-1625 by reason of the figures in the history sheets was torqued to -5 or -6, there is no reason to differentiate it from the gear A7-1600 which proceeds on the same pro forma history sheet with the same torque values printed there. Dr De Luccia was of the view that A7-1625 was unique whereas Mr King was of the view that it was not. Further, if the Boeing Helicopter Company were convinced that A7-1625 was unique, they did not, when asked, carry out any tests to show that it was.

For these reasons, we confirm finding (vi) in its entirety.

3.2.2 Notice of Review, para 2

As far as the challenges contained in the notice of review are concerned, our findings are as follows:

1. The modification (to -6 status) was not improperly effected either in the use of Presto Black (which part of the notice of review has been departed from) or in the application of insufficient torque to the clamping bolts.
2. It is correct that torque was required for each bolt in the range of 1065 - 1215 in.lb. and that on disassembly at RAE Farnborough of the bolts on the failed ring gear, torque was measured in the range of 288 - 804 in.lb.
3. It is not established that if the bolts were insufficiently torqued there may have resulted additional motion and wear which may have created conditions conducive to the initiation of the corrosion process.

3.3.1 Finding (xiii)

Finding (xiii) which is in the following terms "The 'in service' inspection programme, which was based on the results of tests of an aft transmission and previous service experience of both transmissions, was not adequate to reveal the impending failure of

the forward bolted joint" is also the subject of challenge by Boeing Helicopter Company. In so far as that finding relates to SOAP, we have already dealt with the evidence and to that extent would confirm this finding also. In so far as (if at all) the finding relates to the in situ torque check, we have also dealt with that, and would again confirm that aspect of the finding. Accordingly, finding (xiii) falls to be confirmed in its entirety.

3.3.2 Notice of Review, para 3

In relation to the matters in the Notice of Review, we find as follows:

1. The operator did not fail to act on the implementation of SOAP and other maintenance/inspection procedures.
2. The operator did not allow levels of contaminants to exceed the approved critical rates on several occasions prior to the accident.
3. There was no mandatory requirement to replace the transmission at the levels of contaminant which were reached.
4. In so far as the last clause suggests that there was a mandatory requirement to withdraw the transmission, it is true that that is not contained in the Inspector's report. However, the recommendation in terms of the manufacturer's programme was further monitoring which was carried out by the operators.
5. It is not proved that the examination of the transmission A7-1581, some six months before the accident, did or should have put the operator on notice of the mode of failure now reported upon.

It appears to be common ground that the total time in service of A7-1581 was 326 hours but that the transmission had been opened up at 105 hours (14.1525B and 15/2 of process). Mr Binder said that he would have expected to see distress in the gear that was different from anything that would have been seen on a -5 gear - a narrow banded groove (14.1529). Later he said that his view was that in the environment that the aircraft was operating in, we would have got a progressive removal of material through a corrosion process on the gear flange; but he conceded that he was not a corrosion expert and his view proceeded on listening to various metallurgists (15.1572). The fact that the gear A7-1581 had been opened up at 105 hours was only learned about by Boeing Helicopter Corporation and AAIB after the accident. While Mr King saw the gear after the accident he regarded it as impossible to speculate on what the gear may have looked like at 105 hours even with information on gears which had seen service of 300, 600 and 1,600 hours (17.1955C - D). We preferred the view of Mr King that the groove development was likely not to be linear and accordingly it would be impossible to extrapolate the data back with certainty as to the condition of a 105 hour gear (17.1956). This was another instance where a witness, likely to have knowledge of a matter, was not called by Boeing Helicopter Company. The gear A7-1581 was not seen by Mr Binder at 105 hours of service, but he purported to say

what its appearance would be (15.1563C): he had seen photographs of it. But Mr Redhead, who had seen the gear at the time and who had been precognosced by Mr Anderson on that point, was not called as a witness. A further possibility was that in the early stages, there was a slower progression of damage which accelerated, and the damage could have been even less than two to three thousandths of an inch at 100 hours (18.2013). On the other hand, the evidence of Mr Binder proceeded on a lack of expertise in corrosion and on second hand knowledge.

3.4.1 Conclusion as to Cause

The final matter in the report which is challenged by Boeing Helicopter Company is the conclusion as to cause. It is clear that the challenge does not extend to the first paragraph of the cause. Accordingly we confirm that part of the cause. The second paragraph of the conclusion as to cause is in the following terms "Underlying causes were the inadequacy of the hitherto accepted aircraft industry standard of test programme carried out by the manufacturers and the insufficiently stringent inspection programmes required by the FAA and the CAA". It appears from the notice of review, paragraph 4, that in this regard Boeing Helicopter Company are limiting their challenge to the torquing of the nuts on the failed gear and the SOAP programme. Because of the view that we have taken with regard to both these matters earlier in the report, we would merely confirm, without repeating the reasons, the finding as to cause in its entirety.

3.4.2 Notice of Review, para 4

In relation to the matters specified in that paragraph 4, our findings are:

1. There was no impropriety of the operator's technique in effecting SB 234-63 1014.
2. The operator's SOAP technique was a more stringent programme than that proposed by Boeing Helicopter Company.

3.5 Summary

Elsewhere in our report, we deal with our view of the scheme envisaged by the Regulations. At this stage, we would merely refer to the inspector's report especially at pages 30 - 39 where it is made clear that no experience from any source existed before the accident to suggest that it was foreseeable. If that is correct, then it is difficult to see how the reputation of Boeing Helicopter Company has been adversely affected. In this regard, the evidence of Mr King is illustrative:

"Do you consider that any of these findings or the underlying cause adversely affect Boeing's reputation? - I do not believe they do in my interpretation of them. In fact quite specifically adding in the hitherto accepted aircraft industry standard was to hopefully indicate that the thrust of the report was not that this particular

company had in some way been deficient but that perhaps the whole industry really had to learn something from the accident." (17.1991D - F)

Our report, then, in terms of Regulation 14(8), confirms in whole all the findings and the conclusions of the Inspector which were the subject of this review, and that for the reasons specified in the report. The only remaining matter for decision by the Board is the question of expenses in terms of Regulation 14(7)(a). In our view, that provision envisages that the Board in deciding on the question of expenses should have regard to the whole circumstances of the review, but without prejudice to that generality, to consider the application of Regulation 11.

Sundry matters collateral to the facts in issue in this review were raised in evidence and in the submissions. We feel that these matters should be considered by us to see how far they relate to the question of expenses - and possibly also to the question of credibility.

4 Collateral Matters

4.1 Representation of Boeing Helicopter Company

Several witnesses were asked if the evidence which they were giving, represented the position which Boeing Helicopter Company was taking in this review: and in his submissions Mr Cameron for BIH said, "It is quite normal as I am sure you in the Chair, Sir, will know in cases of this kind to have a policy witness to speak on behalf of the organisation who is presenting the case, to tell the Review Board how Boeing see their reputation adversely affected, and the sort of evidence you get is 'Yes, we see our reputation adversely affected where the Board took the decision on that and on the technical advice received from our team we think that this and that all the rest are the items on which our reputation is adversely affected and we challenge it on that basis.'"

It appears to us that the word "representation" in this context is used in two senses: the formal legal representation of a party before the Review Board, and the presentation of the stance of that party in putting forward its case.

In our view, the evidence given by Mr Anderson, the instructing solicitor for Boeing Helicopter Company, gives the correct view of the first sense of that word. Boeing Helicopter Company is a corporation which, being a juristic person, can only appear in court or at a board such as this by means of a representative. The general rule in civil litigation is that a corporation cannot appear by itself, but can only be represented by counsel or a solicitor, not one of its servants: Equity and Law Life Assurance Society v Tritonia Ltd 1943 SC (HL) 88; but in the present proceedings, that rule requires to be qualified: while a corporation, by definition, cannot appear in person, it may be represented "by any other person": Regulation 14(3).

It appears from Mr Anderson's evidence that Boeing Helicopter Company had instructed attorneys at law in one of the states of the United States of America; and they in turn had instructed his firm; that firm in turn instructed Mr Jones as their counsel. Mr Jones is the person who speaks for Boeing Helicopter Company and, no doubt, as Mr Anderson pointed out, if Mr Jones was not representing Boeing Helicopter Company, Mr Anderson himself would.

On the other hand, whether or not it is normal or necessary that in a proceeding of this kind there should be a policy witness may not be of great moment in the circumstances. It is clear that there was no witness who could be put in that category; and even if a policy witness did assert that the reputation of Boeing Helicopter Company was adversely affected by these findings and that cause of the Inspector's report for the reasons specified in the notice of review, that assertion would have little or no weight where, as is the case here, the Board has found that all the material evidence is to the contrary.

4.2 Chronology of actings of Boeing Helicopter Company

A consideration of the scheme of the Civil Aviation (Investigation of Accidents) Regulations 1983 (SI 1983, No. 551) and the chronology of the events from the accident to the hearing of the Review Board, as well as the actings of Boeing Helicopter Company and their servants, are matters to be considered by the Review Board, not only in relation to the credibility of the case put forward by Boeing Helicopter Company, but also to the question of expenses.

The accident took place on 6 November 1986 at about 11.30 am. At about 12.15 pm, the accident was notified to AAIB (as required by Regulation 5(1)) and the investigation began. "The fundamental purpose of investigating accidents under these Regulations shall be to determine the circumstances and causes of the accident with a view to the preservation of life and the avoidance of accidents in the future; it is not the purpose to apportion blame or liability" (Regulation 4). Regulation 4 applies not merely to Part I of the Regulations which deals with accident investigation, but also to Part II, which governs the procedure of the present Review Board. For the purposes of the investigation, the Inspector has wide powers to collect information (Regulation 9). In this case, Mr Twilling, the senior accident investigator of Boeing Helicopter Company, came to Scotland immediately after the accident, and he was made aware of the available evidence; and Mr Pollard and Dr Peel went to USA where Boeing Helicopter Company assisted in the investigation. The Inspector is also required to give public notice to such persons as he thinks fit, inviting them to make representations concerning "the circumstances or causes" of the accident; and a part of the Inspector's function is to resolve any conflict of evidence: Regulation 10(3). From these provisions, it appears that the parties connected with the accident are expected to co-operate with the Inspector without regard to blame or liability.

Meanwhile, in March 1987, another different proceeding was begun while the Inspector's investigation was still under way. Then, notice was given of a Fatal Accident Inquiry to be held in Aberdeen. That Inquiry took place in May. Boeing Helicopter Company was represented at the Inquiry but they led no evidence at it. In June, the Sheriff Principal issued his determination in that Inquiry.

Towards the end of 1987, the Inspector had formulated his proposed analysis of facts and conclusions as to cause - in what has been referred to in these proceedings as the draft report. In terms of Regulation 11(1), Boeing Helicopter Company made representations which extended to over 100 pages: these are appended to their notice of review dated 8 March 1988.

The representations of Boeing Helicopter Company in so far as it related to the conclusions were limited to a challenge of finding (vi) (but without any challenge of torque) and to a challenge of the conclusion as to cause (but without any challenge as to torque

or SOAP). In addition, in their representations, there was no challenge, as there was in the later notice of review, of finding (ii) (under which Boeing Helicopter Company sought later to raise the question of torque and SOAP), finding (xiii) (under which they sought later to raise the question of SOAP) or of the conclusion as to cause (in so far as it related to SOAP). In addition, representatives of Boeing Helicopter Company had met the Inspector on 8 and 9 December and were in correspondence with him in January 1988 about the terms of the report.

As envisaged by the Regulations, the Inspector did take account of the representations and altered the factual information and the analysis; and he modified four of the findings as well as the conclusion as to cause and added two new findings, namely, (xi) and (xii).

In February 1988, the Inspector's final report, which is the subject of this Review Board, was prepared. According to Mr King, the Inspector, Boeing Helicopter Company, or their representatives were generally satisfied with the report: Mr Binder in evidence said, "We read the report and, generally speaking, it appeared satisfactory"; and in this context "we" included Mr Cunningham ("the chief Metallurgist at Boeing Helicopter Company" who was on the list of witnesses for Boeing Helicopter Company but was not called to give evidence by them), Mr Twilling, Mr Albrecht and Mr Paschal. Further, in evidence, Boeing Helicopter Company witnesses departed from the matters apparently raised for the first time in the notice of review. In addition, Mr King's evidence was to the effect that Boeing Helicopter Company had never made any issue of torque: "we did not have a low torque, a loose bolt problem" (17.1847A-B); and no question of additional factors affecting torque, such as lubrication or the use of Loctite, had been raised. Also, Mr Twilling conceded that he had known about the SOAP data and of Mr O'Hara's recommendation to withdraw the transmission A7-1625 while he was in Aberdeen in December 1986. That Boeing Helicopter Company might acquiesce in the terms of report would not be surprising because, in the conclusion as to cause, there are included the words "Underlying causes were the inadequacy of the hitherto accepted aircraft industry standard of test programme carried out by the manufacturers and the insufficiently stringent inspection programmes required by the FAA and the CAA". And a similar view was stated in the body of the report and by Mr King in evidence.

However, concurrently with the procedure under the Regulations, at some date possibly after the Fatal Accident Inquiry in May 1987, but certainly before November, a litigation was raised in respect of the passenger claims against Boeing Helicopter Company but not against BIH. That litigation was initiated in the State of Pennsylvania: by the time of the hearing of the review, at least, the defendants consisted of Boeing Helicopter Company and two of their employees who were also witnesses for them in the hearing, namely Mr Binder and Mr Albrecht. Mr Albrecht was being supported by Boeing Helicopter Company with legal staff, and Mr Binder chose to be represented by Boeing Helicopter Company's lawyers.

From the evidence before the Review Board and as a result of the agreed statements on behalf of Boeing Helicopter Company and BIH, it is apparent that sundry preliminary procedure had already taken place in that litigation in Pennsylvania on the question of choice of forum - whether the action should remain in one of the states of the United States of America, or be transferred to one of the judicial systems of the United Kingdom. Mr Binder understood that if the litigation returned to the United Kingdom, he would not be involved there. Counsel for Boeing Helicopter Company and BIH intimated to the Review Board that the insurers of BIH and the insurers of Boeing Helicopter Company had together agreed to offer settlement without contesting liability of passenger claims presented before the courts in Scotland or England, but without implying fault by either BIH or Boeing Helicopter Company.

In November 1987, the judge in the Pennsylvania court heard or had heard submissions of parties on the question of jurisdiction; and he had taken the matter for consideration. There is a procedure in that state whereby during the period when the case is being considered by the judge, the argument can be re-opened by parties, if further information becomes available. Apparently, this procedure had been resorted to once already by the parties to the litigation, and could be resorted to again - perhaps following the decision of this Review Board: Mr Albrecht said, "Certainly whatever facts are presented here would be available for that particular case, and therefore they must be properly represented". It was anticipated that the judge would give his decision in November 1988, but there would be no right of appeal against his decision. (However, according to a report in the Scotsman newspaper of 29 September a decision has been made. The report states

"An action group representing the two survivors and the families of most of those killed in the Chinook helicopter crash off Shetland in 1986 has won its fight to have damages claims heard in an American court.

The decision by a judge of the State Court of Pennsylvania sitting in Philadelphia opens the door to very large settlements, if the actions are successful."

The judge is quoted as saying that he would give his reasons within 30 days.)

After the Inspector has submitted his report to the Secretary of State but before publication, the Regulations provide a means of redress to a person whose reputation is likely to be adversely affected by unwarranted criticism of him contained in the findings or the conclusions of the report. Such a person may seek to have these reviewed by a Review Board, in terms of Part II of the Regulations. In our view, (as we have indicated earlier) that part provides for a very restricted procedure: it is not an appeal against the decision of the Inspector; it is not a litigation; and it is not an enquiry at large. The person who seeks to review the findings and conclusions in the report must be a person whose reputation is likely to be adversely affected by these findings and

conclusions; he must serve on the Secretary of State written notice of review within 21 days of receiving the report; and the notice of review must specify the findings and conclusion that it is considered should be reviewed, state concisely the grounds on which the findings and conclusion are challenged, and append a copy of the representations previously made under Regulation 11.

In form, Boeing Helicopter Company carried out these provisions. However, not only did the notice of review prepared by Boeing Helicopter Company raise matters which had not been in issue earlier, but also Mr Jones for Boeing Helicopter Company sought to challenge, in addition, findings (ix) and (xv): but the Board rejected that proposal because it was being put forward long after the 21 days specified in Regulation 12(1).

The evidence of the witnesses for Boeing Helicopter Company was that technical employees of the company had been involved in the making of the representations under Regulation 11: the persons involved were Messrs Twilling, Cunningham, Binder, and Albrecht. But they had little, if any, involvement in the matters specified in the notice of review. We have decided, as has already been indicated, that in so far as material the grounds on which the findings and conclusion are challenged by Boeing Helicopter Company as adversely affecting their reputation are unfounded in fact.

From this narration of the actings of Boeing Helicopter Company from the date of the accident until the Review Board, it appears to us that the grounds stated in the notice of review represent a change of front on the part of Boeing Helicopter Company from their attitude before that; and they seek to raise matters which were never previously in contention and which were not the subject of representations to the Inspector in terms of Regulation 11.

It was suggested, particularly by Mr Cameron, that "it is plain here that what they want are findings or comments from the Board, decisions from the Board which will lay a foundation for alleging fault in the United States proceedings". In our opinion, the actings of Boeing Helicopter Company between the time of the accident and the hearing of the Review Board may well bear such an inference; but we feel that it is neither appropriate nor necessary for us to make a finding to that effect. However, these actings of Boeing Helicopter Company are matters which may be properly taken into account along with the whole other evidence in the case in assessing credibility and coming to a decision on the facts of the case; and these actings are also relevant to the question of expenses, especially when Regulation 14(7) singles out one particular consideration, namely, whether or not the person to be found liable in expenses "took advantage of such opportunities as were open to him to make representations under Regulation 11".

5 EXPENSES

5.1 Expenses in General

Expenses before this Review Board are governed by Regulation 14(7)(a) which, as amended in the application to Scotland, is in the following terms: "The Review Board may, if it thinks fit, order any person who appears or is represented as mentioned in paragraph (3) above to pay in respect of the expenses of the Review Board such sum as may be specified in the order, or the taxed amount of those expenses or such part thereof as may be so specified upon such basis as may be so specified, and, without prejudice to the generality of the foregoing, the Review Board shall, in determining whether to make an order as to expenses against any person, have regard to whether or not that person took advantage of such opportunities as were open to him to make representations under Regulation 11 above or, where that person gave new and important evidence to the review and the review was discontinued, whether or not that person could reasonably have given that evidence at the Inspector's investigation". (On the first day of the hearing, the Board specifically referred parties to these provisions.)

Thus, there is power to find a person liable in the expenses of the Review Board: there is no power to find any person who is a party to the proceedings liable to pay the expenses of any other party apart from the provisions of regulation 13(5) which are discussed later. In our view, if it was intended that there should be such a power, the regulations could easily have provided for it. It appears to us that the purpose of the regulations is not to deal with a question of success as in civil litigation but to decide whether the cost of the Review Board should be met by the public purse or not.

5.2 Recommendations on Expenses

In regard to expenses of parties Mr Cameron for BIH said in his general submissions to the Review Board "Now, usually in a case where a party seeks to fight the litigation and they lose at the end of the day, for whatever reasons, there is the sanction of expenses. Not so here - the expenses section is as I have information is very limited and the result has been the parties here have been put to very considerable financial burden on what at best is a hopelessly weak argument on its merits, and at worst is an enquiry for a purpose other than the purpose that an enquiry of this kind should be directed to. And in that situation the Board may feel it appropriate to say something which could have the effect, at least, of preventing, trying to prevent this sort of situation happening again, at least without risk of having to pay all parties expenses". Mr Cameron went on to touch on the possible cost of making tests and the cost of the Review Board and to suggest that the Board might think it appropriate to say something to the effect that if Boeing Helicopter Company had to pay all the expenses of every party they might think twice about coming to this Review Board. We see considerable force in what Mr Cameron said; and one can envisage the reverse of the coin where an individual

such as a pilot who has appeared justifiably throughout the proceedings of the Review Board at considerable expense would be unable to recover his expenses. However, we feel that this is a matter which is a question of policy and which is beyond our remit. On the other hand, the operation of Regulation 14(7)(a) has presented the Review Board with some difficulty which we feel is more of a procedural matter on which we required to make a decision.

Regulation 14(7)(a) envisages that expenses will be dealt with while the hearing of the review is still proceeding: but once the review is completed and the Review Board has reported to the Secretary of State, the Board would be functus and would not be in a position to hear any submissions of parties on expenses; and if the Review Board were minded to hear parties before the report was submitted to the Secretary of State, the parties could not give any worthwhile submissions on expenses unless they knew what the decision of the Review Board was likely to be. As the Regulations stand, there is no power granted to the Board to allow parties to see the report or a draft report before it is made to the Secretary of State.

Parties in this Review Board made suggestions as to how to operate the Regulations in this situation. It was agreed by them, at the end of the submissions on 25 August, that the Review Board should adjourn the review until a date - to be fixed by the Board and intimated to the parties by the Clerk - by which time the Board would have come to a decision on whether the challenge to the Inspector's report had been made out. That continued hearing took place on 16 December 1988: it was "held in private" in terms of Regulation 13(4) it being in the public interest so to do. Prior to the private hearing, the Review Board indicated by confidential letter to the parties that the Review Board would wish to have the submissions of parties (without prejudice to any decisions which the Review Board might make) on expenses on the basis of certain propositions, and on that basis the parties did make their submissions on the question of expenses.

The Review Board feel that consideration might be given to amending the Regulations in this procedural aspect, perhaps in the manner similar to that adopted by this Review Board on this occasion.

5.3 Expenses in this Review Board

As to the submissions made on the question of expenses, the Board took into account the actings of Boeing Helicopter Company in the following particulars: Boeing Helicopter Company failed to establish what they set out to prove; and that they failed properly to take advantage of such opportunities as were open to them to make representations under Regulation 11. (There was no question of new and important evidence being given as a result of the notice of review by Boeing Helicopter Company.) Taking into account these matters, we ordered in terms of regulation 14(7)(a) that Boeing Helicopter Company should pay the expenses of the Review Board as taxed to the extent which we specify later. In our view, the phrase "the expenses of the Review Board" should be given its natural meaning, namely, the proceedings of the Review Board. The

regulation does not in our view restrict it to merely the three members of the Review Board: indeed regulation 14 is headed "Proceedings of the Review Board". By that definition we would exclude the expenses of the parties who appear by virtue of regulation 14(2). On the other hand we regard the expenses as covering the proceedings from the date of the notice of review, and as including the expenses of the persons who are obliged by the regulations to render assistance to the Review Board: these parties are the Crown Agent and the Chief Inspector of Accidents.

We see no reason to specify in our order that Boeing Helicopter Company should be liable for less than the whole expense of the Board except in respect of the periods in this hearing taken up by objections which were, at that time, decided in favour of Boeing Helicopter Company: we specify that the taxed expenses shall be reduced by the sum of £5,000.

We have accordingly made an order by interlocutor dated 19 December 1988 - which will be part of the minutes of the Review Board - ordering Boeing Helicopter Company to pay the taxed amount of the expenses of the Review Board less that sum to be dealt with in terms of regulation 14(7)(b) and (c).

(Sheriff P G B McNeill, QC)

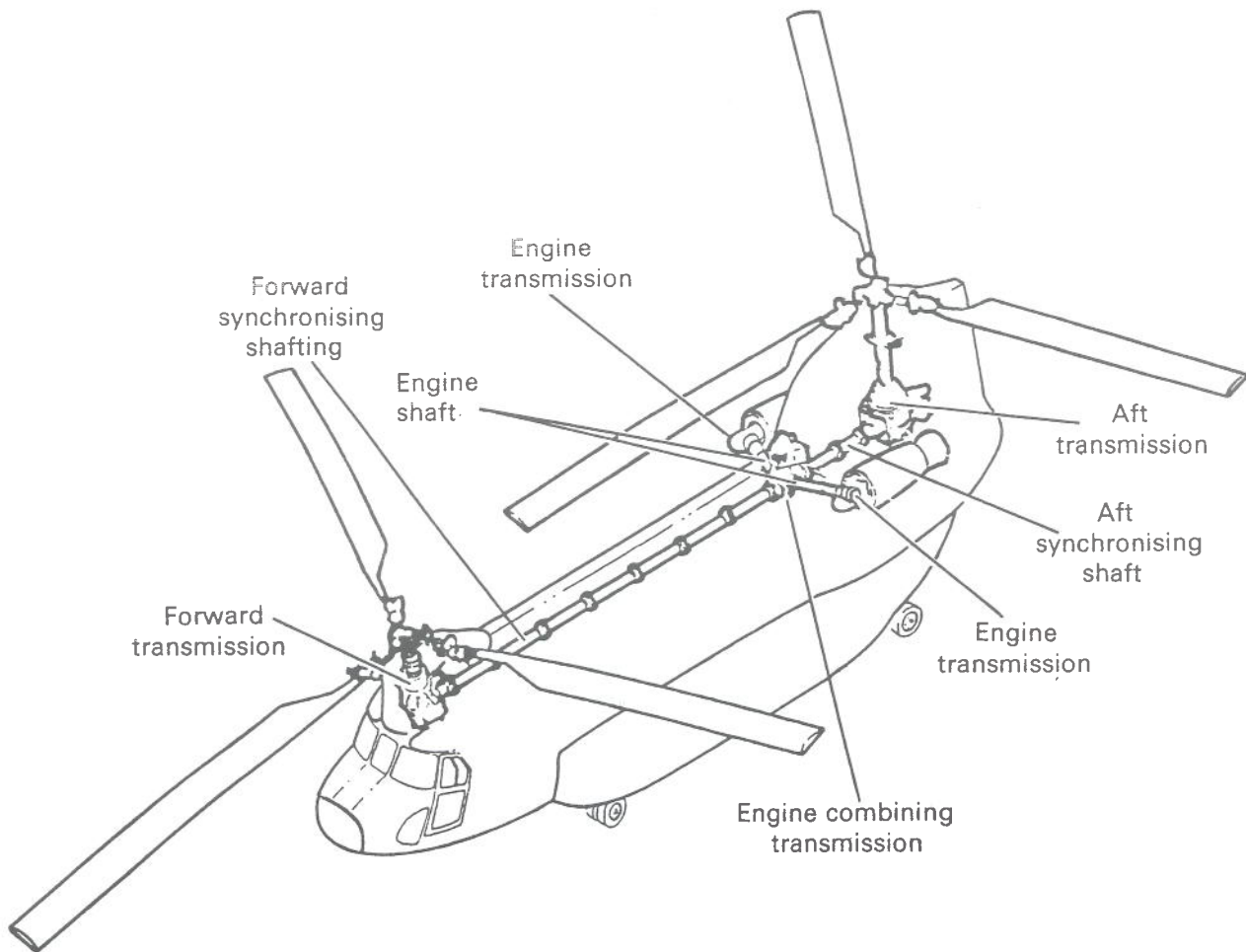
(Professor P Hancock)

(Mr K V Kellaway)

6 Figures

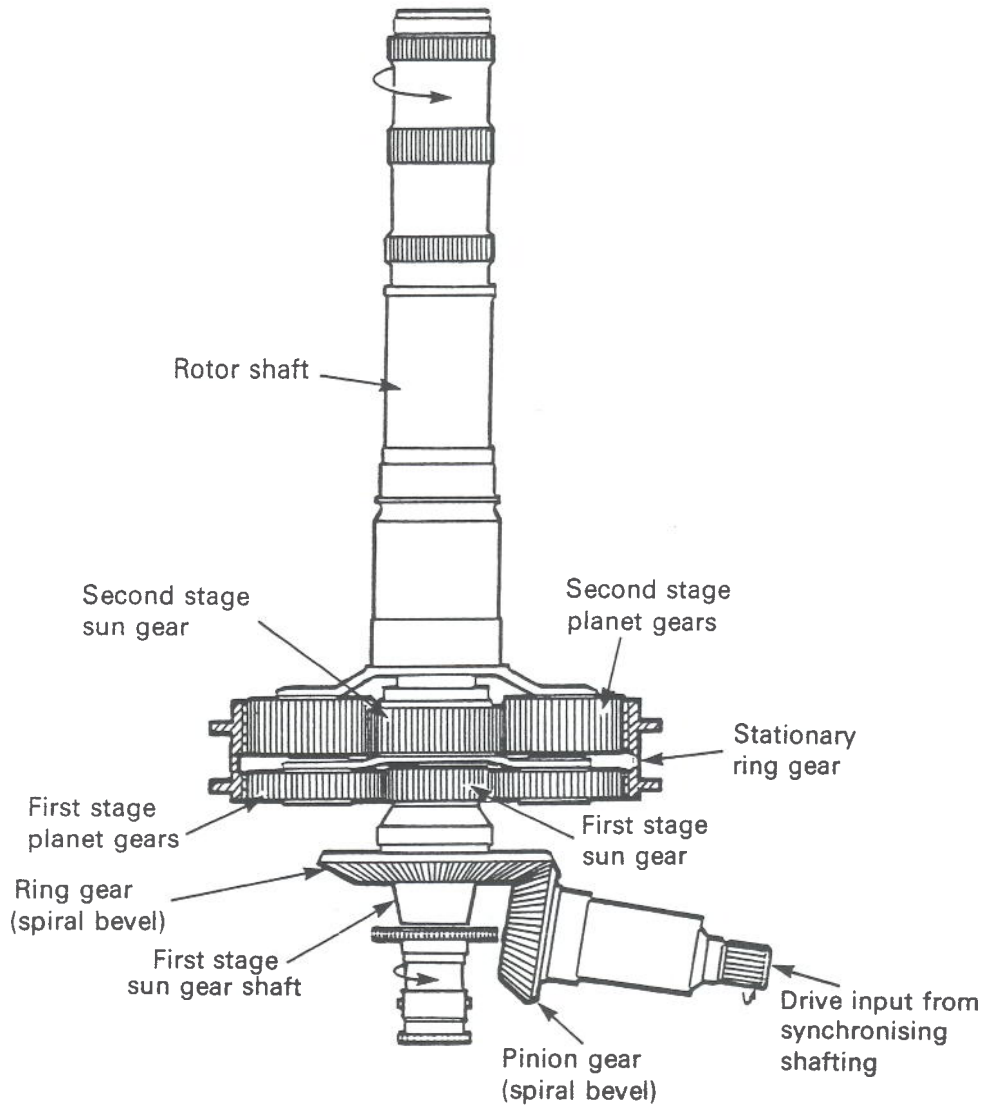
- 1 BV 234 main drive system
- 2 Forward transmission gear train
- 3 Assembly of spiral bevel ring gear
- 4 Spiral bevel ring gear after recovery
- 5 Scalloped shim
- 6 Solid shim
- 7 Breakaway torque values for modified transmissions

FIGURE 1



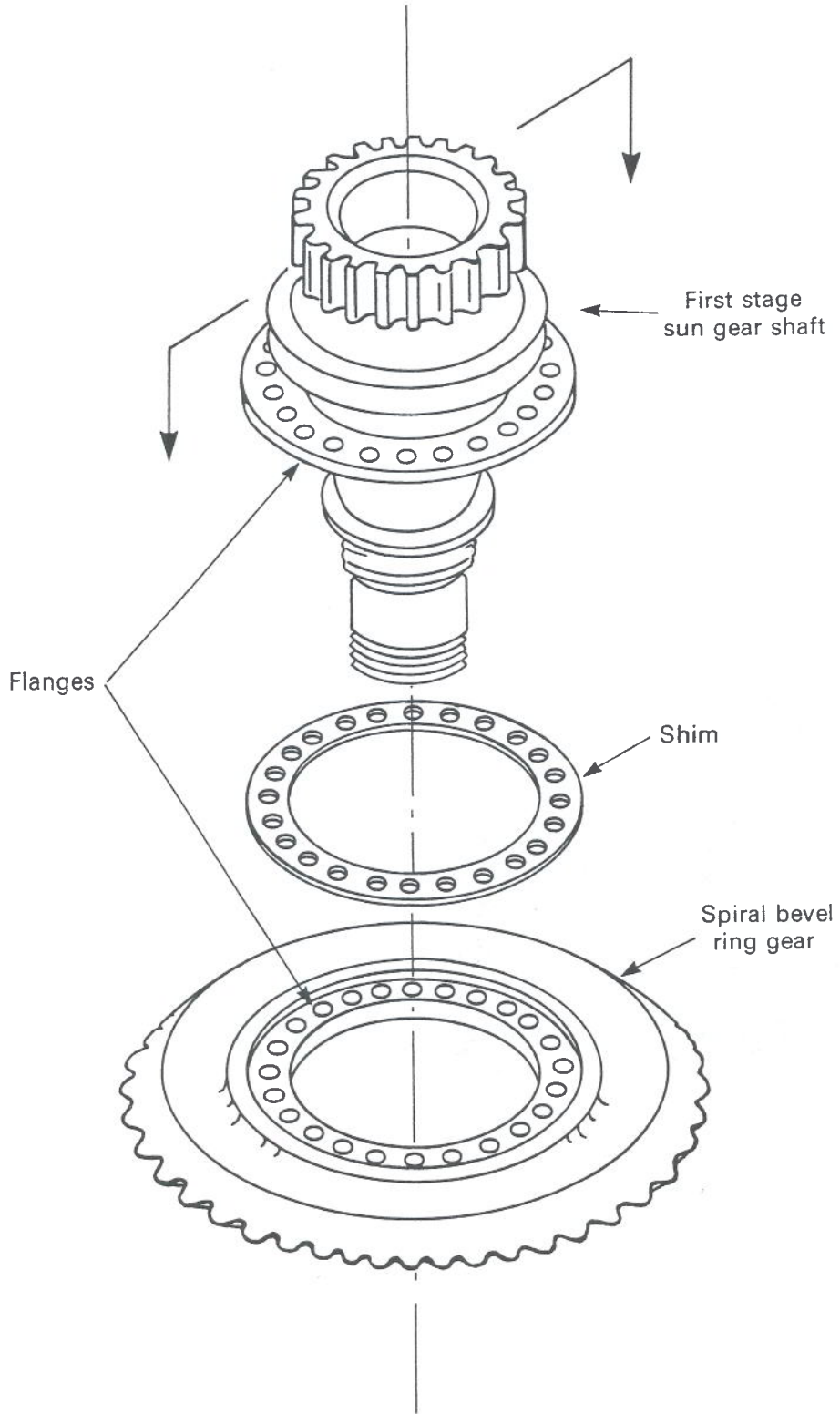
BV234 Main Drive System Component Layout

FIGURE 2



BV234 Forward Transmission Gear Train

FIGURE 3



Exploded Diagram of Assembly of Spiral Bevel Ring Gear onto First Stage Sun Gear Shaft (24 Clamping bolts not shown)

FIGURE 4



(Photograph taken after removal from transmission for clarity)

View of Spiral Ring Gear on Sun Gear Shaft as first seen

FIGURE 5

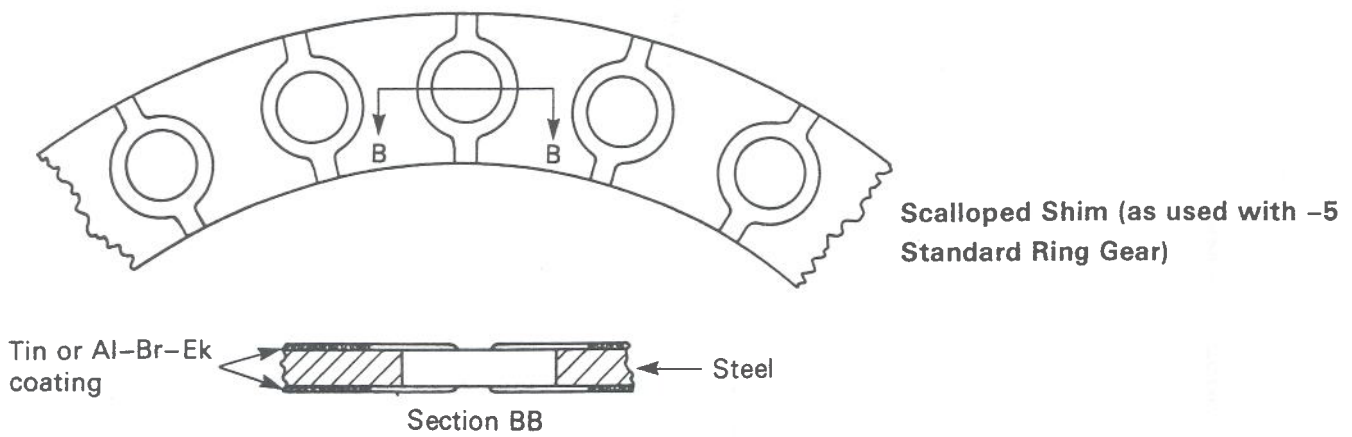
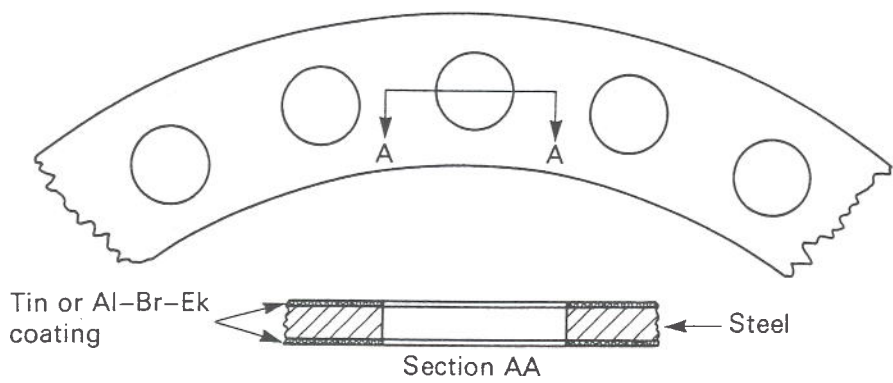


FIGURE 6



Solid Shim (as used with -6 Standard Ring Gear)

BREAKAWAY TORQUE VALUES FOR MODIFIED TRANSMISSIONS OPERATED BY BIH AND HELIKOPTER SERVICES

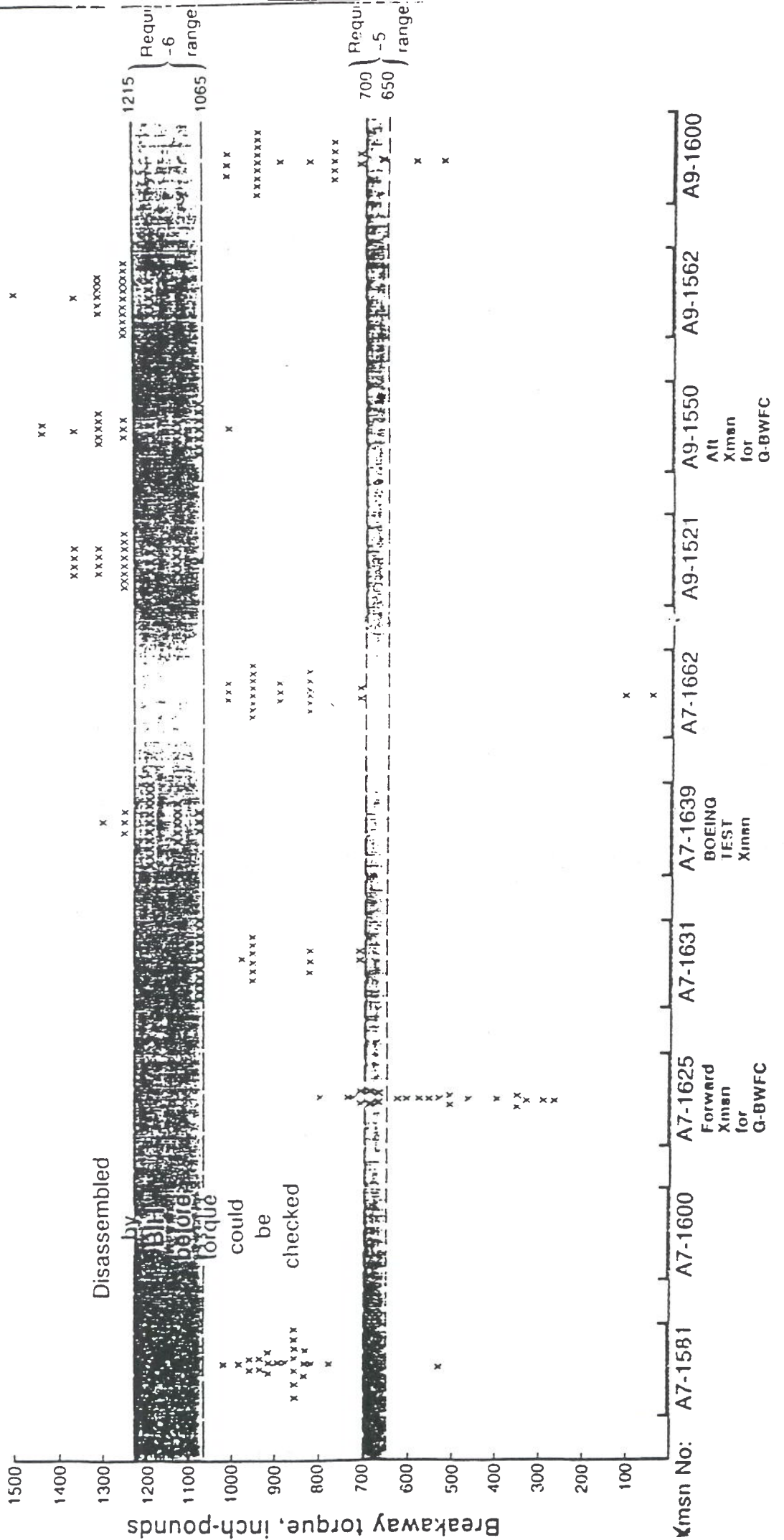


FIGURE 7