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The Canadian Air Force Experience Selecting Aircraft Life Extension as the most economical solution

Major Normand Landry
 Directorate of Technical Airworthiness 3-3
 Senior Structural Integrity Manager
 Canadian Forces
 National Defence Headquarters
 CFB Ottawa (N)
 Ottawa, Ontario, K1A 0K2
 Canada

Summary

Canada like several other countries has limited resources to trade-in its outdated and ageing fleets for state-of-the-art weapon systems. With the CF188 and the CP140, the Canadian Forces (CF) have chosen, as with the CF116 before, to perform a structural and systems upgrade. These upgrades will allow the aircraft to meet their operational requirements until the first quarter of the next century. The choice for this course of action is based on option analysis studies. In the end, fleet modernisation has proven to be the most economical solution. This paper will present the approach taken and the assumptions made for the various scenarios studied to reach that conclusion. Avionics packages are readily available off-the-shelf and in most cases the decision is based mostly on structural limitations. Hence in-service failures and results of full scale fatigue tests obtained through collaborative agreements can be a cost effective way to determine the cost of ownership of each fleet. The paper will briefly talk about the concept taken for the CP140 but will use the CF188 as the demonstration test case.

Background

In the early 1980s, the Canadian Forces rejuvenated their fleets of Anti-Submarine Warfare and Fighter aircraft. Two new platforms were purchased; the CP 140 ASW (Lockheed P-3) and the CF188 multi-role fighter (MacDonnell Douglas F/A-18-A/B). Those aircraft were selected, among other candidates from other manufacturers, after several years of evaluation. Needless to say the aircraft, when purchased, had equipment that was already on the verge of being superseded by improved state-of-the-art avionics systems. Both these aircraft had been expected to stay in service for 20 to 25 years. After such a period, it is reasonable to assume that

they needed replacing. However, there are several factors affecting that decision, some technical and some economical. A significant area of concern is the suitability and supportability of the avionics equipment for the role of the aircraft. Secondly, the structure of the aircraft has to be properly examined to ensure a proper assessment of its current and future airworthiness is made. The easiest aspects to evaluate are the cost of replacing the aircraft with a new weapon system and that of upgrading the avionics suite. This exercise is relatively easy as it requires to make the list of desired capabilities and shop around for either the cost of a replacement aircraft or the cost of the desired avionics components and their installation. Even in the case of simply updating the avionics, the equipment packages are generally off the shelf and can be fitted on different platforms at a reasonable cost. The cost for avionics update is of the order of 10 to 20 times cheaper than the replacement of aircraft fleet depending on the fleet type and its size.

The determinant factor in the decision-making process, in most cases, is to assess the feasibility and cost difference between upgrading the aircraft structure to last long enough or to replace the fleet after the initial 20 year period. This last option may not always be possible. More and more countries, like Canada, are looking at purchasing weapon system platforms off-the-shelf. This implies aircraft manufacturers will have products available on demand. Unfortunately with the cost of new aircraft this is rarely the case and one may have no other choice than waiting for the latest model to appear on the market. As per a latest study in the United States, new platforms may become so expensive that they would be out of reach for most countries if not all. It is therefore required that tools are put in place to ensure Air Forces are in a position to make the best decision for the course ahead. The aim of the exercise, remains in

assessing capability for the aircraft structure to last long enough at a reasonable cost to make the avionics upgrade worth performing. To ensure proper amortisation of the cost of an avionics upgrade, the aircraft structure has to last for a sufficient amount of time after completion of the last upgraded aircraft. Although there are no firm rules on the acceptable number of years post avionics update, it has been estimated that for the Canadian Forces, an extension of approximately 10 to 15 years on a new avionics package is deemed acceptable. Based on this, a past study on the CF18 was performed and indicated that for each year of delay in replacing the CF-188 fleet beyond 20 years, while performing the avionics upgrade and structural modifications, had the potential for savings of the order of approximately C\$30M¹ per year (1993 dollars).

Options review are often based on very cursory estimates and they do not represent well how a specific option can be made viable. Consequently, the CF has put in place some programmes and developed a series of tools to ensure its capability to assess the feasibility and cost effectiveness of upgrading the CF aircraft.

Life Extension Assessment Tools

Aircraft life extension is possible only if both the avionics suite and the structure can be sustained or upgraded at a reasonable cost. On the avionics upgrade, the specifications were produced and an implementation plan was put in place. The CF-188 avionics upgrade will be done in 3 phases starting in 2002 and will be completed in 2007 at a cost of approximately C\$10M¹ per aircraft. The first phase will include upgrade to the Mission Computer, the GPS, the IFF and the radios. Phase 2 will incorporate upgrades to the radar, the DDIs, the Datalink and the Stores Management System. The last phase will provide upgrade to the Radar Warning Receiver, the EW Jammer, the chaff/flares dispensers, the missile approach warning system and the incorporation of a helmet mounted sight. Based on this information, assuming the aircraft structure can be sustained until near 2020, the investment for this work is acceptable.

To properly assess the structure, the first step is to have a well structured Aircraft Structural Integrity Programme (ASIP). The CF-188 has had a programme to that effect since the beginning of the life of the fleet. That programme was very effective

from the outset and it provided data that clearly showed that the CF-188 would not be in service past year 2000. It would be the case unless significant changes to the flying operations were made and steps to determine the safe-life of the primary structure and the economical life of the aircraft were not taken. On the CF-188, the Fatigue Life Monitoring Programme (FLMP) was superimposed on ASIP. The additional responsibility of FLMP was to be able to monitor each mission severity and to educate operators. The aim was to maintain the same operational objective while reducing fatigue damage on the aircraft. On the CP-140, the same diagnosis was made, although the aircraft would be in service until 2010. The ASI programmes have allowed the CF to identify the best possible course of action. With both these aircraft, a Full Scale Durability and Damage Tolerance Test (FSDADT) was identified as the best course of action to determine the cost of maintaining the aircraft for a given period of time; the **"Cost of Ownership"**. The present paper will mostly highlight the CF-188 experience since the CP-140 test being performed in collaboration with the United States Navy (USN), the Royal Australian Air Force (RAAF) and the Netherlands Air Force, is still at the initiation stage. On the CF-188, the test is quite mature and results are already being fed into the long range planning of the fleet.

An additional incentive to perform a Full Scale Test on the CF-188 was that the predicted life from the manufacturer underestimated the usage made of the aircraft in service. Furthermore, in-service defects confirmed higher rate of damage and consequently, it was imperative that the cost of ownership be determined for the remaining life which was then at 4000 hours and for the desired service life. The prediction was based on the going rate of fatigue damage and the fact that the certification test was less severe than fleet usage. The objective was to determine the feasibility and cost for the aircraft to stay in service until it reached the required 6000 Equivalent Test Hours. The fatigue damage on the CF-188 is measured in terms of Fatigue Life Expended Index (FLEI), each hour on a Full Scale Test may not correspond exactly to one flight hour. Once the appropriate scatter factor is applied, the equivalency is done in FLEI rather than in hours. Consequently, assuming that the FLEI will be 1.0 at the end of the Full Scale Test, each aircraft will be measured against that number in relative terms of FLEI. Hence it is possible that some aircraft will

fly more than 6000 hours and others less for a given damage index.

Cost Sharing through collaboration

Performing a FSDADT Test is a very expensive proposition and hence more countries will team up with each other to perform the work. In the present case, the Canadian Forces (CF) have teamed up with the Royal Australian Air Force (RAAF) under the terms of the International Follow-On Structural Test Project (IFOSTP). The structure of the arrangement is that Canada is performing testing on the Centre Fuselage (Figure 1) and Wings while Australia is performing testing on the Aft Fuselage. At half the cost the whole aircraft is covered. Obviously this comes with some compromises but due to the similar nature of the flying between both countries, the spectrum applied to the tests was a good representation of both countries flying. In the end, the cost of the whole project is equivalent to the replacement of slightly more than one aircraft.

The advantage of such a collaboration, is that it does not have to stop at the exchange of Full Scale Test results. In this case it has led to collaboration on a variety of other topics on which exchanges have proven beneficial and cost efficient for both countries. IFOSTP has also been the birth place for testing some life improvement processes such as shotpeening and complex 3-D composite patch applied to thick monolithic Aluminum structures. In the future, there is a potential to share further on the validation of repairs or replacement of major components on the aircraft.

Findings

The centre fuselage test, has accumulated 13,000 Spectrum Flight Hours (SFH). So far it has indicated a series of locations that will need to be addressed either through parts replacement or modifications. The aircraft was subjected to a major inspection at 12,000 sfh. The strategy used during that inspection was based on the failures found prior to reaching that time and their comparison with the results of the certification test conducted by MacDonnell Douglas and also on some in-service failures. It became obvious that some locations would pose a serious risk to the test article and to the fleet if a preventive modification was not developed and incorporated prior to test restart at the end of that inspection. The risk on the test article was that a catastrophic failure could

occur and jeopardise the whole test. The risk for the fleet was that a preventive modification would end up on the aircraft without prior testing on IFOSTP. After a risk analysis was performed, the critical locations were identified and modifications were developed for implementation during the down time.

The aircraft is managed based on a safe-life philosophy. Due to the nature of the material used on the main bulkheads of the CF188, which are the most critical areas, it is difficult to get any kind of damage tolerance from the structure. Aluminium 7050 is generally not very tolerant to damage. In the cases where symmetry was available between the 2 sides of the aircraft, the strategy was to modify the aircraft on one side, and allow the other side to develop the necessary damage to provide actual safe life of the feature location. The advantage is that a modification is being tested and certified, providing economical data, at the same time as the safe life of the primary structure is being established. This is meeting the two main objectives of the test which were to determine the life of the primary structure and the economical life of the aircraft.

As a rule, the centre fuselage test results were at the locations expected from the certification test and from in-service failure. However, most of them occurred much more prematurely and requiring some immediate action on the test and in the fleet. Figure 2 shows the breakdown of failures seen on IFOSTP in comparison with results from other sources or expected results from analytical predictions. In short, 96% of the failure sites were known but half of them occurred earlier than anticipated. Since the fleet was very close behind the test, immediate action was required to verify if some of the damages were present. The results of those inspections demonstrated that there exists good correlation between IFOSTP results and in-service findings. In-service findings were obtained from maintenance results since the aircraft came into service and also from a sampling inspection of 7 aircraft performed in 1997. Figure 3 shows the distribution of defects from the various levels of inspection. A total of 235 defects were found on the primary structure. 90 of them were discovered during depot level repairs, another 90 during squadron inspections and 55 during the Aircraft Sampling Inspection (ASI).

The results were quite significant as already several aircraft had passed their safe-life threshold and unless modifications were performed immediately, there was either an airworthiness concern or a potentially high economical impact in the future. Initially approximately 20 aircraft had to be removed from flying status due to potentially large economical consequences.

The most critical area of the CF-188 is the centre fuselage. There are 3 bulkheads retaining the wings and those bulkheads are fracture critical. It is also on the centre fuselage that the largest number of defects has been found and more are anticipated. There are other critical areas on the wings such as the spars and the attachment points and also on the aft fuselage; mostly on the Horizontal Stabilator attachments. Consequently, it will become obvious that most efforts and most of the cost will be concentrated on that area of the aircraft.

Converting findings into Cost of Ownership

Based on the results, a detailed review was performed of every single location on the aircraft and the associated cost for repair was estimated. This was the first step toward establishing the viability of performing repairs on the CF-188 to provide continuing airworthiness while extending the life. To date 111 locations have been identified as potentially requiring modifications. This number is based on the results of the Full Scale Test but also on the anticipated failure sites that have been identified as likely to cause problems during the rest of IFOSTP testing. The initial cost of these modifications was performed. That number seemed to indicate that embodying modifications would be a viable option. However, an option analysis was required to determine the most viable option.

Available Options – Initial Analysis

Four options were investigated:

- a. replace the fleet before 2010;
- b. perform a Centre Barrel Replacement (CBR) on the whole fleet before 2005;
- c. perform all the modifications identified by IFOSTP results; and
- d. perform a hybrid approach of modifications and CBR.

Option 1: Aircraft replacement was obviously envisaged. Aircraft such as the F-18 E/F and JSF

were considered. The anticipated cost per aircraft was in excess of C\$100M¹. There was also a concern that the most suitable replacement aircraft would not be available in time to replace the CF188 fleet and that at least several modifications would have to be performed on the aircraft just to keep them flying until the new aircraft were delivered.

Option 2: The CBR option had been studied in the early part of the 1990s and initially the cost was deemed to be excessive. However, the USN has had to replace some centre barrels on their F-A/18 fleet and the actual cost was less than C\$5M¹. This option was now very attractive. However, the CBR did not cover all the defects. Some additional areas needed to be modified as they were known to be problematic, hence a CBR+ package was estimated. Once considerations for steady state installations were considered, the cost of this option was not expected to exceed the initial estimate for a CBR replacement of C\$5M. But, this option did not address any wing or aft fuselage defects, which would have to be added.

Nevertheless, this is a very attractive solution. It is more elegant than performing a series of modifications to the structure and potentially, one gets an equal amount of life than with the original structure. Since several early deficiencies were rectified on the replacement barrel, several problematic areas would no longer be a problem.

On the other hand, there are many uncertainties associated with this option. The time to perform the replacement may preclude the CF to have the whole fleet done in a reasonable time. It would require several replacement lines that could make this option more costly than anticipated. And finally, there is no experience outside Naval Air Depot in North Island to perform this work.

Until the results of the wing and aft fuselage tests are known, this option is difficult to really estimate and to determine its overall benefits in comparison with other options. However, it is unlikely that the CF will be able to wait until the results of the wing and aft fuselage test results are obtained, which is likely to be toward the end of year 2000. In order to have the equipment in place and the CBR manufactured on time, the decision has to be reached by the fall of 1999. This option is still under review.

Option 3: Develop and implement the modifications based on IFOSTP results. The initial cost of ownership performed estimated that the centre fuselage modifications would add up to approximately C\$1M¹. However, it was difficult to assess the potential for integrating all the modifications and also to determine the time it would take to embody. Although this approach looked to be the more cost effective, there was insufficient information to complete the analysis.

Pursuing this option could have significant impact on the fleet availability if not properly setup. An other important point, is that the life of the aircraft would be only as long as the certification time on IFOSTP. Contrary to the CBR+ option, it would be less likely that the aircraft centre fuselage last longer than the anticipated 6000 Equivalent Test Hours (ETH).

Option 4: To allow for a potential phased approach to replace the current CF-188 fleet, a combination of option 2 and 3 could be used. A replacement programme could be put in place to have aircraft replaced over a slightly more extended period and hence take advantage of the additional life the CBR+ option would provide over the more limited life that would be provided by the modifications option.

Implementation Planning Tool

A priori, option 3 seems to be the most cost-effective option but option 2 cannot be rejected at this point. Significant planning is required to complete the structural upgrades in a timeframe consistent with the operational requirements and fleet Estimated Life Expectancy (ELE). Hence, there is also a requirement to integrate such a programme with the rest of the maintenance activities.

Requirement: To determine the best option to follow and to derive the most appropriate implementation plan, it was required to develop a Fleet Maintenance Planning tool. A system that will assist the fleet manager to make the most cost-effective decision for the planning of aircraft upgrades while minimising the impact on operational commitments and ensuring continuing airworthiness.

Objectives: The objectives for the development of such a tool were to:

- a. optimise the limited resources available to support the CF-188 fleet while maximising operational availability;
- b. provide the fleet manager with a global view of the numerous programmes and provide the flexibility of effectively incorporating all current and future maintenance initiatives;
- c. provide optimised aircraft induction scenarios for optimal fleet usage and longevity;
- d. perform pro-active planning to prevent unforecasted expenditures and sharp reductions in operational readiness;
- e. provide visibility to priority tasks for appropriate allocation of resources; and
- f. provide the user with a powerful decision making tool to assess potential changes in usage, number of aircraft, budgets etc..

End Product: The end product is a system that integrates/links engineering needs and supporting databases to aircraft maintenance and planning activities. It provides a user interface to the structural information system databases that allows decision-making through "what-if" scenarios. This has been translated into a programme called "ALEX" which stands for Airframe Life EXTension Programme. It has been developed to be flexible enough to allow maximum operational readiness at minimum cost. A conceptual diagram of ALEX is depicted in Figure 4. The programme takes information from both structural and avionics needs, adds in the resources available at the contractor and the cost of using those resources to deliver an optimised schedule and cost breakdown.

Capabilities: ALEX is capable of developing essential and optimal modification packages tailored for each aircraft. It provides realistic induction sequences that best meet budgetary constraints and operational requirements. Furthermore, it gives the customer and the contractor an appreciation of the long term material and personnel requirements through planning and scheduling packages.

Initially a total of 90 items were considered under this programme, each with different access and threshold requirements. This number of items would have been impossible to manage given the Level of Effort (LOE) constraints and required timelines. Also, performing everything in the order established would have proven too costly.

Especially initially since several modifications had to be implemented in the next 3-4 years causing a huge unmanageable demand during these next few years.

A slight change to the approach needed to be taken. Each defect was individually reviewed by a Tiger Team that grouped defects by locations and similar thresholds. The process was further refined using the revised lifing policy for the CF and performing risk assessments on some locations. The result was the development of the control points concept. Basically, **3 control points** were selected around major modification packages. Each control point is based on the safe-life of these locations and hence if left unmodified the aircraft would no longer maintain its airworthiness status. Figure 5 illustrates the centre fuselage of the CF-188 with the definition of the control points and their associated threshold based on CF usage. As shown on figure 6, the majority of the modifications produced by ALEX are in the centre fuselage of the aircraft and generally speaking the highest cost for those modifications is access to the location. ALEX permits optimisation of modifications based on access.

This programme is an effective and powerful tool for the fleet manager. It will allow him to decide the best course of action for each and every aircraft of the fleet. The level of modification for each aircraft will depend on the number of previous modifications, the lot number of the particular aircraft and the number of long term aircraft required for operational readiness. Some aircraft will receive the modifications associated with Control Point 1 while other aircraft will receive those associated with control point 3. Some aircraft may require the full implementation of modifications depending on ELE requirements. This is only possible due to the maturity and rigour of the Structural Integrity Programme. The Individual Aircraft Tracking capability of the CF-188 makes this level of refinement a reality that has not previously been possible. Furthermore, each aircraft will receive just the right amount of work to ensure operational sustainment.

Figure 7 illustrates the fleet decline based on the 3 control points if the required modifications were not embodied. It is an example only of a selected number of aircraft in the fleet. ALEX allows the possibility to predict aircraft availability and level of effort per year until the fleet is retired. It caters

the induction schedule based on resources availability, aircraft usage and yearly flying rate. Figure 8 shows an example of a hypothetical ALEX run. The number of available aircraft has been modified to match with the resources available for each year.

The final decision

A business case is used to establish the best course of action. It seems the modification package will be the preferred option as it offers the most versatility. It allows to cater the level of effort for each aircraft and provides the most optimised solution. With selecting this option, it is possible that some aircraft receive a new centre barrel if it proves to be required to bring some aircraft to the required retirement date. Hence the decision will likely be option 4 using ALEX to guide the implementation of the different choices for each aircraft.

Conclusion

The Canadian Forces have been faced with difficult decisions with respect to maintaining a fleet of fighter aircraft well into the next century. The options ranged from replacing the whole fleet at a very high cost to performing various avionics and structural upgrades at a much reduced cost. The decision could not be made without appropriate information and the development of the right tools. The data was obtained through a well managed ASI programme, which has included a Full Scale Test and the development of a decision making system that allows to run changing scenarios. The main advantage of the tools developed provide the flexibility to cater the right level of upgrades to each individual aircraft hence optimising all the available resources.

Although the final decision has not been made, all the tools are in place to make a business case that will likely lead to the performance of an avionics update supplemented by a series of structural modifications.

¹ All cost numbers have been normalized to provide relative comparisons between the various options and do not necessarily represent actual costs.

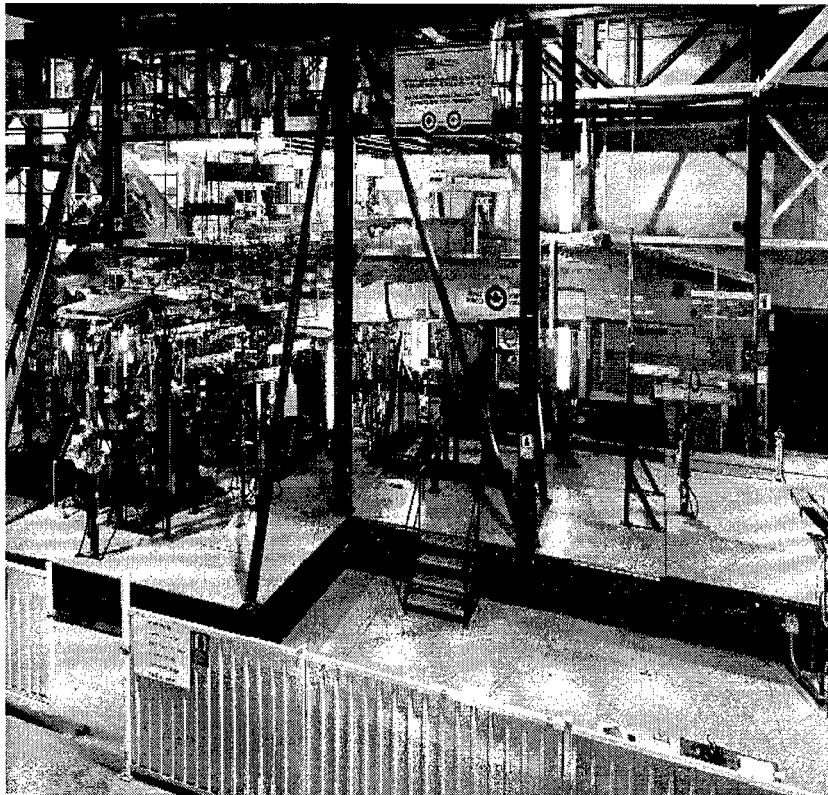


Figure 1 – IFOSTP Centre Fuselage Test Article
Bombardier Aerospace Defence Systems - Mirabel

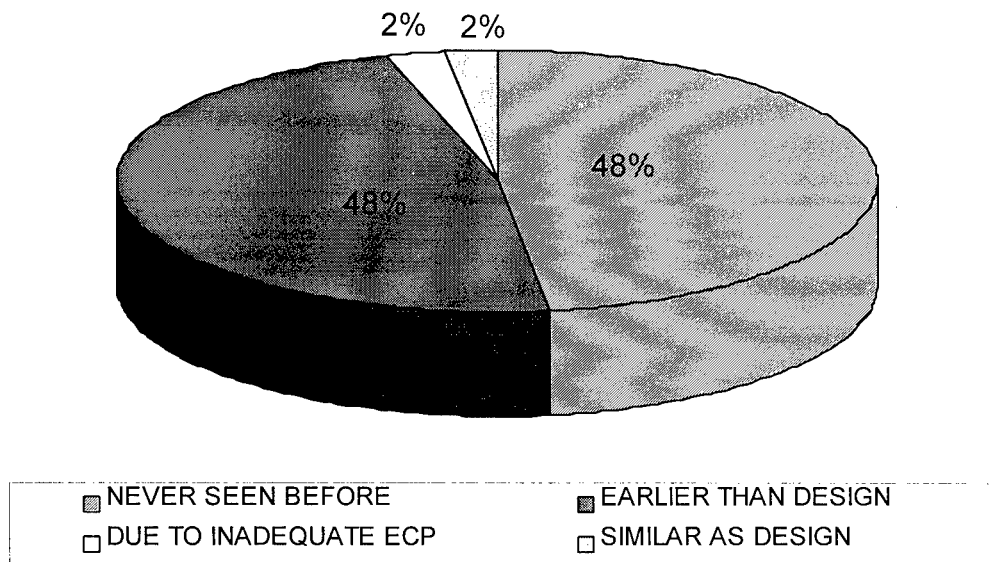


Figure 2 – IFOSTP Results Comparing to Known and Anticipated Failures

IN-SERVICE FAILURES
 PRIMARY STRUCTURES
 (235 FAILURES SINCE 1984)

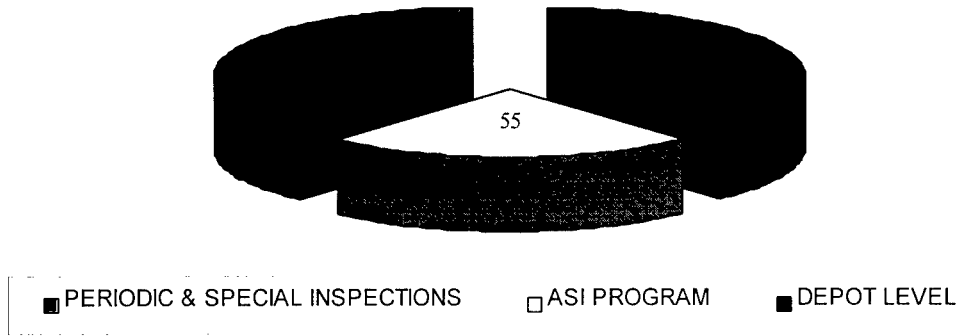


Figure 3 – Distribution of In-Service Failures

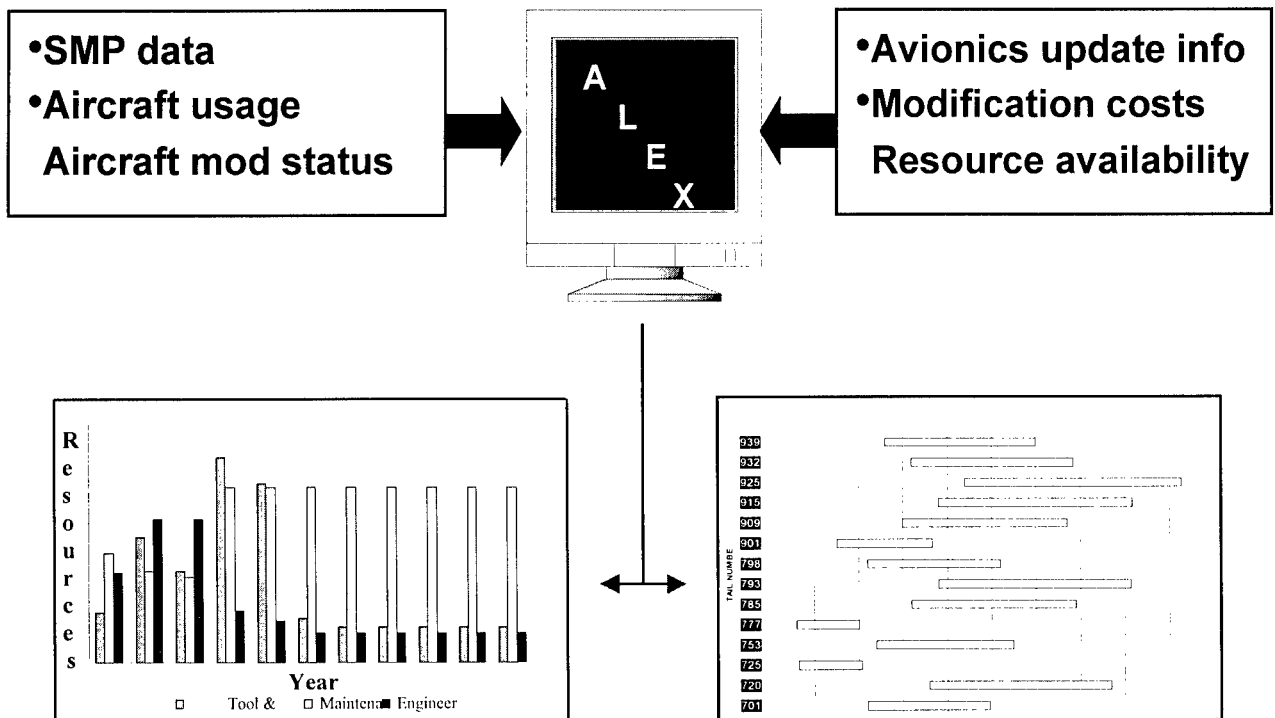


Figure 4 – ALEX - Modification Line Planning

**CP3 - Y453 Web
Taper (FLEI=0.74)**

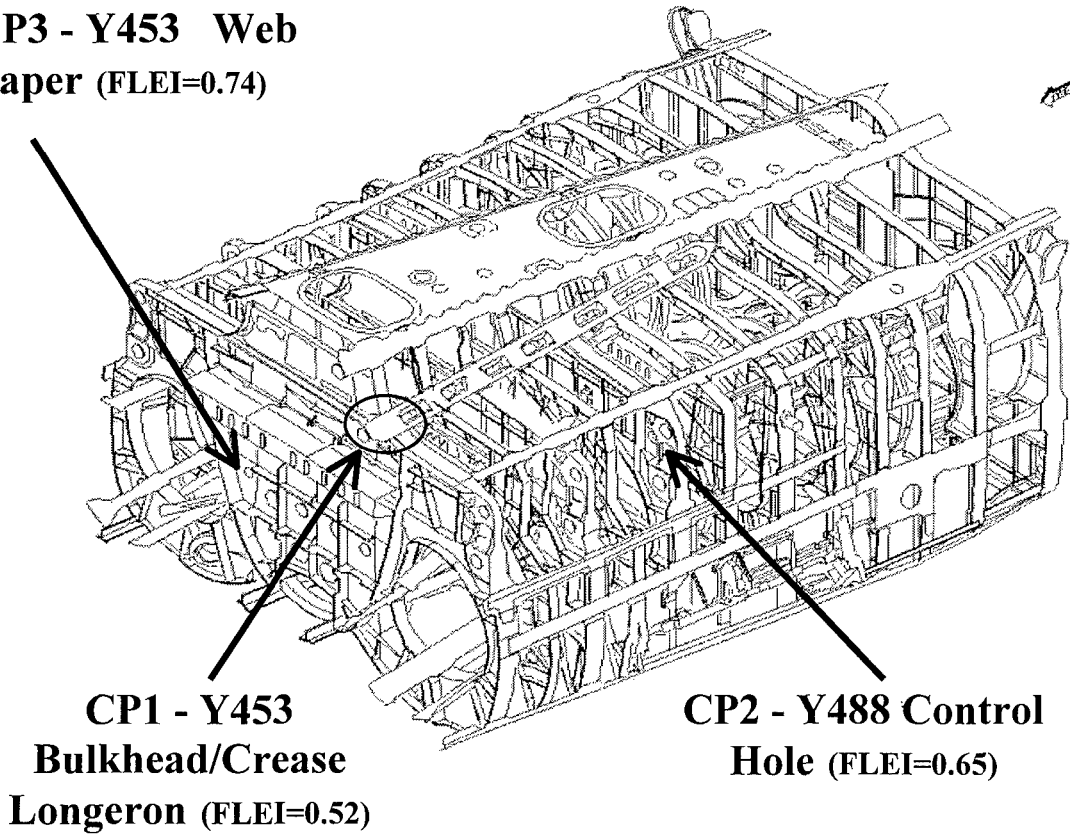


Figure 5- CF188 Centre Fuselage – Control Points Location

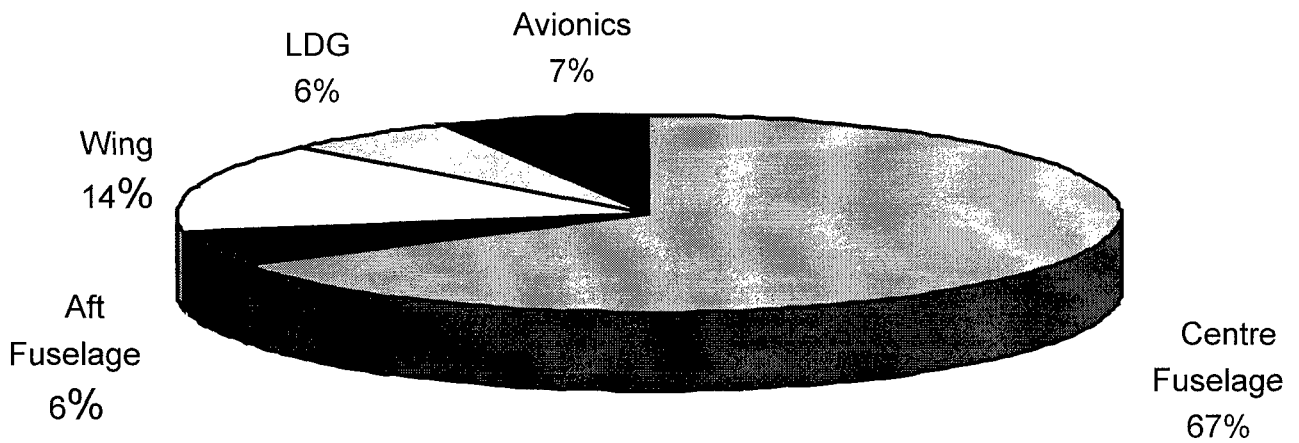


Figure 6 – Modifications Distribution

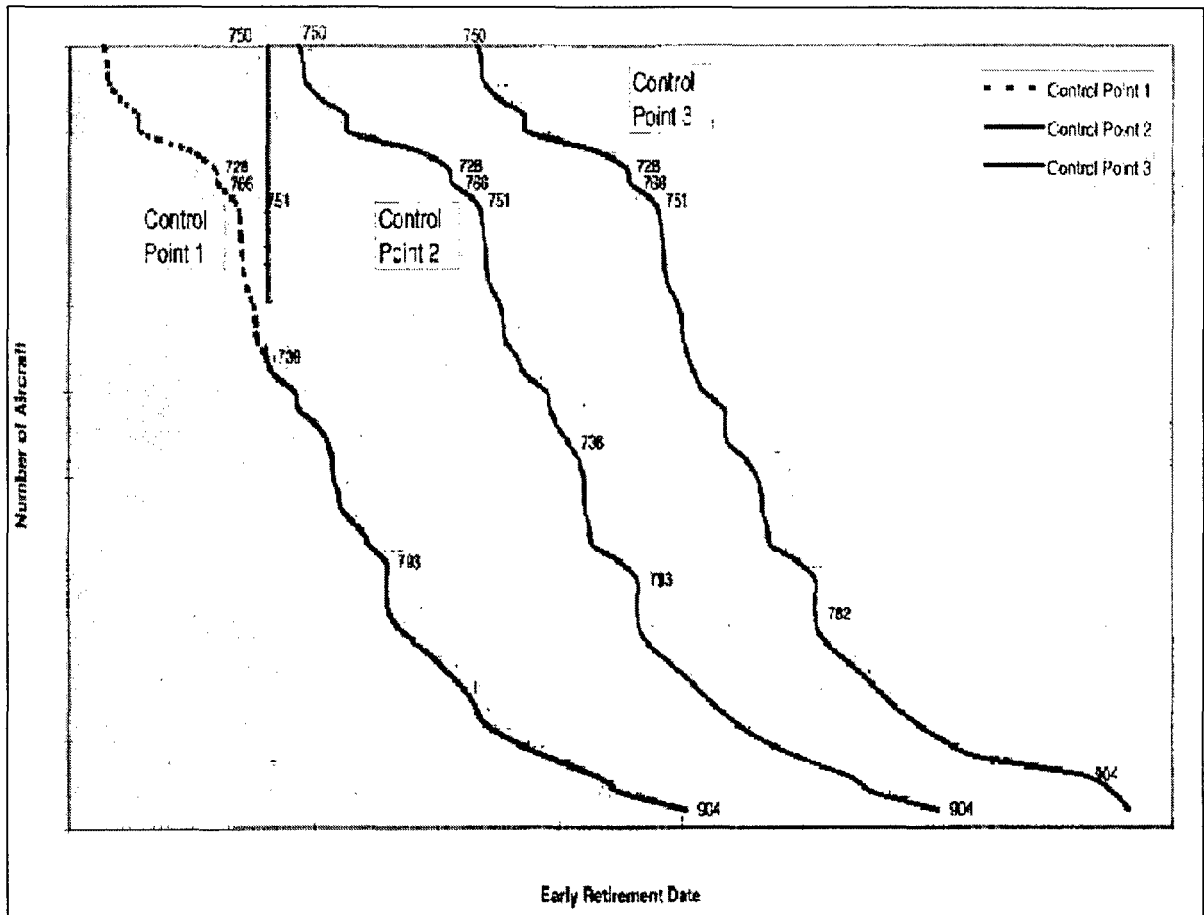


Figure 7 – Aircraft Retirement Dates Based on 3 Control Points

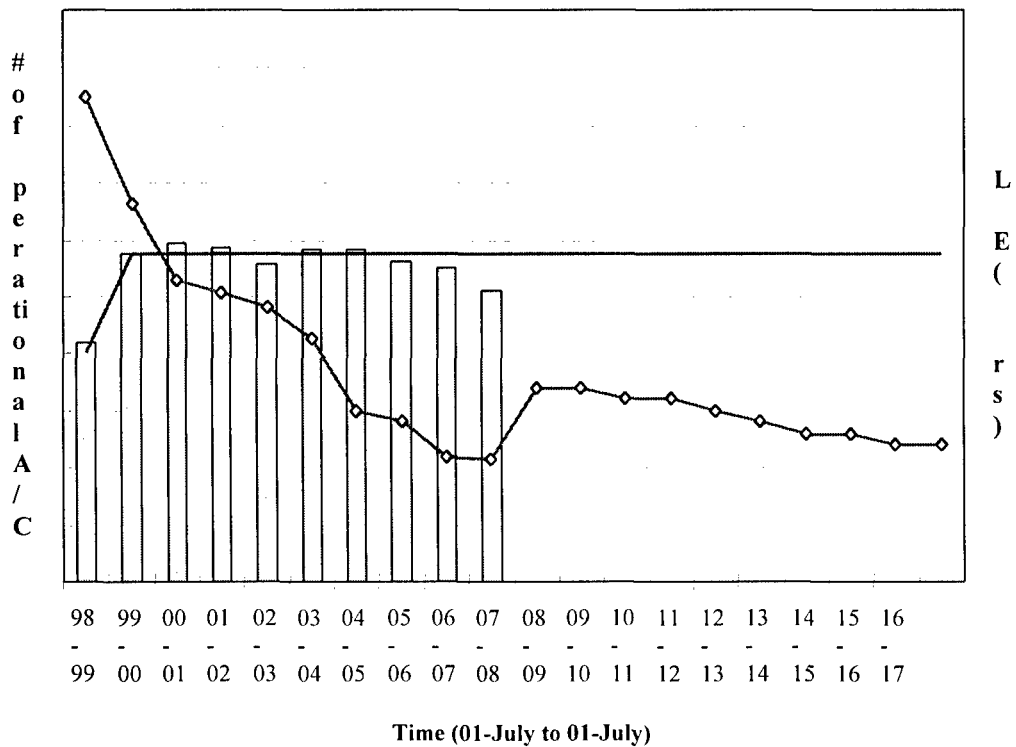


Figure 8 – Example of an Optimised ALEX run
Yearly LOE vs Operationally Available Aircraft