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ROBINSON R22 HELICOPTER AERIAL MUSTERING USAGE INVESTIGATION

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SUMMARY

The Robinson R22 light two-place helicopter is used extensively in northern Australia for aerial cattle mustering. The Australian Transport Safety Bureau (ATSB) is concerned that the usage spectrum of this role may have structural component life effects that were not addressed in the certification of this rotorcraft.

The ATSB contracted AeroStructures to install MaxLife, an aircraft usage monitoring system, in a single Robinson R22 which was then flown and monitored through a full northern Australian cattle mustering season. Flight usage data was returned from the field on removable memory cards throughout the trial. Further data, stored in the MaxLife systems onboard memory, was retrieved at the end of the trial. The MaxLife system behaved well throughout the trial in extremely harsh conditions, with no operator intervention other than removal and replacement of the memory cards.

At the conclusion of the trial, the usage data was analysed. Usage was found to be significantly different to certification usage, both in frequency and type of manoeuvres. To determine the effect of the most severe manoeuvres on the R22, the MaxLife system was fitted to a strain-gauged R22 belonging to the Robinson Helicopter Company (RHC), and typical aerial mustering manoeuvres were performed and recorded.

The results of the usage trial and the flights by the strain-gauged R22 were then combined to assess the impact of aerial mustering usage on R22 structural airworthiness.

TABLE OF CONTENTS

FIGURES

TABLES

ANNEXES

REFERENCES

Reference No **Reference Description**

1. ATSB Aviation Research Paper BE04/75 *Light Utility Helicopter Safety in Australia* dated June 2004
2. ATSB Service Agreement B2004/0292 dated 6 December 2004
3. ATSB Deed to Vary Service Agreement TRS04/091 dated 21 March 2006
4. AeroStructures Engineering Order EO-MAXLIFE-51-ASM369 dated 26 April 2005
5. AeroStructures Engineering Order EO-MAXLIFE-51-ASM370 dated 26 April 2005
6. Teleconference ATSB/RHC/AeroStructures on 8 December 2005
7. CASA Airworthiness Bulletin 02-015 *Helicopter Effects of Fatigue on Time Limited Components*
8. Robinson Helicopter Company Specification R1R-005 Rev B *R22 Flight Spectrum* dated 22 July 2005
9. Robinson Helicopter Company letter *Evaluation of Mustering Data* dated 8 June 2006.

ABBREVIATIONS

Abbreviation	Abbreviation Description
ATSB	Australian Transport Safety Bureau
CASA	Civil Aviation Safety Authority
GAG	Ground-Air-Ground
MAP	Manifold Pressure
OAT	Outside Air Temperature
RHC	Robinson Helicopter Company
TRDS	Tail Rotor Drive Shaft

REVISION CONTROL PAGE

Revision No	Date of Issue	Description
1	13 February 2007	Revision No 1 – Initial Issue
2	3 September 2007	Changes to Section 5 to include revised hours

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1. INTRODUCTION

1.1. This study was prompted by ATSB concerns that aerial mustering usage could have adverse effects on the structural integrity of the light utility helicopters used in this role. The Robinson R22 is the helicopter most commonly used in this role, flying over 67% of the aerial mustering hours in Australia (Reference 1). The R22 fleet comprises 32% of the total Australian helicopter fleet and 37% of the total hours flown by Australian helicopters.

1.2. Under the ATSB Service Agreement (Reference 2), AeroStructures provided the MaxLife usage monitoring system and Heliwork WA Pty Ltd provided a Robinson R22 helicopter for a one-season investigation into the effect of aerial mustering on the R22. Heliwork undertook to fly the R22 in the aerial mustering role, rotating four pilots through the aircraft as the aerial mustering season progressed. By this means, the usage data collected was expected to be adequate for defining the aerial mustering role.

1.3. This investigation of aerial mustering with the R22 included:

a. modification of a MaxLife usage monitoring system to monitor the usage of a Robinson R22 helicopter,

b. fitment of the modified MaxLife system to a Robinson R22 helicopter owned and operated by Heliwork WA Pty Ltd,

c. collection of usage data from that helicopter over a full northern Australian mustering season,

d. analysis of this data to establish typical regimes and significant manoeuvres for this role with respect to fatigue lives of either dynamic or airframe components,

e. repeating manoeuvres representative of aerial cattle mustering during a limited flight trial with an RHC strain-gauged R22 fitted with MaxLife,

f. comparison of strain gauge data from this trial with data from certification type flights,

g. application of the MaxLife usage data to derive a typical load spectrum for aerial mustering usage for components with significant mean or cyclic loads during aerial mustering manoeuvres,

h. assessment of the severity of the aerial mustering usage for these components against the certification baseline usage for the Robinson R22, and

i. identifying additional issues to be considered when estimating component lives for usage of the R22 in the aerial mustering role.

1.4. The original contract with ATSB did not include the aims in paragraph 1.3.d. These aims were added as part of a contact amendment (Reference 3) after the usage trial was complete.

2. ROBINSON R22 HELICOPTER

2.1. The Robinson R22 series of helicopters is certified under Federal Aeronautical Regulation 14 Part 27 dated 1 February 1965. The helicopter provided for the aerial mustering usage trial was a Robinson R22 Beta helicopter, registration VH-LKK (see Figure 2.1), serial number 1625, owned and operated by Heliwork Pty Ltd, Kununurra Airport, Kununurra, WA. The R22 Beta helicopter is a light, two-place helicopter powered by a Lycoming O-320-B2C engine.

Figure 2.1: The Usage Survey Helicopter

2.2. The trial helicopter was fitted with the optional auxiliary tank, increasing its fuel load to 19.8 US gallons in the standard main tank plus 10.9 US gallons in the optional auxiliary tank.

2.3. The only other significant modification relevant to this trial was that the main rotor braking system had been removed, resulting in a very gradual main rotor slowdown after engine shutdown. This is typical for the use of an R22 in the cattle mustering role.

3. MAXLIFE

3.1. Introduction

3.1.1. The MaxLife system was developed for AeroStructures by Altair Avionics Corporation. The system was designed for gathering usage data from United States Navy and United States Coastguard Seahawk and Jayhawk helicopters. It has since been fitted to other aircraft and is intended for use as a general-purpose aircraft usage monitoring system.

3.1.2. The standard MaxLife system consists of a main processor, a pitot-static pressure measurement module, a three-axis fibre-optic gyroscope and a memory card writer, plus various external sensors (see Figure 3.1).

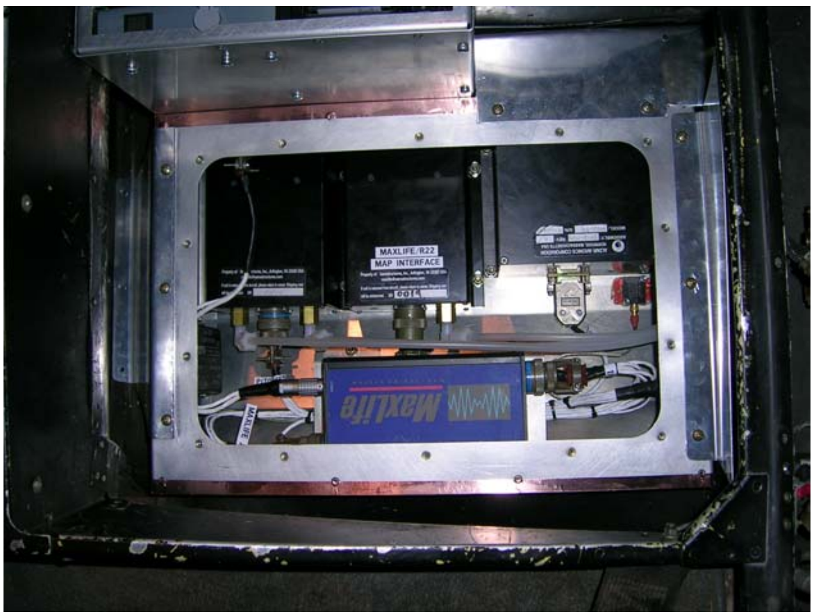

Figure 3.1: The MaxLife Usage Monitoring System

3.2. Modification for the Trial

3.2.1. The Robinson R22 helicopter posed some installation challenges due to its minimal instrumentation, 13.8 volt electrical bus and internal combustion engine. A special module (see Figure 3.2) was designed for the MaxLife system for this trial to overcome these problems, and further functionality was added at the request of the Civil Aviation Safety Authority (CASA) to maintain a permanent non-volatile record of hours data in the modified MaxLife system.

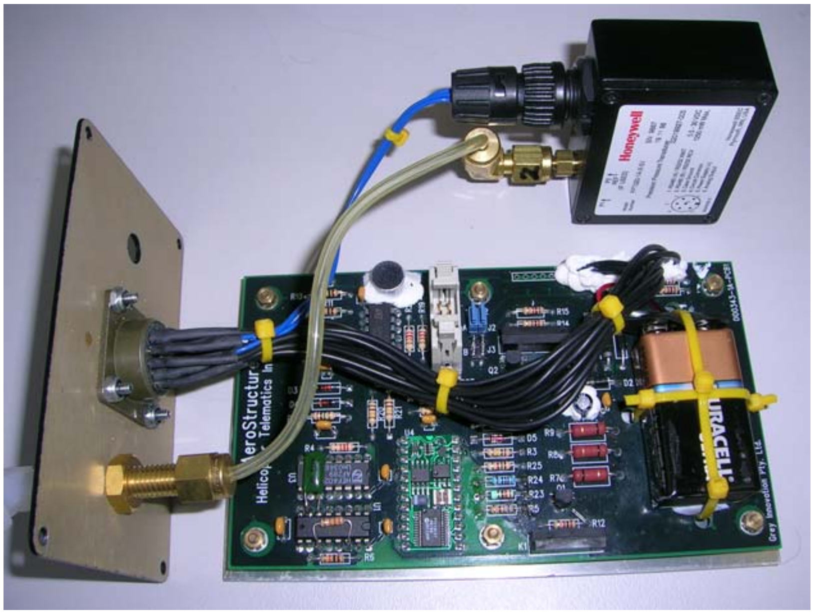

Figure 3.2: Custom Instrumentation Module for the R22 Usage Survey

3.2.2. A custom mounting system was designed for this application, which mounted the MaxLife system at the base of the left hand baggage compartment (beneath the left hand passenger seat – see Figure 3.3). Existing regulations already prohibited carriage of passengers during aerial mustering operations, so the presence of MaxLife beneath the empty passenger seat did not pose a threat to the crashworthiness of the aircraft during aerial mustering.

Figure 3.3: Mechanical Mounting of MaxLife in the R22

3.2.3. Connections between MaxLife and the aircraft systems consisted of an electrical power connection and pneumatic connections to the existing pitot, static and manifold pressure lines. Additional external sensors added to the aircraft included a switch to sense the collective control position, an outside air temperature sensor and a magnetic pickup to sense the aircraft's main rotor speed. The mechanical and instrumentation modifications required to fit MaxLife to the R22 are documented in the Engineering Orders described as References 4 and 5.

3.3. Parameters Recorded

3.3.1. The MaxLife system is intended to measure 16 parameters and in this usage configuration write these to a memory card once per second. Parameters recorded to memory card during the usage trial were:

a. Time (calendar time and flight elapsed time),

b. Collective position (fully down or raised),

c. Outside air temperature (OAT) ,

d. Engine manifold pressure (MAP) ,

e. Main rotor rotation speed,

f. Indicated airspeed,

g. Pressure altitude,

h. Vertical acceleration,

i. Fuselage pitch angle,

j. Fuselage roll angle,

k. Fuselage yaw rate,

l. Fuselage pitch rate,

m. Fuselage roll rate, and

n. Climb rate.

3.3.2. Recording to the memory card requires that the memory card be present in the card writer and that power is applied to the MaxLife system. As this could not be guaranteed throughout the usage trial, a backup system also checked each of the following parameters every 0.1 hours and incremented a counter if the parameter was active. These parameters were read by a subsystem with its own battery backup power, and operated whether aircraft power was available or not:

a. Time (incremented with every reading set),

b. Master power available,

c. Main rotor turning,

d. Collective raised, and

e. Sound pressure level indicates that the engine is running.

3.3.3. MaxLife was configured so that it would begin recording when the main rotor speed exceeded 20 percent of nominal main rotor RPM and would stop recording when the main rotor speed dropped below 15 percent. For this range of RPM, all changes of collective position will be captured.

3.3.4. No weight on ground sensor was available so division of MaxLife data between airborne operations and ground runs was determined on the basis of collective position i.e. fully down or raised.

3.3.5. The rate of climb data was obtained from the increment in altitude each second and consequently is much more variable than the standard measure of this parameter.

4. FITMENT AND FLIGHT TRIAL AT KUNUNURRA

4.1. Introduction

4.1.1. MaxLife was installed in the Heliwork R22 at Kununurra between 27 and 29 April 2005. Once fitted and cleared for flight, a 34 minute flight trial was conducted in the Kununurra Airport training area to gather data to check for correct operation of the system, and to correlate the flight usage data with the aircraft instruments.

4.2. Fitment of MaxLife to the Heliwork R22

4.2.1. A pre-fabricated enclosure had been manufactured to make the task of fitting the MaxLife components to the Heliwork R22 as simple as possible and to protect the MaxLife components from dust, dirt, oil and heavy items such as a fuel transfer handpump (stored in the passenger baggage compartment during transit flights to mustering areas). Custom brackets were manufactured at Kununurra to secure this enclosure to existing fastener locations.

4.2.2. External sensors were connected: these connections were:

a. tubing connections to the pitot, static and MAP pressure lines, connected at existing tubing junctions beneath the cabin floor,

b. a power connection to a dedicated circuit breaker in the R22 circuit breaker panel,

c. a hall effect sensor fitted to the main gearbox to detect the main rotor speed,

d. an OAT sensor mounted directly beneath the cabin, and

e. a microswitch mounted below the collective lever to detect when the collective was raised.

4.2.3. Once MaxLife was installed a Safety of Flight test was conducted to ensure that no conducted or radiated interference was detectable. An audio frequency hum was detected in the pilots headset, and a filter was added to the power line to eliminate the interference. The filter successfully blocked the interference (generated by an inverter that had been added to the MaxLife system specifically to cope with the R22 13.8 volt power supply) and the aircraft was cleared for flight.

4.3. Flight Trial

4.3.1. A flight trial was arranged to check that MaxLife was operating correctly in the R22. The trial consisted of a short flight in the Kununurra Airport training area, initially intended to demonstrate some mustering manoeuvres but after discovering cattle in the area some realistic mustering manoeuvres were performed. The cockpit instruments were recorded on video during the flight for later correlation of the instrument readings with the MaxLife record.

4.3.2. The flight trial was successful. Post flight analysis of the data written to the memory card showed that all parameters written to the card matched a video record of the R22 instruments taken during the trial. The only exception was altitude, which showed occasional random jumps of 160ft. It was decided to edit out these altitude errors during preliminary data analysis.

4.3.3. Because of these errors, the rate of climb data was found to be unreliable without complex data smoothing analysis. As a result, identification of the hover regime was not included in the subsequent usage assessment.

5. USAGE SURVEY

5.1. Introduction

5.1.1. The Heliwork R22 fitted with MaxLife was operated from Kununurra over a 26 week period from 30 April to 10 November 2005. A total of 21 memory cards containing data were returned from Heliwork to AeroStructures for analysis. Although each card could hold up to 40 hours of data, most cards contained considerably less than this. In total 370 hours of data were recorded on 390 files. Some 90 files, which were very short ground runs, were deleted, as was one completed-corrupted file. Approximately 5.4 percent of all data contained corrupted records, in most cases due to the fibre-optic gyro failing partway through a flight and sending error messages rather than valid signals. After removal of these corrupted records, any remaining seconds in which the pitch angle exceeded 75 degrees were deleted. Records were also deleted when the manifold pressure exceeded 30.5inHg in order to limit ground run time after engine shut-off. This left 299 files with 350.0 hours of edited MaxLife data, which were the basis of the usage survey analysis. Table 5.1 lists these 299 files by card number.

Card	Period Covered (2005)	Files	Hours
1	30 April - 5 May	11	24.83
2	6 May - 17 May	12	17.46
3	18 May - 22 May	9	22.51
4	22 May - 27 May	12	19.14
5	30 May – 10 June	18	19.73
6	11 June - 18 June	9	19.31
7	19 June - 21 June	6	17.68
8	24 June - 8 July	20	15.77
9	8 July - 16 July	14	18.31
10	16 July - 22 July	10	18.36
11	26 July - 9 August	71	35.48
12	10 August - 15 August	28	13.32
13	17 August - 25 August	12	18.38
14	26 August - 10 September	10	10.43
15	11 September - 17 September	11	11.23
16	19 September - 19 September	2	3.86
17	27 September - 10 October	13	16.77
18	10 October - 15 October	4	12.66
19	16 October - 24 October	10	15.18
20	25 October - 3 November	13	13.88
21	4 November - 10 November	4	5.74
All	30 April - 10 November	299	350.02

Table 5.1: MaxLife Files

5.1.2. MaxLife registered a file as starting by writing a record with the date and time when the main rotor speed exceeded 20 percent of nominal main rotor RPM.

The file was closed when the rotor speed dropped below 15 percent. Some R22 files were of relatively long duration (four to seven hours), including periods where the R22 was on the ground with engine idling and rotor turning. As these files exceeded the standard R22 endurance, they may indicate the use of hot refuelling (where the R22 was refuelled with main rotor turning). At the other extreme were the 90 files of a few seconds duration which had been deleted. Many of these appear to have been "track and balance" checks during routine maintenance where the main rotor was briefly spun up, checked, and then spun down again.

5.1.3. The MaxLife records of the usage survey had been collated into a single set and the values converted, where necessary, into engineering units. Scale factors and offsets for Main Rotor Speed and MAP were determined from a comparison of a video taken of the R22 instruments during the first trial flight with the MaxLife record for that flight. Angles and rates from the fibre-optic gyroscope were confirmed against the video evidence from the first trial flight. Airspeed, OAT and pressure altitude were also confirmed against the video record, with no conversion required.

5.1.4. Throughout the trial the usage survey records had been analysed as they became available to ensure that the data received was consistent with the early data already verified.

5.2. Hours Monitored

5.2.1. The MaxLife system included a self-powered monitor with its own built-in memory, designed to increment counters (based on various parameters) ten times per hour. Records of these counts were written onto the memory card at the start of 141 of the 299 files in the MaxLife data set. The first of these records was written at 0534 on 30 April 2005 and the last at 0430 on 10 November 2005. Between these limits, a total of 347.6 hours of edited MaxLife data was obtained.

5.2.2. The trial period covered by the self-powered monitor is 194 days less one hour, a total of 4655 hours. Heliwork Maintenance Release sheets for VH-LKK for this period gave a total of 637.8 hours between engine on and engine off entries. By equating these hours with the 8960 counts based on Sound Pressure Level (SPL) it was determined that the count rate with engine on was 14.05 per hour. This increased rate was confirmed by post-trial bench tests.

5.2.3. The counter records from the self-powered monitor over the mustering period then lead to the following periods:

a. Master switch was turned on: 650 hours,

b. SPL indicates engine was operating: 638 hours,

c. Main rotor was turning: 626 hours, and

d. Airswitch indicates collective was raised: 545 hours.

5.2.4. The counter periods, are in logical agreement (i.e. the engine cannot be operating until master switch is energised). The main rotor turning period of 626 hours from 30 April to 10 November 2005, resulted in 347.6 hours of edited MaxLife data, an average capture rate of 56 percent.

5.2.5. When the MaxLife capture rate was examined on a card by card basis, variations from 66 percent for Card 1 to 80 percent for Card 11, to only 30 percent for Card 14 but 57 percent for Card 19 were observed. Hence, the percentage of hours monitored during the trial period varied substantially, but the sample does not appear to be biased to any particular period.

5.3. Distribution of Hours Recorded

5.3.1. Examination of time histories revealed that flights in excess of 90 minutes were spread regularly through the mustering period. A further check of the consistency of data recovery was made by splitting the edited MaxLife set into approximately equal halves, for comparison of data hours for ground and flight phases with durations recorded by the independent counters. This is shown in Table 5.2. The first half contained 111 files from cards 1 to 9, and the second half contained 186 files from cards 10 to 21.

		Cards 1 to 9	Cards 10 to 21	All Cards
MaxLife Hours	On Ground	18.1	19.2	37.3
	In Flight	156.7	153.6	310.3
	Total	174.7	172.9	347.6
Counter Hours	On Ground	34.2	45.9	80.1
	In Flight	254.8	290.6	545.4
	Total	289.0	336.5	625.5
Percentage captured by MaxLife	On Ground	52.9%	41.8%	46.6%
	In Flight	61.5%	52.9%	56.9%
	Total	60.4%	51.4%	55.6%

Table 5.2: MaxLife Data Capture

5.3.2. As the percentages of hours recorded by MaxLife for ground and flight phases varied in a similar way between the two parts of the mustering period, it is likely that the recorded usage for the entire period provides a representative sample of mustering operations.

5.3.3. The reduction of the original set of 390 files to the set of 299 files/350 hours in Table 5.1, created a data set in which 269 files included at least one Ground-Air-Ground (GAG) cycle. The remaining 30 files were restricted to ground runs with an average duration of about 200 seconds. The distribution of in-flight durations for the 269 files with at least one GAG cycle is given in Table 5.3.

In Flight Duration (hours)	Cards 1 to 9	Cards 10 to 21	All Cards
≥ 1.5	34	35	69
1 to 1.5	3	10	13
0.5 to 1	16	35	51
0.167 to 0.5	20	57	77
< 0.167	21	38	59
Total	94	175	269

Table 5.3: In-Flight Durations

5.3.4. Only five of the files with a flight duration greater than 1.5 hours were from afternoon flights. The remaining 64 files were all from aerial mustering flights, which typically commenced around 5AM.

5.3.5. From Table 5.1 it will be seen that the number of files (111) obtained from cards 1 to 9 was much less than the number (186) derived from the cards 10 to 21. A consequent difference between the 34 files with durations greater than 1.5 hours derived from cards 1-9 and the 36 (35 with *flight* durations greater than 1.5 hours) from cards 10-21 is an average duration per file of 4.26 hours for the earlier set, compared with 3.01 hours for the later set. The increased number of shorter flight durations for the later set is evident in Table 5.3.

5.3.6. However, when the data is separated into regimes depending on ground or air operation, forward speed and applied power (taking the power division at 15in.Hg), the composition of the two parts is found to be similar. This is shown in Table 5.4.

Regime	Speed bands (kts)	Cards 1 to 9		Cards 10 to 21		All
		Time (sec)	Percentage	Time (sec)	Percentage	
Ground		64,982	10.3%	69,561	11.0%	10.7%
Forward Flight	0-10	76,051	12.1%	79,382	12.6%	12.3%
(Power On)	10-30	77,337	12.3%	83,390	13.2%	12.8%
	30-50	81,686	13.0%	78,838	12.5%	12.7%
	50-70	136,999	21.8%	129,834	20.6%	21.2%
	70-90	118,225	18.8%	136,175	21.6%	20.2%
	90+	36,849	5.9%	17,450	2.8%	4.3%
Auto-Rotation	0-10	6,366	1.0%	5,811	0.9%	1.0%
(Power Off)	10-30	3,843	0.6%	6,072	1.0%	0.8%
	30-50	11,808	1.9%	12,996	2.1%	2.0%
	50-70	11,948	1.9%	9,795	1.6%	1.7%
	70+	2,923	0.5%	1,753	0.3%	0.4%
Total		**629,017**		**631,057**		

Table 5.4: Flight Regime Comparison

5.3.7. The consistency of the percentages for the two parts of the data shown in Table 5.4 indicates that the difference in the average duration of a file from 1.57 hours in the first part, to 0.93 hours for the second, is not accompanied by a significant change in flight regimes. Consequently further analysis could be carried out using the total set of 350 hours of edited MaxLife data.

5.3.8. On the basis that the airswitch indicated the collective was not raised, 37.37 hours or 10.7% of the MaxLife data set was allocated to rotor turning on the ground. About 10% (3.69 hours) of the ground running time was recorded with MAP between 28.5 and 30.5inHg, a range found during engine shut down. The average value of 44 seconds per shut down (13283 seconds divided between 299 files) reflects the fact that the rotor brake had been removed from the Heliwork R22 (see paragraph 3.3), and data was recorded until rotor speed fell below 15 percent.

5.3.9. The division of flight time for different angles of bank is shown in Table 5.5. The airspeed bands have been chosen for easier comparison with values specified in FAA certification guidance.

Criteria						
Power	**Angle of Bank**	**Airspeed (kts)**	**Seconds**		**% of Flight Time**	
On	<30	All	1,041,393		92.52%	
	>30	0-15	2,573	10,823	0.23%	0.96%
		15-45	5,623		0.50%	
		45-75	2,495		0.22%	
		>75	132		0.01%	
	>45	0-15	281	1,765	0.02%	0.16%
		15-45	989		0.09%	
		45-75	480		0.04%	
		>75	15		0.00%	
Off	<30	All	68,944		6.13%	
	>30	0-15	569	4,371	0.05%	0.39%
		15-45	1,934		0.17%	
		45-75	1,800		0.16%	
		>75	68		0.01%	
	>45	0-15	74	903	0.01%	0.08%
		15-45	410		0.04%	
		45-75	409		0.04%	
		>75	10		0.00%	
Total Time in Flight			**1,125,531**		100.00%	
Total Seconds			**1,260,074**			

Table 5.5: Angle of Bank Distribution

5.3.10. The division of flight time between different levels of Roll angle, Pitch angle and Yaw rate are shown in Annex A, while the distribution of Manifold Pressure, Rotor RPM and Outside Air Temperature (OAT) are set out in Annex B.

5.4. Removal of MaxLife

5.4.1. After the flight trial MaxLife was removed from the R22 and the aircraft returned to its state prior to the usage survey.

6. USAGE ANALYSIS

6.1. The survey of R22 aerial mustering usage by MaxLife provided 350 hours of edited data divided into 299 files, each representing a single rotor start and stop cycle. The average file duration of 1.17 hours can be compared with the certification allowance of four rotor shutdowns per hour in the fatigue spectrum, or an average duration of 0.25 hours

6.2. The relatively high average file duration is a result of the morning aerial mustering flights. These 64 files with an average duration of 3.77 hours contributed 241 of the total 350 hours, nearly 69 percent. The other 235 files with an average duration of only 28 minutes make up the remaining 109 hours of the data set, and are nearer to the certification rotor start and stop cycle of 15 minutes. Additionally, 90 files for very short ground runs were deleted from the original data set.

6.3. The fatigue spectrum used for certification analysis assumes only 1.5 percent of the engine hours are accumulated during ground running. The MaxLife usage survey found 10.7 percent of hours with rotor turning were recorded during ground running, based on the airswitch which depended on collective position. Examination of MaxLife data plots suggested that the percentage of ground running was probably under-estimated since many records were completed with the airswitch still in the collective raised condition. Hence it can be concluded than the R22 usage ground running time is much greater than the certification value.

6.4. Because of this large difference in ground running time, the airborne usage needs to be compared in terms of the percentage of flight time, 98.5 percent for certification verses 89.3 percent for the aerial mustering usage. With this change the R22 certification usage regimes are 4.6 percent Hovering, 86.8 percent Forward Flight with Power On and 8.6 percent Auto Rotation with Power Off.

6.5. Applying the same approach to the R22 aerial mustering usage data presented in Table 5.4 leads to 93.5 percent of Forward Flight time with Power On and 6.5 percent Auto Rotation with Power Off. The 93.5 percent with Power On can be further subdivided into 13.8 percent with forward speed less than 10kts and 79.7 percent at higher speeds.

6.6. As noted earlier, the MaxLife parameter recorded for Rate of Climb does not provide reliable identification of the Hover state. Consequently, the division of the 13.8 percent flight time with forward speed below 10kts into Hover and other regimes was not attempted. The 6.5 percent of flight time assigned to Auto Rotation is comparable with the certification value of 8.6 percent.

6.7. Further comparison of the regimes allocated for certification with the regimes identified by MaxLife for aerial mustering is provided in Table 6.1 for Power On flight and Table 6.2 for Power Off flight hours. While the limitations of the MaxLife data prevent reliable comparison of some transient events, the significant differences between the specification and usage are apparent.

6.8. Combined power on and power off usage with CAS ≤ 30kts is 29 percent of flight time compared with only 12.6 percent in the R22 specification. For forward flight between 30 and 50kts, the same process gives 16.9 percent usage and 3.5 percent specification. Hence aerial mustering usage with CAS below 50kts accounts for 45.9 percent of flight time compared with only 16.1 percent in the specification.

6.9. Between 50 and 90kts usage is close to the specification, but the percentage of aerial mustering usage with CAS above 90kts is only 4.8 percent, which is much less than the 20.8 percent in the specification.

Power On	**Specification**		**Heliwork**
Forward Flight (CAS > 30kts)			
30-50kts	3.0		14.9
50-70kts	18.3		23.5
70-90kts	25.4		22.6
>90kts	20.8		4.8
All	67.5		65.8
Level Turns (AoB > 30°)			
15-45kts	2.1		0.50
45-75kts	2.0		0.22
>75kts	2.0		0.01
All	6.1		0.73
Other (CAS ≥ 50kts)			
Climb	3.9		
Other Transient Events	3.8		
All	7.7		
Other (CAS ≤ 30kts)			
Hover	4.6		
Forward Flight and Landing Approach	3.0	(CAS < 10kts)	13.8
Partial Power Descent	2.0	(CAS > 10kts)	13.2
Other Transient Events	0.5		
All	10.1		27.0
All Power On	91.4		93.5

Table 6.1: Percentage of Flight Hours with Power On

Power Off	**Specification**		**Heliwork**
Forward Flight (CAS > 30kts)			
30-50kts	0.5		2.0
50-70kts	0.75		1.8
>70kts	0.75		0.4
All	2.0		4.2
Level Turns (AoB > 45°)			
15-45kts	0.5		0.17
45-75kts	1.0		0.16
>75kts	0.5		0.01
All	2.0		0.34
Transient Events	2.0		
Other (CAS ≤ 30kts)			
Landing Approach	2.0	(CAS < 10kts)	1.1
Rapid Power Recovery	0.5	(CAS > 10kts)	0.9
All	2.5		2.0
All Power On	8.6		6.5

Table 6.2: Percentage of Flight Hours with Power Off

6.10. Below 50kts the aerial mustering flights exhibit extremely frequent manoeuvring and rapid power changes. However the percentage of flight time between 15 and 45kts, with power on, where the angle of bank exceeds 30° is only 0.5 percent, much less than the specified 2.1 percent. Power off turns with CAS above 15kts and bank angles greater than 45° occupy only 0.34 percent of flight time compared with 2 percent in the specification usage.

6.11. The R22 specification allocates 1.0 percent of flight time to pull ups and 0.5 percent to push-overs, all performed at a CAS of 90kts. From the Pitch angle distribution in Annex A, the aerial mustering usage is found to include pitch angles greater than 15° for 1.7 percent and less than -15° for one percent of flight time. These figures indicate mustering usage requires more pitch up/push-over events, but these will be carried out at lower speeds than the specification.

7. FITMENT AND FLIGHT TRIAL AT RHC

7.1. Introduction

7.1.1. Preliminary analysis of the full flight records from the usage trial showed that aerial mustering contained a significantly higher percentage of low speed manoeuvres than specified for certification. The MaxLife records also contained a number of manoeuvres that are not included in the certification spectrum.

7.1.2. Discussions were held between ATSB, RHC and AeroStructures staff (Reference 6) in which it was determined that RHC had no data to allow calculation of the effect of the manoeuvres peculiar to aerial mustering on the R22. RHC had a strain-gauged R22 with an instrumentation system capable of reading those gauges at high dynamic rates, but had no air data or inertial sensors that would allow aerial mustering manoeuvres, if flown, to be correlated with the usage records.

7.1.3. An agreement was reached where RHC provided access to their strain-gauged R22 for fitment of MaxLife and a short aerial mustering flight investigation to record the effect of the aerial mustering manoeuvres on the R22. ATSB then extended the terms of the contract to allow this to proceed.

7.2. MaxLife Modification

7.2.1. MaxLife was further modified to allow it to be fitted to the RHC strain-gauged R22. The passenger seat and passenger-side baggage compartment of the RHC R22 were occupied by the RHC high speed data acquisition system, so the MaxLife system was modified mechanically to fit under the pilot seat. Although the MaxLife system occupied some of the space under the pilot seat and so reduced the available energy absorption area below the pilot (MaxLife occupied the lower 30 percent of this space) both RHC and AeroStructures staff considered the additional risks negligible as:

a. the intrusion into the area reserved for energy absorption was minimal,

b. the flights would be limited to a few flights flown by the RHC chief test pilot, and

c. the manoeuvres had already been demonstrated during the aerial mustering trial.

7.2.2. To simplify installation further the OAT sensor was incorporated into the MaxLife system external connector. Real-time measurement of true outside air temperature was not considered necessary for this trial.

7.2.3. There was also a need to synchronise the records of MaxLife and the RHC system. As the RHC system operated at high speed it was not feasible to operate it over the entire flight (as MaxLife is operated). Instead the switch used by the pilot to trigger the RHC system in flight was also connected to the airswitch input on the MaxLife system. This allowed MaxLife to record at what times the RHC system was recording.

7.2.4. With these changes made the only external connections between MaxLife and the RHC aircraft were:

a. electrical power from a dedicated circuit breaker fitted to the main R22 switched power bus,

b. a clutch shaft rotation sensor, and

c. pitot, static and MAP connections made to the relevant pressure lines at existing junction points along the lower centreline area of the R22.

7.2.5. The RHC R22 (see Figure 7.1) was an Experimental category aircraft, which allowed RHC to clear the MaxLife temporary modification for flight.

Figure 7.1: The RHC Strain Gauge Instrumented R22

7.3. Fitment and commissioning of MaxLife in the RHC R22

7.3.1. The MaxLife system, modified for the RHC aircraft, was shipped to RHC in Torrance, USA in late March 2006 and fitted as planned to the RHC R22 over 29 March to 4 April 2006. Strain gauged main rotor and tail rotor blades were fitted, which precluded flights if any rain was present. Rain was falling until 5 April, when the weather cleared sufficiently to let the strain gauged main rotor blades be balanced and the R22 readied for flight.

7.3.2. An initial ground run was performed on 5 April once the blades were balanced, and data was retrieved from MaxLife to check the system. All channels recorded data as expected, so the R22 was cleared to perform the aerial mustering flight investigation flights the next day.

7.4. Selection of Manoeuvres

7.4.1. Descriptions of a range of manoeuvres had been prepared before the trial to allow RHC to try to replicate the most extreme manoeuvres observed during the aerial mustering usage survey. These manoeuvres were considered and some were selected for inclusion into the aerial mustering flight investigation. These included:

a. a “quick stop”, where forward speed was suddenly reduced at low level with minimal change of altitude,

b. high-power takeoffs, where very high engine manifold pressures and main rotor speeds were applied and held throughout the takeoff, and

c. extreme manoeuvres including rapid changes in forward airspeed and high roll angles.

7.4.2. One particular group of manoeuvres were rejected as being outside the certification envelope of the R22. These were groups of repeated takeoffs and landings, with flights of short duration (under 20 seconds), where main rotor speeds before the flight were well over the allowable limits and the main rotor speeds once in the air were below the lower limit. Exclusion of these manoeuvres was not of great significance to the usage study overall as these manoeuvres only accounted for about 0.1 hour of flight over the full aerial mustering period.

7.4.3. Further typical aerial mustering manoeuvres were also included, including a range of “hammerhead turns” with different entry speeds, turn directions and rates of control inputs. Finally a group of reference manoeuvres, normally included in RHC flight trials, were included to act as a baseline for comparison with other RHC flight trial results.

7.5. The Flight Trial at RHC

7.5.1. Two aerial mustering flight investigation flights were performed. The first took place on 6 April 2006 and consisted of RHC reference manoeuvres and extreme aerial mustering manoeuvres identified during the usage survey. Post-flight analysis of the flight data showed that one connector between the strain gauges and the RHC data acquisition system had come loose during the manoeuvres, and consequently some measurands were unavailable from midway through the flight. The data was investigated further and it was decided that the measurands affected were not critical and that the flight did not need to be repeated. There were also a group of strain results that were very noisy due to aging slip ring connections between strain gauges on rotating components and the data acquisition system. Replacing slip rings is a complex and time-consuming process, so this deficiency had to be accepted given the limited time window for this trial. Again, on careful consideration it was decided that the lack of these measurands was not critical.

7.5.2. The second aerial mustering flight investigation flight took place on 7 April 2006 and consisted of RHC reference manoeuvres and a range of typical aerial mustering manoeuvres (see Figure 7.2). Post flight analysis of the flight data showed that the connectors had remained connected and that the data on these channels was of good quality. Channels affected by noisy slip rings were still affected by this issue.

Figure 7.2: RHC R22 Performing a Hammerhead Turn

7.5.3. In all flights the MaxLife system behaved correctly and all MaxLife measurands were logged correctly throughout the flights.

8. ANALYSIS

8.1. Introduction

8.1.1. The three primary sets of data used in the analysis were:

a. the strain gauge results from the RHC aerial mustering flight investigation,

b. the MaxLife results from the RHC aerial mustering flight investigation, and

c. the MaxLife results from the aerial mustering usage survey at Kununurra.

8.1.2. In addition a set of reference results was provided by RHC from the certification flights during the certification of the most recent R22 Main Rotor Blade design. These results were used as a baseline for comparison with the aerial mustering flight investigation flights.

8.2. RHC R22 Strain Gauge Results

8.2.1. The strain gauge results from the RHC R22 high-speed data acquisition system were saved by the RHC "DATAQ" data acquisition system as .WDQ files. These files were in a proprietary format that can be read with the WinDaq Waveform Browser software available from Dataq Instruments (Dataq Instruments, 241 Springside Drive, Akron Ohio USA 44333).

8.2.2. Two files were saved during the aerial mustering flight investigation, labelled FLT06-01 and FLT06-02. The list of measurands recorded during these flights is presented in Annex C. The results were scaled by the data acquisition system into engineering units (forces, bending moments and torques) representing the applied loading at that point in the structure.

8.2.3. A zero reading was taken on all channels while the aircraft was stationary with engine off. This was the standard zero reference for both the aerial mustering flights and certification flights, allowing direct comparison of these files.

8.3. Comparison of RHC Reference Results with the RHC R22 Flight Trial

8.3.1. The reference results from the RHC certification flights were made available as data files from fourteen flights labelled FLT03-10-2 to FLT03-08. Each flight was divided into segments and each segment analysed for:

a. the average value of each measurand over the entire segment, and

b. the peak to peak range of each measurand over one main rotor cycle late in the segment.

8.3.2. These results were then summarised into a single table for the entire certification flight programme. The same process was repeated for the two aerial mustering flight investigation flights, and the results compared.

8.3.3. After the known effects of noisy channels and connection disruptions were removed from the analysis only five measurands showed higher peak stresses for the aerial mustering flights than for the certification flights. These were:

a. Tail Rotor Drive Shaft Torque, with a maximum manoeuvre mean torque 1.04 times higher and a maximum cyclic range of torque 2.38 times higher than for the certification flights,

b. Tailcone Forward Vertical Bending, with a maximum manoeuvre mean bending 1.14 times higher than for the certification flights.

c. Aft Push-pull Tube force, with a maximum manoeuvre force 1.12 times higher than for the certification flights,

d. Main Rotor Station 16 Bending, with a maximum manoeuvre mean bending 1.07 times higher than for the certification flights, and

e. Main Rotor Station 32 Bending, with a maximum cyclic range of torque 1.03 times higher than for the certification flights.

8.3.4. The other measurands were either close to the certification values or had a cyclic component significantly below the certification values (see Annex C). Investigation of the reasons for apparently severe aerial mustering manoeuvres causing relatively small stresses indicated that for many measurands the peak values in certification flights occurred during high speed manoeuvres, which were not present in the aerial mustering usage profile.

8.3.5. Of the measurands with higher values in the aerial mustering trial flights the Tail Rotor Drive Shaft (TRDS) torque appeared of most concern. In particular the peak cyclic value appeared as a high-speed high-amplitude damped oscillation at about 5 Hz during a rapid and large power reduction as part of a “quick stop” manoeuvre. This manoeuvre, and others like it with rapid, large power level changes, are not uncommon in aerial mustering usage.

8.3.6. One measurand of interest was not available during the flight trial. The clutch shaft was instrumented with torque gauges, but the slip rings connecting the data acquisition system to these gauges had failed. RHC were able to demonstrate from past flight records that the clutch shaft torques were one fifth of the main rotor shaft torques and that this correspondence extended to the dynamic components with very little error. As good main rotor shaft torques were recorded, and as these torques were within the certification limits, there was no evidence that the clutch shaft torque was a particular concern for aerial mustering flights after analysis of the aerial mustering trial flights. The oscillation clearly visible on the TRDS torque gauges was visible on the main rotor shaft but the dynamic amplitude was reduced by an order of magnitude when compared to the mean torque in the shaft.

8.4. Investigation of the MaxLife Record for the Aerial Mustering Trial Flight

8.4.1. The MaxLife records of the RHC aerial mustering trial flights indicated that medium to high level mustering manoeuvres had been performed, with pitch angles exceeding 35 degrees and roll angles reaching 50 degrees. The manoeuvres did not reach the most extreme angles recorded during the aerial mustering usage survey, but investigation of the manoeuvres indicated that the airframe and rotating component stresses were relatively benign during these manoeuvres and that the rate of increase of stress with increasing severity was not high enough to cause concern.

8.4.2. The area of concern, demonstrated in the "quick stop", caused torsional cycles in the TRDS, consisted of a nose-up manoeuvre combined with a change in engine manifold pressure (MAP) from 25.6 to 7.7 inches of Mercury in under one second, a change of 17.9 inches of Mercury. The trace showing this behaviour occurs 115.5 seconds into the RHC Dataq file FLT06-01.WDQ and at 889.9 seconds into the MaxLife data file MAX06-01.XLS. The amplitude of the oscillation starts at 994 in.lb and concludes 11 cycles later when the cycle has decayed to the typical cyclic torque amplitude of about 220 in.lb (see Figure 8.1). Hence the initial amplitude was 4.5 times the typical value during flight.

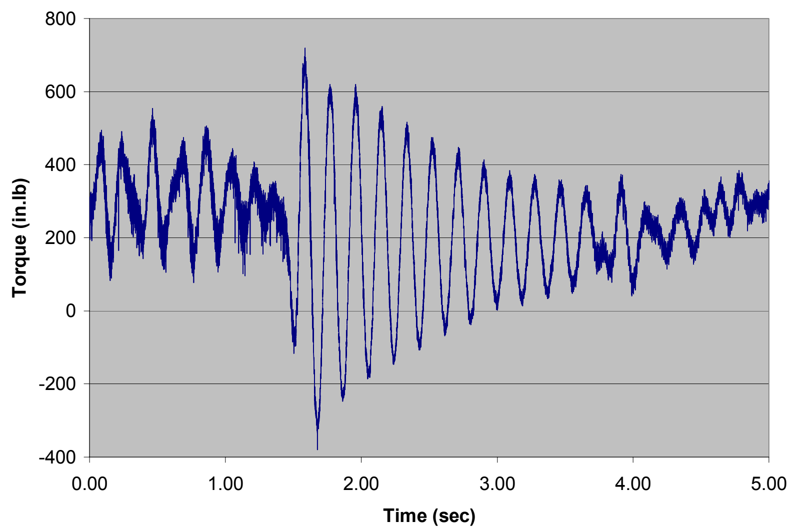

Figure 8.1: Dynamic Torque Oscillation in the TRDS

8.4.3. Main Rotor Blade life is dominated by Main Rotor stop-start cycles. If heavy loads are being lifted then takeoff-landing cycles are also of great significance (Reference7).

8.4.4. In this case the heavy lift influence was not present, but the effect of stop-start cycles should be considered. The RHC certification flight spectrum allows for four stop-start cycles per flight hour (Reference 8). The aerial mustering spectrum derived from MaxLife records consisted of 390 stop-start cycles in 370 flight hours, or 1.05 stop-start cycles per flight hour (including the numerous short start-stop cycles during track and balance checks). So the aerial mustering stop-start usage spectrum is well within the RHC certification flight spectrum allowances.

8.4.5. The most frequent mode of flight in the aerial mustering flight spectrum was low-speed manoeuvring. These manoeuvres often involved high pitch and roll angles and high yaw rates, but were performed at low airspeeds. High speed manoeuvres (over 60 knots and 30 degrees from level flight) are not a significant feature of the aerial mustering flight spectrum.

8.4.6. Occurrence graphs have been generated to describe the frequency of occurrence of manoeuvre-related parameters, giving pitch and roll angles and yaw rate occurrences per flight hour. These graphs are presented in Annex A.

8.4.7. Other operating parameters of interest have also been characterised. The frequency of occurrence of engine and drivetrain-related parameters MAP, Main Rotor Speed and Outside Air Temperature are presented in Annex B.

8.5. Analysis of the TRDS Torque Cycles

8.5.1. The 64 aerial mustering flights at Kununurra with a duration recorded by MaxLife in excess of 1.5 hours were examined to find examples of "Quick Stop" manoeuvres. Figures 8.2 and 8.3 on page 8-6 show flight parameters plotted against time for a flight on the morning of May 5th. Both segments show a reduction in airspeed of approximately 50kts. Figure 8.2 shows part of the initial transit segment of the flight where the drop in airspeed results from a steady climb with a small reduction in manifold pressure and a slightly nose up pitch angle. This is followed by a gentle descent where the airspeed, manifold pressure and pitch angle return to values similar to before the climb. This is very different to the "Quick Stop" manoeuvre shown in Figure 8.3 at approximately 8170 seconds into the flight which has a similar reduction in airspeed. The reduction in airspeed is initiated by sudden drop in manifold pressure and a large nose up pitch angle.

8.5.2. The "Quick Stop" manoeuvre as described in paragraph 8.4.2 for the RHC flight trial is similar to the manoeuvre shown in Figure 8.3 with a large drop in manifold pressure coupled with a sudden nose up attitude; however the periods of the two events are quite different. It is not known if the slower manifold pressure drop from the mustering flight will produce the same sized oscillations of the TRDS as those recorded during the one "Quick Stop" performed during the RHC flight trial.

8.5.3. Using criteria that the manifold pressure decreased by at least 10in.Hg in a period not greater than two seconds and the initial airspeed was greater than 20kts, 480 manoeuvres were identified in the total data set of 299 files, as set out in Table 8.1. This table also shows 225 Manifold pressure drops occurred on the ground and 400 in flight with initial airspeed less than 20kts. A total of

1105 power chops in excess of 9.5in.Hg were recorded from 209 of the total 299 files in the 350 hour set of usage data.

Manifold Pressure Drop (in.Hg)	Occurrences			
	On Ground	In Flight (CAS<20kts)	In Flight (CAS>20kts)	Total
10	50	122	186	358
11	40	80	107	227
12	49	59	69	177
13	31	51	54	136
14	20	33	27	80
15	16	27	13	56
16	7	15	14	36
17	7	7	1	15
18	0	5	4	9
19	0	0	3	3
20	5	0	2	7
21	0	1	0	1
Total	225	400	480	1105

Table 8.1: Manifold Pressure Drops

8.5.4. Twenty five files contained ten or more power chops in excess of 9.5in.Hg, including seven files which had durations less than 1.5 hours. Only one of the 65 morning flights longer than 1.5 hours was completely without a power chop event. A listing by file of the total recorded abrupt power cuts is provided in Annex D.

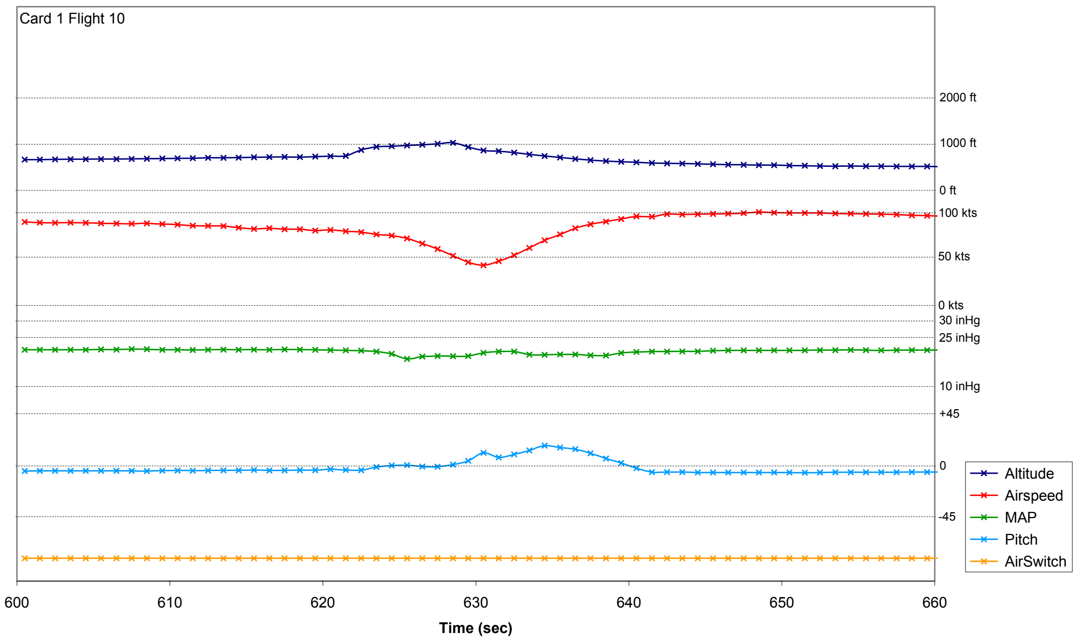

Figure 8.2: Time Plot of Transit Flight Speed Change

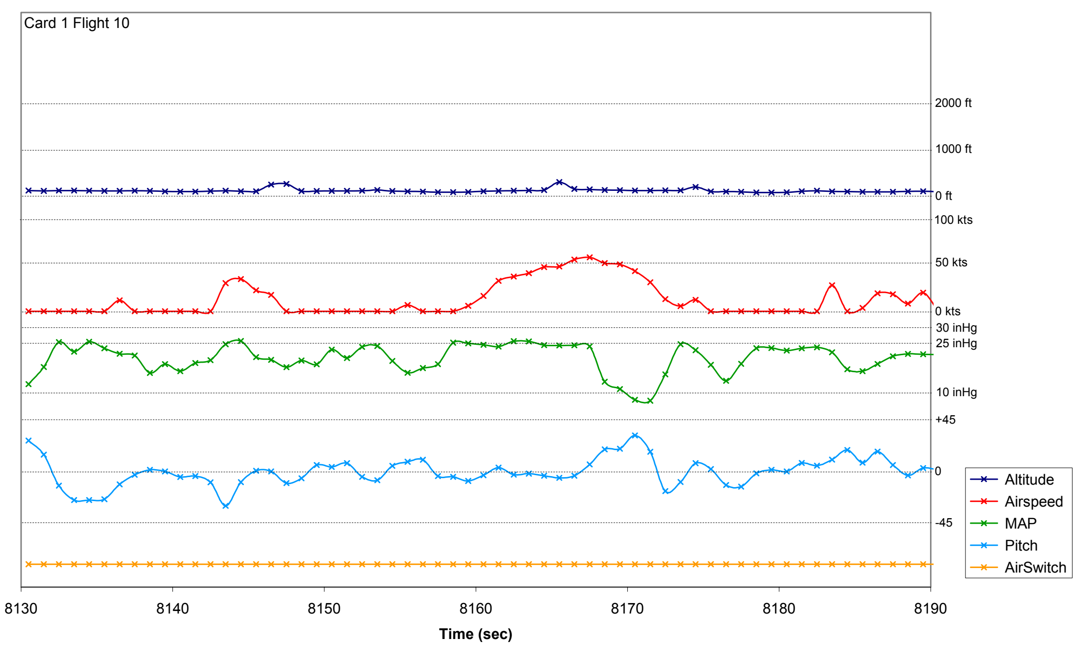

Figure 8.3: Time Plot of a "Quick Stop" Manoeuvre

8.5.5. Only one dynamic oscillation was captured during the RHC flight trial, corresponding to a decrease in engine power of 17.9in.Hg in one second. To extend this single occurrence to the whole usage survey the following assumptions have been made:

a. the oscillation is only triggered by rapid changes in manifold pressure,

b. the oscillation begins with a large amplitude cycle proportional to the change in manifold pressure,

c. the oscillation consists of 11 cycles linearly decreasing from the initial large amplitude cycle to the typical cyclic value of 220 in.lb of torque, and

d. The dynamic oscillation in the TRDS torque that occurred during a rapid power reduction has been converted into a plot of Torque Cycle Amplitude versus Number of Cycles to allow calculation of the effect of this oscillation on the TRDS and associated components.

8.5.6. Based on these assumptions spectra were generated of TRDS torque cyclic amplitudes greater than 450in.lb. This limit is about twice the regular cyclic value of 220in.lb, and was not exceeded in certification flights. Three of the spectra plotted in Annex E were derived from the data in Table 8.1, using the method described in the previous paragraph. The remaining graph was derived during the initial analysis of the usage data, when, due to a file processing error, which resulted in MAP entries in successive files being linked, 249 spurious counts were included of power chops exceeding 16in.Hg.

8.5.7. The three spectra based on valid counts show the contribution of both ground run events and low speed manoeuvres to the derived exceedances. The spectrum for initial CAS above 20kts represents manoeuvres closest to the Quick Stop captured in the RHC flight Trial.

8.5.8. For 1,000 hours of this spectrum, the regular cyclic amplitude of 220in.lb is exceeded by a factor of at least two for 37,000 cycles, by a factor of three or greater for 1,700 cycles and a factor of 4 or more for 115 cycles.

9. RHC ANALYSIS

9.1. RHC was contacted by AeroStructures and asked to investigate the effect of the TRDS torque cycles due to aerial mustering on the R22 TRDS. The TRDS torque cycle spectrum provided to RHC was the one derived during initial analysis. As this spectrum is more severe than those based on valid counts of power chop events, the RHC analysis should provide conservative estimates of relevant component lives.

9.2. RHC responded (Reference 8) as follows:

> "Your identification of the tail rotor driveshaft as a highly loaded component is consistent with our expectations. Mustering manoeuvres, which consist of rapid power changes at low airspeeds, are more likely to impact the drive system than the main rotor system. Consistently high torque and/or high airspeed would have a greater impact on the main rotor system. The wave characteristic shown on your data is similar to what we see in a cruise condition (maximum continuous power) "power chop", which is also an abrupt power reduction. Your amplitudes are likely higher because your starting torque is takeoff power (or even a bit above).
>
> We concur that the assumptions you made to extrapolate one occurrence to the life of a typical mustering helicopter are reasonable. We have continued from these assumptions and recalculated drive shaft limits based on your data.
>
> At present, the tail rotor drive shaft is not a life-limited component and its endurance limit is nearly as high as the loads imposed by your largest cycles. Therefore, only the first few of your 11 cycles for only the more severe MAP changes are damaging. Our present calculated service life (including all safety factors) is approximately 44,000 hours. Adding the mustering data reduces this life to approximately 34,000 hours. Calculated service lives of more than 25,000 hours are considered unlimited. Therefore, although the manoeuvre in question imposes some additional fatigue damage, it does not affect part life."

9.3. The RHC advice was provided without supporting documentation to identify the location(s) selected for the service life analysis. Consequently, the applicability of this analysis to other related structural details should not be assumed, and the potential for these frequent high amplitude torque cycles to affect the service lives of relevant components included in any analysis.

10. CONCLUSION

10.1. This task has investigated the effect of aerial mustering in northern Australia on the Robinson R22 helicopter. A total of 350 hours of edited usage data was recorded in 299 files.

10.2. The 10.7 percent ground running time recorded during aerial mustering usage is very much greater than the 1.5 percent assumed for R22 certification analysis.

10.3. Aerial mustering usage with CAS below 50kts accounted for 45.9 percent of flight time compared with only 16.1 percent in the specification usage.

10.4. Only 4.8 percent of the monitored aerial mustering usage was for CAS above 90kts compared with 20.8 precent in the specification usage.

10.5. Aerial mustering flights exhibit extremely frequent manoeuvring and rapid power changes, generally with CAS below 50kts.

10.6. The frequent pitch up/push over manoeuvres associated with the rapid power changes result in 2.7 percent of flight time being outside the pitch angle band from +15° to -15°.

10.7. A dynamic torque oscillation in the TRDS with an initial amplitude 4.5 times the normal cyclic range of 220in.lb was recorded during a "Quick Stop" manoeuvre of the RHC instrumented R22 aircraft. This oscillation was initiated by a power chop of 17.9in.Hg recorded by MaxLife in one second.

10.8. A total of 1105 power "chops" between 10 and 21in.Hg in less than two seconds were recorded by MaxLife from 350 hours of aerial mustering usage. Twenty five files contained at least ten of these power chops.

10.9. A total of 480 of these events were recorded when initial CAS was at least 20kts.

10.10. Using a linear scaling method, these 480 events lead to estimates of 37,000 cycles per 1,000 hours with an amplitude greater than twice the normal cyclic range, 1,700 cycles per 1,000 hours greater than three times, and 115 cycles per 1,000 hours in excess of four times the normal cyclic range.

10.11. The effect of the TRDS torque cycle oscillations was analysed by RHC who concluded that although the cycles observed in aerial mustering usage were causing more damage to the TRDS than had been allowed for in the original certification usage spectrum, the additional damage was not severe enough to require that the TRDS be listed as a life-limited component. However, the potential of these frequent high amplitude torque cycles to affect structural integrity needs to be considered when reviewing service lives of relevant structural details.

11. RECOMMENDATIONS

11.1. Recommendations are as follows:

a. ATSB seek assurance from RHC that no components in the rotor drive train are adversely affected or life limited under the high amplitude torsional loading measured during aerial mustering operations.

OCCURRENCE OF MANOEUVRE PARAMETERS

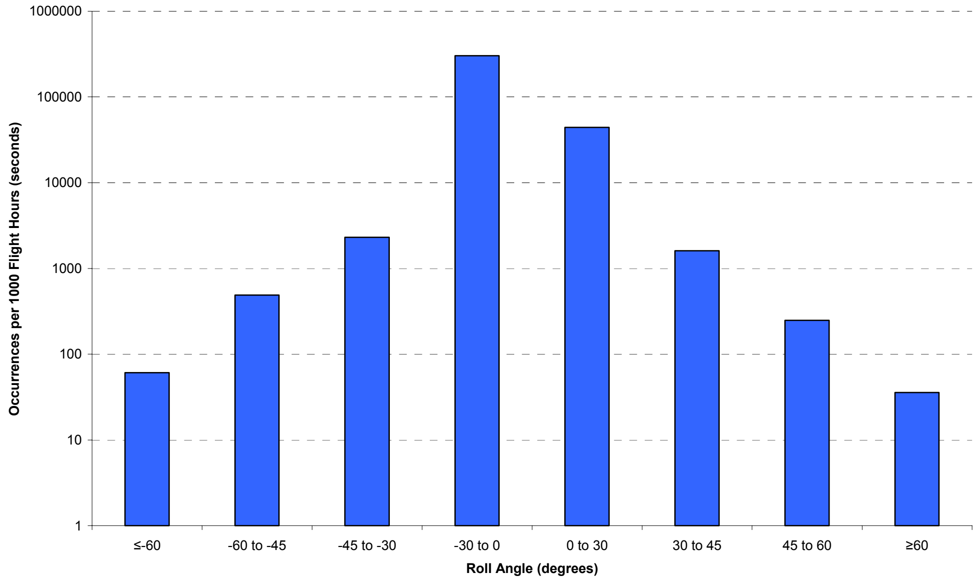

Figure A.1: Roll Angle Occurrence

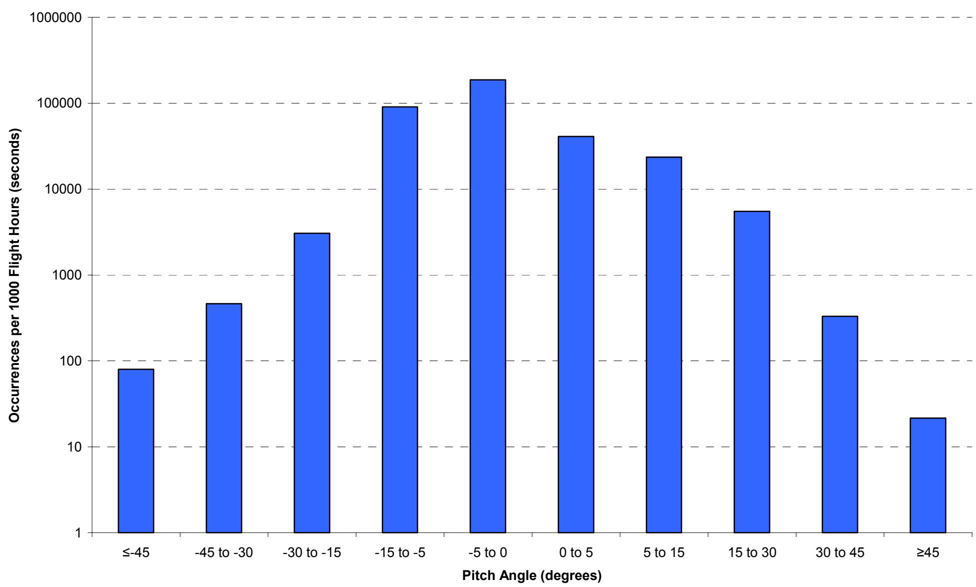

Figure A.2: Pitch Angle Occurrence

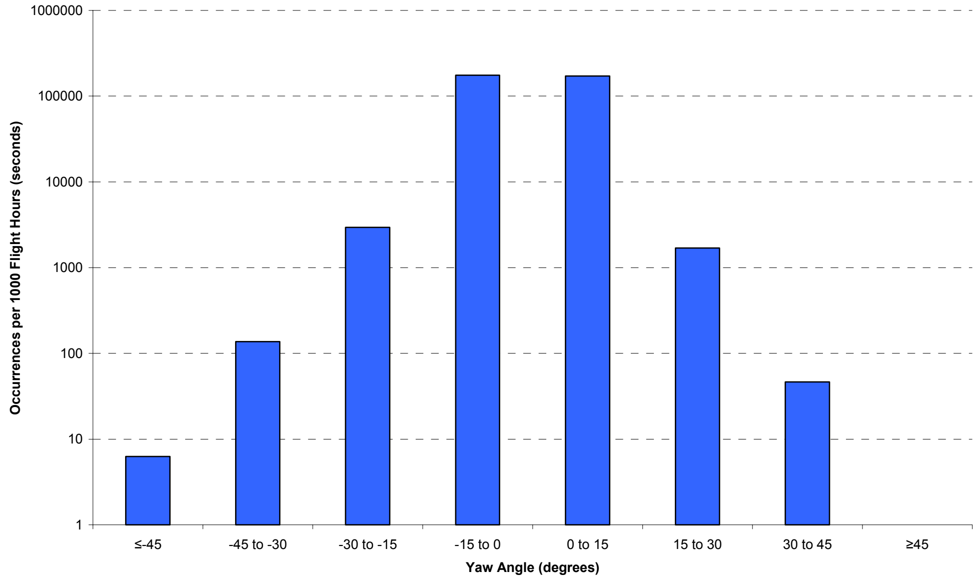

Figure A.3: Yaw Rate Occurrence

OCCURRENCE OF MAP, MAIN ROTOR SPEED AND OAT PARAMETERS

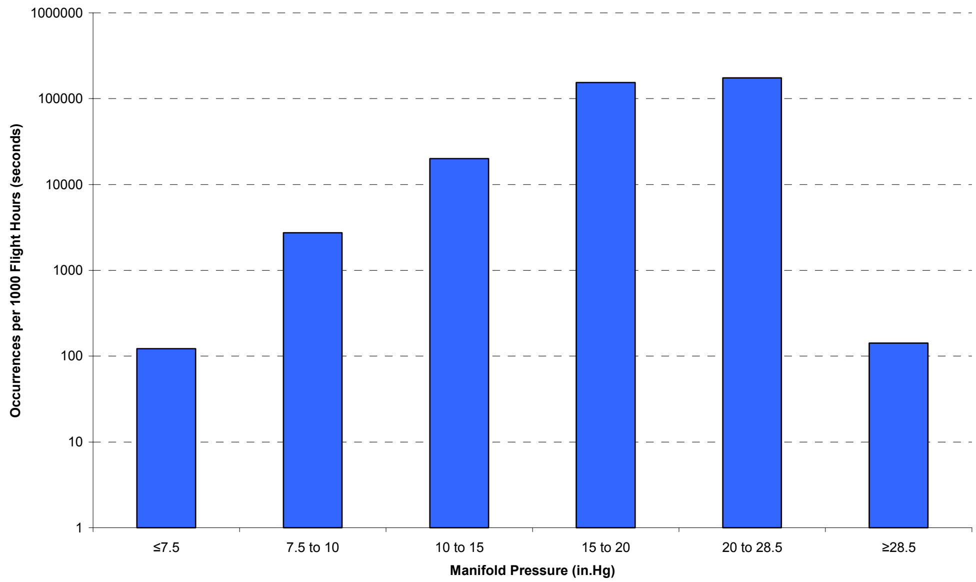

Figure B.4: MAP Occurrence

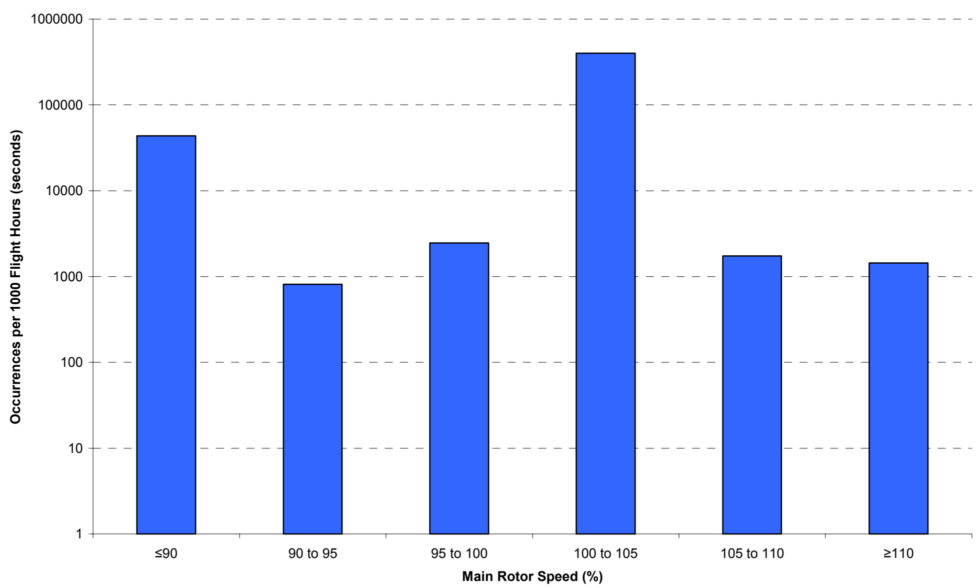

Figure B.5: Main Rotor Speed Occurrence

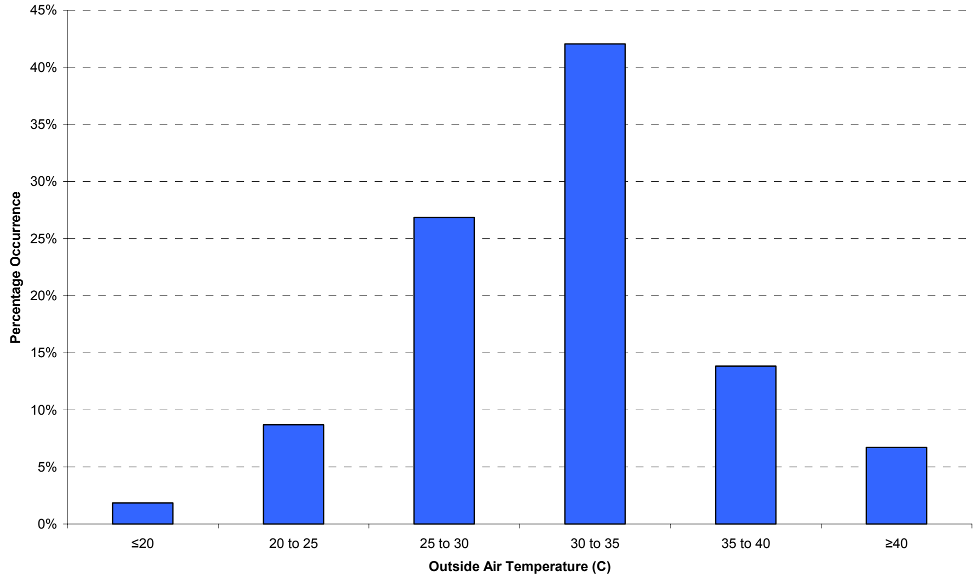

Figure B.6: OAT Occurrence

COMPARISON OF AERIAL MUSTERING TRIAL AND CERTIFICATION FLIGHT VALUES

		Aerial Mustering Trial		Certification Flights		Ratio of Aerial Mustering to Certification Values	
RHC DATAQ Measurand	**Unit**	**Peak-peak**	**Mean**	**Peak-peak**	**Mean**	**Peak-peak**	**Mean**
RS 38 CHORD (A2)	in.lb	26033.1	305.2			Noisy - bad slip rings - no results	
PITCH LINK (A3)	lb	151.5	11.1	218.7	42.1	0.69	0.26
RS 11 FLAP (A4)	in.lb	1655.8	1901.3	17351.8	1893.5	0.10	1.00
RS 16 CHORD (A5)	in.lb	8392.4	6548.1	16688.5	6121.1	0.50	1.07
MR SHAFT TORQUE (A6)	in.lb	2471.9	11977.2	14089.2	12305.4	0.18	0.97
RS 32 FLAP (A7)	in.lb	947.8	1423.2	916.3	1435.1	1.03	0.99
RS 66 CHORD (A10)	in.lb	23791.0	746.5			Noisy - bad slip rings - no results	
TRS 4.6 FLAP (A18)	in.lb	178.9	73.2	Not connected during these flights			
TRS 8.6 FLAP (A19)	in.lb	144.9	33.8	“			
TRS 4.6 CHORD (A20)	in.lb	470.6	19.5	“			
TR SHAFT CHORD (A21)	in.lb	363.8	54.7	“			
TR SHAFT FLAP (A22)	in.lb	367.5	9.6	“			
TR INBD HUB PLATE BEND (A16)	in.lb	62.7	6.4	“			
TR OUTBD HUB PLATE BEND (A17)	in.lb	22.2	1.9	“			
MAST TUBE LAT BEND (C14)	in.lb	2968.0	77.5	8974.8	299.7	0.33	0.26
MAST TUBE LONG BEND (C13)	in.lb	2858.2	2086.9	7109.4	2458.0	0.40	0.85
RIGHT P/P TUBE (B15)	lb	147.7	6.5	438.2	38.7	0.34	0.17
LEFT P/P TUBE (B14)	lb	138.0	5.5	341.3	17.9	0.40	0.31
AFT P/P TUBE (B13)	lb	116.0	9.7	199.4	8.7	0.58	1.12
TAILCONE FWD VERT BEND (B5)	in.lb	3882.1	1030.3	5669.2	906.0	0.68	1.14
TAILCONE FWD HORIZ BEND (B4)	in.lb	3540.1	7850.4	10557.4	8799.0	0.34	0.89
TAILCONE AFT HORIZ BEND (B6)	in.lb	803.9	416.5	1296.5	520.9	0.62	0.80
TAILCONE AFT TORQUE (C4)	in.lb	500.7	43.5	1360.2	234.6	0.37	0.19
ROTOR RPM	%	1.0	102.3	1.2	103.0	0.80	0.99
TRDS TORQUE (C21)	in.lb	994.0	294.2	418.0	282.0	2.38	1.04

Table C.1: Comparison of Maximum Measurand Values for Aerial Mustering Trial and Certification Flight Segments

TOTAL RECORDED POWER CUTS PER FILE

Card	File	Duration	Power Cuts Total	On Ground	In Flight (CAS<20kts)	In Flight (CAS>20kts)
1	1	3.56	32	2	14	16
1	2	0.12	2	0	1	1
1	3	3.69	1	1	0	0
1	4	3.16	27	1	7	19
1	6	2.87	6	6	0	0
1	7	0.81	3	0	1	2
1	8	3.43	9	4	3	2
1	10	6.52	19	3	6	10
2	4	1.95	4	2	2	0
2	5	3.29	3	0	2	1
2	6	0.14	1	0	1	0
2	15	4.29	2	0	2	0
2	17	4.37	12	3	4	5
2	18	0.56	1	1	0	0
3	1	5.69	25	0	7	18
3	3	5.07	8	4	4	0
3	4	0.23	2	2	0	0
3	5	0.69	2	1	1	0
3	8	5.17	5	4	0	1
3	9	0.36	5	5	0	0
3	11	5.01	1	0	1	0
4	4	0.11	2	0	1	1
4	6	0.64	3	1	1	1
4	7	5.41	5	2	3	0
4	8	0.32	6	0	2	4
4	10	4.94	9	0	5	4
4	11	0.30	1	0	1	0
4	13	6.83	7	2	3	2
4	15	0.25	1	1	0	0
5	3	2.85	5	3	2	0
5	4	1.34	2	0	2	0
5	6	4.05	2	1	1	0
5	7	0.57	2	2	0	0
5	14	1.06	2	1	1	0
5	15	0.39	1	0	0	1
5	17	0.68	1	0	1	0
5	19	4.70	4	2	2	0
5	20	0.50	12	0	8	4
5	22	0.24	1	0	1	0
5	23	0.80	1	0	1	0
6	1	1.13	1	1	0	0
6	2	5.39	6	4	2	0
6	4	4.83	27	5	12	10
6	6	0.65	2	2	0	0
6	7	0.93	2	1	1	0

Card	File	Duration	Power Cuts Total	On Ground	In Flight (CAS<20kts)	In Flight (CAS>20kts)
6	10	0.69	2	1	1	0
6	11	4.35	44	3	8	33
7	1	3.80	7	4	2	1
7	3	1.30	34	2	17	15
7	4	4.20	4	3	1	0
7	5	0.69	1	1	0	0
7	6	0.65	1	1	0	0
7	7	7.03	34	3	7	24
8	1	4.50	4	0	2	2
8	2	0.29	4	2	2	0
8	24	0.13	2	1	1	0
8	25	4.25	4	1	1	2
8	26	0.18	2	1	1	0
8	29	3.52	1	0	0	1
9	3	0.67	1	0	1	0
9	4	4.47	3	1	0	2
9	11	1.28	1	0	1	0
9	15	0.91	1	0	0	1
9	16	0.21	1	0	1	0
9	18	6.57	28	4	7	17
10	1	0.41	4	1	1	2
10	3	0.69	1	0	1	0
10	5	0.77	2	1	1	0
10	7	5.10	5	0	4	1
10	9	4.70	14	1	6	7
10	10	4.28	8	0	2	6
10	12	0.96	1	0	1	0
10	16	1.19	1	0	1	0
11	2	5.17	17	1	5	11
11	3	0.56	5	1	3	1
11	4	0.30	2	2	0	0
11	6	1.08	2	1	1	0
11	14	0.64	5	1	3	1
11	15	0.54	2	1	1	0
11	17	0.76	12	0	10	2
11	19	0.15	1	0	1	0
11	20	0.82	3	1	1	1
11	21	0.65	2	1	1	0
11	22	0.35	3	0	1	2
11	23	0.27	12	0	5	7
11	25	0.37	1	1	0	0
11	28	0.62	4	0	2	2
11	29	0.34	1	0	0	1
11	30	1.01	4	0	2	2
11	31	0.25	1	0	1	0
11	32	0.67	1	0	1	0
11	34	0.10	1	0	1	0
11	36	0.18	2	1	0	1
11	40	0.35	1	1	0	0

Card	File	Duration	Power Cuts Total	On Ground	In Flight (CAS<20kts)	In Flight (CAS>20kts)
11	41	0.35	8	0	6	2
11	42	0.68	3	0	3	0
11	43	0.70	3	1	2	0
11	47	0.77	7	0	6	1
11	48	0.44	1	0	0	1
11	49	0.14	3	2	0	1
11	50	0.18	1	0	1	0
11	51	0.70	3	0	0	3
11	53	0.37	2	1	0	1
11	55	0.21	1	1	0	0
11	56	0.35	2	0	1	1
11	57	0.39	3	0	1	2
11	58	0.20	3	0	1	2
11	60	0.95	6	0	3	3
11	61	0.74	5	1	3	1
11	62	0.36	1	1	0	0
11	63	0.72	3	1	2	0
11	64	0.37	3	0	2	1
11	65	0.51	2	1	0	1
11	66	0.88	5	0	1	4
11	67	0.42	3	1	0	2
11	69	1.11	8	2	4	2
11	70	0.39	2	1	0	1
11	71	0.20	3	0	2	1
11	72	1.02	10	0	4	6
11	73	0.24	4	0	3	1
11	75	0.34	1	1	0	0
11	76	0.34	9	2	2	5
11	77	0.35	4	1	2	1
11	79	0.17	6	0	4	2
11	81	0.70	3	0	2	1
11	83	0.37	5	1	1	3
11	84	0.32	3	0	1	2
11	86	0.60	6	1	1	4
11	87	0.23	1	0	1	0
12	1	0.47	4	1	0	3
12	2	0.16	2	1	1	0
12	3	0.52	8	1	3	4
12	4	0.50	3	1	1	1
12	5	0.22	1	0	1	0
12	6	0.09	2	0	1	1
12	7	0.13	4	0	2	2
12	8	0.62	3	1	1	1
12	10	0.38	6	1	3	2
12	12	0.43	2	1	1	0
12	13	0.37	1	1	0	0
12	15	0.54	5	1	3	1
12	16	0.34	2	2	0	0
12	18	0.20	1	1	0	0

Card	File	Duration	Power Cuts: Total	On Ground	In Flight (CAS<20kts)	In Flight (CAS>20kts)
12	19	0.22	1	1	0	0
12	21	0.64	1	0	0	1
12	23	0.16	1	1	0	0
12	24	0.49	3	0	2	1
12	25	0.66	11	0	2	9
12	26	0.34	5	4	1	0
12	27	0.75	2	0	1	1
12	28	0.51	3	1	2	0
12	30	0.14	1	1	0	0
13	3	1.34	1	1	0	0
13	5	5.68	26	1	7	18
13	6	0.40	1	1	0	0
13	7	0.05	1	0	1	0
13	9	0.43	1	1	0	0
13	11	2.40	4	1	1	2
13	13	0.51	2	1	1	0
13	15	1.31	4	1	2	1
13	17	2.04	7	2	0	5
13	19	2.83	38	0	9	29
14	1	3.05	8	1	2	5
14	2	1.30	3	2	1	0
14	4	0.77	1	0	1	0
14	11	0.14	1	0	1	0
14	14	4.04	2	1	1	0
15	1	2.70	2	0	1	1
15	4	2.55	1	0	0	1
15	5	0.14	1	0	1	0
15	6	2.93	6	3	3	0
15	11	0.19	7	0	5	2
16	2	3.43	14	0	5	9
17	1	2.52	6	1	2	3
17	3	2.15	13	12	1	0
17	4	1.92	5	4	1	0
17	5	0.59	1	0	1	0
17	10	2.76	9	1	2	6
17	11	0.18	1	0	1	0
17	12	2.65	8	6	1	1
17	13	0.04	1	1	0	0
17	14	1.41	1	0	1	0
17	17	2.23	1	0	1	0
18	1	0.48	14	0	1	13
18	2	3.81	16	0	4	12
18	3	2.87	5	4	1	0
18	4	5.51	9	0	8	1
19	1	2.98	5	5	0	0
19	2	0.28	1	1	0	0
19	4	1.78	4	1	2	1
19	5	0.56	1	0	1	0
19	6	2.34	1	1	0	0

Card	File	Duration	Power Cuts: Total	On Ground	In Flight (CAS<20kts)	In Flight (CAS>20kts)
19	7	1.60	1	1	0	0
19	11	0.14	1	0	1	0
19	12	2.05	9	2	4	3
19	13	2.94	24	7	4	13
20	1	1.90	1	1	0	0
20	5	0.29	2	0	1	1
20	6	0.94	1	0	1	0
20	8	0.93	9	0	4	5
20	10	1.97	2	0	2	0
20	11	1.16	3	2	0	1
20	14	2.52	4	2	1	1
20	17	0.13	1	0	1	0
20	19	2.97	8	1	5	2
21	1	3.25	19	0	7	12
21	3	0.08	4	4	0	0
21	5	2.34	5	2	0	3
21	6	0.08	1	1	0	0

Table D.1: Power Cuts Per File (Manifold Pressure Drop: 10-21in.Hg)

TRDS TORQUE CYCLE EXCEEDANCES

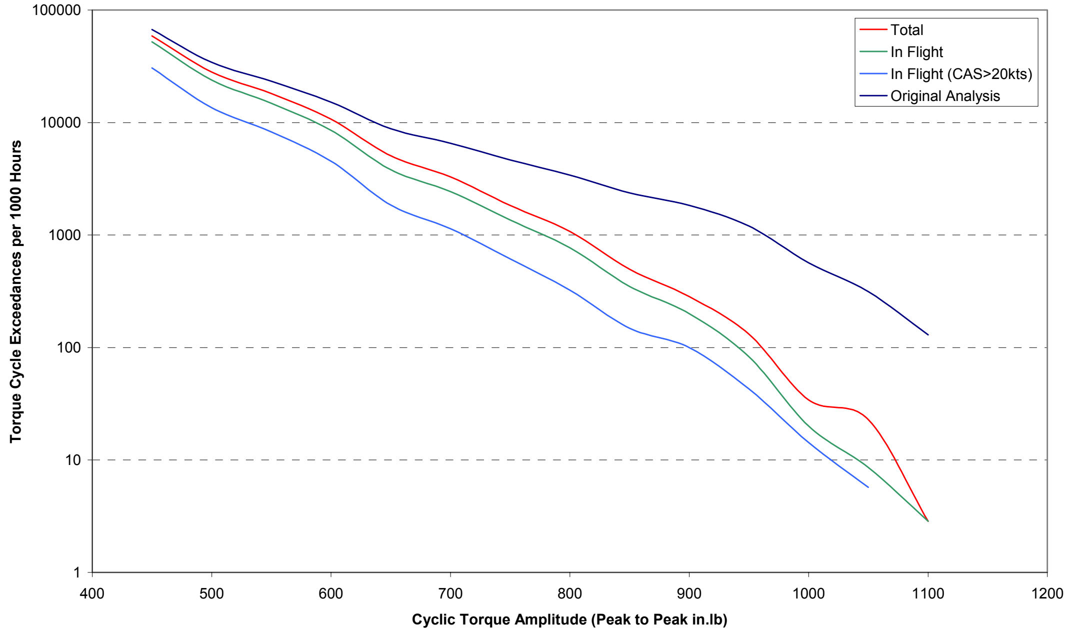

Figure E.7: TRDS Cyclic Torque Exceedance Spectra