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Decision Support Framework for Military Aircraft Fleet Retirement Decisions

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Aircraft fleet managers lack tools to aid decision-making for fleets nearing retirement, which leads to rushed and ill-informed decisions. Accordingly, aging aircraft fleets are underutilized and fleets can be retired before their useful lifetime has been expended. A decision support framework is proposed to solve the aging military aircraft retirement problem. It integrates four steps for fleet managers to simplify the decision-making process: (i) Understanding the structural toll caused by utilization, (ii) Recognizing the indicators that predispose a fleet for retirement, (iii) Determining an optimal fleet size and choosing which aircraft to retire and (iv) Optimizing end-of-life usage prior to retirement. An example using a sample military fleet is used to illustrate the effectiveness of the decision support framework, integrating both computational results and manager judgement. Fleet managers were used to validate the concepts in the framework and their opinions are presented herein. It is shown that fleet managers can utilize a decision support framework to positively impact their decision-making for full-spectrum aging aircraft retirement decisions.

I. Introduction

Computerized decision support tools are necessary because of the complexity of managing a fleet of aircraft. The high number of alternatives for fleet managers and the high cost of making the wrong choice both complicate the process. Decision support is traditionally necessary when one of four conditions is met for the problem: large databases, necessity for a computational strategy, time pressure or expert judgement is required [1]. When addressing a fleet of aircraft that could reach into the hundreds with a yearly operational budget in the tens of millions (USD), all four conditions are met. Aircraft usage and management data are catalogued in dozens of independent database systems no one manager could fully understand. Determining which aircraft to retire quickly becomes a problem requiring a computer-based computational strategy. Clearly in a military aviation application, there is great time pressure to solve the problem but solving quantitatively without a qualitative element cannot satisfy all stakeholders. Expert judgement must be a key element in the analysis of alternatives. For these four reasons, a decision support framework is required.

Decision support frameworks (DSF), decision support tools (DST) and decision support systems (DSS) are sometimes defined interchangeably but do have subtle differences [1-3]. Decision support systems may encompass multiple DST and the DSF provides the structure for either a DST or DSS. We choose to follow Keen and Scott-Morton's definition of DSF, "Decision support frameworks couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions" [4].

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Turban’s landmark work in decision support lists four hallmarks that can be adapted to describe a DSF [5]:

1. They include both data and models
2. They assist managers for semi-structured tasks
3. They support, not replace, managerial judgement
4. A DSF improves effectiveness of decisions

A DSF can be used for tactical as well as strategic decisions, which makes it the ideal architecture for aiding commanders, fleet managers and top military leaders. This work will focus on providing fleet managers with a robust DSF. Applying Mintzberg’s landmark work on the classification of managerial roles reveals the depth of responsibility placed on a fleet manager [6, 7]. Mintzberg’s ten management roles are shown in Table 1, grouped by their types and each with its application to fleet management outlined. It is in this context that we can understand the breadth of authority of a fleet manager to guide the future of a fleet and the necessity for a DSF.

Table 1 Mintzberg’s management roles applied to fleet managers

Type	Management Role	Fleet Manager Application
Interpersonal	Figurehead	Identified as the symbolic leader of the fleet.
	Leader	Maintains organization of employees tasked with managing the fleet.
	Liaison	Liaises with other fleet managers and interprets intent of Major Command and Headquarters decisions.
Informational	Monitor	Evaluates aircraft data and fleet statistics to determine health of the fleet.
	Disseminator	Conveys messages from Major Command and Headquarters. Works to ensure organization is informed.
	Spokesperson	Speaks for the organization in peacetime, during mishaps and during wartime.
Decisional	Entrepreneur	Cultivates improvements to the fleet’s operations and maintenance activities.
	Disturbance Handler	Manages grounding events, budgetary fluctuations and retirement planning.
	Resource Allocator	Receives manpower and budget from Major Command and works to equitably distribute resources within the organization.
	Negotiator	Compromises with interested parties to ensure fleet viability within resource constraints.

The strategic planning and long-term forecasting involved in fleet management decisions means that they can demand multiple management roles [4, 8]. Fleet decisions blend knowns with unknowns, requiring both data and judgement by the manager. Managers must have mastery of all three of Mintzberg’s types: Interpersonal, Informational and Decisional.

In the United States Air Force (USAF), fleet managers possess a variety of backgrounds that may or may not include extensive experience with decisional types of managerial roles or complex decision support tools. Fleet managers therefore must rely on their surrounding incumbent expertise and the tools available to them. This research’s goal was to provide fleet managers with a comprehensive framework for making military aircraft fleet retirement decisions.

Decision support framework (DSF) is a generic term, similar to decision support tools (DST) and decision support systems (DSS) used to describe computerized systems that aid an organization with decision-making [9]. For this work, DSF will be the term employed to describe the combination of analytical models and best practices. Fleet managers already use DSFs for a multitude of tasks that include depot planning and structural integrity monitoring, for example. However, the aperiodicity of major fleet retirements has left a DSF gap for fleet managers planning fleet retirements.

The focus of this paper is technical decision-making for aging military aircraft retirement decisions. The objective of this paper is to provide a decision support framework to fleet managers that synergizes computer tools along with managerial opinion to aid decision-making. This work is the first known DSF for aging military aircraft and reduces the problem complexity in a novel way by emphasizing the fleet manager's experience to reduce uncertainty.

The remainder of this paper is divided into six sections. The Literature Review summarizes current research in the DSF field. Then the Elements of the DSF section presents the DSF both graphically and with explanatory text. Next, the Applying the DSF section addresses military aircraft specifics, the role of expert judgement and implementing the DSF. The Discussion section posits a method to evaluate the value of the DSF and uses an example for fleet managers to use to better understand how to apply the DSF. Finally, the Conclusions section summarizes the research and includes areas for future research.

II. Literature Review

Sorensen and Bochtis resolved that an effective fleet management system can aggregate disparate data and documentation for a manager [10]. Their work focused on agricultural equipment resource allocation where each asset's location and assigned tasks could be optimized. They found that the agricultural community desired a fleet management framework so their proposed conceptual framework filled a gap.

Andersson and Varbrand built decision support tools for ambulance relocation and dispatching to increase readiness inside an area of responsibility [11]. This role is analogous to military aircraft fleet management's role of ensuring the fleet is available to meet peacetime and wartime demands in similarly conceptualized areas of responsibility. Their work found that an integrated framework for managers could increase preparedness.

Decision support frameworks must combine data-driven analysis with expert opinion. As Fagerholt concluded in his work on the DSS named TurboRouter, the optimization backbone of a problem is perhaps less important than the user and system under development [3]. Military fleet planning's focus is often on the exact solution instead of being focused on finding a feasible solution that satisfies stakeholder desires. Fagerholt's work with sea-based shipping vessels uncovered the need to convert the industry's decision support systems from a paper-based approach to one that capitalizes on computer technology. Similarly, military aircraft decision support systems have lagged behind the ground transport and airline industries.

The United States Coast Guard approached its cutter scheduling with a decision support system [12]. Darby-Dowman et al found not only usefulness for the day-to-day scheduling of assets with their model but they also found incredible value in the investigative capabilities of the tool. Their decision support framework could be used to detect problems in the future utilization plan.

Abdelghany et al built a decision support tool for airline disruption operations that could be employed by an airline's operations control center [13]. Their work synergized a simulation model with optimization models to resolve hard problems.

The team of Vaidya and Rausand tackled the issue of decision-making for life extension versus retirement for undersea oil and gas systems [14]. They emphasized the multi-disciplinary nature of their problem, concluding that technical data, computational results and manager opinion together could yield a satisfactory solution. Their model found that service life estimates for undersea equipment were too conservative – similar to military aircraft service life forecasts – which is a driving force behind needing a DSF that can determine the effects of retaining aging capital equipment.

Couillard developed a decision support system for vehicle fleet planning, tackling the problems of adjusting fleet size and assigning assets to operations [15].

III. Elements of the Decision Support Framework

The four elements of the DSF include (i) Understanding the structural toll caused by utilization, (ii) Recognizing the indicators that predispose a fleet for retirement, (iii) Determining an optimal fleet size and choosing which aircraft to retire and (iv) Optimizing end-of-life usage prior to retirement. These four actors are presented in the following subsections, including their tie-in to the overall framework.

The DSF must be capable of taking the fleet manager from understanding the status of the fleet using a fleet health snapshot to a place where decisions can be made about the future of the fleet. The approach to understand the current fleet capability is prescribed in Fig 1.

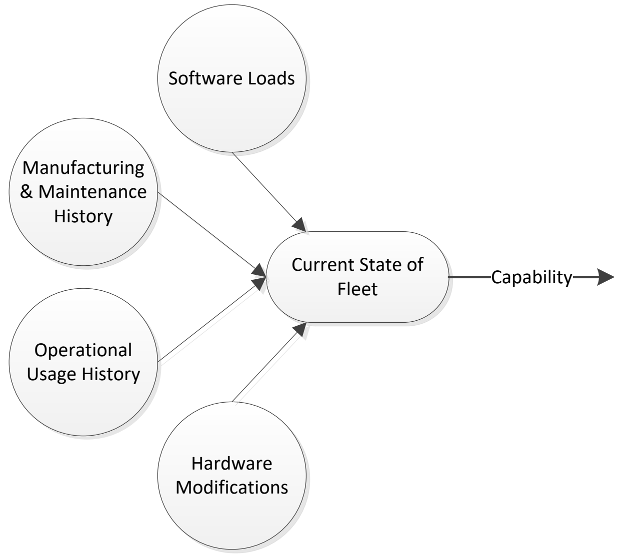

Fig. 1. Factors contributing to the fleet health snapshot.

Software loads, manufacturing and maintenance history as well as hardware modifications are well documented knowns. However, the operational usage history's impact on the current state of the fleet is a rather large unknown because individual aircraft tracking data and the particular physics behind aircraft structural degradation are complex. Hence, this DSF emphasizes only one numerical input from Fig 1, the operational usage history. Expert opinion is critical for the remaining inputs.

Focusing on how the DSF fits together to help decision-makers, Fig. 2 shows a start-to-finish flow. On the left, a fleet manager initiates a fleet evaluation. Fleet data, network data and demand data allow the four main DSF elements to proceed (numbered). Element one is represented in the "Fleet Data" process block. Element two is represented by the sub-process blocks labelled "External Influences" and "Internal Influences." Element three is represented by those process and data blocks that utilize the Fleet and Aircraft Retirement Model (FARM) software. Element four is represented by the process and data blocks that utilize the Retirement Optimization Tool for Aircraft Transfers and Employment (ROTATE) software.

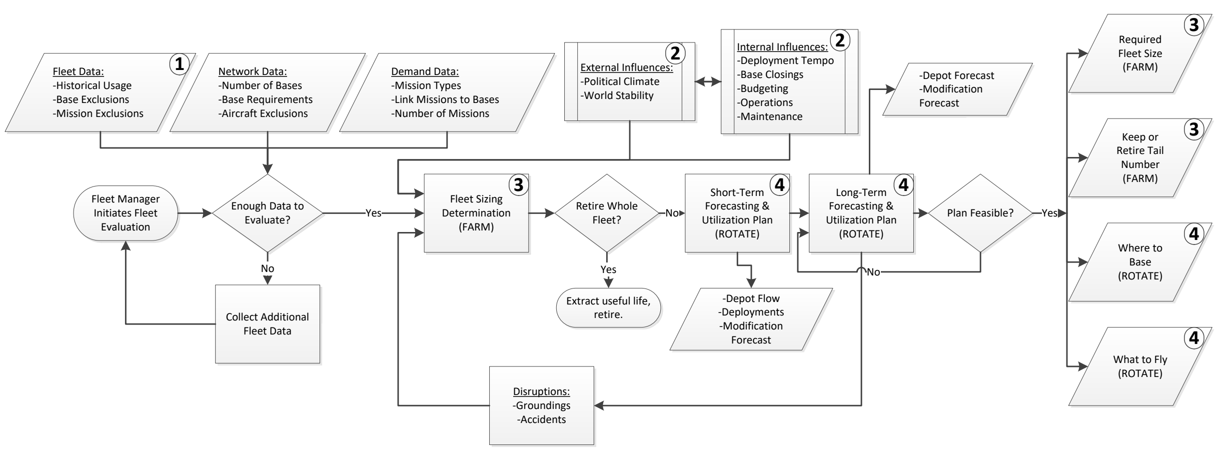

Fig. 2. Military aircraft retirement DSF.

A. Understanding the structural toll caused by utilization

This phase of the DSF is a preliminary step for decision-makers because its purpose is to inform the starting point for the determination of retirement eligibility. Absent a budgetary or capability-deficit requirement for retirement, accumulated usage drives fatigue-based or corrosion-based retirement. Fleet managers must recognize the amount of expended lifetime in their fleet to make important decisions, which is addressed thoroughly by Newcamp et al [16]. If the data are insufficient with which to make structural health decisions, a fleet manager would need to find a workaround. This represents the informational type of management where a manager must absorb structures data to determine health impact. Fleets already possess many tools to report on the structural health of a fleet. Most are specific to individual aircraft, leaving a fleet manager to aggregate information at the fleet level. It is this link, being able to interpret the trends in each asset at the system level, that requires the second element of the DSF.

B. Recognizing the indicators that predispose a fleet for retirement

Individual aircraft are now tracked closely in air forces across the globe but what hints can be seen in the fleet that should warn fleet managers about waning fleet health? Newcamp et al found a series of aging aircraft milestones that predispose a fleet for retirement consideration [17]. The co-mingling of fleet utility and fleet cost can be an early indicator of degrading fleet health. Here fleet managers must maintain an informational type approach to management because fleet health indicators are an input of the information-gathering process. Managers must marry the structural degradation information gained in the first element of the DSF with the fleet-indicators from this element to form a full-spectrum view of their fleet.

C. Determining an optimal fleet size and choosing which aircraft to retire

Optimal fleet size is not solely dependent on fleet health – rather, fleet size is a product of available budget and required capability [18]. Choosing which aircraft to maintain in a fleet is a product of past usage, which is an output of the first DSF element. This element outputs the number of aircraft that should be retired to remain within budget and capability. This element also outputs which aircraft, giving actual tail numbers, that should be divested based on past usage and performance [19]. It is important to account for the future unknowns for the fleet. This DSF element in no way encourages fleet sizing based on current utilization, rather, the basis should be maximum expected utilization plus a wartime reserve buffer. The risk of retiring too much of the fleet when it might be needed in the future can outweigh the cost of maintaining spare capability. With this element of the DSF, a fleet manager can imagine his ideal fleet and then work to achieve that state. Now a fleet manager can understand how many aircraft and which aircraft can be retired. If the economic determination to retire the whole fleet is made, the DSF then instructs fleet managers to extract any residual value from the fleet. This element can be the conclusion of the DSF if a fleet manager is unwilling to invest additional resources to optimize the remaining fleet's usage. Fleet managers deal with the composition of their fleet in this element using Mintzberg's decisional leadership types.

D. Optimizing end-of-life usage prior to retirement

This element of the DSF describes how a fleet manager can use the knowledge he has gained through the other elements of the DSF to create fleet savings through optimizing usage. Knowing the aircraft that are pending retirement from the third element gives fleet managers the opportunity to utilize those aircraft in a way to preserve useful life for the remaining fleet. Fleet managers exercise both the decisional and informational leadership types in this DSF element, requiring judgements as well as actions to gain buy-in from stakeholders. Outputs from this element include a basing strategy and utilization plan [20]. Aircraft can be allocated to operational locations with consideration of usage history and expected future utilization rates. The aircraft most vulnerable to structural failures can be assigned to low-impact mission types at low-usage bases, information derived from the first DSF element. This element of the DSF is where a disruptions feedback loop is shown in Fig. 2 because no retirement plan is without problems.

Expert judgement is applied throughout the DSF, but it is particularly essential at the feasibility decision diamond. A feedback loop allows the expert judgement to impact the long-term plan, which is necessary to arrive at a feasible and desired solution.

The decision-maker can expect the DSF to provide both a starting place and structure during the decision-making process. The inputs directly influence the outputs and also the quality of the inputs are important to the DSF. Several generalizable, sensible tenets should be noted. First, some fleets are incapable of meeting threshold requirements set by the fleet manager. In these cases, the only solutions are to acquire new aircraft or to transfer some fleet requirements to another fleet. The second generalizable tenet is that when faced with a retirement scenario, the aircraft with the lowest residual value as measured by the fleet manager must be the first aircraft to be retired. Rare exceptions include aircraft with special mission equipment.

IV. Applying the Decision Support Framework

A. Applying a DSF to Military Aircraft

DSF are not immune to faults like group member biases or conflicting interests, but military aircraft present some peculiar challenges. Military assets exhibit long forecast horizons because they are designed, built and flown over spans of decades. Because of this a DSF is even more useful but for the same reason, a DSF has fewer chances to refine iteratively and is thus a less precise tool. A second peculiarity with DSF for military applications is that military conflicts trump standard business practices. While equipment replacement policy may seem germane in a corporate environment, the military may make economically irrational choices in the name of national defense.

The military fleet decision structure is illustrated in Fig. 3, an adaptation of the work of Aronson, Liang and Turban [8]. The decision environment is contained in the outer ring of the figure. This is where national defense posture impacts the decision process – as well as the other external influencers. Inside the decision system boundary, it is clear that the inputs, processes and outputs yield a very complex problem formulation for the decision-maker. A DSF for military aircraft is essential due to this complex decision structure.

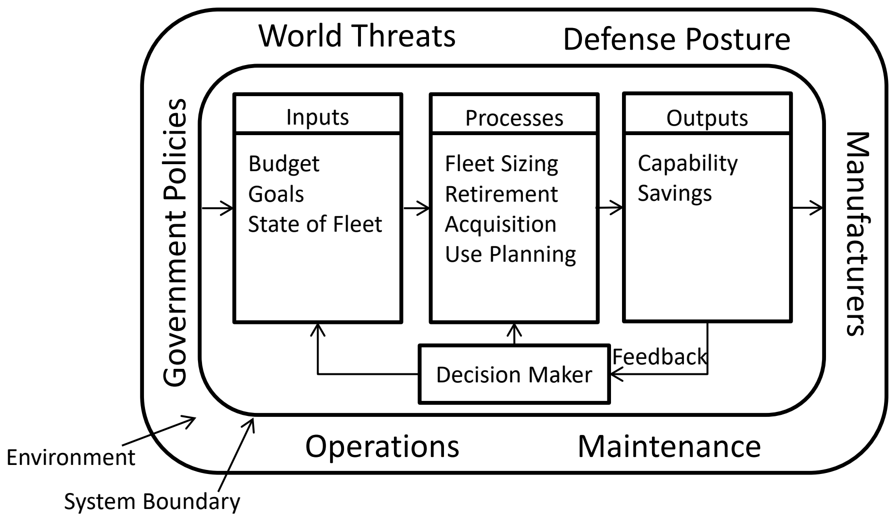

Fig. 3. Structure of the military fleet decision.

Military aircraft fleet retirement decisions are non-programmed problems conducted in a semi-structured environment. The decisions do not recur and each is a new occurrence, but they occur in an environment that has some rigid elements such as timelines and budgets and some judgemental aspects [1]. The fleet manager is the problem owner, but there are a multitude of stakeholders and higher authorities. Complicating facets of military fleets are that no standing, published heuristics or frameworks exist that are specific to military fleets. Further, refinement of a DSF is difficult since the ability for trial and error is limited.

Given the inherent complexity of retirement decisions, it is vital to reduce the number of decision variables to only those that impact the decision process. The Air Force's Fleet Viability Board valuated fleets based on 74 metrics but found approximately six of those metrics to be important resulting from a principal component analysis. The team dramatically reduced the complexity of their problem by reducing their decision variables. The decision variables chosen for each fleet should be unique to that fleet's peculiarities [21].

A DSF for aircraft retirements must be supported by human judgement as well as computer-based optimization. The previous work for this project has focused on the optimization component whereas this effort synthesizes the computer models and provides a framework approach.

B. Role of Expert Judgement

Expert judgement must be combined with quantitative assessment for DSF success. Requiring a formal, defined process ensures that expert judgement can be more dependable in the decision-making environment [22]. While the formalization of expert judgement is unique to each problem, some generalizable rules persist. Expert judgement must originate from qualified sources possessing relevant backgrounds. For aircraft retirements, fleet managers can delegate judgement to the appropriate managerial level. Structural health questions should be answered by an aircraft structural integrity program manager while budget questions should be answered by a budget analyst, for example. Fleet managers must determine how many experts should be involved in the DSF – too many stakeholders risks an inability to reach consensus while too few or the wrong experts risks making an ill-informed decision [23].

Expert judgement suffers from conflicting stakeholder inputs therefore DSF outputs are subject to stakeholder priorities. Fleet managers must adopt a process to evaluate and weigh stakeholder inputs. Analytic hierarchy process (AHP) is just one recommended option for what should be a problem-specific choice [24, 25]. Fleet managers may recognize the financial analyst as holding the greatest weight for stakeholder input, but it is still valuable to assemble alternatives not constrained by budget for purposes of discussion and analysis.

C. Implementing the DSF

Promulgation of a DSF in an immensely large organization such as the USAF is a particular challenge. Though the USAF follows a hierarchical structure, disseminating a new vision for fleet decisions is a near impossible task. Instead of a vertical integration, a horizontal integration is proposed. Fleet managers and Aerospace Vehicle Distribution Officers (AVDO) meet yearly to discuss retirement planning. This group is led by a chief AVDO who is the focal point for a potential DSF implementation. This is the most sensible avenue toward institutionalization. The challenge of infrequent retirements means there must remain a cadre of DSF proponents within the organization to voice support for the continued evolution and use of the DSF [26]. The implementation strategy should follow an evolutionary approach, where feedback from each retirement is implemented in the DSF. The disadvantage to this approach is that the users must deal with continuous change.

Little's work on managerial models emphasizes the need for a model to be "simple, robust, easy to control, adaptive, as complete as possible, and easy to communicate with" [27]. There exist several major challenges for DSF implementation within the USAF, both technical factors and behavioral factors. For institutionalization to take hold, the DSF must not require special software. It must be freely accessible to all parties with no confidentiality concerns. The DSF also must have a low level of complexity – it must be a framework anyone can pick up and understand. Lastly on the technical side, the DSF must be flexible enough to adapt to multiple fleet types or military services.

The primary behavioral factor of concern with DSF implementation is resistance to change, especially within the civilian employee population. Employees and managers will be unwilling to change their paradigm from the ad-hoc approach to aircraft retirements to a structured system. The second behavioral factor is the slow organizational climate in the USAF. While it is sensible to think that a military service so reliant on advanced technology would have a fast-moving organizational climate, the opposite is true. The sheer size of the USAF is the reason that makes it hard to change paradigms. Lastly, apathy could be detrimental to DSF implementation. Many will feel that making change will be more trouble than it is worth. These personnel challenges can be combated using the proposed horizontal integration.

V. Evaluating the Decision Support Framework

A. Evaluating the DSF

Since the biggest challenge to managerial models is in getting them used, it is important to evaluate the likelihood that a DSF would be used. Regan et al developed a simulation framework to evaluate fleet management systems and found gaps between simulation and realism must be addressed [28]. Their technique for evaluation compared different operating strategies to outcomes. Regan et al addressed the effectiveness of the decision support framework but did not assess the manager's subjective opinion of the system.

Usage of this DSF must be evaluated long-term to determine if the ideas were valuable to actual retirement scenarios. The DSF must stand up to time – meaning that it was structured broadly enough to maintain pertinence even when technology and management techniques progressed.

Determining whether a DSF has been valuable relative to its cost may involve measuring the potential savings between a DSF solution and a non-DSF solution. While many uncertainties exist when making cost projections of fleets, there are well-established baseline costs for a fleet. Deltas from these values can be more easily established.

The best evaluation tool for a DSF is assessing whether the fleet manager found value in the framework. The DSF is designed to help the manager make better decisions. Assuming the model was constructed properly, any decision utilizing the DSF would be a better decision than those made without the DSF. Thus, if the DSF makes the job of the fleet manager easier, then a net benefit exists.

B. Applying the DSF to a Sample Fleet

This section discusses the practical steps a fleet manager would take to apply this DSF to a fleet of military aircraft. It is organized to mirror the steps presented in Section 3, where the four principal elements of the DSF are presented below. Here, the fleet manager initiates fleet evaluation.

1. Understanding the structural toll caused by utilization

The sample fleet comprised 200 generic transport aircraft acquired over a period of 20 years and possessing ages normally distributed with mean, $\mu = 10$ years and standard deviation, $\sigma = 3$ years. It was assumed that fleet data, network data and demand data were all available. For this application, a normal distribution of flight hours was assumed with $\mu = 1000$ yearly flight hours and $\sigma = 300$ yearly flight hours with a lower cut-off at 250 yearly flight hours. It was assumed that future utilization would match current-year utilization. The aircraft were randomly assigned to their current yearly usage levels. The basing network was assumed to have four equally equipped locations, $loc = \{A, B, C, D\}$ each possessing a corresponding utilization severity factor which represents different mission types (one per base) having different structural degradation of the aircraft, $SF = \{0.25, 0.50, 0.75, 1.0\}$. Service life was set to 20,000 flight hours. No specific basing or mission restrictions were included. Enough data were present to evaluate the fleet, thereby affirmatively satisfying the first decision triangle in the DSF.

2. Recognizing the indicators that predispose a fleet for retirement

The sample fleet was assumed to have been flown during contingency operations, thus resulting in the overuse of some airframes. Additionally, a fleet could include aircraft with undesirable existing damage, antiquated modifications or could fail to meet mission capable rate thresholds. These indicators were represented in the sample fleet via the age and yearly flight hours standard deviations. This step includes both external and internal inputs. These inputs were ignored for this example implementation. However, it is evident that base closings could force a reshuffling of assets or political climate could alter the capability desired from a fleet, for example. These influences are key inputs for a decision-maker and must be methodically evaluated to determine their impact on a fleet's retirement outlook.

3. Determining an optimal fleet size and choosing which aircraft to retire

The capability threshold for the fleet was set to 75% of current, resulting in the fleet manager making a fleet sizing determination to retain 150 aircraft and retire 50 (retire whole fleet decision triangle). In this simple implementation, those aircraft already over the 20,000 flight hour service life were immediately slotted for retirement and are shown as x's in Fig. 4. To reach 50 total aircraft for retirement, the remainder were the aircraft with the highest flight hour utilization. These are shown as circles in Fig. 4. Because of the random distribution of aircraft to bases and missions, the aircraft in the list of 50 to retire were not solely those that were oldest by age. The aircraft slated for retirement were generally older aircraft with the greatest flight hour accumulations. The short-term plan for this fleet is to immediately retire those above the service life limit, to use the remaining flight hours of the remaining identified retiring aircraft and to move the lowest flight hour aircraft to the highest severity factor bases. This strategy is fleet manager dependent based on fleet needs and management preferences.

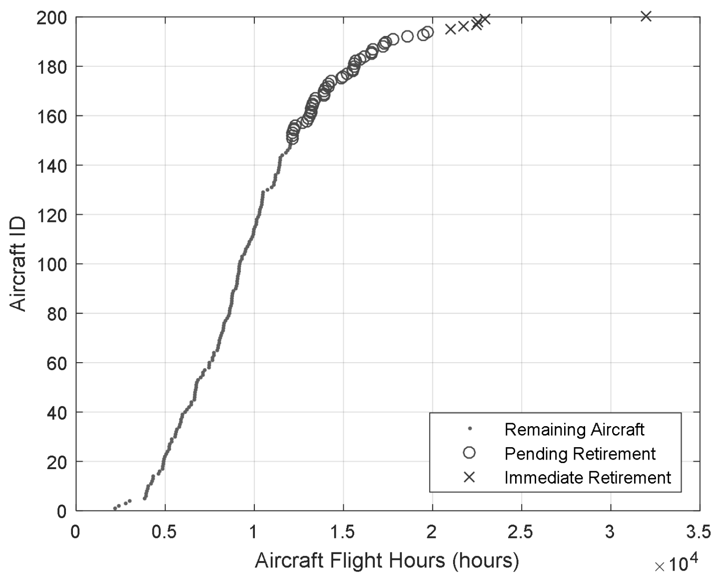

Fig. 4. Flight hours for sample fleet, showing retirement eligible aircraft.

4. Optimizing end-of-life usage prior to retirement

The long-term utilization for this simple fleet was then readjusted to ensure set coverage for the four bases. High-time aircraft were shifted to low severity factor bases and vice versa. As each aircraft at the high severity factor base surpasses the mean flight hour accumulation, they are rotated to the less severe bases. The long-term management strategy implemented in this example was to maintain the remaining 150 aircraft as long as possible. Consequently, the remaining 150 aircraft were distributed among the four bases in this way: split the population into flight hour quartiles based on remaining aircraft flight hours (20,000 less current flight hours) and assign the lowest remaining flight hour quartile to the base with the lowest severity factor, the second lowest remaining flight hour quartile to the second lowest severity factor base and on. Fig. 5 shows the initial base assignments (right side) and the fleet after 11 years of base reassignment and usage (left side). Aircraft IDs 151-200 are not shown in Fig. 5 because they are assumed retired and the minimum number of aircraft at each base was fixed: $loc = \{A = 38, B = 37, C = 38, D = 37\}$. The DSF's disruptions feedback loop will impact the yearly usage during this stage. An output of this step is forecasting data such as depot and modification forecasts, which can be extremely useful to a fleet manager.

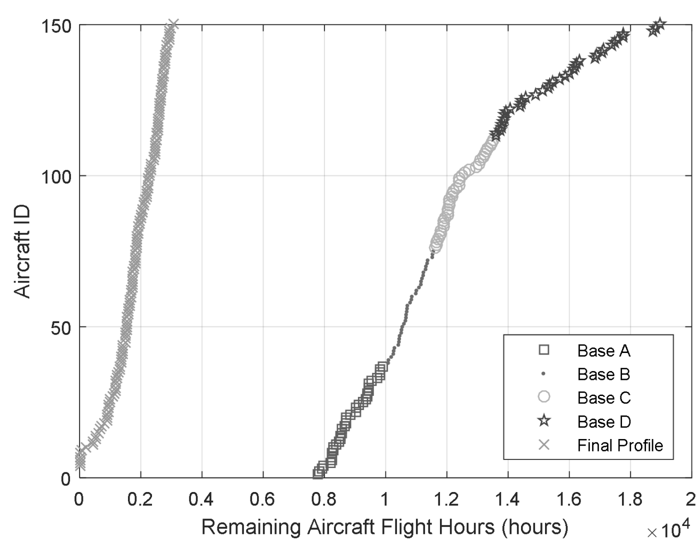

Fig. 5. Remaining aircraft base reassignment quartiles.

The decision triangle after the long term planning determination asks if the plan is feasible. While the answer in this example is yes, a no forces another look at the long term plan.

This management strategy used the aircraft with the lowest remaining flight hours the least over the 11 years in the simulation, thereby maintaining a larger standing fleet as long as possible. In the twelfth year, aircraft reached zero remaining flight hours and therefore the fleet would need to shrink smaller than 150 aircraft. The baseline case allowing no aircraft rotations would have resulted in the next aircraft retirement in the seventh year, so the methodology correctly prolonged the fleet's desired size for four years. This application of the DSF used simulated fleet data, simulated network data and simulated demand data to build a notional fleet. Enough data were present for a fleet sizing determination that resulted in 50 aircraft being retired in the short-term. The long-term forecasting and utilization plan called for the rotation of the aircraft between the four locations to equalize remaining flight hours. External and internal influences, while ignored, can be injected into the short and long term planning horizons and dealt with as disruptions. The DSF successfully directed the fleet manager to proceed through the steps resulting in a methodological approach to sizing and utilizing the fleet. The DSF emphasized common sense decisions such as retiring aircraft that have overflown their safe life limit first, then rotating the aircraft within the base network to maximize fleet longevity. The most important aspect of the DSF is that it is not a static framework, but should adapt through time and be referenced repeatedly.

C. Expert Validation

In accordance with the policies outlined in USAF Instruction 38-501 and the Human Research Ethics Committee of the Delft University of Technology, eight USAF fleet managers were surveyed for expert validation of the DSF [29]. This was the maximum number of survey participants allowed by USAF policy. The managers were chosen based on their job titles, with an attempt to receive responses from managers representing a variety of aircraft types (fighter aircraft, bomber aircraft, unmanned aircraft, cargo aircraft). Four samples collected in November 2017 (50% response rate) included managers in the USAF whose positions related to fleet management. The survey is reproduced in its entirety in Appendix A. The survey was delivered as a fillable PDF to recipients by e-mail.

Each respondent validated the need for a decision support framework for USAF fleet management, indicating that they would implement the DSF presented herein. All respondents also believed that aircraft usage data contribute to the understanding of fleet health and that the USAF retires aircraft with remaining residual life, thus necessitating a better end-of-life strategy. The respondents were equally split in their responses to the statement, "I believe that fleet management decisions are driven purely by budgets: true/false" (question 8). This disagreement echoes the value of expert opinion within the DSF because fleet management courses of action contain subjectivity. The presented DSF encourages fleet managers to proactively evaluate their fleet based on a chorus of internal and external influences. Lastly, the validation survey found that senior managers believe that data required for fleet management decisions are collated from too many disparate systems. The DSF addresses this concern by including a decision point where a fleet manager must decide if enough data – the right data – are present for decision-making.

VI. Conclusion

This paper presented a decision support framework for military aircraft fleet retirement decisions. Military fleet retirement decisions are infrequent and the supporting discussions are not published nor widely shared, resulting in a very small body of knowledge. Fleet managers often view their decisional tasks as one-off for which they are underprepared and ill-experienced. The presented DSF was built with flexibility in mind, able to represent decisions across military services worldwide. The DSF accounts for internal and external factors while allowing the fleet manager flexibility in deciding what is important to his fleet. The role of expert opinion was held paramount in this work because numerical solutions ignore the prescient inputs from many key stakeholders like senior managers.

To illustrate the efficacy of the DSF, a sample application problem was considered. This scenario used a fleet of 200 aircraft within a network of four base locations. The desired future capability was 75% of the current capability, resulting in the retirement of 50 aircraft. The remainder of the fleet was managed using the DSF's short term and long term functions to prolong fleet longevity. The result was 11 years of utilization before the next aircraft consumed its flight hour lifetime. The baseline case, with no change to current operating patterns, would have resulted in a first retirement in the seventh year of utilization. This approach ensured fleet viability for an additional four years. This application study showed the ease of applying the DSF to a transport aircraft fleet of nominal size.

It was shown that the developed decision support framework was useful to solve the complex problem of aircraft fleet retirement for fleet managers and it was validated through a survey of senior leaders in the USAF. Future work in this area should focus on the development of tools and database concepts that more fully integrate the existing data sources for military aircraft. Further, this DSF should be applied to a military aircraft fleet to gain pragmatic insights for its use. Fleet managers who implement this DSF can further refine the methods and uncover more fleet-specific problems that arise during retirement discussions. Lastly, more fleet managers should be surveyed to gather more expert validation of the DSF.

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Conflict of interest statement

The authors declare no conflict of interest.

Appendix A

Fleet Management Survey
Conducted by: Jeff Newcamp

Thank you for taking the time to answer this survey. Its results will directly impact the research direction taken by the Air Force Institute of Technology. This survey includes 12 questions. There are no right or wrong answers and you may elaborate on any question(s) using the box provided at the end of the survey. This survey is anonymous.

Position Title:_________________

1. Rank these items in their order of importance to you when you make decisions that impact a fleet:	**1 (most important) to 4 (least important). Use each number only once.**
Experience	
Expert opinion	
Structured approach	
Tools available	

Circle One:
2. I believe that individual aircraft tracking data can contribute to the understanding of fleet health. true/false/NA

3. I believe that a correlation exists between base locations, mission types and aircraft loading. true/false/NA

4. If given the opportunity to change a fleet size (increase or decrease) to better match need, I would do so. true/false/NA

5. I believe that the Air Force retires aircraft that have residual lifetime left in the airframes. true/false/NA

6. I would implement a decision support framework to help me make fleet management decisions: true/false/NA

7. I believe commercial off the shelf management tools apply to Air Force fleet management: true/false/NA

8. I believe that fleet management decisions are driven purely by budgets: true/false/NA

9. I believe my ideas about managing aging aircraft would be accepted by leadership: true/false/NA

10. I feel that I have a strong support network around me if/when I make important fleet decisions: true/false/NA

11. The current capability of an Air Force fleet depends on:	**True**	**False**	**NA**
Software load			
Manufacturing & maintenance history			
Operational usage history			
Hardware modifications			

12. How do fleet managers ensure they have enough data to make a fleet management decision?

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Please elaborate on any question:

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