National Defence Défense nationale

Canada

T56 PROPULSION SYSTEM COST STUDY

Defence and Civil INSTITUTE OF ENVIRONMENTAL MEDICINE

INSTITUT DE MEDECINE ENVIRONNEMENTALE pour la défense

1133 Sheppard Avenue West, PO Box 2000, North York, Ontario, Canada M3M 3B9
Tel. (416) 635-2000
Fax. (416) 635-2104

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

November 1996

DCIEM No. 96-R-68

T56 PROPULSION SYSTEM COST STUDY

K.M. Jaansalu
R.R. Hastings
G.N. Nelson *

DCIEM Air Vehicle Research Detachment
National Defence Headquarters
Ottawa Ontario K1A 0K2

DEPARTMENT OF NATIONAL DEFENCE - CANADA

* Directorate of Technical
Airworthiness

Executive Summary

This study analyses operating costs and flight safety data of the propulsion systems on the CC-130 Hercules and CP-140 Aurora/Arcturus aircraft to identify where R&D investment could provide airworthiness or program cost benefits. The T56 engine, in three basic variants, is used to power both of these aircraft types. Operational impact and R&O cost data are provided on the gas turbine engine, the reduction gearbox, and the propeller systems. Data are presented on each of the aforementioned sub-assemblies for each of the three T56 engine types employed by the Canadian Forces.

For the 66 month period beginning on 01 January 1991 and ending 30 June 1996 the propulsion system on the CC-130 Hercules was the cause of 339 flight safety incidents which is 13% of the total number of flight safety incidents (2590) and 32.5% of the materiel cause factor flight safety incidents. During this same period the propulsion system of the CP-140 Aurora was the cause of 362 flight safety incidents which is 20% of the total flight safety incidents (1789) and 46% of the materiel cause factor flight safety incidents (784). Normalized by flying rate the propulsion incident rate is 2.1/thousand aircraft flying hours for the CC-130 and 3.7 for the CP-140. The propeller system has a greater impact for both aircraft types on flight safety occurrences than the engine itself. The propeller, coupled with the oil debris sensor, on the CP-140 powerplant are the reasons for the much higher occurrence rate of flight safety incidents on the CP-140. The much greater number of throttle transients required in the operation of the CP-140 is the most probable cause for the propeller system problems.

The engine impact on airworthiness of the CC-130 Hercules and CP-140 Aurora aircraft is relatively benign, however benefit to airworthiness could be realized by R&D investment in advanced health usage monitoring systems, most notably oil debris monitors. The propeller systems used on both aircraft are very similar and very old. Modern propeller systems are much less complex and more reliable. The improvement of this older design propeller system would be difficult and R&D investment to reduce propeller system impact on the flight safety performance of these aircraft is unlikely to yield significant benefits.

The costs of operating the propulsion systems of the CC-130 and CP-140 aircraft during the period 01 January 1991 through 30 June 1996 are summarized in the table below. Maintenance Person Hour (MPH) figures include all first and second line CF maintenance manhours for all un-scheduled maintenance and all maintenance actions arising from scheduled inspections with no overhead factored into military manpower costs. The total R&O contract value for the T56 propulsion system is expected to be $17.0 M for FY 96/97.

The increased cost of operation of the -7B engine over the more powerful -15 engine used on the CC-130 Hercules is primarily the result of a much shorter -7B turbine life. The -7B employs an older design, non-cooled first stage turbine which offers only half of the operational life of the T56-A-15 Series III engine. While R&D investment in such initiatives as Thermal Barrier Coatings and repairs to the -7B would offer some potential for cost savings, a much more prudent approach is to re-configure the Series II engines to Series III and thus significantly reduce operating costs and increase performance capabilities without R&D investment.

Table ES - Overall Costs for T56 Propulsion Systems.

Element / Work Unit Code	MPH /1000 FH	Military Manpower Cost /1000 FH [1]	Overhaul Cost /1000 FH [2]	Total Cost /1000 FH
CC-130 Total	1393.8	$55,752.00	7B $408,700.00 15 $330,000.00	7B $464,500.00 15 $385,800.00
CP-140 Total	2079.3	$83,172.00	$385,300.00	$468,500.00
CC-130 Engine - BCA	216.8	$8,672.00	7B $306,000.00 15 $227,300.00	7B $314,700.00 15 $236,000.00
CP-140 Engine - BCA	211.3	$8,452.00	$288,600.00	$297,100.00
CC-130 RGB - BCC	95.6	$3,824.00	$42,600.00	$46,400.00
CP-140 RGB - BCB	110.3	$4,412.00	$41,300.00	$45,700.00
CC-130 Propeller - CD	521.1	$20,844.00	$56,000.00	$76,800.00
CP-140 Propeller - CD	786.4	$31,456.00	$50,600.00	$82,100.00

RGB=Reduction Gear Box, FH= Aircraft Flying Hours

Notes: [1] Assumes military manpower cost at $40.00 per hour with no overhead.

[2] Overhaul costs as derived and assumes nominal life of 6000 hours for all components.

Modest cost improvements can be achieved for the T56 engines via repair scheme development or rework development such as erosion/corrosion or thermal barrier coating development. Additional effort will be required to develop a business case for repairs/reworks of specific high rejection rate, high cost components.

Modest to good cost and airworthiness improvements should be achievable through simple trend monitoring systems application which would reduce hot section duress by ensuring, in particular, turbine inlet temperature thermocouple and engine fuel management system integrity. The expertise exists now to effect this capability with a minimal investment in R&D and engineering funds.

Investment in On-Line oil debris monitoring systems having higher failure prediction reliability would improve the airworthiness of both propulsion systems. The capability exists to effect this change with minimal R&D or engineering investment.

Significant cost savings and operational readiness improvements could be achieved through the fitment of an advanced design propeller system to both aircraft, but most significant advantage would be accrued to the CP140 Aurora/Arcturus programs. This would involve a significant R&D and engineering investment and would likely be most effective if coupled to an engine refit program.

Table of Contents

Annexes

List of Tables

T56 Propulsion System Cost Study

Capt K.M. Jaansalu, Mr R.R. Hastings
Air Vehicle Research Sector
&
Capt G.N. Nelson
Directorate of Technical Airworthiness

PART I - INTRODUCTION

1. A major development project has been initiated to investigate and implement engine component repairs and reworks for the CF-188/F404 engine. This project is nearing a successful completion: successful in that several technologies are being used to achieve program cost reductions in the overhaul of the F404 engine. The methodologies and technologies developed from this major project can be applied to other engine fleets. The first step in this process is to determine the costs of doing business today with these other engines. The next largest engine program in the Canadian Forces is the Allison T56. There have been a number of studies over the past years which have addressed T56 costs to varying degrees and much data already exists within DAEPM(TH) and contractor organizations. This study will provide an overall repair and overhaul cost picture for T56 engines used on the CC-130 Hercules and CP-140 Aurora aircraft fleets.

Aim

2. This cost study is undertaken to identify the costs of operating the T56 propulsion system in order to identify potential areas where R&D effort could achieve cost reductions.

PART II - DESCRIPTION OF EQUIPMENT

Propulsion Systems

3. The Allison T56 propulsion system is widely used in military forces and in civilian transport aircraft with the designation Allison 501. The Canadian Forces use the military system on two aircraft types, the CC-130 Hercules and the CP-140 Aurora / 140A Arcturus aircraft. There are three engine types currently in CF inventory. They are the T56-A-7B, a Series II engine used on the E model Hercules; the T56-A-14LFE Series III used on the Aurora; and the T56-A-15/15LFE Series III used on the H model Hercules. The total numbers of engines are 99×A-7B, 103×A-14, 63×A-15.

4. The Hercules propulsion system consists of a propeller, a Reduction Gear Box (RGB),

torque meter (TQM), and the T56 power section. The first three are common to both the E and H models. An H model power section (i.e. an A-15 engine) can be installed on an E model Hercules, but the power section performance must be downgraded to match the other power sections on wing. Conversely, an E model power section (i.e. an A-7B) can be installed on the H model, but then the A-15 engines' performance must be downgraded to match the A-7B performance. The installation of an A-15 engine on an E model is rare, the installation of an A-7B on an H model is almost never, if ever, done. It should be noted that as all Canadian Forces CC-130 aircraft are fitted with H model wings, the fleet can fully utilize the more powerful A-15 engine.

5. The propulsion system used on the Aurora is very similar to the Hercules and there are many common parts and sub-components. However, the propellers, RGBs, torque meters, and engines are kept separate even at third line repair and overhaul. The RGB is essentially identical to that used on the C-130, but it is mounted upside down relative to the Hercules and requires a different oil system design.

T56 Engine

6. The T56 engine is a single spool, axial flow turboprop that runs at a constant speed (13,820 (100%) RPM). Originally designed in the late 1940's, it has evolved over the years and major improvement packages have been designated by differing series numbers. The largest difference between the T56 engines used by the CF is between the Series II-A-7B and the Series III-A-15. The A-7B has an overhaul interval of 5100-6000 hours, but the turbine assembly is removed and replaced every 2250-3150 hours. By comparison, the Series III design incorporates first stage turbine cooling to reduce the duress in the hot section. The A-15 has an overhaul interval of 5100-6000 hours and the A-14 an interval of 5400-6000 hours. In terms of performance, the T56 Series II engine produces 4050 shaft horse power, whereas the Series III engine produces 4600 SHP.

7. Rolls Royce / Allison are now marketing the AE2100 engine which can be described as the next generation T56 engine. The AE2100 has a 14 stage compressor similar to the T56 engine, but makes extensive use of compressor variable geometry components. The AE2100 also employs a separate free turbine for power output in a two spool engine configuration. The AE2100 is the powerplant designated for use on the C130J model Hercules..

Propeller Systems

8. The Aurora and Hercules both use Hamilton Standard 54H60 propeller systems. The propeller is hydraulically controlled and the relatively complex design dates back to the mid 1950's. The Aurora propeller, the 54H60-77, is optimised for high speed and endurance. The Hercules propellers, 54H60-91 or -117, are optimised more for high take-off thrust which sacrifices performance at higher speeds. Although the -77 and -91/117 blades are significantly different, many of the sub-components and parts are identical. The overhaul intervals are

slightly different; 6000-6600 hours for the 54H60-77 (Aurora) and 5100-6000 hours for the 54H60-91/117.

Torque Meter and Reduction Gear Box

9. The torque meter transfers the torque from the power section to the reduction gear box. The TQM is of a fairly simple design and quite rugged. The overhaul interval for the torque meter is 11100-12000 hours for the CC-130 and 11400-12000 for the CP-140. The overhaul interval for the RGB is identical to the power section for the aircraft type.

Maintenance Schedules

10. The maintenance schedules for the engine are dependent on the airframe inspection schedule and are also environmentally driven. As a result, the periodic interval for the engine is slightly different between the two aircraft types: the Hercules is on a 850-950 hour periodic with a 405-495 hour supplementary check and the Aurora is on a 550-650 hour periodic interval with a 270-330 hour supplementary check.

PART III - OPERATIONAL IMPACT ANALYSIS

11. A previous study, reference A, has identified the relative impact of the four aircraft subsystems, namely powerplant, avionics, weapons, and airframe and other systems, on the operations of CF aircraft, including the CC-130 and the CP-140. This engine cost study builds upon the methodologies and results of this previous study, particularly in the identification of those specific propulsion system components that are causing cost significant events such as mission aborts and delays. Throughout these surveys, the time period of 1 January 1991 to 30 June 1996 was used to ensure a consistent and statistically valid database.

Aircraft Maintenance Information Data

12. In this section, data generated from the Canadian Forces Aircraft Maintenance Management Information System (AMMIS) is presented. Each maintenance action that is carried out on an aircraft to rectify an unserviceability is annotated on a CF349 - Aircraft Maintenance Report. Data from these reports are input into the AMMIS database and subsequently available for analysis. One item of information that is noted on each CF349 is the impact of the unserviceability on the mission. The impact is rated as having no mission effect, part/delayed mission, or abort. The staff at the Directorate of Technical Airworthiness generated the reliability and maintainability reports in support of this study and these reports are attached in Annex A.

13. A hierarchial code system is used to identify the aircraft system and sub-assemblies on which maintenance actions have been performed. These work unit codes, WUC, are allotted to

those items that are lifed, subject to regulated inspection, or are deemed sufficiently important to warrant coding. Equipment that is common to various types of aircraft usually have the same WUC. For example, the work unit code BCA designates a turboshaft power section, in this case the T56. The WUC BCAC represents the turbine module. In this study, all results expressed for a certain component represented by a WUC take into account all of the sub-assemblies of that component or item in question. For example, data presented for the WUC BCA includes data for all sub-WUC such as BCAC. The components considered in this study and their respective work unit codes are listed below:

Item	WUC
Engine Assembly	BC
T56 Engine	BCA
RGB	BCB on CP-140, BCC on CC-130
Propeller System	CD
Propeller	CDA
Propeller Controller	CDB

14. In the following operational impact analysis, all figures are given on a 'per 1000 aircraft flying hour' basis to allow for a comparison between engines and aircraft types. DTA 4 also has on-line access to the Aircraft Accident and Incident Information System (ACAIRS) and thus has also provided an important link between the maintenance data and the flight safety data. The operational impact as seen by the Flight Safety network will be examined in the next section.

15. The reliability of the Aurora propulsion system, both the engine and propellers, is significantly lower than for the Hercules. This difference is most likely attributable to mission/operational usage differences. The Aurora patrols typically have several throttle movements, including shutting down an engine for loitering, and altitude changes during a flight. These high abort rates are worthy of further ACAIRS analysis.

16. In the table below, the last column lists the number of Flight Safety incidents which arose from the total number of aborts attributed to that Work Unit Code. For each flight safety incident raised against the CP-140 propeller system (CDA&CDB), there are roughly three more mission aborts which were caused by a maintenance malfunction. (ie the aircraft aborted because of a mechanical problem, as opposed to weather or a higher operational priority). In the CC-130 Hercules community, roughly one out of every two mission aborts are reported through the flight safety network. This likely reflects a difference of reporting policy and must be kept in mind when using the flight safety network as an indicator of the impact of these systems on aircraft operations.

Table 1- Operational Impact Analysis: Mission Effect and Flight Safety Incidents.

WUC	AC Type	Aborts / 1000 FH	Delays / 1000 FH	Incidents / 1000 FH	FS Incidents / Abort
BC	CC-130	1.46	1.34	-	-
	CP-140	4.6	1.88	-	-
BCA	CC-130	0.17	0.06	0.21	20/28
	CP-140	0.46	0.05	0.46	31/45
BCC	CC-130	0.01	0.01	0	0/1
BCB	CP-140	0.19	0.03	0.12	11/19
CD	CC-130	0.71	0.61	-	-
	CP-140	2.3	0.49	-	-
CDA	CC-130	0.35	0.32	0.87	64/109
	CP-140	0.69	0.16	0.47	17/67
CDB	CC-130	0.22	0.14	0.30	43/58
	CP-140	0.95	0.16	0.37	22/92

Canadian Forces Flight Safety Data

17. The ACAIRS survey considered only those incidents where there was a materiel cause factor assigned as this gives the best indication of the effects of the inherent reliability of the propulsion system on CF operations. As a consequence of this methodology, the data comes out as the number of cause factors assigned, not necessarily the number of incidents; however, these figures are similar as the instance of one incident having two material cause factors assigned was very rare. For basis of comparison between the two aircraft fleets, a cause factor assignment rate is used, expressed as per 1000 aircraft flying hours. In other words, this expresses the number of materiel cause factors that will be assigned every 1000 flying hours.

Table 2a - Flight Safety Incident Materiel Cause Factor Breakdown: CC-130 Hercules.

	Total Number	Per 1000 FH
Total Cause Factors Assigned:	2590	16
Of these, total of materiel cause factors:	1042	6.4
Of these, total of propulsion system:	339	2.1
Of these, the top three systems are:		
Propeller System	180	1.1
Oil Pressure Indicating System	24	0.15
Bleed Air System	22	0.14

Table 2b - Flight Safety Incident Materiel Cause Factor Breakdown: CP-140 Aurora/Arcturus.

	Total Number	Per 1000 FH
Total Cause Factors Assigned:	1789	18
Of these, total of materiel cause factors:	784	8.1
Of these, total of propulsion system:	362	3.7
Of these, the top three systems are:		
Chip Lights/Detectors	185	1.9
Propeller System	77	0.79
Oil Lines and Seals	13	0.13

18. The overall incident rates generated from the AMMIS data do not compare well with the cause factor assignment rate for the entire propulsion system. However, a comparison of the propeller systems on both type of aircraft (WUCs CDA & CDB) show excellent agreement. Thus, the propeller data is consistent and observations can be made with some confidence.

19. In examining the propeller system on the CC-130, the latest 39 of the 179 incidents were caused by a failure of the propeller float switch (10) followed by the valve housing assembly (5). The latest 27 incidents on the CP-140 propeller system showed 11 due to pump housing assembly failures, and there were no other major discernable causes. The impact of these failures is an engine shutdown and the aircraft returns to base. As discussed above, these incidents reflect only a portion of the mission aborts, particlarly for the CP-140.

20. Regarding the incidents involving the oil indication system on the CC-130, the prime cause was a faulty oil pressure transmitter which occurred in 13 out of the 23 incidents reviewed.

Another common cause is corrosion or water ingress at cannon plugs. Only in one case was there an unexplained oil loss that resulted in an engine shutdown. The oil pressure transmitter is a component which should be assessed further for improvements.

21. The Hercules is an older aircraft and as such, the bleed air ducts leak. Duct failures caused 8 out of the 21 incidents reviewed on the bleed air system. The most serious failure that had clear potential for an accident occurred on 31 Oct 92 when, during the take-off roll at 100 knots, there was a 4000 in-pound torque loss across the four engines. The root cause was that a weld along a bleed air duct failed. Another finding is that the gaskets in the bleed air system were determined to be a cause in another 6 of these incidents. These gaskets have just recently been changed from asbestos based to polymeric based and there have been some failures with the new gaskets. Problems with the duct system are symptomatic of ageing aircraft and the maintenance of this system is currently the subject of a major investigation by DAEPM (TH) and DTA staffs.

22. On reading the ACAIRS narratives for the chip detector system used on the Aurora, there is a clear preponderance of incidents associated with the RGB vice the engine. The RGB and engine have a common oil system but there are two chip detectors. One is located in the RGB return and the other in the power section return. The chip detector is automatic: nuisance debris is burnt off and only when the debris cannot be burnt off does the light illuminate in the cockpit. The action taken is an emergency engine shutdown and the aircraft returns to base.

23. On examination of the chip indications, roughly one quarter of the 32 incidents in the period 1 January 1992 to 1 January 1994 were due to a system failure and nothing was found wrong with the RGB or engine. This clearly demonstrates the requirement for the chip detector system to be inherently more reliable than the system which it monitors. The proportion drops to roughly one eighth in the time period of 1 January 1995 to 1 January 1996 as the reliability of the system has been increased. Of the chip indications in this later time frame that were caused by metal particles, less than one in ten resulted in an actual removal of the RGB or the engine. The remainder have been attributed to normal, progressive breakdown.

24. The high number of oil leaks was investigated and for the majority of the incidents, the gaskets/packings were installed incorrectly. In a few incidents, the packings had deteriorated to the point where the connection leaked. By comparison, the Hercules fleet suffers from the same problems, but has a cause factor assignment rate of 0.05 per 1000 FH. This rate difference may merely be the result of a difference in reporting policy. Given the large number of oil lines on an aircraft engine, a realistic solution may simply be to bring these trends to the technicians' attention.

PART IV - MAINTENANCE ANALYSIS

25. The maintenance manpower expended, or burden, on the T56 power section, the RGB, and the 54H60 propellers have been reviewed using AMMIS data from 1 January 1991 to 30 June 1996 and are presented in the tables below. This large time interval was taken to ensure a good historical average for the maintenance requirements. The first, or 'a', tables account for all unscheduled maintenance actions, including those arising from time expired components. The second, or 'b', tables exclude the time expired components. For purposes of comparison between fleets and components, the maintenance actions are given per 1000 aircraft flying hours (FH). The initial reports from the AMMIS cell are appended to this report at Annex A.

26. The parameters used in the table are defined as follows:

a. MPH - Maintenance person hours. This parameter represents the cumulative person hours associated with unscheduled maintenance actions. The figure of MPH/1000 FH is also referred to as the maintenance burden in this report,

b. UMA - Unscheduled maintenance action. This parameter represents the cumulative maintenance actions carried out to rectify the component unserviceabilities. UMA's are any reported actions, e.g. repairs, removals, no-fault-found, robs, CF modifications, etc. This parameter is a reflection of all activities carried out to support the component in question. It should be noted that there may be multiple maintenance actions for a single aircraft unserviceability event,

c. First Line - On Aircraft - This reflects the time spent, as indicated on the CF349 reports, by the first line maintenance organization in performing aircraft maintenance. Such activities include repairs to the aircraft on the flight line, the replacement of minor components, the embodiment of modifications, and carrying out special inspections,

d. Second Line - On Aircraft - This represents the time spent as listed on the CF349 those activities such as repairs resulting from a supplementary or periodic inspection (not the inspection itself), and associated major maintenance, and

e. Second Line - Off Aircraft - This represents the total time taken by shops personnel in repairing aircraft components that have been removed from the aircraft. These times are generated from a different form, the CF543 Off Aircraft Maintenance Report.

Engine Assembly

Table 3a - Engine Assembly Reliability and Maintainability Performance - including time expired components.

WUC: BC	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
First Line - On aircraft	CC-130	445.9	31.5	14.2
	CP-140	628.7	44.4	14.2
Second Line - On aircraft	CC-130	132.9	15.7	8.5
	CP-140	266.7	32.0	8.3
Second Line - Off aircraft	CC-130	293.9	39.7	7.4
	CP-140	397.5	69.1	5.8
Second Line - TOTAL	CC-130	426.8	55.4	7.7
	CP-140	664.2	101.1	6.6

Table 3b - Engine Assembly Reliability and Maintainability Performance - no time expired components.

WUC: BC	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
First Line - On aircraft	CC-130	436.4	31.2	13.9
	CP-140	623.6	44.3	14.1
Second Line - On aircraft	CC-130	93.1	13.8	6.8
	CP-140	244.7	31.7	7.7
Second Line - Off aircraft	CC-130	219.6	34.8	6.3
	CP-140	379.0	68.2	5.6
Second Line - TOTAL	CC-130	312.7	48.6	6.4
	CP-140	623.7	99.9	6.2

27. The two tables above give an overview of all the manhours associated with the maintenance of the engine assembly. All sub-work unit codes are included in this analysis and the major subcomponents and WUCs are listed in Annex B. Immediately, there is a significant difference in the maintenance burden of the two aircraft fleets At first line, the Aurora burden is on the order of 40% more than the Hercules and at second line, over 50% higher. There are roughly twice as many maintenance actions on the Aurora as for the Hercules, but this figure must be taken with caution as one unserviceability event may result in more than one maintenance action being taken and this is a matter of local reporting policy. The MPH/UMA are quite similar between the two fleets, particularly at first line, and in Table 3b, for the total second line. At this work unit level of BC and discounting all time expired components, the difference at second line on and off aircraft work in Table 3b is a result of differing maintenance practices for the Aurora and Hercules fleets. This result is not unexpected as there would be the same tasks performed on the engine system, but perhaps not on the aircraft. There is, however, a much higher maintenance burden associated with the Aurora.

Table 4a - T56 Reliability and Maintainability Performance - including time expired components.

WUC: BCA	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
First Line - On aircraft	CC-130	82.9	1.7	47.9
	CP-140	80.7	1.7	48.2
Second Line - On aircraft	CC-130	44.7	1.2	38.3
	CP-140	61.9	1.9	32.2
Second Line - Off aircraft	CC-130	89.2	6.3	14.1
	CP-140	68.7	5.0	13.8
Second Line - TOTAL	CC-130	133.9	7.5	17.8
	CP-140	130.6	6.9	18.9

Table 4b - T56 Reliability and Maintainability Performance - no time expired components.

WUC: BCA	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
First Line - On aircraft	CC-130	75.8	1.6	46.3
	CP-140	75.7	1.6	46.9
Second Line - On aircraft	CC-130	15.9	0.59	27.0
	CP-140	45.9	1.6	27.9
Second Line - Off aircraft	CC-130	43.9	4.9	8.9
	CP-140	56.6	4.5	12.6
Second Line - TOTAL	CC-130	59.8	5.49	10.9
	CP-140	102.5	6.1	17.2

28. Considering the T56 power section, the first line maintenance burdens for both aircraft types are very similar in both tables, and the difference due to time expired components is minimal at first line. On review of the first line data, the maintenance hours recorded against the power section were very high relative to the downtime of the aircraft. Specifically, downtimes of 48 hours or less have associated with them person hours recorded ranging from 100 to 202 hours. One possible explanation is that the maintenance crews, in trying to meet the flight schedule, are performing the guaranteed fix such as replacing the engine as opposed to lengthy troubleshooting. However, the reporting policies and procedures at first line must be clearly understood prior to making cost decisions.

29. In comparing the second line maintenance burden in the first table, the overall second line maintenance is about the same for both aircraft types. This is somewhat surprising considering the shorter overhaul life of the A-7B hot section. The impact of the time expired components on the CC-130 maintenance burden can be seen when comparing figures from Table 4a to Table 4b as the second line maintenance burden drops from 44.7 to 15.9 and 89.2 to 43.9 on and off aircraft respectively, a total reduction of 55%. When examining the CP-140 maintenance burden in the same fashion, the reduction is 22%. Thus the 23% difference between

the CC-130 and the CP-140 maintenance burden including time expired components can be largely attributed to the A-7B hot section. This reduction is further supported by examining the workload figures as provided by the 8 Wing Trenton engine bay (Annex C) which showed that the A-7B accounted for roughly 20% of their work. This agreement is excellent.

30. The impact of the shorter overhaul life of the A-7B turbine section requires some clarification as part of the overhaul actually takes place in the engine bay. To start the process, the entire engine comes off wing and is routed to the engine bay. The turbine assembly is removed and the rotor is returned to the contractor for overhaul. At present, all 102 of the first stage turbine blades are replaced and the remaining stages are inspected and replaced as required. The 100% first stage replacement is due to a series of turbine blade failures and future overhauls will take into account a service life that has yet to be established. The first stage turbine guide vanes are completely replaced, with the other stage vanes inspected and replaced as required by CF personnel at the operational unit. The manpower and materiel cost are detailed under the third line costs discussed below. An overhauled turbine rotor is then installed and the engine is built back up, ready for installation. Normally, the turbine sections are matched to the compressor sections so that the turbine overhaul and power section overhauls coincide. However, with a recent lifing of the 2-3 turbine disk spacer, several rotors had to be returned to overhaul for part replacement. One result is that there are turbine sections on wing that do not match the overhaul cycle of the compressor section. The consequence is that power sections will be sent to the overhaul facility without a turbine when the turbine has over 1000 hours of life remaining. As this relifing is fairly recent, the full impact of this situation has yet to manifest itself.

31. Accounting for the impact of the A-7B on the second line burden for the CC-130, the A-14 engine has a higher second line burden than that of the A-15 engine. There are several explanations for this such as maintenance organization, policies, procedures, and even the fact that, on average, the A-15 engines are younger than the A-14. For instance, Canada procured four tanker H model CC-130 aircraft with 16 new A-15 engines in 1990-91. Yet, by far the largest difference is caused by the maintenance schedule and practices. The periodic inspection schedule for the Aurora is a 600 hour cycle vs a 900 hour cycle for the Hercules. As the Aurora propulsion system is inspected more frequently, a higher maintenance burden would be expected. The maintenance organization at 14 Wing Greenwood also has a maintenance test stand for the T56 and propeller system. The impact of this added capability is difficult to discern within the scope and level of analysis of this study. Another major factor is the nature of operations as mentioned above. A maritime patrol mission has many more throttle movements, ranging from engine shutdown for loitering to full power climbs and this has a direct impact on engine reliability and component consumption.

32. In comparing the on/off aircraft figures, more work is done on wing for the CP-140, including the changing of time expired components, as compared to the CC-130. The maintenance practice for the Hercules is to remove the quick engine change unit and route it to engine bay when a component change is required, whereas for Aurora maintenance items such as

the RGB and turbines are changed on wing. Hence, the second line on wing maintenance burden is higher for the Aurora and conversely, the off wing maintenance burden higher for the Hercules.

Table 5a - RGB Reliability and Maintainability Performance - including time expired components.

WUC: BCB/C	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	25.0	1.3	20.1
	CP-140	39.5	0.99	39.9
2nd Line - On aircraft	CC-130	15.1	0.95	16.0
	CP-140	14.3	0.61	14.3
2nd Line - Off aircraft	CC-130	55.5	1.6	34.1
	CP-140	56.5	2.1	26.9
2nd Line - TOTAL	CC-130	70.6	2.6	27.7
	CP-140	70.8	2.7	26.1

Table 5b - RGB Reliability and Maintainability Performance - no time expired components.

WUC: BCB/C	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	24.5	1.2	19.7
	CP-140	39.5	0.99	39.9
2nd Line - On aircraft	CC-130	12.5	0.92	13.6
	CP-140	9.1	0.57	16.0
2nd Line - Off aircraft	CC-130	43.1	1.1	39.2
	CP-140	52.8	1.9	28.4
2nd Line - TOTAL	CC-130	55.6	2.0	27.5
	CP-140	61.9	2.5	25.0

33. The statistics for the RGB are included above and a few interesting observations can be made. The Aurora has a higher maintenance burden at first line, but the second line burden is very much the same between the two fleets. The higher first line burden is likely due to the chip detector system as seen in the operational impact analysis above. However, the impact of the chip detector does not pass into second line as only few RGBs are removed due to metal chips. The increased periodic frequency also does not appear to influence the maintenance of the RGB at second line. This is not unexpected as beyond first line servicing, there is very little maintenance that is actually performed on an RGB. If the RGB has to be opened for repair, it is usually sent back to the contractor. The Hercules has encountered problems with case cracks and RGBs have been sent back for repair. The Aurora fleet has had significant problems with its RGB, not the least of which is the engine driven compressor (EDC). The EDC supplies the cooling for the avionic systems on board the aircraft and operates at or above the maximum rated power output of the RGB. From the above tables, the additional maintenance burden due to

these problems is larger for the Aurora.

Propeller System

Table 6a - 54H60 Reliability and Maintainability Performance - including time expired components.

WUC: CD	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	274.9	18.4	14.9
	CP-140	407.4	29.3	13.9
2nd Line - On aircraft	CC-130	63.3	7.6	8.4
	CP-140	98.3	12.5	7.9
2nd Line - Off aircraft	CC-130	182.9	16.3	11.2
	CP-140	280.7	42.3	6.6
2nd Line - TOTAL	CC-130	246.2	23.9	10.3
	CP-140	379.0	54.8	6.9

Table 6b - 54H60 Reliability and Maintainability Performance - no time expired components.

WUC: CD	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	272.2	18.3	14.9
	CP-140	403.7	29.1	13.9
2nd Line - On aircraft	CC-130	49.9	6.9	7.3
	CP-140	83.8	11.6	7.2
2nd Line - Off aircraft	CC-130	164.6	14.8	11.1
	CP-140	257.7	41.0	6.3
2nd Line - TOTAL	CC-130	214.5	21.7	9.9
	CP-140	341.5	52.6	6.5

34. The two tables above give an overview of all the manhours associated with the maintenance of the propeller assembly. All sub-work unit codes are included in this analysis and the major subcomponents and WUCs are listed in Annex B. Immediately, there is a significant difference in the maintenance burden of the two aircraft fleets. The Aurora burden is on the order of 50% more than the Hercules. There are roughly twice as many maintenance actions per 1000 FH on the Aurora as for the Hercules, but this observation must be made with caution as one unserviceability event may result in more than one maintenance action being taken and this is a matter of local reporting policy. The number of maintenance actions directly influences the MPA/UMA figures and this can be seen at second line off aircraft. The Aurora clearly has a higher maintenance burden, but it is not known to what extent the increase in UMA/1000 FH is due to unserviceabilities and not a difference in maintenance reporting policy.

Table 7a - Propeller Reliability and Maintainability Performance - including time expired components.

WUC: CDA	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	127.8	6.1	21.0
	CP-140	175.6	10.6	16.6
2nd Line - On aircraft	CC-130	34.3	2.8	12.4
	CP-140	66.4	8.7	7.6
2nd Line - Off aircraft	CC-130	124.1	6.4	19.4
	CP-140	189.0	19.0	9.9
2nd Line - TOTAL	CC-130	158.4	9.2	17.2
	CP-140	255.4	27.7	9.2

Table 7b - Propeller Reliability and Maintainability Performance - no time expired components.

WUC: CDA	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	126.5	6.0	20.9
	CP-140	173.4	10.5	16.5
2nd Line - On aircraft	CC-130	27.8	2.5	11.3
	CP-140	58.7	8.4	7.0
2nd Line - Off aircraft	CC-130	109.9	5.8	18.9
	CP-140	168.3	18.6	9.1
2nd Line - TOTAL	CC-130	137.7	8.3	16.6
	CP-140	227.0	27.0	8.4

35. The maintenance burden for the propeller system is significantly higher for the Aurora. The two most significant factors are that the Aurora propellers are located near ground level, where the Hercules propellers are much higher and the Aurora propellers are dynamically balanced. The Aurora propellers are easily damaged by rocks, sand, and other debris, especially when reversing thrust on landing. The damage to the blades must be repaired through manually filing down the leading edges and then treating the metal with corrosion preventative compound. These tasks are time consuming. As the blades wear, the propellers are regularly balanced so as to prevent any excessive deterioration of the propeller components.

36. The propeller system on the Aurora is dynamically balanced and only recently have the propellers been dynamically balanced on the Hercules aircraft. The impact of this practice will not be seen in the Hercules maintenance statistics. Although it was informally reported to the author that the technicians find it significantly more challenging to balance propellers on the A-7B than the A-15 engines, this has not been fully substantiated. When this observation was made to Standard Aero for their comment, they felt that this could be due to a drive train looseness in these older engines. Given that the propeller and RGB are interchangeable for these two engine

types, it may be difficult to see how differences in the power section affect the dynamic propeller balance. The most probable reason is that the E model airframe engine mounts are older and not as stiff as those on the H model and thus have a lower vibration dampening characteristic. The consequences may be that the MPH/1000 FH figures will rise to be more along the lines of the Aurora or the figures will decrease as the vibration induced failures of propeller components decrease.

Table 8a - Controller Reliability and Maintainability Performance - including time expired components.

WUC: CDB	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	98.4	8.4	11.8
	CP-140	158.4	12.7	12.5
2nd Line - On aircraft	CC-130	19.8	2.7	7.3
	CP-140	24.8	2.1	11.8
2nd Line - Off aircraft	CC-130	48.9	7.9	6.2
	CP-140	68.6	18.9	3.6
2nd Line - TOTAL	CC-130	68.7	10.6	6.5
	CP-140	93.4	21.0	4.4

Table 8b - Controller Reliability and Maintainability Performance - no time expired components.

WUC: CDB	Aircraft Type	MPH/1000 FH	UMA/1000 FH	MPH/UMA
1st Line - On aircraft	CC-130	97.0	8.3	11.7
	CP-140	156.9	12.5	12.5
2nd Line - On aircraft	CC-130	13.1	2.3	5.6
	CP-140	17.9	1.6	11.4
2nd Line - Off aircraft	CC-130	44.9	7.1	6.4
	CP-140	66.3	18.1	3.7
2nd Line - TOTAL	CC-130	58.0	9.4	6.2
	CP-140	84.2	19.7	4.3

37. The propeller controller as installed on the Aurora takes a significant level of effort to maintain, again particularly at first line. The division of labour between second line on and off aircraft maintenance is also in accordance with previous observations for other components. The total second line burden for the Aurora is 45% higher than that for the Hercules. This is likely a result of the different operational mission profiles, the higher periodic inspection frequency and differing maintenance practices as has been described above.

PART V - THIRD LINE OVERHAUL COSTS

38. The third line maintenance for the engines and propellers is contracted out to Standard Aero of Winnipeg, Man. The anticipated value for FY 96/97 of the Repair and Overhaul contract for the T56 engines, RGBs, and accessories is $12.5 million. The propeller contract is valued at $4.5 million.[1] Based on 1994-1995 data provided by the contractor, the total overhaul costs for each component and their annual arisings are given below.

39. It is useful to first examine the propulsion system in terms of the overhaul schedule and the part lives. An overhaul cycle of 6000 hours translates to about six years of actual time on wing, barring any engine replacements. Also, the hours flown by the fleet varies from year to year. This can, and does, translate into some wide variances in the overhaul schedule. For example, there were 18 A-14 engine overhauls in 1995, with only 6 scheduled for 1996. For the Hercules, the combined 1994 & 1995 authorized flying rate was 57,000 hours. This would require 38 RGB (or engine) overhaul's to regenerate the hours consumed. There were only 28 RGBs in overhaul during this time - the other overhauls either were performed in the past or will be performed in the future. There were 36 power sections overhauled during this time frame which corresponds very well with the 38 that is required to sustain the fleet. In managing the engine fleets, it is common to see the majority of the engines at roughly the same engine hours. As the engines reach, say, 12,000 hours or the second overhaul cycle, there will be high cost components that, although not lifed, will be replaced as they will have failed inspection criteria. In some cases, previously un-lifed components will have a life imposed. A good example is the second stage turbine blade in the A-14 engines, where a life of 12,000 hours was established based on several failures and OEM recommendations. The impact on the overhaul cost is that it will rise and fall, depending on the parts consumed. In an extreme case, such as for the A-15 fleet, one A-15 overhaul cost the CF $395K, another only $190K. The difference was solely due to the number of parts that had to be replaced.

---

[1] This includes propellers for the DASH8, Buffalo, and Twin Otter aircraft, but these represent a relatively small portion of the contract.

Table 9 - Contractor Overhaul Costs for Propulsion System Components, 1994-1995.

	This Study		Previous Studies		
Item	Qty/Yr	Cost(K) / Unit	Qty/Yr	Cost(K) / Unit	Remarks
A-7B	15	$362		$283*	High due to poor hot section durability.
A-14	14	$395	11	$320	Highest cost due to part rejection (salt environment). Reference C
A-15	3	$341		$322*	
RGB/CC-130	14	$64			CC-130 costs are higher due to higher time RGBs.
RGB/CP-140	10.5	$62	8.5	$68	Reference C
TQM/CC-130	4.5	$6			Overhaul interval 11100-12000 hours.
TQM/CP-140	3	$7	6.75	$8.2	Overhaul interval 11400-12000 hours. Reference C.
54H60-77	4.5	$76			
54H60-91/117	12	$84			CC-130 costs are higher due to higher time barrel assemblies.
A-7B Turbine Overhaul	15	$70		$53*	

* 1993-94 data not including mark-up or accessories. (Reference B)

40. These costs reflect total costs incurred by the CF at the contractor and include all materiel costs, labour and mark-ups. The rates used in this study were somewhat lower than those used for the calculation in reference C for the Aurora systems. This is a result of Standard Aero winning a portion of the USAF T56 maintenance contract which increased the output of their facility. As the labour and fixed costs are distributed over more work and inventory, the rates have decreased.

CC-130 Engine Overhaul Cost Observations

41. The cost of the A-7B through one complete overhaul cycle of 6000 hours must include the $70K for the turbine overhaul. This amount does not include the cost of the first stage vanes, $16.5K, which are replaced at second line coincident with the turbine overhaul. Also, the labour cost of removing the engine from wing, replacing the turbine, re-installing the engine, and run-up comes to roughly 250 manhours. At $40.00 per hour direct labour costs, this is another $10K.[2] The fuel consumed for the run-up would amount to some $800. In total, a rough estimate puts an

---

[2] Indirect labour costs, which can be estimated at 200% of the direct labour costs, are not included in these calculations.

A-7B overhaul at $459K, or $118K over that for an A-15, or 34% more.

42. Converting the A-7B engines to A-15 configurations is possible and has been studied for the past ten years. In 1995, Standard Aero conducted a third line life cycle cost study to perform the necessary conversions, reference B. Their costs do not include any second line costs, such as the mentioned first stage guide vanes or the added labour/downtime to perform the maintenance on these engines. These and other cost factors such as maintaining a separate parts pool and maintenance tools/pubs are being addressed by the DAEPM (TH) staff.

43. A real concern of the DAEPM(TH) staff is the availability of A-7B parts at a reasonable cost. Part availability for the A-7B is entirely dependent on the USAF continuing operations with their A-7Bs. The USAF has not committed to converting, nor staying the course. It very well may happen that the USAF will convert on a parts non-availability basis, meaning that they will guard their stock and use it up before converting their engines to the series III configuration. If this happens, Canada will forced to convert A-7B to A-15 out of necessity and any cost savings that could have accrued would be lost. Clearly, the worst case is that Canada would be forced to convert just at the end of the useful life of the E model Hercules.

44. The other issue is that the H model Hercules outperforms the E model Hercules. Pilots on squadron will not accept taking an E model on a deployment where high altitudes, hot temperatures, and heavy loads are expected. A Statement of Capability Deficiency was submitted in 1995 by ATGHQ about deficiencies in deployed operations with the A-7B engines. In that instance, DARFT staff initially supported the conversion to the series III engine on the third proposal for operational reasons, however the conversion was not finally approved. It would appear that there are solid grounds for series II to III fleet conversion based on operational needs, R&O cost issues, and parts security of supply.

CC-130/CP-140 Overhaul Cost Observations

45. The A-14 overhaul costs $395K, which is $54K more than the A-15 engines. Although the A-14 operates in a salt environment, hot corrosion in the turbine does not appear to be a major retiring cause factor. An examination of the studies provided by Standard Aero reveal that corrosion is a problem in the compressor section. A-14 compressor components are replaced considerably more often than the A-7B/15, at a cost difference of roughly $30K per engine. The maritime role requires more throttle movement than the transport role and is therefore more demanding on the hot section parts in terms of thermal cycling and fatigue. Historically, the hot section part rejection rates at overhaul for the A-14 have been roughly 5% higher than the A-15 - not large enough to account for all of the higher overhaul cost. A cost item that is not included in these figures, but has a direct impact, is that the A-14 turbine inlet guide vanes are commonly replaced once between overhauls at second line, a somewhat similar situation to the A-7B. The cost for a set of series III inlet guide vanes for one engine is roughly $27K based on costs listed in the Canadian Forces Supply System. Assuming similar labour and fuel costs as for the A-7B, the cost for using the A-14 for 6000 hours is roughly $433K.

46. The RGBs for both aircraft types cost about the same to overhaul, although the costs drivers are different. In the case of the CC-130, the RGBs are older and have higher times since new, resulting in some high cost component work at overhauls. The CP-140 RGBs have had several problems and marginally successful redesigns/repairs. The engine driven compressor is also demanding on the RGB as the EDC operates at or above the maximum rated power output of the RGB.

47. The propeller systems, aside from the blades, are nearly identical. The lower overhaul cost of the CP-140 propeller can be attributed to the lower average hours on these components, especially the barrel assemblies, as compared to the CC-130. It is possible that the lower costs may also be in part due to propeller balancing and hence a lower wear rate is seen on overhaul but this is not clear from this study. However, the LCMM has indicated that because the life of the Aurora blades is on the order of 12,000-14,000 hours compared to the Hercules blade life of 20,000 to 22,000 hours, the Aurora propeller costs are expected to soon exceed those for the Hercules.

PART VI - THIRD LINE REPAIR COSTS

48. Similar to overhauls, repairs can vary in costs over time; however, these costs are not scheduled. For an overhaul, there are historical rejection rates as well as lifed components that will drive the cost. For repairs, a technician may discover a crack in a critical location. A special inspection may be called to examine the fleet and perhaps 15% of the components in question may be returned to contractor for repair. Some of this is due to the age and service life of the component that had not yet been taken into account in the planned maintenance activities. Sometimes a small change in maintenance practices will set the problem right. However, there are some items that occur with surprising regularity - on average, there will be a compressor damaged by foreign objects once per year for each aircraft type. There will be at least one engine involved in a birdstrike. Given the considerable costs involved, safety and prevention are still important to reduce the hazards and risks involved with these accidents.

49. The causes for the repairs of each component were examined to assist in interpreting the results. For example, the costs associated with a power section repair varied greatly with the cause. Compressor damage from FOD or birdstrike typically costs $110K to repair, regardless of engine type as they all have identical compressors. Repairs to the hot section will cost $220K and up. Of the 7 A-7B engine repairs in 1995, three were due to turbine failures and one due to a #2 bearing failure. The repair costs have more than doubled when compared to a previous study. This is due to a rash of turbine failures which has been resolved through the 100% replacement of the first stage blades at overhaul.

Table 10 - Repair Costs for Propulsion System Components, 1994-1995.

	This Study		Previous Studies		
Item	Qty/Yr	Cost (K) / Unit	Qty/Yr	Cost (K) / Unit	Reference
A-7B	4.5	$183	4.6	$87	B
A-14	1.5	$133	4	$140	C
A-15	1	$78	1.6	$59	B
RGB/CC-130	12	$24			
RGB/CP-140	6	$29	13	$28	C
TQM/CC-130	9	$5.3			
TQM/CP-140	2.5	$3.7	6.75	$4.2	C
A-7B Turbine			13	$13	B

50. The RGB repairs also showed marked increases from 1994 to 1995. The CP-140 RGB repair costs rose from an average of $25K to $33K. The CC-130 RGBs rose from $11K to $39K. The cost data was examined to determine these relatively large increases in repair costs. The cost figures from 1995 CC-130 RGB repairs showed a bimodal distribution - one mode averaging $14K the other $59K. The latter high cost repairs were as a result of a special inspection looking for case and mount cracks. The increase for the CP-140 costs was due to an increase in component consumption.

PART VII - COST SAVING CHALLENGES

51. The cost saving challenges are to increase the reliability, maintainability and survivability (or longevity) of the propulsion system and hence lower the operational costs of operating the equipment. The costs of aborted or delayed missions have not been determined in this study as it is a complex issue on its own: the operational costs of dispatching another aircraft, changing the flying schedules, and the logistical costs of sending out new parts, providing additional TD funds for the mobile repair party are obviously situational dependent and can be operationally critical.

Operational Costs

52. The most obvious place to start monitoring costs is in the actual flying of the aircraft. The chip monitoring and oil indication system failures do not inspire confidence in these systems. The flying community works very hard to stay alert and treat every occurrence as real; however, the costs associated with repeat failures is lost or part missions, added aircraft hours to meet the mission, the disruption of the schedule, and the effort to fight the complacency and lost confidence in system reliability. Significant R&D investment has been made in on-line oil debris monitoring technologies as well as portable oil screening devices. The expertise exists to now make use of these technologies with a minimal investment in R&D or engineering funds.

53. Another large cost is the fuel consumed. In this regard, the successful experience of the RAF with their engine trend monitoring program is being reviewed by the Integrated Health Monitoring Group at Aerospace and Telecommunication Engineering Support Squadron. Not only has there been a demonstrated benefit of lower fuel costs, there will be a trickle down effect as the hot section will not be exposed to as degrading a condition as when overfuelled. A monitoring program will also enhance such tasks from troubleshooting to component repair design.

54. The T56 engine is not trended in any way. A T56 engine trending study was carried out by the TTCP HTP-7 panel and the report has just been released (Reference D). Even without the benefits of the latest model engine software and the limitations imposed by manual data capture, the RAF has demonstrated savings on the order of 5% of annual fuel costs, or £500K. This cost saving largely results from the detection of defective thermocouples which cause the fuel system to overfuel the engine. This figure does not include any savings achieved through a correspondingly lower hot section temperature which would result in lower component rejection rates at overhaul.

55. One can examine the costs of failure on aircraft operations, but the impact of aircraft operating practices on the support costs is at least as important, if not more. *It is the actual use of the engine that consumes life.* It has been shown for civilian transport operations that there is a strong correlation between engine service life and overhaul costs and the manner in which the engine is used. Thus, civil airline pilots are trained to treat the engines with care. Military requirements can and will dictate the power demands from the propulsion system, however, the resultant engine life usage and those associated costs must be recognized and accepted for what they are. This concept of life usage costs is not new and has been in use for CF-18 airframe management for quite some time. For the T56, there is a dearth of knowledge of the impact of operations on life usage as the engines are not monitored. The poor reliability of the thermocouples and the lack of a method to recognize their failure is a serious problem for the T56 fleet. It is not uncommon for an engine to deliver high torque with an acceptable turbine inlet temperature. What has happened is that a thermocouple has failed and the temperature indication is subsequently lower than the actual temperature in the engine. More fuel is added to bring the temperature indication back to normal. This results in higher turbine parts consumption, and an increase in overhaul costs.

Maintenance Practices

56. There are some maintenance practices that are currently performed that do save the CF money. For the propellers, a new blade can cost upwards of $20K and the practice of blade dressing does save the CF money. In conversations with the repair contractor, users who do not routinely dress blades have a significantly higher blade replacement rate. The cleanliness of the propeller oil also influences the overhaul cost of the controller as there is less erosion and corrosion of key components. Relative to newer propeller system designs, these hydraulic controls are complex, delicate, and less reliable. Some users neglect oil quality and entire

propeller control assemblies can be replaced at overhaul. The CF is very good at monitoring oil quality. The same observation about the oil quality in the engines can be made, and the contractor has indicated roughly the same concepts and comparisons.

57. The influence of good maintenance practices on cost reduction are passed on to the technicians, but there is a lack of any fundamental understanding of why things are done the way they are, *nor the cost involved.* The senior technicians that met with the author were all keen and eager to use their knowledge and experience to meet the Air Force requirement to lower costs. However, the maintenance personnel that the author met unanimously expressed their frustration at not knowing what the impact of their day-to-day decisions would have on costs. Providing the technicians with some information would allow them to rise to the challenge of providing an efficient maintenance service.

Component Repairs

58. The technology base capabilities that will enable cost savings to be achieved through the repair of gas turbine components have been identified in reference E. The concepts and methodologies expressed therein can be broadened and applied to the T56 propulsion system as a whole. The capabilities necessary for the development and certification of repairs can be summarized in three areas:

a. Knowledge of the repair environment and the ability to implement, or make use of the knowledge,

b. A control process to certify that the repair is safe and to prove confidence in the repair, and

c. The engineering authorities must define and be capable of performing the high technology and demanding test requirements to carry out the repair and prove its effectiveness.

59. The most obvious requirement is to understand the metallurgical principles which pertain to the components of interest. A second area of prerequisite experience which needs to be developed relates to the understanding of the actual operating environment in which these components perform their design function. In this regard, the knowledge base for the T56 engine is not well developed due to the lack of monitoring programs as detailed above. Although some parameters are known about the engine environment, not much is known about the RGB nor the propeller system.

60. In the past, a major obstacle to airworthiness certification has been the existence of adequate test facilities for coupon, component and full scale engine verification testing of repair redesigns or reworks. As a part of the collaborative R&D program between DND and NRC a number of the required facilities have been established, or improved, and valuable experience

gained in their operation. Repairs to flight critical gas turbine components are now being attempted by DND and engineering authorities now have access to demanding test requirements to prove the effectiveness of the repair.

61. To give some idea of the value of the parts consumed by the propulsion system, the work done in FY95/96 at third line included the installation of parts (high cost - low volume or lower cost - high volume, all greater than $500.00) to a value of $11.5 million, not including any mark-ups. In the case of the RGB, bearings alone can cost up to $2K apiece. A quick look of the cost of parts replaced for bearings and gears in the engine and RGB is given in Table 11.

Table 11 - Value of Gears and Bearings in T56 Propulsion System.

Components	Number of Parts >$500	Total Value of Parts > $500	Number of Parts > $2K	Total Value of Parts > $2K
RGB Gears	157	$497K	57	$409
RGB Bearings	225	$774K	150	$715
Engine Gears/Bearings	75	$90K	15	$46

62. The T56 itself has some very expensive components. As an older engine, some may believe that the components are relatively inexpensive. This is only partially true. Parts in the compressor section are the original stainless steel, but the turbine materials have been upgraded. For the Series II engine, the turbine inlet guide vane has an open market price that has ranged from $3.6K to $8.2K while the price that the CF pays through COLOG varied from $2.7K to $3.6K. The Series III turbine inlet guide vanes are less expensive, but there are 30 per engine, vice 6 for the Series II. The open market price for the Series III turbine inlet guide vanes is on the order of $2K. The COLOG price for this component is roughly $850 to $1000. By comparison, the price for an F404 inlet guide vane is $3.6K.

63. The prevalent cause for rejection at overhaul for the inlet guide vanes is thermal fatigue. Standard Aero is pursuing the development of braze repair and thermal barrier coating processes for selected Series III components with the objective of reducing costs. Through the major project D6214 Gas Turbine Repair and Airworthiness Certification, a substantial cost savings for the similar repairs and coating processes for the F404 inlet guide vane have been calculated by Orenda. This will save money in terms of a longer life and a lower parts consumption as repaired components enter service. Although a similar repair of the Series II inlet guide vanes is tempting, the part is much larger and more complex than the Series III component. A more prudent approach would be to reconfigure the Series II to Series III engines and focus on the Series III components. In combination with the potential of the RAF trending program to control overfuelling, the deterioration of the hot section can be lessened considerably with a relatively low implementation cost.

PART VIII - CONCLUDING MATERIAL

64. The challenge is to reduce the cost of operating the T56 propulsion system and this can be done. The key is to gain an improved understanding of the reliability of various components and their impact on actual aircraft operations. The opposite is also true - the impact of operations on support costs is also not well understood. With the increasing demands placed on the fleets, the influence of the day-to-day decision making can have a profound effect on costs.

65. This cost study determined the major cost drivers of the propulsion system in terms of flight operations, maintenance burden, and overhaul costs. Several small areas have been identified that with some improvements can lead to significant cost reduction to the operation of the propulsion system.

66. Trends or areas of the propulsion system that have an operational and safety impact are as follows:

a. The reliability of the propeller assembly is very poor and that this is common to both aircraft types,

b. For the Hercules, the oil transmitters and bleed air system are cause for concern. The poor transmitter reliability results in unnecessary engine shutdowns and aborted missions which translate to unnecessary costs. Although some of the bleed air problems are a result of the ageing aircraft, there is some indication that the gaskets in the system are failing and compromising the safety of flight, and

c. For the Aurora, the chip detector system is a visible, major cost driver. Although the reliability of the system has improved greatly, the routine occurrence of nuisance wear debris needs to be accounted for in the monitoring system.

67. In examining the maintenance burden for the T56 propulsion system, the following conclusions can be drawn:

a. The increased maintenance burden for the Aurora fleet over that for the Hercules is offset by the additional maintenance required by the A-7B power section, and

b. The significantly higher maintenance burden for the Aurora propeller system over that for the Hercules is due to the lower ground clearance and more frequent inspection schedules.

68. The overhaul costs for the A-7B and A-14 power sections do not give a complete cost picture associated with the overhaul interval of 6000 hours. The cost of the components changed out over the interval and the manhours used to replace these components should also be

considered when comparing thses engines. In summary, the real overhaul costs for the power sections are:

a. for the A-7B - $459K,

b. for the A-14 - $433K, and

c. for the A-15 - $341K.

Recommendations

69. The propeller system can benefit from an R&D effort. However, the propeller design is very old and is substantial improvements in this hydraulic design would be difficult to achieve. Based on this study, there is justification for an effort to examine an advanced design propeller system for both aircraft that would improve the reliability and to reduce the maintenance burden.

70. There are solid grounds for Series II to Series III conversions based on operational needs, R&O cost issues, and parts security of supply. This study supports those efforts of the DAEPM (TH) staff in their conversion analysis.

71. Monitoring technologies can be exploited to improve the operational use of the T56 power section which would act to increase the life of hot section components. Expertise exists within the T56 user community to effect this capability with a minimal investment in R&D and engineering funds.

72. Innovative component repair programs must be supported to achieve the potential cost savings. Much of the development work has been completed for erosion/corrosion or thermal barrier coating systems and the technology exists to repair components and return them to service at a lower cost. Additional effort will be required to develop a business case for specific high rejection rate, high cost components.

73. Investment in On-Line oil debris monitoring systems having higher failure prediction reliability would improve the airworthiness of both propulsion systems. The use of a portable oil screening device, previously developed for the CH-124 Sea King which essentially scrubs and reconditions the oil, may also be of benefit in reducing spurious debris indications. The capability exists to effect these changes with minimal R&D or engineering investment.

PART IX - REFERENCES

A. Aircraft Subsystem Cost and Reliability. RR Hastings & WL Macmillan DRDA and M. Tobin GasTOPS Ltd Ottawa, CRAD Technical Note DRDA/9301/06.

B. T56-A-7B Engine Supportability and Conversion to T56-A-15LFE Cost Benefit. Standard Aero, Winnipeg Manitoba. Engineering Report 030-01-95 18 March 96

C. T56-A-14LFE Life Study of the CP140/A Propulsion System. Standard Aero, Winnipeg Manitoba, 26 June 96.

D. Allison T56 Engine Health Monitoring Evaluation. WCdr M Duguid RAF, TTCP HTP-7 Study Assignment SA 102, May 1996

E. Qualifying Repaired Parts for the General Electric F404 Turbofan Engine. Capt KM Jaansalu, RR Hastings DND/CRAD/ Air Vehicle Research Sector & Dr PC Patnaik Orenda Aerospace Corporation. CASI Symposium 29 April 1996.

Annex A

T56 Propulsion Cost Study

DTA 4 ANALYSIS STUDY REPORTS AND ADDENDA

Contents:

DTA 4 Analysis Study Report

T-56 Reliability and Maintainability Analysis

23 Jul 96

Background and Problem Statement

1. An R&M analysis was carried out to support a project undertaken by AVRS 3-2 to determine the total operating costs associated with the T56 engine and the propellers for both the CC130 and CP140 fleets. The Work Unit Code for engines is BCA and for propellers is CDA. For analysis purposes, sub-assembly maintenance actions were included. The following information is listed for each fleet:

a. the CC130 fleet operates with 2 different engine model types, the A7 and the A15. The cumulative flying hours (FH) for the period of 910101 to 960630 for the CC130 was 161738.6 flying hours. All engine models of the T56 engine have an overhaul life of a min 5100 hrs max 6000 hrs. The propellers have an overhaul life that coincides with the engine overhaul. Both, aircraft and engine periodics are carried out between 850 and 950 flying hours; supplementary inspections between 405 and 495 flying hours; and

b. the model type for the CP140 is the A14. The cumulative flying hours (FH) for the period of 910101 to 960630 for the CP140 was 97293.3 flying hours. The T56 engines have an overhaul life of a min 5400 max 6000 hrs. The propellers have an overhaul life of a min 6000 hrs max 6600 hrs. Aircraft periodics are carried out between 540 and 650 flying hours; supplementary inspections between 270 and 330 flying hours. No specified engine periodic is carried out for the CP140 fleet although during the aircraft periodic and supplementary inspections, engines are inspected on both fleets.

Study Aim

2. This study examined the maintainability (R&M) performance levels of the T56 engines between the CC130 and CP140 aircraft. This is a higher level analysis of the maintenance activity reported against the T56 engines, including its sub-components. It is expected that from these performance levels, it will be possible to identify areas where an improvement in reliability and maintainability could result in lower support costs.

Study Methodology - Data Retrieval and Analysis Techniques

3. This study was directed at unscheduled corrective maintenance actions only associated with on and off aircraft maintenance activity. The unscheduled analysis reflects the operational performance of the T56 engines and propellers as recorded by unit maintenance organizations. Analysis was broken down into three parts: 1st line on-a/c, 2nd line on-a/c, and 2nd line off-a/c. The first part represents the reliability and maintenance burden that directly impacts operational capability due to unserviceabilities reported by aircrew or 1st line technicians. The second part represents CF349 corrective maintenance actions associated with preventive maintenance for the CP140 and CC130, such as aircraft periodic and supplementary inspections and includes CC130 engine periodics. The third part represents CF349 and CF543 corrective maintenance actions associated with off-a/c maintenance activity carried out in labs or engine bay (which includes CC130 eng periodics). All data retrievals exclude any 3rd line maintenance actions.

Data Sources

4. Maintenance and failure data for the T56 engine and propellers was extracted from the Aircraft Maintenance Management Information System (AMMIS) and the Accident Incident Reporting System (ACAIRS) to which DTA 4 has on-line access.

R&M Parameter Definitions

5. The R&M parameters used in this study are identified below:

   a. UMA - Unscheduled Maintenance Action. This parameter represents the cumulative maintenance actions carried out to rectify engine and propeller unserviceabilities. UMAs are any reported actions, ie. repairs, removals, no-fault-founds, robs, CF mods, etc. This parameter does not just represent failures but is a reflection of all activities carried out to support the aircraft. It must also be noted that there may be multiple maintenance actions for a single downing event;

   b. MPH - Maintenance Person Hours. This parameter represents the cumulative person hours associated with unscheduled maintenance actions;

   c. Aborted Missions/1000 FH. This is a mission (if air ops) and dispatch (if gnd ops) reliability parameter and represents those reported unserviceabilities that resulted in aborted missions as recorded on CF349 forms at 1st line;

   d. Part or Delayed Missions/1000 FH. This parameter represents mission (if air ops) and dispatch (if gnd ops) reliability in that missions are either partially completed or delayed as recorded on CF349 forms at 1st line.

e. UMA/1000 FH - the unscheduled maintenance actions per 1000 flying hours is an indicator of reliability and is calculated using:

$$UMA/1000FH = \frac{Total\ unsched\ maint\ actions}{Total\ flying\ hrs} * 1000$$

f. MPH/UMA - The maintenance person hours per unscheduled maintenance action is used as an indicator for aircraft maintainability and is calculated using:

$$MPH/UMA = \frac{Total\ maint\ person\ hrs}{Total\ unsched\ maint\ actions}$$

g. MPH/1000 FH - the maintenance person hours per 1000 flying hours is an indicator of maintenance burden and is calculated using:

$$MPH/1000FH = \frac{Total\ maint\ person\ hrs}{Total\ flying\ hrs} * 1000$$

R&M Analysis

6. Table 1a shows the initial engine performance levels for those activities carried out at 1st line. The table shows that, for the most part, the reliability and maintenance burden are the same between the two fleets. The only difference being the dispatch/mission reliability where the CP140 is experiencing more aborted missions than the CC130. Further investigation reveals that, for the CP140, 31 out of 45 aborted missions resulted from a flight safety (FS) incident; for the CC130, 20 out of 28 aborted missions resulted from a flight safety incident.

7. Normalizing all flight safety incidents over the amount of flying, recorded against the engine and its sub-components, indicates a rate of .46 FS/1000 FH for the CP140 and .21 FS/1000 FH for the CC130. The higher rate of aborted missions and flight safety incidents may be due to a number of factors such as mission role, environment, preventive maintenance, or even training. If required, a more detailed analysis can be performed to determine cause and operational impact factors.

8. An effort was made in order to determine why the MPH was so high on average. After reviewing the raw data, it was found that 1st line person hour recording is high in comparison to the amount of downtime reported against the unserviceability (eg. for both fleets, downtimes of 48 hrs or less have associated person hours recorded ranging from 100 to 202 hrs). Any inferences made based on 1st line person hours should be viewed with caution

when making "cost" decisions. Further investigation on reporting procedures may be necessary as these records may indeed be legitimate as the high times are recorded specifically against the engine itself and may be a true representation of the amount of effort expended to correct the unserviceabilities.

Table 1a - T56 R&M Performance: 1st line, on-a/c
WUC: BCA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	82.9	1.7	47.9	0.17	0.06
CP140	80.7	1.7	48.2	0.46	0.05

9. Table 1b shows the initial performance levels for propeller maintenance activities carried out at 1st line. The table shows that there is a significant difference between the reliability and maintenance burden for the two fleets. It is interesting to note that the CP140 has more mission aborts but less delayed/part missions. Of the 57 aborts and 52 delay/part missions for the CC130, 29 and 36 respectively resulted from flight safety incidents. The CP140 had 17 flight safety incidents out of 67 mission aborts.

10. Normalizing all flight safety incidents over the amount of flying, recorded against the propellers and its sub-components, indicates a FS rate of 0.87 FS/1000 FH for the CC130 and 0.47 FS/1000 FH for the CP140. It is evident from Table 1b and the FS rate, for the CC130, that the higher reporting of flight safety incidents are due to not only air ops, but ground ops as well. The differences between the two fleets may be a result of reporting policy as well as factors listed above. If required, a more detailed analysis can be performed to determine cause and operational impact factors.

11. As above, Table 1b shows high person hour reporting and the same considerations should be given as in para 8.

Table 1b - T56 R&M Performance: 1st line, on-a/c
WUC: CDA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	127.8	6.1	21.0	0.35	0.32
CP140	175.6	10.6	16.6	0.69	0.16

12. Table 2a shows the initial engine performance levels for all on-a/c 2nd line activities which includes aircraft periodics and supplementary inspections. It does not include any maintenance activities carried out off-a/c, ie. lab or engine bay activity. The table shows that the difference between the reliability and maintenance burden for the two fleets is significant. This could be due to differences in preventive maintenance, mission roles, environment, model types, training, etc.

Table 2a- T56 R&M Performance: 2nd line, on-a/c
WUC: BCA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	44.7	1.2	38.3
CP140	61.9	1.9	32.2

13. Table 2b shows the initial propeller performance levels for all on-a/c 2nd line activities which includes aircraft periodics and supplementary inspections. It does not include any maintenance activities carried out off-a/c, ie. lab or engine bay activity. As with engines, the CP140 propellers are experiencing lower reliability and a higher maintenance burden, although the time taken to carry out the maintenance activity is lower. This could be due to differences in preventive maintenance, mission roles, environment, model types, training, etc.

Table 2b- T56 R&M Performance: 2nd line, on-a/c
WUC: CDA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	34.3	2.8	12.4
CP140	66.4	8.7	7.6

14. Table 3a shows the initial engine performance levels for all off-a/c 2nd line activities which includes lab and engine bay activity. It also includes any maintenance activities carried out due to engine periodics. As expected, the reliability and maintenance burden is

significantly worse for the CC130 fleet. The person hours per maintenance action is the same for both fleets.

Table 3a - T56 R&M Performance: 2nd line, off-a/c WUC: BCA Analysis Period: 910101 to 960630			
ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	89.2	6.3	14.1
CP140	68.7	5.0	13.8

15. Table 3b shows the initial propeller performance levels for all off-a/c 2nd line maintenance which includes lab and engine bay activity. The table indicates that CC130 propeller maintenance is extensive compared to the CP140. If required, a more detailed analysis can be performed to determine cause and operational impact factors.

Table 3b - 56 R&M Performance: 2nd line, off-a/c WUC: CDA Analysis Period: 910101 to 960630			
ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	1022.8	6.4	161.1
CP140	189.0	19.0	9.9

Conclusion

16. From the above analysis it was determined that:

a. engine dispatch/mission reliability is lower for the CP140 possibly due to factors listed in para 6;

b. 1st line propeller maintenance for the CP140 is significantly higher;

c. there is a larger maintenance burden associated with on-a/c 2nd line engine and propeller maintenance activities for the CP140 fleet, possibly because of the type of inspections carried out in comparison to the CC130, ie. there is no engine periodic associated with the CP140;

d. there is a larger maintenance burden associated with engines and propellers at off-a/c 2nd line maintenance activities for the CC130 fleet, possibly as a result of inspections being carried out during engine periodics; and

e. engine flight safety incidents for the CP140 is higher than that for the CC130 but the reverse is true for propellers.

17. The statistical processes and models used for the above analysis are highly dependent on the amount of data available and the accuracy of reporting. Every effort was made to screen known discrepancies and account for unique maintenance policy procedures. For further clarification or if there are any questions, please contact the undersigned or Capt Drew Ritonja, 998-9677.

G. Nelson
Capt
DTA 4-2
CP140
998-3640

Appendix 2

Annex A

T56 Propulsion Cost Study

Tables from

“DTA 4 Analysis Study Report, T-56 Reliability and Maintainability Analysis - 23 Jul 96”

which do not include time expired component maintenance actions.

Table 1a - T56 R&M Performance: 1st line, on a/c
WUC: BCA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	75.8	1.6	46.3	0.17	0.06
CP140	75.7	1.6	46.9	0.46	0.05

Table 1b - T56 R&M Performance: 1st line, on a/c
WUC: CDA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	126.5	6.0	20.9	0.35	0.32
CP140	173.4	10.5	16.5	0.69	0.16

Table 2a - T56 R&M Performance: 2nd line, on a/c
WUC: BCA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	15.9	0.59	27.0
CP140	45.9	1.6	27.9

Table 2b - T56 R&M Performance: 2nd line, on a/c
WUC: CDA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	27.8	2.5	11.3
CP140	58.7	8.4	7.0

Table 3a - T56 R&M Performance: 2nd line, off a/c
WUC: BCA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	43.9	4.9	8.9
CP140	56.6	4.5	12.6

Table 3b - T56 R&M Performance: 2nd line, off a/c
WUC: CDA Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	109.9	5.8	18.9
CP140	168.3	18.6	9.1

Appendix 3

Annex A

T56 Propulsion Cost Study

Addendum to T56 R&M Analysis

5 Sep 96

ADDENDUM to T-56 R&M Analysis (dated 23 Jul 96)
5 Sep 96

1. Table 1c shows the initial performance levels for propeller control sys maintenance activities carried out at 1st line. The table shows that there is a significant difference between the reliability and maintenance burden for the two fleets. Of the 36 aborts and 22 delay/part missions for the CC130, 19 and 14 respectively resulted from flight safety incidents. The CP140 had 22 flight safety incidents out of 92 mission aborts.

2. Normalizing all flight safety incidents over the amount of flying, recorded against the propeller control system and its sub-components, indicates a FS rate of 0.3 FS/1000 FH for the CC130 and 0.37 FS/1000 FH for the CP140.

3. The stats listed below are further divided into TX'd and Non-TX'd categories:

TX'd Items Included

Table 1c - T56 R&M Performance: 1st line, on-a/c
WUC: CDB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	98.4	8.4	11.8	.22	.14
CP140	158.4	12.7	12.5	.95	.16

Table 2c - T56 R&M Performance: 2nd line, on-a/c
WUC: CDB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	19.8	2.7	7.3
CP140	24.8	2.1	11.8

Table 3c - T56 R&M Performance: 2nd line, off-a/c
WUC: CDB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	48.9	7.9	6.1

CP140	68.6	18.9	3.6

TX'd Items Excluded

Table 1c - T56 R&M Performance: 1st line, on-a/c
WUC: CDB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions 1000 FH
CC130	97.0	8.3	11.7	.22	.14
CP140	156.9	12.5	12.5	.95	.16

Table 2c - T56 R&M Performance: 2nd line, on-a/c
WUC: CDB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	13.1	2.3	5.6
CP140	17.9	1.6	11.4

Table 3c - T56 R&M Performance: 2nd line, off-a/c
WUC: CDB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	44.9	7.1	6.4
CP140	66.3	18.1	3.7

Appendix 4

Annex A

T56 Propulsion Cost Study

T56 Study - Reduction Gear Assy (BCB)

12 Sep 96

ADDENDUM to T-56 R&M Analysis (dated 23 Jul 96)
12 Sep 96

1. Table 1d shows the initial performance levels for the reduction gear assy maintenance activities carried out at 1st line. The table shows that there is a significant difference between the reliability and maintenance burden for the two fleets. There were no mission aborts, delays or FS incidents reported for the CC130, but the CP140 had 19 aborts and 3 delays of which 11 and 1 respectively resulted from flight safety incidents.

2. Normalizing all flight safety incidents over the amount of flying, recorded against the propeller control system and its sub-components, indicates a FS rate of 0.0 FS/1000 FH for the CC130 and 0.12 FS/1000 FH for the CP140.

3. The stats listed below are further divided into TX'd and Non-TX'd categories. The CC130 had no reported TX'd items at 1st or 2nd line maintenance and the CP140 had no reported TX'd items at 1 st line.

TX'd Items Included

Table 1d - T56 R&M Performance: 1st line, on-a/c
WUC: BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	.72	.09	7.8	0	0
CP140	39.5	.99	39.9	.19	.03

Table 2d - T56 R&M Performance: 2nd line, on-a/c
WUC: BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	.12	.02	6.3
CP140	14.3	.61	14.3

Table 3d - T56 R&M Performance: 2nd line, off-a/c
WUC: BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	.98	.04	26.3
CP140	56.5	2.1	26.9

TX'd Items Excluded

Table 1d - T56 R&M Performance: 1st line, on-a/c
WUC: BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	.72	.09	7.8	0	0
CP140	39.5	.99	39.9	.19	.03

Table 2d - T56 R&M Performance: 2nd line, on-a/c
WUC: BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	.12	.02	6.3
CP140	9.1	.57	16.0

Table 3d - T56 R&M Performance: 2nd line, off-a/c
WUC: BCB Analysis Period: 910101 to 960630

ACTYPE	MPH 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	.98	.04	26.3
CP140	52.8	1.9	28.4

Appendix 5

Annex A

T56 Propulsion Cost Study

T56 Addendum - BC,CD, BCC

23 Sep 96

ADDENDUM to T-56 R&M Analysis (dated 23 Jul 96)
20 Sep 96

1. Table 1e shows the performance levels for the overall engine powerplant maintenance activities carried out at 1st line. The table shows the difference between the reliability and maintenance burden for the two fleets. There is a significant difference between the aborted missions.

2. The CC130 had a total of 236 aborts and 216 delays reported and the CP140 had 450 aborts and 183 delays reported.

3. Tables 2e and 3e show the performance levels for the overall engine powerplant maintenance activities carried out at 2nd line. The table shows a significant difference between the two fleets with respect to reliability and maintenance burden.

4. The stats listed below are further divided into TX'd and Non-TX'd categories.

TX'd Items Included

Table 1e - T56 R&M Performance: 1st line, on-a/c
WUC: BC Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	445.9	31.5	14.2	1.46	1.34
CP140	628.7	44.4	14.2	4.6	1.88

Table 2e - T56 R&M Performance: 2nd line, on-a/c
WUC: BC Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	132.9	15.7	8.5
CP140	266.7	32.0	8.3

Table 3e - T56 R&M Performance: 2nd line, off-a/c
WUC: BC Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	293.9	39.7	7.4
CP140	397.5	69.1	5.8

TX'd Items Excluded

Table 1e - T56 R&M Performance: 1st line, on-a/c
WUC: BC Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	436.4	31.2	13.9	1.46	1.34
CP140	623.6	44.3	14.1	4.6	1.88

Table 2e - T56 R&M Performance: 2nd line, on-a/c
WUC: BC Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	93.1	13.8	6.8
CP140	244.7	31.7	7.7

Table 3e - T56 R&M Performance: 2nd line, off-a/c
WUC: BC Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	219.6	34.8	6.3
CP140	379.0	68.2	5.6

ADDENDUM to T-56 R&M Analysis (dated 23 Jul 96)
20 Sep 96

1. Table 1f shows the performance levels for the overall propeller maintenance activities carried out at 1st line. The table shows that there is a significant difference between the reliability and maintenance burden for the two fleets.

2. The CC130 had 115 aborts and 98 delays reported and the CP140 had 228 aborts and 48 delays reported.

3. Tables 2f and 3f show the performance levels for the overall propeller maintenance activities carried out at 2nd line. The table shows the difference between the two fleets with respect to reliability and maintenance burden.

4. The stats listed below are further divided into TX'd and Non-TX'd categories.

TX'd Items Included

Table 1f - T56 R&M Performance: 1st line, on-a/c
WUC: CD Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	274.9	18.4	14.9	0.71	0.61
CP140	407.4	29.3	13.9	2.3	0.49

Table 2f- T56 R&M Performance: 2nd line, on-a/c
WUC: CD Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	63.3	7.6	8.4
CP140	98.3	12.5	7.9

Table 3f- T56 R&M Performance: 2nd line, off-a/c
WUC: CD Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	182.9	16.3	11.2
CP140	280.7	42.3	6.6

TX'd Items Excluded

Table 1f- T56 R&M Performance: 1st line, on-a/c WUC: CD Analysis Period: 910101 to 960630					
ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	272.2	18.3	14.9	0.71	0.61
CP140	403.7	29.1	13.9	2.3	0.49

Table 2f- T56 R&M Performance: 2nd line, on-a/c WUC: CD Analysis Period: 910101 to 960630			
ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	49.9	6.9	7.3
CP140	83.8	11.6	7.2

Table 3f - T56 R&M Performance: 2nd line, off-a/c WUC: CD Analysis Period: 910101 to 960630			
ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	164.6	14.8	11.1
CP140	257.7	41.0	6.3

CORRECTION TO ADDENDUM (dated 12 Sep 96)
20 Sep 96

1. Table 1d shows the initial performance levels for the reduction gear assy maintenance activities carried out at 1st line. The WUC for the CC130 is BCC and sub-assys and for the CP140 it is BCB and sub-assys. The table shows slight difference between the reliability of the two fleets and a significant difference in the maintenance burden and mission aborts. There was only 1 mission abort, 1 delay, of which none resulted from a FS incident. reported for the CC130, but the CP140 had 19 aborts and 3 delays of which 11 and 1 respectively resulted from FS incidents.

2. Normalizing all flight safety incidents over the amount of flying, recorded against the reduction gear assy and its sub-components, indicates a FS rate of 0.01 FS/1000 FH for the CC130 and 0.12 FS/1000 FH for the CP140.

3. Tables 2d and 3d show very little difference between the two fleets with respect to reliability and maintenance burden at 2nd line.

4. The stats listed below are further divided into TX'd and Non-TX'd categories. The CP140 had no reported TX'd items at 1st line.

TX'd Items Included

Table 1d - T56 R&M Performance: 1st line, on-a/c
WUC: CC130-BCC/CP140-BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	25.0	1.3	20.1	0.01	0.01
CP140	39.5	.99	39.9	0.19	0.03

Table 2d - T56 R&M Performance: 2nd line, on-a/c
WUC: CC130-BCC/CP140-BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	15.1	.95	16.0
CP140	14.3	.61	14.3

Table 3d - T56 R&M Performance: 2nd line, off-a/c
WUC: CC130-BCC/CP140-BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA

CC130	55.5	1.6	34.1
CP140	56.5	2.1	26.9

TX'd Items Excluded

Table 1d - T56 R&M Performance: 1st line, on-a/c
WUC: CC130-BCC/CP140-BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA	Aborted Missions/ 1000 FH	Delayed Missions/ 1000 FH
CC130	24.5	1.2	19.7	0	0
CP140	39.5	.99	39.9	.19	.03

Table 2d - T56 R&M Performance: 2nd line, on-a/c
WUC: CC130-BCC/CP140-BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	12.5	.92	13.6
CP140	9.1	.57	16.0

Table 3d - T56 R&M Performance: 2nd line, off-a/c
WUC: CC130-BCC/CP140-BCB Analysis Period: 910101 to 960630

ACTYPE	MPH/ 1000 FH	UMA/ 1000 FH	MPH/ UMA
CC130	43.1	1.1	39.2
CP140	52.8	1.9	28.4

Annex B

T56 Propulsion Cost Study

WORK UNIT CODES FOR T56 PROPULSION SYSTEM

Hercules and Aurora

INDEX - TURBO PROP/SHAFT POWER PLANT SYSTEM (QEC)

INDEX - HYDRAULIC PROPELLERS

INDEX - TURBOPROP ENGINE ASSY

INDEX - HYDRAULIC PROPELLER

Annex C

T56 Propulsion Cost Study

8 WING TRENTON ENGINE BAY MAINTENANCE WORKLOAD DATA

8 AMS TRENTON ENGINE BAY

TASK	MAN HOURS	
	AET	IET
REDUCTION GEARBOX CHANGE	100 HR	20 HR
POWER SECTION CHANGE	180 HR	40-60 HR
BUILD-UP QECU	240 HR	40-60 HR
TEAR-DOWN QECU	180 HR	10 HR
PERIODIC INSPECTION	130 HR	15 HR
ACCEPTANCE CHECK (ENG)	20 HR	10 HR
QEC CHANGE	180 HR	30 HR
TURBINE CHANGE	120 HR	10 HR
COMBUSTION LINER CHANGE	60 HR	10 HR
APU/GTC PERIODIC	50 HR	5 HR
QECU P.S.I.	250 HR	10 HR
QECU ACCEPTANCE	100 HR	2 HR
PROP BUILD-UP	50 HR	
PROP TEAR-DOWN	24 HR	

NOTE: ALL TIMINGS ARE APPROXIMATE

ENGINE BAY STATISTICAL REPORT
JAN 94 TO JAN 95

HERCULES SECTION

1.	ENGINE	BUILD UP "E" AND "H"	32
		TEAR DOWN/ TX'D	17
		REPAIRS	13
		PERIODICS	68
2.	TURBINE	BUILD UP/ REPLACEMENT	15
		TEAR DOWN	13
3.	RGB'S	BUILD UP/ REPLACEMENT	12
		TEAR DOWN	10
4.	QECU'S	ACCEPTANCE CHECKS	11

GTC/APU/QECU SECTION

1.	QECU'S:	ACCEPTANCE CHECKS	16
		PSI	6
2.	GTC's:	ACCEPTANCE CHECKS	9
		PERIODICS	14
		RETURNED TO R/O	5
3.	APU's:	ACCEPTANCE CHECKS	2
		PERIODICS	4
		RETURNED TO R/O	1

PROPELLER SECTION

1.	PROPS:	BUILD UPS	22
		TEAR DOWN	21
		REPAIRS	60
		PAINTED	18
2.	VALVE HOUSING:		
		REPAIRS/RETURNS TO R&O /PIC	101
3.	PUMP HOUSING:		
		REPAIRS/RETURNS TO R&O /PIC/	98

BOEING SECTION

1.	ENGINE	BUILD UP	3
		TEAR DOWN	1
		REPAIRS	12
		PERIODICS	6

SECURITY CLASSIFICATION OF FORM
(Highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g., Establishment sponsoring a contractor's report, or tasking agency, are entered in section 12.) Air Vehicle Research Detachment National Defence Headquarters, Ottawa, Ont. K1A 0K2	2. DOCUMENT SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable) Unclassified

3. DOCUMENT TITLE (the complete document title as indicated on the title page. Its classification should be indicated be the appropriate abbreviation (S,C,R or U) in parentheses after the title.)

T56 Propulsion System Cost Study

4. DESCRIPTIVE NOTES (the category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Report

5. AUTHOR(S) (Last name, first name, middle initial. If military, show rank, e.g. Burns, Maj. Frank E.)

Jaansalu, Capt. Kevin M., Hastings, Robert, R., Nelson, Capt. Greg N.

6. DOCUMENT DATE (month and year of publication of document) November 1996	7.a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.) 64 pages	7.b. NO. OF REFS. (total cited in document) 5

8.a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant) Project 3GA	8.b. CONTRACT NO. (if appropriate, the applicable number under which the document was written) N/A
9.a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) 96-R-68	9.b. OTHER DOCUMENT NO.(S) (any other numbers which may be assigned this document either by the originator or by the sponsor.) - none -

10. DOCUMENT AVAILABILITY (any limitation on further dissemination of the document, other than those imposed by security classification)

☒ Unlimited distribution
☐ Distribution limited to defence departments and defence contractors; further distribution only as approved
☐ Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
☐ Distribution limited to government departments and agencies; further distribution only as approved
☐ Distribution limited to defence departments; further distribution only as approved
☐ Other

11. ANNOUNCEMENT AVAILABILITY (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (10.) However, where further distribution (beyond the audience specified in 10) is possible, a wider announcement audience may be selected.)

12. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

Air Vehicle Research Detachment
National Defence Headquarters
Ottawa, Ont. K1A 0K2

DSIS DCD03
HFD 09/94

Unclassified

SECURITY CLASSIFICATION OF FORM
(Highest classification of Title, Abstract, Keywords)

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

This study analyses operating costs and flight safety data of the propulsion systems on the CC-130 Hercules and CP-140 Aurora/Arcturus aircraft to identify where R&D investment could provide airworthiness or program cost benefits. Operational impact and R&O cost data are provided on the gas turbine engine, the reduction gearbox, and the propeller systems. The propeller system has a greater impact for both aircraft types on flight safety occurrences than the engine itself. The engine impact on airworthiness of the CC-130 Hercules and CP-140 Aurora aircraft is relatively benign, however benefit to airworthiness could be realized by R&D investment in advanced health usage monitoring systems. Modest cost improvements should be achievable via component repair scheme development, simple trend monitoring, in-line oil debris monitoring, and advanced propeller design.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible, keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Allison T56
Hamilton Standard 54H60
Gear Boxes
Propellers
Engines

CC-130 Hercules
CP-140 Aurora
Propulsion Systems
Costs