[5]Tijdeman, H. and Zwaan, R.J., "Unsteady Aerodynamics for Wings with Control Surfaces," AGARD-CP-80-71, April 1971.

[6]Forsching, H., Triebstein, H., and Wagener, J., "Pressure Measurement on an Harmonically Oscillating Swept Wing with Two Control Surfaces in Incompressible Flow," AGARD-CP-80-71, April 1971.

[7]LaBarge, W.L., "Correlation of Theoretical and Experimental Pressure Distributions over an Oscillating Wing and Two Control Surfaces," Lockheed California Company, Rept. LR-24737, Sept. 1971.

[8]Ashley, H. and Rodden, W.P., "Wing-Body Aerodynamic Interaction," *Annual Review of Fluid Mechanics,* Vol. 4, 1972, pp. 431-472.

[9]Rowe, W.S., Winther, B.A., and Redman, M.C., "Unsteady Subsonic Aerodynamic Loadings Caused by Control Surface Motions," *Journal of Aircraft*, Vol. 11, Jan. 1974, pp. 45-54.

[10]Rowe, W.S., Sebastian, J.D., and Redman, M.C., "Recent Developments in Predicting Unsteady Airloads Caused by Control Surface Motions," *Journal of Aircraft*, Vol. 13, Dec. 1976, pp. 955-961.

[11]Turner, D. and Astle, D.C., "A Study of the Effect of Control Surface Aerodynamics on Flutter Analysis," *Proceedings of the Conference on Finite Element Methods and Technology*, March 1981.

AIAA 81-1681R

Navy A-7 Fuel Conservation Program

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Background

THE 1973 embargo by OPEC (Organization of Petroleum Exporting Countries) and the resulting increase in the cost of petroleum-based fuels prompted the United States government and citizenry to undertake comprehensive fuel conservation measures. The U.S. Navy is doing its share through the Navy Energy Office (OPNAV-413).[1] The Navy Aircraft Fuel Conservation (NAFC) Program is a subelement of the energy program. The specific goal for aircraft is a 5% *reduction in fuel consumption per flight hour* by 1985, based on recorded fuel use for 1975.

Six aircraft types annually use nearly 75% of the total Naval aviation fuel. In the order of highest to lowest usage, the aircraft are the F-4, P-3, A-6, A-7, A-4, and F-14. The following discussion provides an example of the NAFC program. The research, development, test, and evaluation (RDT&E) approach to achieve the fuel conservation goal for the Navy's fleet of A-7 aircraft is highlighted.

A-7 Fuel Saving Technology Applications Study

The A-7 fuel conservation project started (as did the other projects within the NAFC program) with a technology applications study. The three-phase study was conducted by the Vought Corporation. Representative technologies and concepts for increasing the aircraft's fuel efficiency included composite applications for weight reduction, drag reduction through clean-up and fairing additions, engine modifications to reduce thrust specific fuel consumption, and even added collection systems to eliminate small fuel losses. A total of 59 concepts were defined. Evaluation criteria included the practicality and ease of retrofit, implementation period and cost, fuel savings potential, and impacts on reliability, maintainability, and survivability.

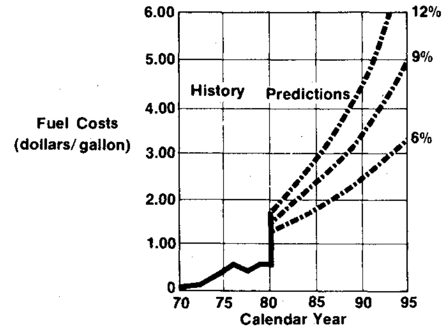

Fig. 1 JP-5 fuel cost increases through 1995 (based on 1981 dollars).

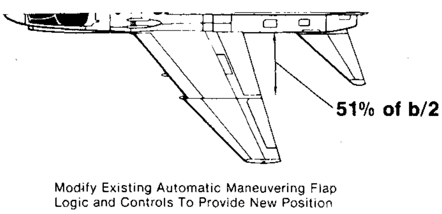

Fig. 2 Trailing-edge cruise flap.

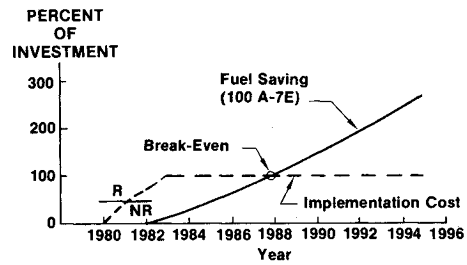

Fig. 3 Payback potential for cruise flap.

Elements of the concept evaluations are illustrated below. Fuel costs are shown in Fig. 1. The history is included along with the future increase projections, which range from 6 to 12% annually (based on 1981 dollars). The drooped flap concept, Fig. 2, would improve performance during cruise flight by lowering the large, semispan trailing-edge flaps about 5 deg. On the A-7, the modification is primarily a control system change which permits the intermediate stop. Figure 3 indicates the relative implementation cost, fuel savings, and payback for this modification.[2] Nine concepts survived the evaluations with positive payback potential. Navy evaluations resulted in the selection of eight for validation and development. Without exception, the concepts exhibit a savings potential of 1-3% and a cost break-even period of 3-6 years. This cost payback compares favorably with the remaining 15 years of planned A-7E service with the Navy. The status of each is given below.

Validation and Development Status

The drooped trailing-edge flap concept, shown in Fig. 2, has been tested. The wind-tunnel tests have shown a trim drag reduction of approximately 8-10 counts ($\Delta C_D = 0.0008$-0.0010). This translates into a 3% improvement in cruise

Presented as Paper 81-1681 at the AIAA Aircraft Systems and Technology Meeting, Dayton, Ohio, Aug. 11-13, 1981; submitted Oct. 14, 1981; revision received Nov. 23, 1981. This paper is declared a work of the U.S. Government and therefore is in the public domain.

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specific range. Currently, the concept is being flight tested at the Naval Air Test Center to determine flying qualities and fuel savings potential. Design and development efforts leading to an engineering change proposal will be undertaken as the next step.

Several aerodynamic fairings aimed at reducing the total drag of the A-7 aircraft have been identified. Three small fairings which are currently under consideration for implementation reduce drag on the tailhook, gun port, and air-conditioning overboard dump. The pylon cavity fairing for unused pylons remains in the RDT&E phase at the present time. As part of this RDT&E, a single fairing design, common to all wing pylons, will be tested to examine feasibility and practicality of such an approach. Concurrent with the static installation evaluation, a wind-tunnel test will be conducted to establish the potential drag benefits.

The TF41 low-pressure turbine blade and vane replacement modification will reduce thrust specific fuel consumption by approximately 2-2½%. This estimate is based on analytical studies which parametrically varied turbine efficiency. The RDT&E effort consists of a full-scale performance proof-of-concept rig test which will be followed by a prototype flight test. In addition to fuel saving, this concept also offers reliability and maintainability improvements due to the resulting lower turbine inlet temperature requirements.

Removal of unused equipment is a recommended operational procedure throughout the Navy. Such removals yield immediate fuel saving through weight reduction (for internal equipment), and through weight and drag reduction (for external equipment). The A-7 Fuel Conservation Program specifically addresses the feasibility and practicality of frequent removal of wing pylons. Wing pylon removal offers significant drag reduction (10-20 counts) at no cost (excluding personnel cost) to the Navy. The recently completed RDT&E phase included engineering design reviews, analytical studies to compute fuel savings, and extensive discussions with A-7 maintenance and flight personnel.[3]

The onboard flight performance advisory system (FPAS) is a simplified extension of the computerized thrust/fuel management system used extensively by commercial airlines. The FPAS being considered for the A-7E aircraft[4] will utilize available memory space within the TC-2A tactical computer, and the existing cockpit display. This is a valid, cost-effective approach since the military qualified TC-2A is already installed in the aircraft and integrated with the air data computer. The only modification required is the revision of the TC-2A software tape to include the FPAS algorithm. In accordance with current plans, an A-7E FPAS algorithm will be developed and incorporated into the TC-2A tape during CY 1982. This effort will be followed by a fleet test and evaluation of the FPAS program's utility, accuracy, and contribution toward fuel conservation.

The stand-alone flight performance advisory systems, functionally similar to the onboard FPAS, are not integrated into the aircraft. Two stand-alone systems are currently being considered for the A-7E. The first is a desk-top minicomputer, similar to the HP-45C or the INTEL 8086, to be used for complete mission planning. The second is a pocket-sized programmable calculator, similar to the HP-41C,[5] to be used inflight for mission segment data. All FPAS configurations will use algorithms developed from a single performance data source. Fleet evaluation of the pocket-sized FPAS has demonstrated practicality as well as fuel savings.

Concluding Remarks

The A-7 study results led to two primary conclusions: first, the fuel savings from drag reduction and engine specific fuel consumption reduction modifications are large, and the payback potential is significant; and second, the fuel savings from weight reduction modifications are small, and the payback potential is nil.

The NAFC program has found similar results for other aircraft. The most cost effective (fuel savings exceed implementation cost) concepts are of the type illustrated by the A-7, i.e., drag improvements rather than airframe modifications, and more efficient operations through unused bomb rack/pylon removal and FPAS.

The active, ongoing fuel conservation program of the U.S. Navy has been briefly outlined. The systematic process of determining cost-effective, current-inventory aircraft modifications and operational procedure changes leading to improved flight-hours per gallon of fuel consumed has been described. The current status of the items under development for the A-7 aircraft is given. Positive demonstrations will result in the recommendation for and incorporation of modifications which will meet the schedule and fuel conservation goals for Navy A-7 fleet aircraft. The additions of the operational changes will provide fuel conservation in excess of energy program goals.

References

[1] "Department of the Navy Energy Plan FY 1981," OPNAV 41P4.B, Sept. 1980.

[2] Mallett, W.E., "A-7 Fuel-Saving Technology Applications Study," NADC-79015-60, Feb. 1980.

[3] Mallett, W.E., "A-7 Pylon Removal/Modification Study for Fuel Conservation," NADC 79293-60, Aug. 1980.

[4] Mallett, W.E., "A-7E Computerized Flight Performance Advisory System—Feasibility and Implications Investigation," NADC-80068-80, March 1981.

[5] Herskovitz, M., "The A-7E/HP41-C Pocket-Sized Flight Performance Advisory System," NADC-80241-60, Dec. 1980.

AIAA 82-4087

Expansion Series of Integral Functions Occurring in Unsteady Aerodynamics

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Introduction

IN the kernel of singular integral equations for subsonic unsteady lifting surfaces (see, e.g., Ref. 1), the following real integral functions occur with arguments k, r, and X, which correspond to the reduced frequency, spanwise distance, and modified coordinate in the flow direction, respectively.

$$B_R^{(\nu)}(k,r,X) = \int_{-\infty}^{X} \frac{\cos kv}{(v^2+r^2)^{\nu+1/2}} \mathrm{d}v \tag{1}$$

$$B_I^{(\nu)}(k,r,X) = \int_{-\infty}^{X} \frac{\sin kv}{(v^2+r^2)^{\nu+1/2}} \mathrm{d}v \tag{2}$$

Two of the arguments, k and r, are assumed non-negative. For coplanar surfaces, the parameter ν takes the value of 1. For nonplanar geometry of lifting surfaces,[2] the case $\nu=2$ occurs as well as $\nu=1$. If the flow is supersonic, the lower limits of these integrals are interrupted by the Mach cone and therefore have finite values, as can be seen in Ref. 3. Integral functions Eqs. (1) and (2) are evaluated in most existing lifting

Received Dec. 7, 1981.

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