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Aircraft Design for Fuel Efficiency

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ABSTRACT

The U.S. Navy is currently investigating various methods for improving the fuel efficiency of existing fighter, attack and patrol aircraft. Methods include: design modifications which will reduce drag or lower weight, subsystem changes to propulsion systems that enhance efficiency, the addition of new Flight Performance Advisory/Management Systems (FPA/MS) to improve mission fuel utilization and finally mission planning and training techniques to improve operational effectiveness. Concurrently, the Navy is attempting to identify energy-efficient aircraft design and fuel management concepts that can be applied over the next five to ten years to planned Navy and Marine aircraft. The Navy is also pursuing a program of technology development for the year 2000+ aircraft. The design modifications stated above are included in the Navy Aircraft Energy Conservation Research, Development, Test and Evaluation (RDT&E) Program. This paper presents a summary of that program and will emphasize design approaches that yield the largest payback in barrels of fuel saved for the total investment.

BACKGROUND

The high cost and uncertain availability of petroleum based fuels for aircraft are of critical concern to both military and civilian aviation. In addressing this concern, the U.S. Navy is pursuing several efforts in the areas of fuel conservation. These efforts include operational and flight planning changes, modifications to existing aircraft to reduce weight and drag, subsystem enhancements to improve flight fuel efficiency, and advanced technology concepts for future generation aircraft. The procedure adopted by the Navy Aircraft Energy Conservation RDT&E Program commenced with an analysis of the amount of fuel consumed by Navy and Marine aircraft based on aircraft type and mission. Then using these data, high-fuel-utilization aircraft which are at present in current inventory and will continue to be in inventory for 10 to 15 years were selected. The next phase of this effort is to develop aircraft technologies and systems that emphasize energy conservation.

The approach is as follows:

1) Conduct fuel-saving aircraft modification RDT&E on selected current inventory Navy aircraft. Investigate aircraft aerodynamics, propulsion, materials/structures, flight control systems, crew systems, and subsystems.

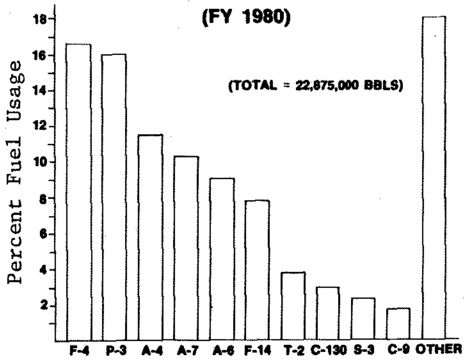
2) Conduct operations RDT&E to identify alternative fuel management procedures which could result in fuel savings. Investigate payloads, equipment, tactics, mission profiles, training, mission planning, and procedures.

3) Identify energy-efficient aircraft designs and fuel management concepts that can be applied to planned Navy aircraft.

4) Identify and develop energy-saving technologies and subsystems.

The fuel saved by these modifications can be utilized for additional pilot training flight hours or for reduced fuel allotments to maintain existing training hours. Examples of aircraft where fuel conservation techniques are currently or planned to be employed include the F-4, F-14, F-18, A-4, A-6, A-7, P-3, S-3, E-2, C-130, and C-9 aircraft.

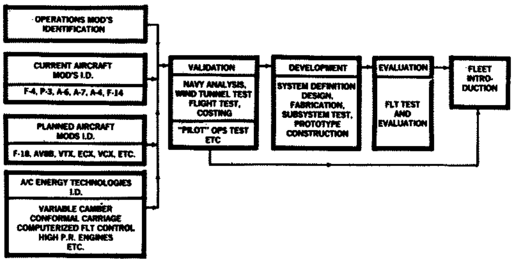
The F-4 and P-3 are currently the highest users of aircraft fuel followed in descending order by the A-4, A-7, A-6 and F-14. Together these six aircraft use nearly 75 percent of the total Naval aviation annual fuel allotment. Figure 1 is a summary of the total fuel currently being expended by Navy aircraft as a function of their type. Approximately 23 million barrels of fuel were used in FY 1980 for aircraft operations.



PERCENT FUEL USAGE BY AIRCRAFT TYPE

Figure 1

The approach (Figure 2) is first to identify fuel savings concepts for operations, current aircraft modifications, planned aircraft modifications, and aircraft energy technologies. The next step is to validate the concept through analysis, wind tunnel and flight test. If the concept is cost effective, that is it yields a payback in barrels of fuel saved over the lifetime of the aircraft, then design, fabrication, and system test is undertaken. A thorough flight test and evaluation is conducted prior to fleet introduction.



APPROACH

Figure 2

DESIGN MODIFICATIONS/EXISTING AIRCRAFT AERODYNAMICS

Efforts have commenced on aircraft modifications for fuel-efficiency pertaining to the F-4, P-3, A-6, A-7, A-4, F-14 E-2, C-130, S-3 and C-9 aircraft. As part of this effort, the temporary removal of unused equipment for subsystems that are no longer being utilized is included to reduce weight and drag of these aircraft. The aerodynamic modifications are oriented toward drag clean-up or weight reduction in existing aircraft where typically 1/2 to 1 percent fuel savings is realized and the R&D investment is minimal. Also considered are minimal modifications to subsystems where flight fuel efficiency can be improved by reducing power requirements or improving subsystem accuracy.

As an example of modifications to existing aircraft, consider the P-3 aircraft (1, 2) and the on-going modifications shown in Table 1. By installing a seal at the skin juncture of the nose radome and fuselage, the flow field can be smoothed and the corresponding drag from the gap reduced. Also, by extending the wing leading edge tape from 8% to 14% of the mean chord, the laminar flow can be extended thereby reducing drag and increasing fuel efficiency. By improving the P-3 wing walkway coating, the surface roughness can be reduced thereby reducing skin friction drag. As an example of a subsystem modification to the P-3, the fuel quantity gauging system can be replaced to provide more accurate data on fuel quantity thereby reducing the required "on-top" fuel reserves. Reducing the "on-top" fuel requirement will reduce the aircraft fuel consumption during the execution of the mission.

Other aerodynamic modifications that apply to existing aircraft include flap or aileron setting optimization for cruise, removal or modification of pylons and the inclusion of fairings or other drag reduction coverings. For example, initial studies indicated that the A-6, A-7, and F-4 could benefit from additional camber to reduce induced drag by drooping the trailing edge flaps approximately three degrees. Actual wind tunnel tests show these benefits only for the A-7 (about one to two percent fuel savings) while the F-4 and A-6 benefits were cancelled due to increased trim drag requirements. The removal of pylons and inclusion of pylon fairings on the A-6 and A-7 aircraft is a modification showing approximately one to three percent fuel savings. It should also be noted that engine modifications including blade replacement, engine derating to reduce thrust, and operations at higher temperatures can all have beneficial effects on fuel efficiency.

FLIGHT PERFORMANCE ADVISORY/MANAGEMENT SYSTEMS

Fuel Saving FPA/MS concepts for preflight planning and on-board systems are currently being investigated by the Navy Aircraft Energy Conservation RDT&E program. Using the aircraft performance data the goal of these investigations is to identify, develop, test and evaluate cost-effective operational concepts for Navy aircraft that reduce aviation fuel consumption per flight hour. These fuel saving concepts are as follows:

- Computer Assisted Mission Planning System (CAMPS)
- Pocket-Size Aircraft Performance Advisory Computers (P/S APAC)
- Avionics Flight Performance Advisory/ Management Systems (FPA/MS)

The CAMPS goal is to demonstrate the total mission planning fuel savings which can be achieved using a desk top pre-flight mission computer. The four fundamental aircraft modes, climb, cruise, loiter and descent are evaluated in order to optimize these segments or flight modes for fuel efficiency. In planning this way, the pilot can save fuel for use during the required high performance

Modification	Objective	Estimated Fuel Savings
Nose radome to fuselage seal	Fuel saving by drag reduction by reducing turbulence	0.5%
Wing leading edge tape extension	Extend wing laminar flow from 8% to 14% of $\bar{c}$	0.75%
Improved wing walkway coating	Fuel saving by drag reduction	0.5%
New fuel quantity gauging system	Improve gauge accuracy & reduce needed fuel reserves Provide more accurate input of gross weight for FPAS	1.2%

Table 1 - P-3 FUEL-SAVING AIRFRAME MODIFICATIONS

periods of flight, tactics or maneuvering. The aircraft could then take-off with less fuel and perform the same mission without the penalty of reduced time on station or could take-off with full fuel for an expanded mission scenario. The objectives of CAMPS are as follows:

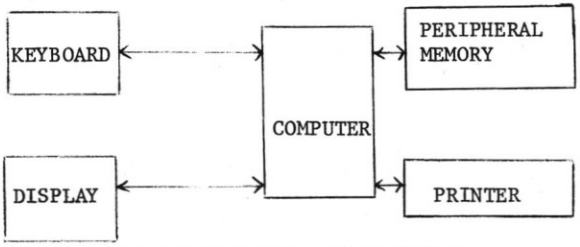
- Fuel savings in every mission segment
- Fuel savings by total mission planning
- Reduction in pre-flight planning time

The approach to the pre-flight mission planning program is to utilize the existing mission planning common software and off-the-shelf desk top computers in order to minimize the required software development for each aircraft. The software for the desk-top computer is developed using equations based upon the performance curves/characteristics of each aircraft.

Each pilot shall be able to use the desk-top computer with minimal training. It is expected that the pilot will only have to key in the data requested by the software program and thus require no actual software programming experience. After the second or third time using the desk-top computer assistance system the pilot will have become familiar with the computer "planner" and use it for tactical mission planning. The program language will be the Beginners All-Purpose Symbolic Instruction Code (BASIC). The features of the desk-top computers are summarized as follows:

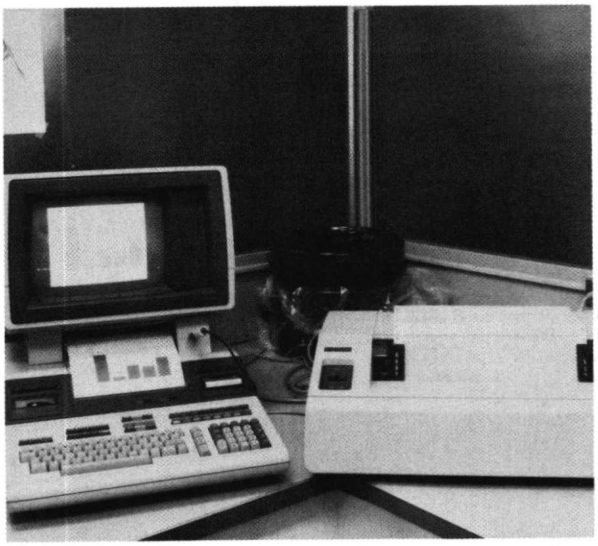
- Large memory and programmable cassettes
- Extended (BASIC) language
- Interactive conversational operation between the pilot and the computer
- Selection of specific mission profiles
- Capability to build your own mission and save it with the hard copy from the printer.

A function block diagram of the CAMPS pre-flight mission planning desk-top computer system is shown in Figure 3 below.



CAMPS FUNCTIONAL BLOCK DIAGRAM

Figure 3



CAMPS CONFIGURATION

Figure 4

A Hewlett-Packard HP-9845C desk-top computer is currently being used in the design, development and evaluation of the CAMPS pre-flight mission planning program. The CAMPS will supply the user with data to display the mission profiles and other items such as:

- Fuel remaining
- Fuel used in each leg
- Fuel flow
- True airspeed
- Distance travelled
- Mach number at each checkpoint

Sample input data to the computer consists of the following:

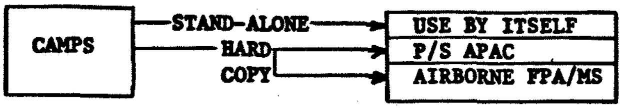
- Gross weight in pounds
- Fuel weight in pounds
- Windspeed
- Drag Count
- Ambient Temperature
- Number of checkpoints
- Low level groundspeed

Sample outputs consist of the following:

- Time of flight
- Flight distance in miles
- Leg fuel quantity
- True airspeed in knots
- Fuel remaining
- Fuel flow
- Mach number
- Mission profile(s)

Limits of the above input and output values are consistent with the established NATOPS Flight Manual operating range. Initial evaluation of the A-7E, P-3C, S-3A and TA-4J CAMPS will take place in the 1983 time frame at selected Navy sites. Efforts on the A-6, F-14, F-4, A-4M, EA-6B, KA-6D, KC-130, C-9B and E-2C will commence in the 1983 through 1984 time frame.

A hard copy of the output from the CAMPS will be used for pre-flight check out and data entry on the Pocket Size Aircraft Performance Advisory Computer (P/S APAC) (Figure 5) and avionics onboard Flight Performance Advisory/Management System (FPA/MS).



CAMPS UTILIZATION

Figure 5

The Navy has also commenced operation of a system called Optimal Path Aircraft Routing System (OPARS) as specified in the "Subsystems Specifications Document for Optimum Path Aircraft Routing System/Flight Planner"; Fleet Numerical Weather Center (FNWC) dated 31 August 1978. The currently available OPARS will require cross talk (handshake compatibility) between the OPARS and CAMPS systems.

The objectives of the Pocket Size Aircraft Performance Advisory Computer (P/S APAC) program are definition, development, test and evaluation of carry-on pocket-size computers to provide fuel savings for Navy aircraft. These portable computers will provide the Navy pilot with the altitude and airspeed combinations that yield the maximum in-flight fuel efficiency. Unique algorithms and associated software will be developed for each aircraft type to permit maximum accuracy and in-depth considerations of human factors engineering relative to the pilot workload and environment. The P/S APAC is intended as an interim fuel savings system for aircraft which may in the future receive an integrated system on-board.

The baseline computer selected for the P/S APAC effort is currently the Hewlett Packard model HP-41C programmable calculator. It is recognized that the pocket-size APAC is less capable in memory capacity than the on-board flight performance advisory/management computers currently being used by the commercial airlines and the Air Force. However, Navy pilots can still achieve fuel savings for the following reasons:

- The P/S APAC is inexpensive, lightweight, portable and simple to use, making in-flight computations simpler and more convenient than those accomplished using the NATOPS manual.
- Because the APAC is portable, it can also be used during pre-flight planning in conjunction with data obtained from the desk-top FPAS to prepare an on-board fuel efficient flight plan.
- The APAC program will be developed using equations from the performance curves/characteristics of each aircraft.

Due to memory and processing restrictions the APAC equations will not be as complex or as accurate as those developed for the desk-top FPAS. However, the P/S APAC will provide more accurate and consistent information than can be achieved through the in-flight use of NATOPS charts. The pilot will also obtain information for non-standard day/non-zero wind conditions and a readout for a particular flight condition rather than estimating data from NATOPS charts.

Most aircraft APAC systems shall have the following capabilities or primary modes:
- Data input, initialization and display
- Climb performance computations
- Cruise performane computations
- Loiter performance computations
- Descent performance computations

The P/S APAC software program will be designed so that each primary mode can be executed independently. This will provide the flexibility to save fuel in the operational environment when the modes of operation have been specified. An example of this would be the return leg (cruise-back) portion of the flight for fighter and attack aircraft.

The secondary modes and outputs are as follows:

- Data review (I/O Review)
- Time computations
- Range computations
- Fuel computation
- Bingo fuel and range
- Combat fuel computations
- Mission planning

It should be noted that the secondary mode is a subroutine of the primary mode and therefore must be executed when the applicable primary mode is selected.

The input variables to the HP-41C program shall be limited to readily available instrument panel readings. Therefore, input variables shall be in units consistent with those indicated by the instruments. Algorithms will be included to extrapolate this information to other altitudes such as the maximum range cruise altitude. All input variables shall be prompted for by the P/S APAC utilizing user-defined terminology. The prompts shall include the unit of measurement. All inputs shall be limited to numerical values or a "Yes" or "No" entry.

Output variables shall be those which can readily be compared with instrument panel readings and those which are used for planning such as fuel and time remaining. The program is structured to allow the user to review pertinent input values should the validity of the output data become questionable. For design and development purposes, the initial ~~HP~~-41C program for each aircraft will use Random Access Memory (RAM) modules. The RAM module can be modified or updated during the flight test phase for each platform. Upon completion of the flight test phase the program will be finalized and an 8,000 byte Read Only Memory (ROM) module will be manufactured. The HP-41C units will be procured by the model manager for distribution to the user communities in the form of kits. Each kit will contain the P/S APAC hardware with the ROM module and keyboard overlay (see Figure 6), a user's manual, and maintenance instructions including repair/replacement procedures.

P/S APAC HARDWARE/PILOT INTERFACE

Figure 6

APAC fuel saving programs will be developed for the P-3, S-3A, A-6, A-7E, TA-4J, F-4S, F-14A, F/A-18, C-9, KC-130 and UC-12B platforms.

The on-board Flight Performance Advisory/Management System (FPA/MS) is defined as that avionics system having an autopilot and autothrottle interface which will automatically fly the aircraft and will also provide the pilot with the advisory information relative to the most fuel efficient flight parameters. A Flight Performance Advisory System (FPAS) will provide the pilot with advisory information relative to flying the aircraft in the most fuel efficient manner; however, the FPAS does not have the autothrottle/autopilot interface. The objectives of the on-board FPA/MS R&D efforts are as follows:

- Investigate the feasibility of incorporating the FPA/MS on the selected aircraft.
- Investigate the candidate FPA/MS configuration for the selected aircraft.
- Determine those aircraft which will provide significant fuel savings through the 1980's and 1990's with the incorporation of the avionics FPA/MS. Significant fuel savings are defined as those savings which will provide a "payback" in barrels of fuel saved when compared with the cost for the implementation of the avionics FPA/MS, over the life cycle of each aircraft.

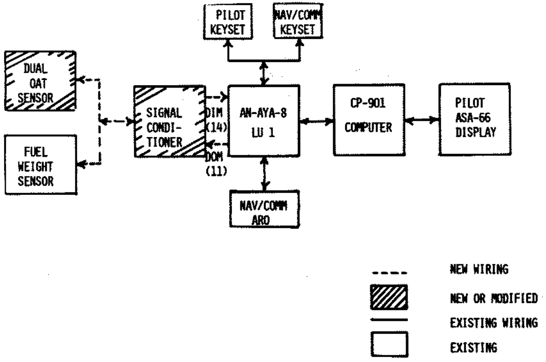
The criteria used in the selection of the candidate FPA/MS include the following:

- "High fuel consuming" aircraft as shown in Figure 1 which will be used by the Navy at least thru the early 1990's.
- Extent of avionics hardware design modifications or additions.
- Human Factors Design Requirements (e.g., number of controls, location of displays, etc.).
- Life cycle cost (non-recurring, recurring and maintenance).
- Impact on the ability of the aircraft to execute its mission (e.g. Is there a decrease in the Weapon System Mean Flight Hours Between Failure (MFHBF) or an increase in the pilot/copilot workload?).
- Impact on Operational and Maintenance Ground Based Simulators/Trainers.
- Schedule.

Design and implementation are not being pursued relative to the FPA/MS on the A-4 and F-4. Both aircraft will be phased out of the active fleet by the late 1980's and the incorporation of the on-board system would require the addition of a computer, display and control equipment and navigation sensors to provide the accurate inputs to the computer. This would not result in a significant payback in barrels of fuel saved over the life of the aircraft. Preliminary design and algorithm development are currently underway with the A-6, F-14A and S-3A aircraft. Design and development are occurring with the A-7E and P-3 Aircraft Systems. Initial investigation relative to the incorporation of the avionics FPA/MS in the E-2, C-9 and C-130 aircraft will commence in the late FY 1982 time frame.

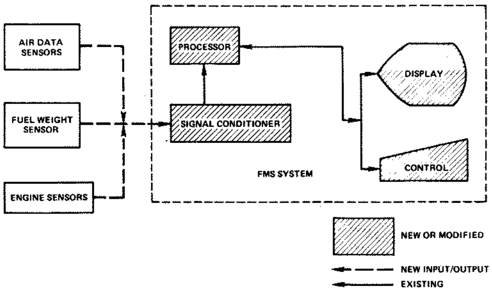
Two FPAS configurations are currently being developed for the P-3 aircraft. One configuration is applicable to the P-3C only. It utilizes the existing computer, the central processor (CP-901/ASQ-114(V)), the pilot's AN/ASA-66 display, and the pilot's keyset control (C-7629/AYA-8). All of the data with the exception of the outside air temperature and fuel quantity information is available in the CP-901/ASQ-114(V) operational software program.

Inputs from these sensors will be transmitted to the CP-901/ASQ-114(V) computer via a signal conditioner. This signal conditioner is similar to the one currently used on the U.S. Air Force RC-135 aircraft. Formal TECHEVAL/OPEVAL on this configuration will be completed in 1983. Fleet incorporation will follow formal TECHEVAL/OPEVAL. The second P-3 configuration is also in the development phase. This system is the stand-alone FPAS and has its own computer, control, and display capability. This system is applicable to those P-3 aircraft which have limited or no computer, control or display capability, namely, the P-3A and P-3B. This configuration is not limited to the P-3A and P-3B, but is applicable to all P-3 configurations. The computer, display, and control are off-the-shelf systems and are currently in production and qualified to fly in commercial aircraft. Stand-Alone Systems are presently flying in the RC-135 aircraft and will be flying in the C-5A, C-141 and KC-135 aircraft. Test and evaluation of the stand-alone system is scheduled to be performed by the Air Test and Evaluation Squadron One (VX-1), Naval Air Test Center, in 1983. The integrated and stand-alone system configurations are shown in Figures 7 and 8. Initial investigation will take place during FY 1983 and FY 1984 relative to the incorporation of an autothrottle capability (FPA/MS) for the P-3C.



P-3C FPAS INTEGRATED CONFIGURATION

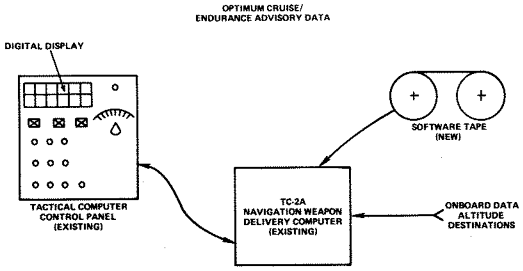
Figure 7



P-3 FPAS STAND-ALONE CONFIGURATION

Figure 8

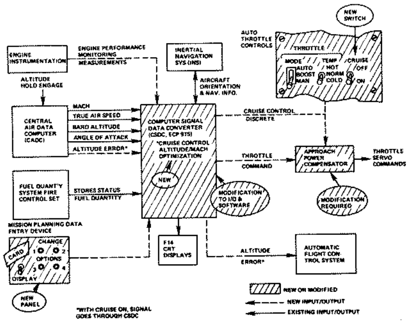
A FPAS capability for the A-7E aircraft is currently being designed. This configuration, Figure 9, takes advantage of the existing TC-2A Tactical Computer (AN/ASN-91B) resources and the cockpit control and display. Aircraft performance equation development has been completed. These equations will provide the data to the pilot for either the total mission or discrete mission segments, including maximum-range cruise and maximum-endurance conditions for either optimum altitude or a specified altitude. Pilot inputs include drag count, fuel remaining, external stores, and altitude. Initial tests of the operational module will occur in 1983. Formal TECHEVAL and OPEVAL will occur in 1984 by VX-5 at the Naval Weapons Center. No hardware modifications are required.



A-7E FPAS

Figure 9

The current F-14A configuration provides an altitude-hold mode which will increase the speed of the aircraft as the fuel is consumed. However, to fly the aircraft in the most fuel efficient manner, speed should be held constant and altitude varied to accommodate the stores and fuel remaining (weight). System design is currently taking place for the FPA/MS. Implementation of the FPA/MS in the F-14A will make use of the Approach Power Compensator, the Central Air Data Computer, and the Fuel Quantity System and Fire Control Set. The above will interface with the existing computer Signal Data Converter as shown in Figure 10. The FPA/MS will have the following capability:



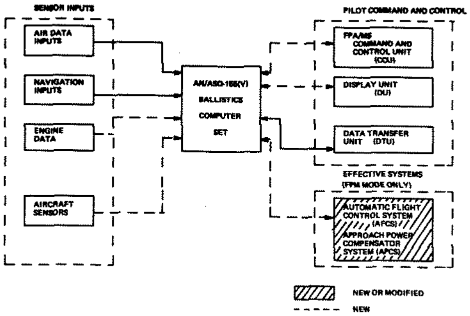
F-14A FPA/MS

Figure 10

- Mission profile changes to suit the pilot's needs.
- Mission profile entered by magnetic card or keyboard.
- System monitoring on the existing display.
- Climb, cruise, loiter, and descent modes for optimum fuel efficiency.

The system configuration will have little, if any, effect on pilot workload and can be incorporated with minor hardware modifications as noted above.

System design and aircraft performance equation development are currently underway with the A-6E and EA-6B FPA/MS. The A-6E FPA/MS configuration is shown in Figure 11. The A-6E configuration utilizes existing aircraft sensor equipment and spare AN/ASQ-155(V) digital computer resources. On the EA-6B the AN/AYK-14(V) will have spare computer resources to perform FPA/MS functions. An existing or off-the-shelf display and control unit will be incorporated with the FPA/MS. Minor hardware modifications (additional input/output modules) and additional aircraft cabling are required. An automatic flight control system and autothrottle are currently on the aircraft.



A-6E FPA/MS

Figure 11

The S-3A FPA/MS will utilize the existing computer, control, and display resources for the incorporation of an FPA/MS capability. The S-3A's AN/AYK-10(V) control processor will be utilized and minor hardware interface modifications are required. Use of the autopilot and autothrottle will provide the aircraft with the fuel management system capability.

Design of the FPAS or FPA/MS on the above aircraft has taken advantage of the existing computer, display, and control resources. This design philosophy enables the fuel savings to be incorporated into the fleet at an earlier date, since no new hardware development and qualification is required. Training is minimized and the reliability of the Weapons Systems is not decreased since little, if any, new hardware is required.

The initial study has commenced on the feasibility and potential fuel savings for the incorporation of an FPA/MS on the E-2C, C-9B and C-130 (KC-130F, KC-130R and EC-130) aircraft. Studies on these aircraft will be completed by June 1983.

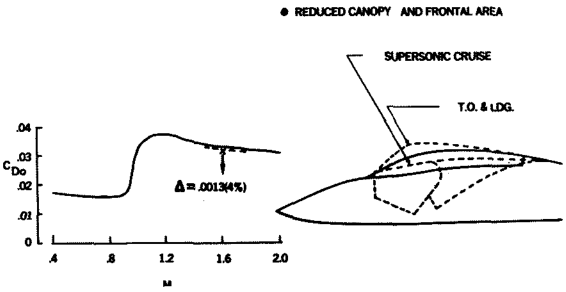
PLANNED AIRCRAFT DESIGN CONCEPTS

The Planned Aircraft Design Concepts include finding affordable ways to save fuel for aircraft entering production and defining technology applications that can reduce fuel consumption in future aircraft developments. For example, aircraft such as F/A-18, AV-8B, and VTX/TS are evaluated based on possible production modifications or ECP's (Engineering Change Proposals) that include high-payoff items to reduce fuel utilization over the life-cycle of the aircraft. These modifications include primarily weight and drag reduction items, subsystem modifications for power and/or weight reduction, and engine modifications for increased fuel efficiency. In the case of projected fleet aircraft, such as a VFMX, JVX, ECX, or VPX, a fundamental analysis of operational mission utilization, design approach, and future technologies is considered to provide an assessment of the optimum fuel efficient configuration. Plans are currently underway to develop fuel efficiency methodology that will apply to a wide range of fighter, attack, and patrol aircraft.

A Grumman Aircraft Corporation Study (3), "Advanced Fighter/Attack Aircraft Energy Savings Concept Investigation", addresses a wide range of generic technology concepts that can be applied to next generation fighter/attack aircraft. Several concepts that may apply to planned aircraft are as follows:

- Variable Attitude Cockpit
- Tailored Component Distribution
- Variable Lip Inlet
- Laminar Flow Control
- Maneuver Vortex Flap
- Vortex Lift (High Lift)

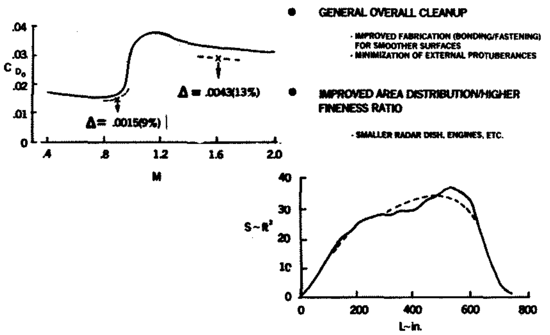
The Variable Attitude Cockpit concept (Figure 12) allows the pilot to be positioned in a normal viewing attitude for take-off, climb, descent, landing and subsonic cruise. However, during supersonic cruise, the cockpit is rotated downward to blend into the fuselage forebody and therefore provide reduced frontal area and associated reduction in C_{D_0} (approximately 4%).



VARIABLE ATTITUDE COCKPIT

Figure 12

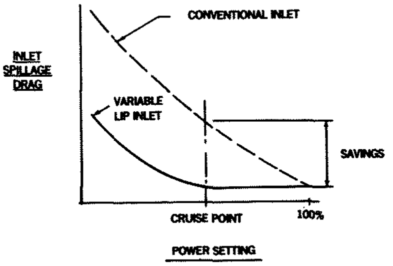
Through the Tailored Component Distribution concept (Figure 13), the aircraft designer attempts to reevaluate his configuration based on a general overall cleanup approach that includes items such as improved fabrication for smoother surfaces and minimization of external protuberances. For supersonic aircraft, attempts are made to improve the area distribution or increase the fineness ratio by attempting to reduce the radar dish size, or engine location, etc. Through these approaches fuel savings can be realized by a reduction in C_{D_0} ranging from 9% (subsonic) to 13% (supersonic).



TAILORED COMPONENT DISTRIBUTION

Figure 13

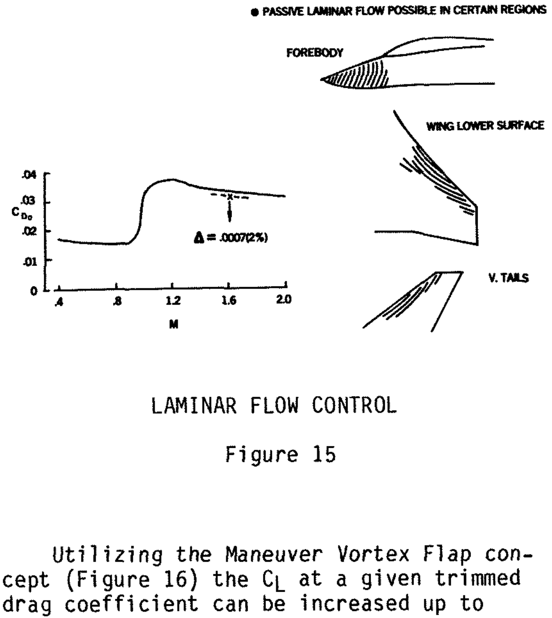
A Variable Lip Inlet (Figure 14) would reduce the inlet spillage drag over a conventional inlet and therefore provide fuel savings especially at the design cruise point where lower power settings are used.



VARIABLE LIP INLET

Figure 14

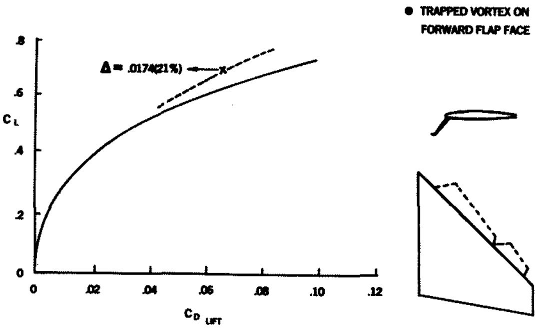
Laminar Flow Control (Figure 15) is a concept that has been gaining increased attention in recent years. By selective application of passive laminar flow control in certain regions such as the forebody, wing lower surface, and vertical tails, the supersonic C_{D_0} can be reduced up to 2%.



LAMINAR FLOW CONTROL

Figure 15

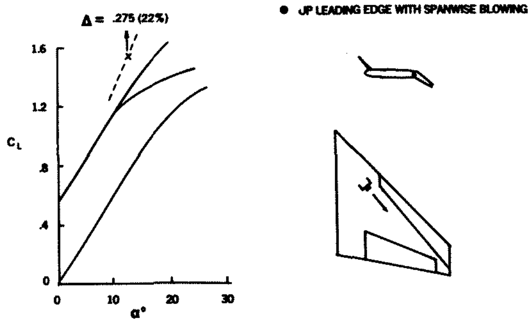
Utilizing the Maneuver Vortex Flap concept (Figure 16) the C_L at a given trimmed drag coefficient can be increased up to approximately 20% due to trapping the vortex flow on the forward flap face.



MANEUVER VORTEX FLAP

Figure 16

Finally for high C_L flight conditions, employment of Vortex Lift (Figure 17) where you have an up leading edge with spanwise blowing, can provide a significant increase in lift coefficient (up to 22%) for angles of attack of 10 degrees.



VORTEX LIFT (HIGH LIFT)

Figure 17

Additional aerodynamic concepts (4, 5, 6) that can be applied to planned aircraft include the following:

- Relaxed Static Stability
- Variable Camber Wing
- Blended Body
- Conformal Fuel Tank
- Advanced Airfoils
- Winglets
- Forward Swept Wings
- Advanced High Lift Systems

For rotary wing vehicles, additional aerodynamic concepts include:

- Rotor Hub Fairings
- Low Drag Hubs
- Fuselage Drag Reduction
- Advanced Rotor Airfoil
- Advanced Tail Rotor Concepts

Table 2 shows additional concepts that apply to propulsion, structures, flight controls, and other subsystems.

Propulsion

- Advanced Engines
- Reduced Installation Losses
- Advanced Engine Controls
- Advanced Transmissions
- 2800° Engine Fixed Geometry
- 2400° Ceramic Turbine
- Variable Cycle Engine (Single/Double Bypass)
- Variable Lip Inlet
- 2-D Vectored Nozzles
- Advanced Digital Engine Control
- Advanced APU/EPU
- Modulated Turbine Cooling

Structures

- Advanced Composites/Metals
- Post Buckling Design Criteria
- Integrally Molded Assemblies
- SPF/DB Titanium, HIP Titanium
- Weld Bond Aluminum
- Advanced Metals/Fabrication

Flight Controls

- Flight Management System/Flight Control Laws
- FBW DFCS
- Fiber Optic FCS Data Buss
- All-Electric FCS
- Combat Energy Management

Weapon System

- Semi-Submerged Stores
- Wing-Tip Mounted AIM-9
- Gun/Ammo Removed
- 1-Man Crew
- Advanced Avionics (Weight Reduction)
- Reduced Radar Antenna Diameter

Subsystems

- High Speed Electrical Generators
- 8000 psi Hydraulics
- Fiber Optic Controls
- Closed Loop ECS

ENERGY REDUCTION CONCEPTS

Table 2

TECHNOLOGY DESIGN APPLICATIONS

The aircraft energy-savings technology effort attempts to identify, develop, and evaluate technologies and subsystems needed to support advanced air vehicle designs (year 2000+) and subsystems which promise significant reduction in use of petroleum derived energy. This effort includes definition and application of energy efficient vehicle configurations, research in technologies for advanced systems and subsystems, and mathematical methodology to evaluate future air vehicle configurations.

Examples of air vehicle configurations that show promise of future application in the year 2000+ include:

- Electric Powered Aircraft
- Nuclear Powered Aircraft
- Advanced LTA (Lighter-Than-Air) Vehicles
- Long Endurance Reconnaissance RPV's (Remotely Piloted Vehicles)

For example, an LTA airship provides an alternative concept to satisfy existing Naval requirements. This advanced LTA airship may be able to support the following missions with greatly reduced on-board energy needs.

CONVOY ESCORT
TOWED/DIPPING SONAR
MINE COUNTERMEASURES
CARRIER OPERATIONS
SUBMARINE TRAIL
SURVEILLANCE/RECON
OCEANOGRAPHY
OVER-THE-HORIZON TARGETING
AIR-TO-SURFACE MISSILE WARNING
ICBM TRANSPORTER/LAUNCHER
C^3 (COMMAND, CONTROL, COMMUNICATIONS)

Because of the versatility and proven concept of LTA vehicles, studies are planned to carefully examine specific Navy mission scenarios constructed from current and future Naval requirements. Areas that show promise in a cost effective and fuel efficient manner will be defined for further evaluation. Computer analyses will be performed to size various vehicle configurations and estimate performance.

The second area that is specifically oriented toward research in technologies for advanced systems and subsystems includes, as examples, the following concepts:

- Energy Efficient Environmental Control System (ECS)
- 270 Volt DC Power Systems

The Energy Efficiency ECS objective is to significantly reduce the power required by the ECS to provide a given amount of cooling. The approach is to demonstrate the feasibility of installation and projected fuel savings potential for a closed loop ECS directly driven by a variable speed D.C. motor. If successful the concept will be flight tested in an existing aircraft and will be specified for future aircraft. The closed loop ECS system is capable of saving fuel by reducing the ground cooling requirements of the APU (Auxiliary Power Unit) as well as in-flight cooling.

Energy Efficient 270 Volt DC Electrical Systems offer an energy savings potential of 3% to 4%. These fuel savings are attributed to a high efficiency power generation system and to the application of high efficiency power supply technology for avionics. The basic advantage of the high voltage DC system is as follows:

- Reduced weight in power distribution
- Reduced weight in power generation
- Reduced power generator complexity
- Simplified redundant power distribution busses
- Better suited to solid state power control
  - Less complexity
  - More efficient

Another area for technology design applications includes methodology development specifically oriented toward energy savings applications. Examples of the types of methodology development that are applicable to technology design include:

- Store Drag Reduction
- Aircraft Design Modification Analysis
- Configuration Evaluation

Store Drag Reduction technology includes reducing drag and fuel usage penalties associated with carriage of external stores. Through optimization of conformal carriage of weapon systems, a large payoff can be achieved in relative specific range due to a reduction in drag. Mathematical models that optimize the carriage of these weapons for future aircraft is a methodology that is gaining greater attention within the Navy.

The aircraft modification methodology includes assessing energy efficient concepts through mathematical modeling as applied to aircraft systems. Many energy savings concepts yield only 1% to 2% fuel savings and are therefore difficult to measure in wind tunnel or flight tests. By utilizing advanced aerodynamic paneling techniques, estimates can be obtained for potential fuel savings.

Finally, the need for Mathematical Methodology development to assess and evaluate various future aircraft configurations based on their energy efficiency has been realized. A new effort to support this development will commence in FY83.

SUMMARY

Current Naval aircraft are being evaluated to determine potential fuel savings benefits from aerodynamic modifications that reduce drag and weight, subsystem enhancements such as flight advisory/management systems and by fleet operational changes. Near term next generation aircaft will benefit from design enhancements that improve fuel efficiency. Efforts are currently underway to investigate year 2000+ fuel-saving technologies that show high potential paybacks to future Naval attack, fighter and patrol aircraft.

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