Table 2 Design sensitivity of the fifth eigenvector of a tail boom truss with respect to the third design variable where design sensitivity of the fifth eigenvalue with respect to the third design variable is −19,479.0

		30 EVs		5 EVs and 1 LDRV		5 EVs and 2 LDRVs		5 EVs and 3 LDRVs	
5th Eigenvector	y'_E	y'	$\frac{y'}{y'_E}$, %	y'	$\frac{y'}{y'_E}$, %	y'	$\frac{y'}{y'_E}$, %	y'	$\frac{y'}{y'_E}$, %
−0.4732D−1	−0.1400D−1	−0.6790D−2	48.5	−0.144D−1	102.5	−0.130D−1	99.3	−0.141D−1	100.1
0.1111D−1	0.4264D−1	0.4269D−1	100.1	0.4796D−1	112.5	0.4294D−1	100.7	0.4269D−1	100.1
−0.1880D+1	−0.7757D−1	−0.7816D−1	100.8	−0.6976D−1	89.9	−0.7785D−1	100.4	−0.7764D−1	100.1
−0.4750D−1	−0.1344D−1	−0.5631D−2	41.9	−0.1383D−1	102.9	−0.1333D−1	99.2	−0.1344D−1	100.0
−0.1525D−1	−0.9496D−1	−0.9496D−1	100.0	−0.9838D−1	103.6	−0.9488D−1	99.9	−0.9489D−1	99.9
−0.1886D+1	−0.7971D−1	−0.8036D−1	100.8	−0.6962D−1	87.3	−0.7959D−1	99.8	−0.7966D−1	99.9
0.4748D−1	0.1405D−1	0.6234D−2	44.4	0.1446D−1	102.9	0.1394D−1	99.2	0.1405D−1	100.0
0.1459D−1	0.4950D−1	0.4952D−1	100.0	0.5253D−1	106.1	0.4940D−1	99.8	0.4943D−1	99.9
−0.1885D+1	−0.7801D−1	−0.7858D−1	100.7	−0.6789D−1	87.0	−0.7788D−1	99.8	−0.7796D−1	99.9
0.4735D−1	0.1275D−1	0.5903D−2	46.3	0.1302D−1	102.1	0.1265D−1	99.2	0.1275D−1	100.0

Note: EV stands for eigenvector.

eigenvectors gives excellent results. Adding three LDRVs, nevertheless, does not yield a significant improvement.

VI. Conclusion

A unified continuum-based sizing DSA of eigenvectors using LDRVs has been proposed. This method does not require derivatives of stiffness and mass matrices. Furthermore, use of LDRVs makes this method inexpensive and improves the accuracy and convergence of sensitivity. A helicopter tail boom truss is studied and very good sensitivity results for eigenvectors are obtained by adding two LDRVs to the existing eigenvector basis.

Appendix

Energy bilinear forms for the truss element can be written as

$$a_u(y, \bar{y}) = \int_0^l AEy_{,x}\bar{y}_{,x}\,\mathrm{d}x, \qquad d_u(y, \bar{y}) = \int_0^l A\rho y\bar{y}\,\mathrm{d}x \tag{A1}$$

where y and $\bar{y}$ are the eigenfunction and virtual eigenfunction, respectively, A is the cross-section area, E is Young's modulus, ρ is density, and $(\ )_{,x}$ is the derivative with respect to x. The first design variation of the bilinear form $a_u(y, \bar{y})$ with respect to the cross-sectional area A is

$$a'_{\delta u}(y, \bar{y}) = \int_0^l Ey_{,x}\bar{y}_{,x}\delta A\,\mathrm{d}x = E\int_0^l (N_{a,x}y)(N_{a,x}\bar{y})\delta A\,\mathrm{d}x \tag{A2}$$

where the shape function is

$$N_a = \left[\frac{l-x}{l}, 0, 0, \frac{x}{l}, 0, 0\right] \tag{A3}$$

In the same way, $d'_{\delta u}(y, \bar{y})$ can be obtained.

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Scheduled Maintenance Optimization System

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Introduction

THE cost of scheduled maintenance is significant. However, cost is not always considered in the up-front design stages. Weapon systems require many scheduled maintenance and ground support activities to insure safe and successful missions. Scheduled maintenance is needed to assure meeting mission requirements, and at the same time can restrict maximum sortie generations due to the downtime required to perform inspection and ground handling tasks.

The MDA maintainability attainment independent research and development (IRAD) no. 7-925 studied methods of reducing Air Force and Navy aircraft turnaround and scheduled maintenance requirements. The results of the IRAD study were provided during a symposium at Warner Robins AFB in 1990.[1] A data base management system (DBMS) was developed to analyze and study both Air Force and Navy air-

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craft. This DBMS allows a study of technology insertion candidates. The DBMS system can also include additional data bases to study aircraft carrier operations (i.e., catapults, arresting gears, deck vehicles, weapons storage/handling, and maintenance handling).

DBMS Methodology History

In-depth studies of existing Military Standards (MIL-STDs) and requirements were accomplished to understand current aircraft turnaround and scheduled maintenance demands during field and carrier operations. Analysis of field data related to Air Force and Navy aircraft turnaround and scheduled maintenance helped identify the current burdens (Fig. 1) for the flow of this process.

To understand current aircraft, data bases of the most recent turnaround inspection requirements for Air Force and Navy aircraft were investigated. The data base system consists of maintenance inspections, operational support, mission configurations, and weapons loading requirements related to daily aircraft flying.

The data bases can be used to determine the best method to analyze the current turnaround requirements. The initial investigation concentrated on elapsed inspection times for the aircraft under study. Pareto analysis techniques identify high man-hour consumers. Timelines provide visibility of turnaround tasks and support problem identification. A prioritizing of design improvement candidates can be provided using this information. Other sources of information such as field service reports, trouble reports, lessons learned, field reports, related IRADs Navy maintenance engineering inspections of the F/A-18 and AV-8B can be used. Also, current methods which are used to identify aircraft inspection requirements can be reviewed.

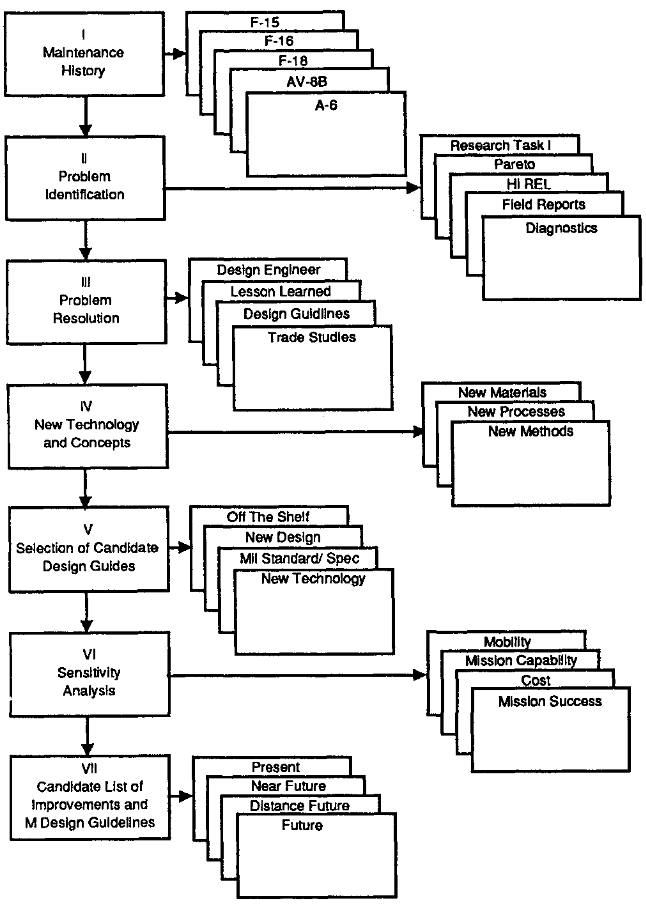

Fig. 1 Scheduled maintenance optimization development flow is detailed.

Summary of Results

Candidate improvement areas identified were as follows:

1) Minimizing the time required to operate systems (i.e., inertial alignment times eliminated with the use of ring laser gyro systems).

2) Minimize the number of consumables, technical manuals, safety devices which require removal before flight streamers, and ground time for operational checkout of systems.

3) Improve diagnostics (application of digital electronics, vehicle management systems, expert systems, and neural networks).

4) Enhance pilot debrief with expert systems.

Results of this study provided 1) a DBMS containing existing inspection requirements for the selected aircraft, 2) a rule based method to reduce turnaround requirements, and 3) a prioritized list of improvement candidates.

Problem Resolution

After the list of prioritized improvement candidates was established the problem resolution task began. A search of current technologies to be applied to current aircraft is the first step. Features in current use were identified for application to inventory aircraft. Any improvement areas identified after review of the current turnaround requirement processes were recommended for current inventory aircraft as well as future aircraft designs. An example of improving aircraft is the replacement of the liquid oxygen system (LOX) as the primary source of oxygen with an on-board oxygen generating system (OBOGS). The OBOGS eliminates the need for daily servicing and reduces combat turnaround time by 3 min for an air to ground mission.

Results and Recommendations of Study

Selection of Candidates and Establishment of Design Criteria

Selection of current "off the" shelf candidates and new design improvements were identified and submitted to a sensitivity analysis. Also, design criteria/guides for providing minimum scheduled maintenance was developed.

The output of this phase provided 1) improvement candidates, 2) updated DBMS system including candidate improvements, and 3) cost savings impact for improvements.

Establish Air Force and Navy Baseline

Outputs from the data base of current aircraft provided the sources needed to establish an Air Force and Navy aircraft turnaround baseline based on current technologies. In addition to the current technologies, the use of near future (1993–1998) and future (beyond 1999) technologies can be investigated for applications to reduce the aircraft turnaround time for future fighter/attack aircraft designs. The established baseline will provide a rule base for optimization of future aircraft design. Based on the knowledge of future technologies the design of future aircraft can be influenced.

The work performed under the scheduled maintenance study identified a need to develop an integrated system. The modules developed to study scheduled maintenance identified the need to reanalyze current fleet aircraft and perform a failure mode effects and criticality analysis (FMECA) on candidate items. The need to perform a reliability centered maintenance (RCM) candidate was also identified. The identification of these needs has led to the development of the schedule maintenance optimization system (SMOS).

SMOS System Configurations

A brief description of SMOS is as follows. Each section describes a particular submodule of the SMOS. A flow diagram depicting the flow of information (data) from one module to another for the SMOS is provided in Fig. 2. This sys-

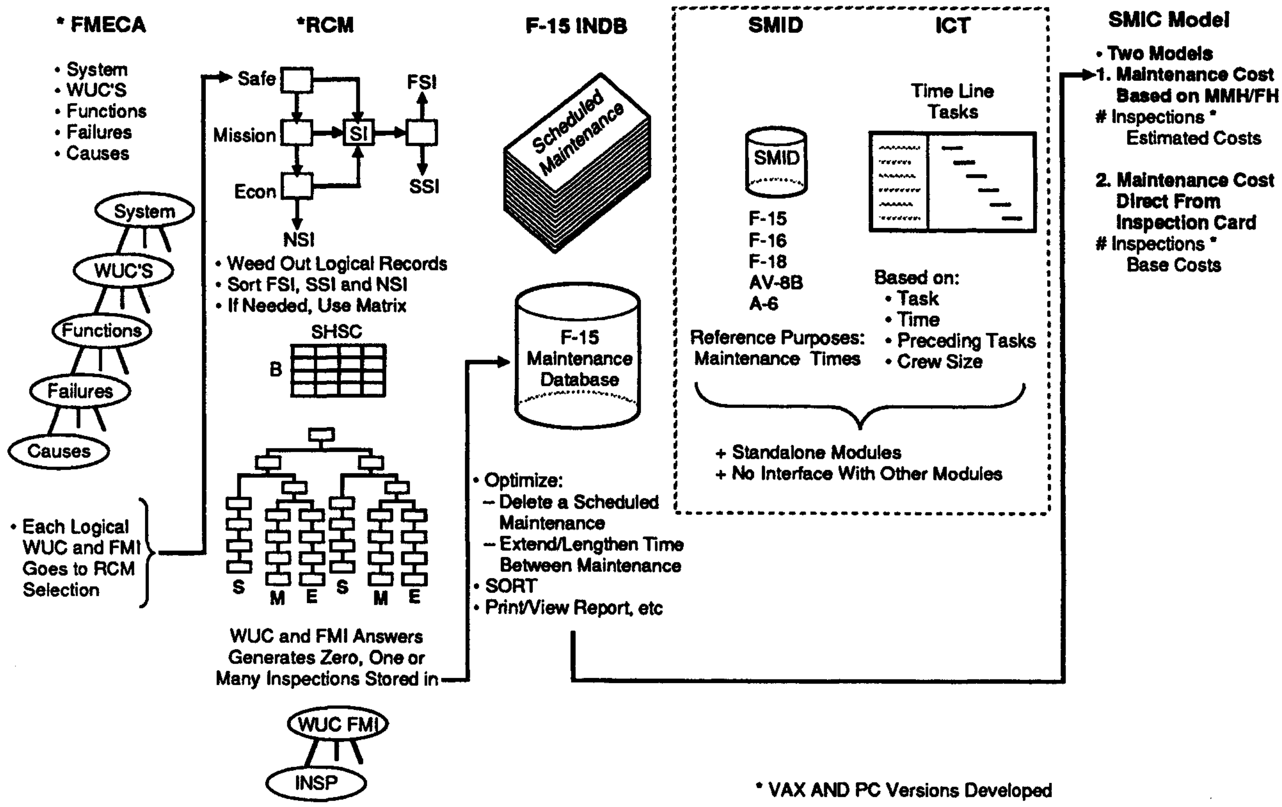

Fig. 2 Scheduled maintenance optimization system.

Table 1 Commercial software/hardware

Software	Vendor
Turbo C++	Borland
VAX 'C'	Digital
VAX VMS Operating System	Digital
Disk operating system (DOS)	Microsoft
'C' Database development	MIS Press

tem was developed using commercial hardware/software (Table 1).

Failure Mode Effects and Criticality Analysis Module

This process documents predictable and potential failure modes and causes, including those for environmental and accidental damage. This is done by taking each item, describing its functions, the failure modes for the function(s), and the causes of each failure mode occurring. Following this description, the analyst describes how the failure affects aircraft performance, how to fault isolate the failure, how often the failure occurs, and if any design provisions, such as redundancy or operator actions, are available to compensate for the failure. Although task 103 of MIL-STD-1629 makes no provisions for input of probability of failure, this system will provide that capability to assist in the decisions made during RCM. A copy feature allows for copying of a completed FMECA so that an additional failure mode can be added with only minor changes required.

Reliability Centered Maintenance Module

This module provides access to failure analyses performed in the FMECA module and builds upon this data to determine which failures should have scheduled maintenance tasks developed for them based on the logic provided in MIL-STD-1843 RCM USAF. This module provides the automation of expert knowledge of MDA engineers applied to RCM and is derived solely for use on F-15 aircraft and approved by WR-ALC. The defaults provided here should in no way influence eventual users of this software on other aircraft to use these quantitative numbers or default answers. Each RCM program developed should be aircraft specific (tailored).

F-15 Inspection Task Data Base Module

The F-15 inspection task data base module contains an up-to-date listing of the scheduled maintenance requirements cards (adjusted to include work unit codes for each task). Once an RCM analysis has been completed, the user is provided the opportunity to update or optimize the data base. Any analysis (generated FMECA/RCM records from RCM module) that deletes or elongates the interval between scheduled maintenance inspections for a system or equipment item, qualifies as an optimizer, and subsequently can be incorporated into the F-15 inspection task data base.

Scheduled Maintenance Inspection Database (SMID)

SMID is designed to read a data base file containing the inspections and inspection times for a particular airplane, extract the data requested by the user, and then write the data to an output file. This module also allows the file to be viewed on screen. This module is not directly tied to any of the other modules (as can be seen by the flow diagram).

Integrated Combat Turn Module

The integrated combat turn (ICT) system is a C-coded module which uses an operations research technique called "critical path methods" to aid in timelining a set of tasks within the least amount of time given a set of resources. This module can also generate timeline based on inputs from the SMID. It is a "stand alone" program which allows the user to pictorially view a timeline of maintenance tasks (which the user inputs) as well as develop a data base containing the ICT maintenance information. Also included is an inspection turnaround time (ITAT)—this is a data base of inspection requirements related to turnaround/daily flying types of scheduled maintenance for current fighter aircraft in the U.S. Air Force and U.S. Navy. These inspections are abbreviated but provide traceability to scheduled maintenance requirements for previous aircraft of similar types. The data is also helpful for establishing task times.

Scheduled Maintenance Inspection Cost (SMIC) Module

This module will present and track current F-15 SMI costs related to the current requirements for scheduled maintenance. The U.S. Air Force model was used to derive many of the cost parameters associated with this maintenance cost model.

F-15 Work Unit Code (WUC) Data Base

This data base stores the current listings of WUC breakdowns and nomenclature for F-15 aircraft.

Phase/Special/Periodic Inspection Data Base

This data base, developed by MDA, contains scheduled inspections not related to turnaround/daily type maintenance.

Automated Computer System (ACS) Inspections

This system contains the current F-15 inspection requirements for inclusion to the SMOS central data base.

Future Work

SMOS adds software development to analyze fielded aircraft with FMECA and RCM modules interfacing with the modules already developed. Enhancements to software development currently in work will also be investigated in the future.

Conclusion

An integrated software package composed of a FMECA module, a RCM module, a SMID, a SMIC module, and an ICT module are in development. These modules provide an integrated consolidated process for rapid assessment of previous aircraft scheduled maintenance requirements, combat turnaround times, and the necessary analysis tools to provide future scheduled maintenance requirements and optimum elapsed time for ICTs. MDA has already developed PC-based SMID, ICT, SMIC, FMECA and RCM modules.

This system will identify and document current and emerging technologies available to reduce aircraft turnaround during both ground and carrier operations. It will identify candidate improvement areas to increase war fighting capabilities through increased aircraft availability; decrease mobility requirements by reducing the number of personnel and support equipment to sustain a deployed location; and decrease manpower requirements by eliminating, combining, and optifjmizing inspection requirements, therefore reducing operations and support cost. Candidate improvement areas include aircraft design areas (inertial navigation alignment, refuel, health monitoring, and enhanced methods to reduce fault diagnostics time, etc.), arresting gears, ground and deck vehicles, weapons storage/handling and storage, and maintenance operations.

Acknowledgments

The initial investigation to identify technologies/methodologies to reduce the burden of scheduled maintenance was funded by MDA as Independent Research and Development (IRAD). The use of software tools to study current aircraft gained the interest of WR-ALC which led to funding for a scheduled maintenance optimization system. Warner Robins AFB, Air Force Material Command has funded the development of the FMECA, RCM, and software development to integrate existing modules.

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Aerodynamic Properties of Crescent Wing Planforms

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Introduction

SOME years ago, an interesting paper from Van Dam[1] focused attention upon a possible benefit of the so-called crescent planform. The argumentation is based on the observation that this kind of planform has been selected through millions of years of evolution by several species of "efficient" flying and swimming animals. Good examples are given by the swift wings (flapping flight) and the shark tail (carangiform motion), many other examples can be found in Ref. 1

It is obvious that any living system is very subtle machinery as compared to human designs. The wing itself must be considered as a fully "active" or "adaptative" system as opposed to the passive aircraft wing: its camber, planform, and dihedral react to any flight situation. Despite that complexity, it seems natural to question if the wing planform can have some interest for aircraft applications.

Van Dam has published several contributions on that subject.[1-4] Considering the induced drag properties of crescent wing planforms, a numerical investigation seems to demonstrate a spectacular reduction in comparison with the conventional unswept elliptical wing.[2] An 8% reduction of the induced drag coefficient ratio $K_i = C_{Di}/(C_{Di})_{\text{eff}}$ is claimed ($AR = 7$, $\alpha = 4.0$ deg), using a nonlinear surface panel method.

An experimental study undertaken later[4] shows a much smaller difference between the basic (unswept) elliptical wing and the crescent planform. The efficiency of the wing is described by means of the Oswald efficiency factor e

$$e = \frac{C_L^2}{(C_D - C_{D_0})\pi AR}$$

where C_{D_0} is the drag coefficient at zero lift, C_L is the lift coefficient, and AR is the aspect ratio of the wing. Some differences are observed between the basic (unswept) elliptical wing and the crescent wing, but the improvement is within 2 and 4%, with an estimated uncertainty of 3%.

The present work has been performed before the publication of the preceding results. The experimental variation of the lift-dependent drag with the mean sweep of several wing planforms is carefully investigated and no definite gain has been observed. It is pointed out that attempting to separate the "inviscid" induced drag from the total lift-dependent drag can lead to erroneous conclusions if only very small effects are expected.

Experimental Setup

Four wing planforms have been analytically defined by means of a chord length and a quarter-chord position law. The same elliptical chord length function is applied on every model, namely:

$$c(\eta) = c_r\sqrt{1 - \eta^2}$$

where η is the reduced spanwise coordinate, $y/(b/2)$. The root chord c_r is related to the aspect ratio $AR = b^2/s$ through

$$c_r = 4 \cdot b/(\pi \cdot AR)$$

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