TITLE

RE-ENGINING THE CC130 HERCULES TRANSPORT AIRCRAFT AS A FLEET MANAGEMENT OPTION

ISABE
INTERNATIONAL SOCIETY FOR AIR BREATHING ENGINES

ISABE 97-7215

RE-ENGINING THE CC130 HERCULES TRANSPORT AIRCRAFT AS A FLEET MANAGEMENT OPTION

R.R. Hastings, P.R. Sully
Department of National Defence
Ottawa, Ontario, Canada

J.W. Bird, R.A. Anderson
National Research Council of Canada
Structures, Materials and Propulsion Laboratory
Ottawa, Ontario

XIII INTERNATIONAL SYMPOSIUM
ON
AIR BREATHING ENGINES

September 7 - 12, 1997
Chattanooga, Tennessee

RE-ENGINING THE CC130 HERCULES TRANSPORT AIRCRAFT AS A FLEET MANAGEMENT OPTION

R.R. Hastings, P.R. Sully
Department of National Defence, Canada
J.W. Bird, R.A. Anderson
National Research Council of Canada

Abstract

The Canadian Forces will be required to make a decision prior to the year 2010 on how it will maintain a military airlift capability in the next century, when its current fleet of CC130E aircraft reach their originally estimated life expectancy date. A brief description of the status and configuration of the Canadian Forces (CF) fleet of CC130 aircraft is presented along with the critical factors which will precipitate fleet management decisions. Potential replacement aircraft are briefly discussed with the conclusion that the C130J might be the sole feasible CC130E replacement option available in this time period. The tailoring and validation of an aircraft performance prediction model, required for systems trade studies, is next presented. Predicted performance improvements for a Pratt and Whitney Canada PW150 engined CC130 are discussed in an attempt to understand how range and endurance benefits can be achieved through advanced technology propulsion systems. In conclusion, a proposal is submitted for an airframe refurbishment/re-engining program as an alternative to procurement of new aircraft.

Introduction

Two elements of the mandate of the Defence Research and Development Branch (DRDB) of Canada's Department of National Defence (DND) are:

- Facilitate and enhance DND's ability to make informed decisions on defence policy, force development and procurement by providing expert scientific and technical advice.
- Enhance the preparedness of the Canadian Forces by assessing technology trends, threats and opportunities and by exploiting emerging technologies.

This paper describes a project wherein the DRDB has developed and validated a simplified aircraft performance prediction capability to enable the CF to evaluate aircraft manufacturer performance claims, perform systems trade-off studies, and to assess the option of airframe upgrade and re-engining its fleet of CC130 aircraft with Pratt and Whitney Canada (PWC) PW150 turboprop engines rather than procure replacement aircraft.

A summary of the status of the CF CC130 fleet is first provided to identify when fleet replacement decisions may be required. A brief description and discussion of some of the potential replacement aircraft, their anticipated capabilities, and any pertinent program issues is next provided. The procurement and adjustment of an aircraft performance prediction code is summarized and the validation results for that code briefly described. The final section attempts to identify the cost and implications of a refurbishment/re-engining program for Canada's CC130 fleet which would maintain or enhance operational capability at a cost much less than the procurement of new aircraft.

Background

Canada operates a fleet of 30 CC130 E and H model aircraft, and has recently purchased two additional airframes of the stretched version of the H model. This fleet is heavily tasked, operating approximately 30,000 hours per year in a variety of missions which range from Search and Rescue (SAR), to Air-to-Air Refuelling (AAR), in addition to the more typical transport/logistics roles. Recent peacekeeping and SAR commitments have increased this task load and have added a new dimension to aircraft structural damage modes and accumulation rates. Canada flies 19 CC130E aircraft supported by 99 T56-A-7B engines and 13 CC130H aircraft with 55 T56-A-15 and 8 501-D22A engines. The current plan is to retire the CC130E fleet in 2010, although there is a likelihood that a program life extension will be required in order to address major CF capital acquisition funding shortfalls. This paper will concentrate primarily on alternate management approaches to enable the accomplishment or enhancement of Canada's military airlift function as conducted by the CC130 aircraft.

The high time CC130 E has just in excess of 40,000 airframe hours and the E model airframe average life is over 37,000 hours. The mission severity in the past has been slightly less than that of the United States Air Force (USAF) and it is anticipated that a safe life of 70,000 airframe hours can be achieved in Canadian Forces operations. The Center Wing (CW) sections of all CF E model Hercules were replaced with H model components between 1972 and 1974, and all E model outer wings were replaced with H model components between 1984-87, by a Canadian contractor (North-West Industries Ltd, now CAE Aviation Ltd, Edmonton, Alberta). It is felt that the H model outer wing has an essentially infinite design life; the CW however, is again demonstrating some manageable fatigue and corrosion related problems. The current E model CW's were replaced at CC130E airframe hours of between 8,000 and 12,000 hours and those CW's now have as many as 30,000 flying hours of service. A recent study [1], building on data generated by Lockheed, and the United States Air Force, has identified that significant remedial action will be required on those CW's as early as 1998, with the majority of the fleet CW's requiring damage recovery between 2001 and 2004.

The CF continues to upgrade its CC130 fleet to ensure an airworthy and cost effective program. The CF has contracted with CAE Aviation Ltd, to perform a significant CC130 avionics update including: standardization of flight critical instruments, replacement of unreliable avionics systems, replacement of systems that do not meet international requirements, increasing the navigational accuracy to complete stringent mission profiles, and enabling communication on marine and mobile land radios. Rockwell-Collins is the prime equipment supplier for this Can$130M+ program, who will supply and integrate off-the-shelf commercial and/or military avionics systems for installation by CAE Aviation Ltd. Systems being replaced include: Automatic Flight Control and Display System, Flight Management System, Display and Instrument System, Navigation System, Communication System and Recording System. The CF is also in the process of upgrading all T56-A-7B engines to a common T56-A-15 configuration at an estimated program cost of approximately $40M.

CC130 Aircraft Replacement Options

It was not intended to conduct a comprehensive replacement aircraft options analysis as part of this study. If, however, there were an aircraft which offered itself as an obvious CC130 replacement by virtue of cost and performance parameters, that aircraft would be used to validate performance modelling capabilities and to establish an initial understanding of what that aircraft could contribute to the achievement of CF military transport operational commitments. A brief discussion of some salient points of each of the reviewed aircraft options is provided below.

In consideration of roles such as SAR or treaty verification, it may be possible to replace a number of E model Hercules with a smaller and less capable aircraft such as the upgraded Alenia G-222/C27-J. It has been proposed to fit this aircraft with the same powerplant and avionics system as that of the C130J. No actual performance data is available for this aircraft as the program is in preliminary design. It was felt that the CF's desire to minimize the number of aircraft types flown, and the lessening in operational flexibility inherent in selecting this aircraft would make this an unlikely option for the CF.

On the other end of the scale, some consideration has already been given to larger aircraft types - the McDonnell-Douglas C-17, and the Airbus Military Company (AMC) Future Large Aircraft (FLA). The C-17 is a truly remarkable aircraft offering almost 5 times the cargo volume and 3.5 times the maximum payload of the CC130H. Its design role and estimated US$200M price tag make it an unlikely selection for the CF to replace the CC130. The FLA offers an operational design mission similar to that of the C130, has twice the cargo volume of the C130, and a 25% increased maximum payload capacity of 55,000 pounds. The aircraft will likely be available in the time frame required for CC130E replacement. However, some program issues related to development stability, and price, anticipated to be as high as US$150M, are cause for concern. The selection of a powerplant has not been made and it would have been impossible to attempt prediction of this aircraft's performance.

There are Former Soviet Union (FSU) and Chinese aircraft which may require further assessment. The Ukrainian AN-70 is an advanced aircraft design with four very large powerplants (13,800 HP) and 14 (8+6) bladed counter-rotating propellers. Operational statistics are impressive, cargo volume is 3.5 times that of the C130 and maximum payload is 1.5 times that of the C130. Airworthiness, reliability and supportability are issues which will require further assessment. The SAC Y-8C is a Chinese version of the AN-12 with Western avionics and Lockheed input on airframe airworthiness. Its maximum payload approaches that of the C130, however its range is extremely meagre, 687 nautical miles with 40,000 pounds of cargo, and that in itself would eliminate the SAC Y-8C as a contender for CC130 replacement.

At this point in time, the C130J appears to be the most obvious replacement option for operators of older versions of the C130. The Royal Air Force (RAF) and the Royal Australian Air Force (RAAF) are currently procuring this aircraft, as is the USAF in limited quantity. The C130J airframe is essentially identical to that of the C130H but offers future optional replacement of control surfaces with composite skinned components. The Allison Gas Turbine T-56-A-15 engines on the C130H are replaced with Rolls-Royce/Allison Gas Turbine AE2100D3 engines which offer a significant reduction in fuel burn (15-18% at cruise). The Hamilton-Standard 54H60 four bladed aluminum propellers are also replaced on the C130J by Dowty R391 six bladed composite propellers. This propeller change provides significant improvement in take-off roll reduction and climb performance. The final significant change embodied in the C130J is the avionics system which includes a state-of-the-art glass cockpit, MIL-STD-1553 avionics bus and mission computers, among other improvements. Comparative performance figures are provided in Table 1 below which identify some key Lockheed-Martin performance calculations of improvements in the J Model over previous types.

Table 1 - C130 Performance Comparison
(ISA, MIL-C-5011A Fuel Reserves, Payload = 40,000 pounds)

	C130E	C130H	C130J
Take-Off Roll (ft)	3830	3585	3125
Time to Climb to 20,000 ft (min)	28	22	14
Range (nm)	2020	1945	2835
Cruise Altitude (ft)	20,000	23,000	28,000

In summary, compared to earlier versions of the aircraft, the C130J is purported to offer 40% increased range, a 40% higher cruise ceiling, 50% decrease in time to climb, 21% increase in maximum speed, 20% decrease in maximum effort take-off roll, and a 21% decrease in maintenance manhours/flying hour (MMH/FH). In light of the significant change in aircraft performance based almost solely on powerplant/propeller changes, it was considered essential for the DRDB to gain an understanding of the technology which has produced this impressive performance improvement.

Of greatest interest is the increased range capability of the C130J. Based on an assumption of 40% range improvement, it may be possible to purchase fewer C130J aircraft to replace the current 19 CC130E aircraft. Knowledge is required to increase the CF confidence that range improvements are realistic, and in ensuring that those range improvements are not bought with an unacceptable airframe life reduction, as could result from increased power transfer to the structure or by increased Ground-Air-Ground cycle damage associated with the increased cruise altitude.

Study Methodology

The steps pursued in the conduct of this study were as follows:

- Evaluate AE2100D3 engine/Dowty R391 propeller performance, or alternatively, obtain similar advanced propulsion system data for aircraft performance assessment.
- Obtain and tune, or generate an aircraft performance model which could be used for CC130 mission analysis. Inherent in this step is the need to validate that aircraft performance prediction code with current and known CC130 data.
- Conduct mission analyses using the advanced propulsion system data, and CF operational missions, to validate C130J performance claims, and to enable the future assessment of the benefits/costs of new mission profiles.
- Conduct and present an initial options cost analysis.

Powerplant Characteristics

The major change which has improved C130J performance is the advanced propulsion system. To evaluate how performance improvements had been achieved, it was felt necessary to gain an understanding of the differences between the T56 and the AE2100D3 engines and propellers. Dowty was unwilling to provide the propeller map for the R391 propeller and it was considered unlikely that Allison Gas Turbines would make available an AE2100 performance deck. Pratt and Whitney Canada, however, was willing to provide a computer model of its PW150 engine, and that engine was used in this study. The PW150 engine is an advanced technology engine of comparable performance to that of the AE2100D3. Hamilton-Standard Division, United Technologies Corp. also tailored an advanced design propeller, and provided a model for use in this study.

Table 2 below provides a summary of the design features of the T56-A-7B and T56-A-15, PW150 and AE2100 engines. The Series III T56-A-15 engines utilize different materials in hot section components to enable a Turbine Inlet Temperature (TIT) of 1077 °C and a power output of 4600 SHP, versus 971° C and 4050 SHP for the Series II T56-A-7B. Both engines are gearbox limited at 4291 HP in CF service.

Table 2 -Study Powerplant Design Features

	AE2100	PW150	T56
Configuration	Two shaft	Three shaft	One shaft
Overall PressureRatio	16.6	18.0	9.5
Compressor Type/ Configuration	14 Stage axial	3 Stage axial +1 centrifigual	14 Stage axial
Variable Stators	5 Stages	None	None
Combustor	Annular, through flow	Annular, folded reverse flow	Can-annular, through flow
Gas Generator Turbine	2 Stage axial	1 Stage axial HPT, 1 stage axial LPT	4 Stage, axial
Power Turbine	2 Stage axial	2 Stage axial	
Length (in.)	124	95	146
Max Diameter (in.)	46	45	32
Weight (lb)	1661	1521	1886
Control System	Two one channel FADECs	Dual channel FADEC	Hydro-mechanical

Tables 3, 4 and 5 provide performance figures at take-off and cruise power for each of the three engines of interest in the study. The power setting was based on open literature AE2100 data.

Table 3 - Series III T56 Engine Representative Performance Data

Flight Phase	Altitude (ft)	Mach No.	T_{amb}	Power (SHP)	ESFC (lb/hr/ ESHP)
Take-off	0	.15	90 °F	4637	.517
Cruise	32,000	.58	ISA	1950	.436

Table 4 - PW150 Engine Representative Performance Data

Flight Phase	Altitude (ft)	Mach No.	T_{amb}	Power (SHP)	ESFC (lb/hr/ ESHP)
Take-off	0	.15	90 °F	4637	.437
Cruise	32,000	.58	ISA	1950	.367

Table 5 - AE2100 Engine Representative Performance Data

Flight Phase	Altitude (ft)	Mach No.	T_{amb}	Power (SHP)	ESFC (lb/hr/ ESHP)
Take-off	0	.15	90 °F	4637	.430
Cruise	32,000	.58	ISA	1950	.369

Model Validation

An initial attempt was made to use an older aircraft performance model originally designed to predict the performance of foreign technology aircraft. This model proved too difficult to update, did not allow usage of more complete engine performance data, and was discarded. The analysis was then conducted with the aid of RDS Professional, an aircraft design and performance package. The first step in the study was to validate the RDS code by running the program with current engine and flight data from the CC130H fitted with the T56-A-15 engines and compare the results with actual flight test data and performance curves.

Aircraft drag information derived in a previous study [5] was improved upon by fitting an equation of the form
$C_D = C_{DO} + KC_L^2$
to drag curves in [6] for representative Mach numbers. These were the key aerodynamic data required for the operation of the RDS aircraft performance code.

RDS requires three different types of engine tables in order to perform an analysis: maximum thrust versus

Mach, TSFC versus Mach and part-power tables of TSFC versus thrust at different altitudes. The data for engine performance were taken from the CF Aircraft Operating Instructions [2] which gave shaft horsepower and fuel flow. Jet thrust was estimated from a USN test cell report [3]. These data were converted into total thrust and TSFC (lb/sec/lbf) by converting shaft horsepower to thrust with a 54H60 propeller model supplied by Hamilton-Standard, and accounting for jet thrust.

Model validation was performed by comparing mission fuel burn data with results obtained from the RDS model. Mission profiles for the Canadian Forces Hercules fleet were given in a previous study [4] which was conducted prior to re-winging the CC130E aircraft. The majority of missions flown were long range, medium range and short range logistics missions, occupying 36%, 16% and 22% of total aircraft utilization respectively. These missions were chosen as a baseline in order to validate the CC-130 data and RDS model.

The mission specifications outlined taxi, takeoff, several climb segments, cruise segments, several descent segments, landing, roll-out and final taxi. The takeoff and landing segments were approximated with a known fuel burn, with reserve fuel as part of the landing fuel burn. Table 6 gives the actual mission results and the RDS output for comparison.

Table 6 - Comparison of RDS Output To Actual Missions

Logistic Mission	Long Range	Medium Range	Short Range
Take-Off Weight (lb)	141,427	118,427	108,427
Fuel (lb)	60,000	35,000	25,000
Cargo (lb)	4,858	6,858	6,858
Range (nm)	2,612	1,350	531
RDS Model (nm)	2,596	1,379	462
Difference	(-0.6%)	(+2.1%)	69 nm

The RDS ranges were calculated for given flight conditions. If RDS optimization were selected to calculate the maximum range, a cruise speed of 290 knots TAS at an altitude of 28,000 ft resulted, rather than the 317 knots TAS and 24,000 ft specified for CF mission profiles [4]. This did not however, provide a significant increase in range.

A further comparison was made with Lockheed C130H published data. The Lockheed range quoted for the C130H aircraft at ISA conditions with a 40,000 pound payload and MIL-C-5011A fuel reserves is 1945 nautical miles whereas the model predicted 1970 nautical miles, or agreement within 2%. Tables 7a and 7b below provide additional payload-range data points for maximum take-off weights of 155,000 and 175,000 pounds to allow comparison of RDS model and Lockheed specification data.

Table 7a - Comparison of RDS Output to Lockheed Specification Ranges

MTOW=155,000 Pounds

Payload (pounds)	Range(nm)		Difference %
	Lockheed Specification	RDS Output	
42,753	2,000	2,040	2.0
15,589	4,100	4,220	2.9
0	4,825	4,815	0.2

Table 7b - Comparison of RDS Output to Lockheed Specification Ranges

MTOW=175,000 Pounds

Payload (pounds)	Range(nm)		Difference %
	Lockheed Specification	RDS Output	
42,753	3,100	3,100	0
35,589	3,550	3,457	2.6
0	4,800	4,815	0.3

Given the foregoing, it was concluded that an aircraft performance prediction model of sufficient fidelity had been generated to allow the assessment of CC130 aircraft performance with different propulsion systems installed, and for a range of mission profiles.

Performance Improvement Discussion

Although the PW150 is not optimized for CC130 constant propeller speed operation, it was felt that the performance improvement provided by this advanced technology engine would be comparable to that of the AE2100D3. Accordingly, PW150 data [7] and advanced six bladed propeller data was input to the RDS model. The propeller map was tailored to CC130 operations. Engine installation correction factors were made for intake and exhaust losses, customer service horsepower and bleed air.

Tables 8 and 9 below provide the RDS model predicted range for the current CC130H, and as fitted with a PW150 engine and advanced propeller. As can be seen, the range improvements accrued from fitment of the PW150 engine are consistently 13% at 40,000 pounds of cargo, and vary between 13 and 15% for the zero payload ferry range. This performance improvement agrees with a preliminary assessment [5] which was based solely on the cruise portion of the flight profile.

Table 8 - CC130 Range @ Payload = 40,000 pounds

Cruise Altitude (ft)	CC130H (nm)	CC130H with PW150 (nm)	Difference %
20,000	1,940	2,196	13
23,000	1,970	2,226	13
28,000	1,941	2,194	13

Table 9 - CC130 Range @ Payload = 0 pounds

Cruise Altitude (ft)	CC130H (nm)	CC130H with PW150 (nm)	Difference %
20,000	4,277	4,928	15
23,000	4,414	5,035	14
28,000	4,439	5,030	13

While the advanced propeller does provide significantly improved take-off performance characteristics, it will likely not produce significant improvements at cruise. Improved SFC at cruise conditions is the dominant factor affecting range and endurance, and one would anticipate a 15% range improvement from an engine which offers a 15% SFC reduction (refer to Tables 3,4 and 5). The 13-15% range improvement predicted appears to be a reasonable estimate of likely range improvement.

For further amplification, Tables 10, 11 and 12 provide model predicted payload range values for the CC130 at Maximum Take-Off Weights of 155,000, 165,000 and 175,000 pounds respectively. These calculations were made as the C130 has an emergency 2.25g flight envelope which allows MTOW at 175,000 pounds, and consideration is being given to increasing the normal operational MTOW.

Table 10 - CC130 Predicted Range at Maximum Take-Off Weight = 155,000 Pounds

Payload (pounds)	Range (nm)		Difference %
	CC130H with T56-A-15	CC130H with PW150	
42,753	2,040	2,299	12.7
15,589	4,220	4,750	12.6
0	4,815	5,466	13.5

Table 11 - CC130 Predicted Range at Maximum Take-Off Weight = 165,000 Pounds

Payload (pounds)	Range (nm)		Difference %
	CC130H with T56-A-15	CC130H with PW150	
42,753	2,588	2,903	12.2
25,589	3,897	4,367	12.1
0	4,815	5,466	13.5

Table 12 - CC130 Predicted Range at Maximum Take-Off Weight = 175,000 Pounds

Payload (pounds)	Range (nm)		Difference (%)
	CC130H with T56-A-15	CC130H with PW150	
42,753	3,100	3,615	16.6
35,589	3,457	4,030	16.6
0	4,815	5,466	13.5

Preliminary Options Cost Analysis

Airframe Refurbishment

Three separate areas are considered: CW repair/replacement, main fuselage repair/refurbishment, and enhancements including an advanced cargo handling system. The first element, the CW, has already been identified as a key factor in terms of timing and criticality. CAE Aviation Ltd has identified [1] three options for managing the CW problems identified or anticipated on the existing CC130E model aircraft. The first CW alternative is to conduct repairs on the CW as they arise. This worst case option will allow continued aircraft operation until 2010 but will cost approximately $160M and result in aircraft being removed from fleet operations for some 2058 weeks in total. The second option would entail the replacement of the CW with a new component and would provide a program life to the year 2025, and cost approximately $154M. Total aircraft downtime is anticipated to be approximately 12 weeks per aircraft (228 weeks in total) which is an improvement over the continuous maintenance approach. A third option would involve a scheduled refurbishment program for the CW which would enable safe aircraft operation to the year 2025 at a cost of approximately $34M and with a total aircraft downtime of 26 weeks per aircraft (494 weeks in total). The latter option, Center Wing Improvement Program (CWIP), would entail the removal of the CW, planned repair/improvement of all known or anticipated CW problem areas, and concurrent wiring replacement.

No significant fuselage centre barrel structural issues have been identified at this point in time. Although the current CF mission severity exceeds that of the USAF, it has been generally less severe than that of the USAF in the past. Overall it is felt that the main fuselage can be cost effectively supported for an additional 25-30 years. The CF now monitors individual aircraft operational loads and it is felt that a good understanding of key structural issues has been achieved.

Any re-engining/refurbishment program will have to include operationally necessary upgrades including a new cargo handling system, and GTC replacement or removal. Recent experiences in low intensity conflicts have also highlighted the need for systems to increase aircraft survivability. A refurbishment program would ideally include such options as an infrared signature suppressor, an enhanced EW countermeasures suite, and aircrew protective armour.

Re-Engining/Refurbishment Cost Estimation

Canadian contractors have provided non-recurring and recurring cost projections for re-engining the CC130E with PW150 engines and for specific airframe upgrades. Non-recurring costs for the entire package are estimated at $140M and rely heavily on the use of analytical tools and recent Dash 8 400 engine integration experience. While this is significantly less than what the final bill will be for C130J non-recurring engineering costs, it is of the same order as the original C130J estimate of $300M. For a second comparison, the actual non-recurring price tag to transform the Canadair Challenger into the Canadair RJ was $255M, an arguably more significant challenge than re-engining the CC130. Canadian industrial experience: Pratt and Whitney Canada's with engine/airframe integration and CAE Aviation's depth of experience on the CC130 aircraft, promotes confidence in achieving success within the cost envelope identified. Table 13 below provides a summary of non-recurring and recurring costs for retro-fitting a PW150 engine with an advanced design propeller to the CC130 aircraft, and for the refurbishment of those airframes such that an additional 25 years of airworthy service can be realized.

Table 13 - CC130 Re-engining/Airframe Refurbishment Costs

Element	Non-Recurring Cost (Can$M)	Recurring Costs (Can$M) (per aircraft)
Engines	25	7
Propellers	25	1.2
Nacelles	20	1.6
Modification Kits	28	3
Engine Instrumentation	0	3
Systems	0	1
Center Wing Improvement	0	2
Fuselage Improvements and Airframe Enhancements	0	6.2
Flight Test	42	0
Total	140	25

Preliminary Options Cost Assessment

Option 1 - Status Quo

To maintain the current fleet of CC130E aircraft flown by the CF it will be necessary, at minimum, to repair the fatigue and corrosion damage in the CW. CAE Aviation have estimated the cost of this option at approximately CAN$34M. This would extend the life of the CC130E fleet until 2025 barring any unforeseen structural problems. The CW Improvement Plan would have to begin as early as 1998 and would last until 2006. During that period, aircraft would be out of service for remedial action a total of 494 weeks. This is a medium risk option which is the least costly for maintaining the existing CF military transport capability. This option does suffer from the limitations presently imposed by aging systems such as the cargo handling system and may lead to increasing operations and maintenance costs.

Option 2 - C130J Procurement

Current C130J prices are approximately US$55M, however given the current program delays and cost overruns it is not unreasonable to assume that aircraft costs will escalate somewhat. For the purposes of this study, a replacement cost for C130Js, in Canadian funds of $75M is assumed, roughly equivalent to US$55M. The return from the sale of existing CF CC130E aircraft is considered negligible, and no program cost benefit has been assumed. Thus, to replace 19 CC130E model aircraft with 19 C130J aircraft would cost CAN$1,425M. Due to a C130J range improvement of 40% over the E model, it might be simplistically assumed that 12 C130J aircraft could perform the missions now performed by 19 E model C130s. For a reduced aircraft buy, 12 C130Js would then cost CAN$900M. It is assumed that the C130J program problems will eventually be rectified and that procuring C130J aircraft at the end of the first decade of the next century will be a low risk option.

Option 3 - Airframe Refurbishment/Re-engine with PW150

To refurbish the 19 CC130 E aircraft would cost CAN$140M in non-recurring engineering, and CAN$475M (19 X $25M) for airframe refurbishment and re-engining, yielding a total cost of CAN$615M for 19 aircraft. Re-engining of the 13 C130H model aircraft in the CF inventory would cost an additional CAN$260M (assuming no CWIP, and only CAN$3.2M for airframe upgrades), producing a consistent, upgraded fleet of 32 aircraft at a cost of $875M. Obviously this option is the highest risk option, due to the non-recurring engineering aspect, but also offers a number of potential benefits, including increased Canadian job creation.

Concluding Comments

Re-engining and airframe life extension programs are becoming a standard way of achieving operational objectives and can be a cost effective method of maintaining an airworthy flying asset. The replacement of the JT3D engines with CFM56 engines on the KC135 aircraft fleet, involving in excess of 250 aircraft, is one of the reasons why some aircraft in that fleet will have an economical safe life in excess of 70 years [8]. The availability of high powered computational tools has also made possible re-engining challenges such as fitting the CFM56 to the Boeing 737 airframe, a task which would have been impossible without advanced analytical codes.

The original intent of the study conducted by DRDB was to develop a computational tool which would allow the evaluation of C130J or other replacement aircraft performance improvements. It is intended that the performance tool be used for mission tailoring to assess optimal systems effectiveness. It will be necessary to continue this aspect of the study as it is still not understood how the C130J range has been improved so dramatically. The 15% range improvement estimated for a PW150 powered CC130 appear reasonable in light of the roughly 15% SFC reduction offered by the PW150 at cruise conditions over the currently fitted T56 engines.

It is felt that the C130J will be the only viable replacement for aging C130 aircraft over the next two decades, as the AMC FLA will likely be prohibitively costly. As such, it will be necessary to provide planners with at least one alternative to the C130J, and to provide those planners with the tools necessary to evaluate C130J, a re-engined CC130E, or other aircraft as potential replacements for the CF fleet of CC130E aircraft. This study will be continued to further understand how best to achieve enhanced capability and then to assess Life Cycle Cost issues.

It is felt that re-engining the CC130E aircraft with the PW150 engines offers some positive benefits and would be a cost effective alternative to procuring the C130J. The engine offers operational benefits, potentially lower life cycle costs due to reduced engine parts count, a more erosion resistant gas path and commercial equivalence. It would also be possible to encourage more political support for a re-engining program involving Canadian produced engines than procuring new aircraft in a tight budgetary environment.

Nomenclature

AAR	Air-to-Air Refuelling
CF	Canadian Forces
CW	Center Wing
CWIP	Center Wing Improvement Plan
DRDB	Canada's Defence Research and Development Branch
ESFC	Equivalent Specific Fuel Consumption (Includes residual thrust)
ESHP	Equivalent Shaft Horsepower
EW	Electronic Warfare
FADEC	Full Authority Digital Electronic Control
FH	Flying Hours
FSU	Former Soviet Union
GTC	Gas Turbine Compressor
HPT	High Pressure Turbine
LPT	Low Pressure Turbine
ISA	International Standard Atmosphere
Kts	Nautical Miles per Hour
MMH	Maintenance Man-Hours
MTOW	Maximum Take-Off Weight
NWI	North West Industries (now CAE Aviation)
PWC	Pratt and Whitney Canada
SAR	Search and Rescue
SFC	Specific Fuel Consumption
SHP	Shaft Horsepower
TAS	True Air Speed
TIT	Turbine Inlet Temperature
TOW	Take-Off Weight
TSFC	Thrust Specific Fuel Consumption

References:

[1] Center Wing Service Life Extension Program Feasibility Study: Final Report, CAE Aviation Report 11-783-SE-009-003, May 1997

[2] C-12-130-000/MB-002 20 June 1985- Aircraft Operating Instructions for the C 130

[3] NAEC-AEL-1836, US Navy Report Allison T56-A-14 Engine - Official Sea Level Low and High Temperature,and Altitude Performance Tests, July 1966

[4] Lockheed-Georgia Company Report ER/S-7100M Model Specification for the Lockheed Model 382C-44C-05 Lockheed Hercules Long Range Cargo and Troop Carrier Transport, Revised 1 February 1987

[5] A Preliminary Operational Benefits Analysis for Re-engining the CC130 Aircraft, Sully P.R., Hastings R.R., Bird J.W., Canadian Aeronautics and Space Institute Proceedings of the 8th Symposium on Propulsion April 29 1996

[6] Lockheed-Georgia Company Report LG76ER-0081, C-130H Flight Simulator

[7] PW150/9 Estimated Performance Program Users Manual, EEPP3015-12.1, January 1997 (Proprietary)

[8] AGARD Lecture Series LS-206, Aging Combat Aircraft Fleets - Long Term Applications, October 1996

#506960