LIFE EXTENSION AND AIRWORTHINESS
We are all being asked to work longer before retirement – even military aircraft!

Ian Glazebrook and Mike Sleath, Safety Consultants, Atkins Defence

The Barbican, East Street, Farnham, Surrey, GU9 7TB

Abstract

The effective management of risk coupled with maintaining a platforms operational capability beyond that which was initially envisaged by the initial design intent, in the face of a changing financial, organisational, technological and regulatory environment is a difficult and challenging activity. There have been a number of military and civil procurement and modification programmes which have faltered as a result of these issues and factors, e.g. the Chinook MK3 which did not receive airworthiness certificates due to issues with the avionics software (which have now been addressed by MK4). This paper discusses some of the key factors, the associated risks and their relationship to each other which need to be considered for aircraft life extension programmes. This paper also discusses the implications associated with retrospective application of rules and standards.

The key factors and their associated risks in relation to aircraft life extension are common across all platforms and domains and pose specific challenges when changing an aircraft baseline. Risk is generally a well understood discipline and in its broadest terms is assessed through evaluating the probability and consequence of an event. Effective management of these factors and the risks is essential to ensure that a platform can return to service.

These areas which pose risk and which have a direct influence on the platform, for the purposes of this paper have been classified as being Influencing Factors (IF's). Although at first these would appear to be obvious, Atkins experience across a number of programmes and domains has indicated that they are often addressed separately and the inter relationships between the risks associated with each is not fully understood or managed. This can result in significant detrimental risk to the programme. Processes including the MOD Architecture Framework (MODAF) (Ref.7) provides a means to analyse the risks associated with capabilities, systems and business processes in accordance with the CADMID [1] lifecycle. However, this is more easily applied to new build programmes and is often not easily applicable to a life extension programme and the risks associated across all the disciplines.

The Procurement Lifecycle and Process

The lifecycle for most military platforms and systems is defined in the CADMID lifecycle. The requirement and issues associated with life extension, manifest themselves during the "in service" phase of CADMID lifecycle for a platform and or system. It is reasonably certain that all military platforms will be subject to change at some point during their "in-service" life due to the significant period of time that aircraft systems are required to operate. It is likely that operators and manufacturers will need to address issues during the "in service" phase of a platform which were not identified, considered or mitigated when the initial design and baseline were accepted and released into service. This coupled with the fact that aircraft rarely maintain currency with technological advancement means that life extension as a means of providing for technology insertion extending the life of a platform is common consideration. Life extension activities can be and are often initiated as a result of an event, such

[1] MoD UK procurement policy; Concept Assessment Development Manufacturing In-Service Disposal

as component obsolescence, which has a direct effect upon the operational, airworthiness, regulatory and or the safety aspects of the platform resulting in a requirement to modify or change the aircraft baseline.

Influencing Factors (IF's)

Extending the life of a platform is a complex and involved activity where disparate factors and risks need to be balanced, specifically in relation to those areas which contribute to the safety and assurance of the aircraft platform. The primary IF's can be broadly classified as being:

- (IF1) Understanding the operational requirements and imperative
- (IF2) Establishing and understanding the Functional Baseline
- (IF3) Implementing a suitable certification basis for the platform (including the life extension)
- (IF4) Satisfying, demonstrating and assuring compliance to a fixed point in an evolving Regulatory Framework
- (IF5) Airworthiness compliance and assurance (IF6) Establishing suitable organisation
- (IF7) Addressing safety aspects
- (IF8) Agreeing suitable contractual basis for the extension
- (IF9) Suitable commercial construct addressing IF1 through IF8 to be established

The relationship between each of the IF's is outlined in Appendix A, which provides a process map outlining the key considerations and relationship between the IF's. Although the process map implies staged activities, it is acknowledged that consideration of the different IF's generally occur as parallel activities. The process map includes two review points at which a critical examination of the proposed approach and solution should be undertaken, i.e. a "Go / No Go" decision point.

(IF1) Understanding the operational requirements and imperative

The user and operational requirements for aircraft platforms are dictated by the Front Line Commands (FLC's), the operators within them and the operational and statutory requirements from national and international governments and regulatory authorities. Each have specific requirements which need to be addressed and should ensure that:

- Operational requirements will satisfy the operator and user requirements
- The risk posed by the life extension programme to be managed and controlled and that the resultant modifications will have a positive operational impact
- Timescales and operational requirements are such that the modification can be addressed in line with the operational urgency
- There is demonstrable long term operational benefit

In addressing the above the main issue is always to manage the balance between continued operational capability and assuring the safety of the aircraft platform whilst addressing the operational requirement. Where life extension addresses a Safety (IF7) and / or Airworthiness (IF4) issue, the urgency and benefit can be readily apparent and easy to justify.

(IF2) Establishing and understanding the Functional Baseline

Before considering the viability of establishing and demonstrating adequacy in relation to the Functional Baseline questions including those relating to the long term operational requirement (IF1) post the life extension need to be considered during the initial feasibility assessment to determine whether life extension is a viable consideration. This should include ensuring that the original concept of the aircraft and its initial design intent can be maintained post and during the life extension and modification process to ensure that the operational requirement (IF1) is not adversely impacted.

In addition to considering the operational requirement (IF1), the viability of the proposed platform life extension from a technical feasibility perspective needs to be understood. Feasibility is influenced by the maturity of the current platform functional baseline and from an evaluation of the cost and benefit associated with extending the life of the platform. Although the life extension may not encompass all of the functional aspects of the existing baseline, the impact of the modification on the unchanged and changed systems needs to be understood, evaluated and

managed. Where life extension requires a significant change either to an existing baseline or impacts critical systems which interface to a number of other systems such as engines, safety related avionics, flight instrumentation, mission systems then the importance of understanding the risks associated with each IF becomes more important. Where the extension requires only minor or simple modification which can be bounded to specific standalone systems and subsystems with limited impact to other systems not affected such as fuselage or hull extensions, interior furnishings, additional fuel storage, additional (non-safety related) instruments or other electronic systems the risk is more easily managed.

(IF3) Implementing a suitable certification basis for the platform (including the life extension)

The establishment of a certification basis (IF3) for the platform and functional baseline (IF2) addressing the in service platform and the life extension programme is a key consideration and risk to be managed. This should provide the basis for the Contract (IF8) and should address:

- The level of systematic risk in relation to the new or modified systems to be managed and its impact on the current level of residual risk to be understood.
- The assurance requirements to be fully understood for the systems and the impact on the functional baseline (IF2) to be modified and or impacted by life extension
  Systems Assurance and the Certification Basis for System, Software, Complex and Non Complex Hardware and Data Quality assurance to be planned, agreed and contracted.

The Certification Basis should provide the basis for assurance in relation to the aircraft modification process and should establish minimum requirements in relation to the level of rigor required by the evidence required to support the aircraft life extension. This should encompass all new, modified elements, operational requirements, unmodified legacy systems and additional considerations which need to be addressed to enable release of the aircraft back into service post modification.

A significant number of life extension programmes have included the addition of new systems encompassing technology insertion, for example the introduction of glass cockpits and mission management systems in military helicopters. Issues, particularly those associated with software intensive systems, and a changing certification (IF3) including acceptance and assurance basis results in requirements and risks which are not always fully understood or mitigated at the point of contract, particularly when introducing systems developed to civil standards into a military platform. This, coupled with, and compounded by a changing regulatory and standards framework, has resulted in significant issues for a number of government programmes in both the military and non-military domains. It is widely acknowledged that lessons should be learnt from these programmes to ensure that suitable mitigating action and best practice can be introduced to future procurements to prevent a repeat of these issues. This can however be problematic as every project, programme and platform is different having different issues to address and different levels of maturity associated with the functional baselines (IF2), however understanding and agreeing (IF8) the certification basis (IF3) at the start of a programme is essential if the risk is to be effectively managed.

(IF4) Satisfying, demonstrating and assuring compliance to a fixed point in an evolving Regulatory Framework

Changing standards and regulations and an evolving regulatory framework means that the methods and processes associated with assurance and compliance will change at some point during the “in service” phase of the platform which will impact life extension. Standards in

theory should standardise, however this is often not the case and differences make compliance difficult and complicated. As previously intimated, the design concept for a platform may remain unchanged from the initial design intent and concept and therefore in theory the overall certification requirements should also remained un-changed. However this is rarely the case. By way of example, if a non-combat aircraft, and life extension programme and modification do not result in increased exposure to battle conditions, then there is a good case to say compliance with the initial Certification Specification (CS), namely CS-29 (Ref. 2) is unchanged and the modification will be acceptable as they follow the original design intent. If the original aircraft was a UK-sourced combat aircraft, it can probably be assumed that the original design should have been compliant with Defence Standard 00-970 (Ref. 1), and compliance of the changed platform should be a formality. However, the current UK defence strategy and policy of using civil systems wherever possible means that platforms often now include systems developed to a number of specifications and coupled with changes to standards and regulations over the last 15 to 20 years resulting difficulties and issues with read across.

(IF5) Airworthiness compliance and assurance

When considering the standards and or regulations (IF4) that need to be met in relation to ensuring the validity and stability of the pre and post life extension baseline, the impact and airworthiness risk posed by the changes to the functional (IF2), certification (IF3), and regulatory (IF4) baselines need to be fully understood and assessed. In addressing and ensuring airworthiness, it is important to consider what standards were initially applied to the platforms functional baseline (IF2) and those required for the life extension and modification (IF4). Almost certainly the same design and build standards that were applied to the original aircraft will remain for the modification, for example, an aircraft designed and built explicitly for the UK MOD should have complied with Defence Standard 00-970 (Ref.2) or one of its predecessors which has a history dating back to 1918. However as noted above this can be problematic as changes to the certification requirements (IF4) often result in a complex aircraft baseline (IF2 through IF4).

(IF6) Establishing suitable organisation

It is essential to implementing a suitable organisation to address the life extension to enable management of all the IF's risks, associated all disciplines, prior to contract award (IF8) resulting in risk principally to certification (IF3), regulatory compliance (IF4), airworthiness requirements (IF5). This is often difficult to achieve as it is common for organisations to address and be responsible for specific areas and or technologies of the life extension programme. There is often however no overarching assessment of the certification (IF3) and assurance issues associated with all the IF's, managing the risk associated with each, including the potential impact and escalation risks that one IF may have related to another. This problem is often compounded with the drive towards commercial systems and "multi-nation" procurement which results in reporting lines which are complicated as each nation addresses their own individual requirement which has a tendency to result in a complex i.e. poor contracting basis (IF8) for the life extension.

(IF7) Addressing safety aspects

As previously noted, the risks associated with the IF's and their impact on a platform may change over its lifetime as the platform remains within the "in service" phase for increasing periods of time. The requirement to assure safety and governance however remains a constant throughout all stages of the platforms life. Demonstrating safety assurance, and satisfaction of the safety requirements and assuring continued safety management is a fundamental aspect of the platform and life extension programme. It is often the case that when an aircraft is modified from its initial airworthiness (IF5) and functional (IF2) baseline, governance and issues relating to the level and adequacy of safety assurance evidence for the systems change and obtaining additional assurance and demonstrating and assuring safety becomes difficult and complex to realise. This can be as a result of an evolving certification (IF3) and regulatory compliance framework (IF4). To elaborate:

- Defence Standard 00-970 (Ref.1) has evolved iteratively whereby the 10 sections have been up-dated and issued separately with six sections being re-issued in 2007.

The other six sections have been re-issued in 2010; however its size and complexity makes it quite difficult for the authors to keep up to date, for errors to be noticed and corrected, and for users to keep track of its issue status.

- CS-29 (Ref.2) has not evolved significantly in its short existence; its simplicity appears to make it more stable or unnecessary to change.
- Military Standard 882 (Ref.4) and Defence Standard 00-56 (Ref.3) have changed significantly in approach over the past decade, principally in relation to the adoption of goal based standards and assurance. This has often made it difficult to enable an agreed baseline to be established and modified. Alternatively, the civil aerospace industry has a mature set of specifications which are not modified, however they are supported by guidance and advisories supporting application.

A common approach for large scale life extension and modification is often through progressive modification. This provides for "staged" functional maturity to be introduced over time, whereby a system is progressively modified providing capability (limited) during multiple phased modifications, thereby in theory reducing some of the risk associated with large scale "monolithic" modification.

Demonstrating the safety of a platform and realising sufficient safety assurance evidence requires the effective management of risks and the control of issues which could pose risk to the platform. Assessing and managing the risks should address the associated mitigation strategies required to prevent undue programme impact and management of risk to operational (IF1), functional (IF2), certification (IF3), regulatory (IF4) and airworthiness requirements (IF5).

As noted above there is a relationship between all the IF's which is particularly involved when considering the risks associated with the platform design requirements for airworthiness (IF4) and the system safety requirements (IF7). Standard best practice as an over-riding principle for aircraft platforms is compliance to in CS-29 (& CS-25) (Ref.2 and Ref. 6) which requires that "there shall be no catastrophic failure condition caused by a single point of failure (SPOF) that is not extremely improbable". This requirement has implications on the life extension programme when considering modification particularly in relation to a major modification to an aircraft baseline (IF2) as the principle needs to be satisfied for the unchanged and changing elements of the modification. There are various potential design options available to address this principle for most occurrences, namely:

- Simple (dual) redundancy in aircraft and ships – e.g. engines
- Diverse redundancy – e.g. fuel gauges & low level sensors, cockpit software based primary & secondary flight displays

This issue becomes more problematic when dealing with systems and hazards that cannot be controlled by redundancy alone e.g. helicopter transmission whereby if the main rotor stops, or is put out of balance through loss of a single blade, the helicopter cannot be controlled resulting in a potential catastrophic failure condition. Here the mitigation is robust build and inspection techniques (including Health and Usage Monitoring Systems (HUMS) and chip detects) and cautious application of "lifing".

(IF8) Agreeing suitable contractual basis for the extension

The key technical requirements must be the establishment and realisation of a suitable assurance programme for the life extension programme accounting for the required level of technical redundancy and / or diversity required to assure platform safety (IF7). Once this has been established a suitable contracting basis can be agreed by all parties addressing the requirements (IF1 through IF7) in a suitable, cost-effective manner which is agreed by both parties. In the absence of a clearly defined operational (IF1), functional (IF2) and certification (IF3) basis for the life extension it is often not possible to adequately bound a contract to equally protect both parties and there is a risk either party may not adequately address all the risks associated with the life extension and IF's. Contracting against a coherent and agreed operational (IF1), functional (IF2), certification (IF3), regulatory (IF4) ensuring platform airworthiness (IF5) and safety (IF7) will enable appropriate assessment of the level of incentive and penalty required by the contract to provide sufficient protection to both parties. This will also enable the effective management of

performance in relation to contractual compliance and management of the IF risks.

(IF9) Suitable commercial construct addressing IF1 through IF8 to be established

As previously noted with the advent of an evolving (IF1) Operational, (IF2) Functional, (IF3) Certification, and (IF4) Regulatory basis for platforms, life extension is rarely a cheap option when considering the risks from the IF's and the requirement to understand the inter relationship between them. Contracting needs to address and ensure that the contractual requirements are suitable, and the life extension is commercially viable cost-effective, and agreed by both parties of the contract and that sufficient commercial cover is provided.

Conclusions and recommendations for the future

Contracting organisations and authorities need to ensure that so far as possible all of the key risks associated with the IF's (IF1 through IF9), their relationship and escalation impacts are understood before contract award and that there are suitable strategies in place to mitigate known and emergent risks posed by each during the life extension programme.

Prior to any modification to an aircraft baseline an Integrated Baseline Review (IBR) should be undertaken which (IF2) provides an evaluation of the benefit (IF1) in conjunction with the risks posed by the life extension to IF2 through IF9, specifically focussing on those areas impacted by the modification. This will need to consider the certification strategy (IF3) in relation to assuring the coherence of the existing functional baseline (IF2) including the life extension elements (IF1) and addressing how this will be achieved for the new post modification aircraft platform (IF3 through IF9).

Key considerations should be:

- Understanding the risks associated with the IF's with particular regard to those which pose a potential safety impact (IF7) to the functional baseline (IF2) should be managed to ensure wherever possible that potential errors and or omissions including the probability and impact of assurance deficits are identified before they impact the programme impact and management of risk to operational (IF1), functional (IF2), certification (IF3), regulatory (IF4) and airworthiness requirements (IF5).A suitable organisation (IF6) which is adequately resourced by qualified resources, underpinned by competency criteria sufficient to address the certification (F3), technical risks (IF7) and technically challenging aspects of the life extension should be established at the start of the life extension programme.
- Prior to a contract (IF8) being let an Acceptable Means of Compliance (AMC) and certification (IF3) and safety strategy (IF7) should be agreed between all parties and should be used as basis for the contract.
- The effective management and control of the aircraft baseline (IF2) should occur at all stages of the life extension. This should include the active management and control of risks and issues associated with the established and modifying aircraft baselines and a process implemented and agreed prior to contract award.
- Established, proactive supplier management and governance of supplier technical, contractual (IF8) and financial management should be a key requirement for all future contracts.
- Contracting organisations should introduce an effective process for managing change with particular regard to managing and controlling aircraft and airworthiness assurance (IF5) and managing the associated risks.
- Understanding systematic and assurance risk in relation to certification (IF7) and monitor it throughout the life extension programme.
- Let contracts (IF8) which have incentive and penalty clauses in accordance with the level of assurance risk, whilst having a suitable commercial basis (IF9) having sufficient protection under law and which are risk based and proactively monitored.

Abbreviations

AMC	Acceptable Means of Compliance
AP	Aircraft Publication

CADMID	Concept, Assessment, Development, Manufacturing, In-service, Disposal
CS	Certification Specification
FAR	Federal Airworthiness Requirements
HUMS	Health and Usage Monitoring Systems
IBR	Integrated Baseline Review
IF	Influencing Factors
MOD	Ministry of Defence
MODAF	MOD Architecture Framework
UOR	Urgent Operational Requirement

References

1. Defence Standard 00-970 Part 7, Design and Airworthiness Requirements for Service Aircraft – Rotorcraft (10 sections, at different issue states between 2007 and 2010)

2. European Aviation Safety Agency CS-29, Certification Specifications for Large Rotorcraft, Amendment 2, November 2008

3. UK Ministry of Defence, Interim Defence Standard 00-56 Part 1, Safety Management Requirements for Defence Systems, Issue 5, 29 January 2014

4. US Department of Defence, Mil-Std-882E, Standard Practice for System Safety, May 2012

5. UK Ministry of Defence, Defence Standard 00-55 Part 1, Requirements for Safety of Programmable Elements (PE) in Defence Systems, Draft Issue 3

6. European Aviation Safety Agency CS-25, Certification Specifications for Large Aeroplanes, Amendment 3, September 2007

7. https://www.gov.uk/mod-architecture-framework

Appendix A, Influencing Factors (IF's) - Risk Management Process