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Civil Aircraft Challenges in Engine/Airframe Integration

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ABSTRACT

The demand for economic and efficient aircraft has focused more attention on the integrated design process. In addition, supersonic flight speeds pose unique design constraints on both propulsion and airframe technologies. This paper addresses some of the key features of engine/airframe integration in both the subsonic and supersonic flight regimes, and addresses both design and test implications.

INTRODUCTION

The design challenge for civil aircraft has always involved a multi-disciplinary approach among technologies (aerodynamics, propulsion, structures, systems, etc.), economics (DOC, LCC), and marketing. Given the current competitive climate internationally, the challenges have intensified in all these areas. This paper addresses some of the key features of engine/airframe integration in the design process and identifies some of the resulting implications for subsonic and supersonic designs.

Four technology areas are examined from a design integration perspective: subsonic propulsion integration, supersonic inlets, integrated flight and propulsion controls, and laminar flow controls. Each of these technology areas contains unique challenges that have made an integrated design the pacing consideration in civil aircraft development.

SUBSONIC PROPULSION INTEGRATION

Engine selection for the next generation subsonic cruise applications is focused on the increased bypass ratio turbofan. The unique features of high bypass ratio turbofan engines from a propulsion/airframe integration standpoint derive from the large relative diameter of the nacelle. The typical installation uses a conventional turbofan core geared to a variable-pitch fan. A significant feature of this approach is the ability to design the fan for reduced noise and high efficiency, coupled to a smaller high-speed core. This arrangement, depicted in Figure 1, makes it possible to avoid a fan duct thrust reverser, thereby providing a slimline nacelle configuration which reduces the weight and drag of the propulsion system. In recent studies at Douglas, the nacelle size alone, as illustrated in Figure 2, is shown to have a significant impact on weight and drag. Elimination of the conventional thrust reverser has a favorable affect on nacelle cost, weight, and maintenance, at the expense of some increased complexity of the variable pitch fan system. Engine company investigations have confirmed the feasibility of this system, and detailed testing will be used to develop fan/nacelle features to explore the benefits of variable-pitch technology in high-bypass designs.

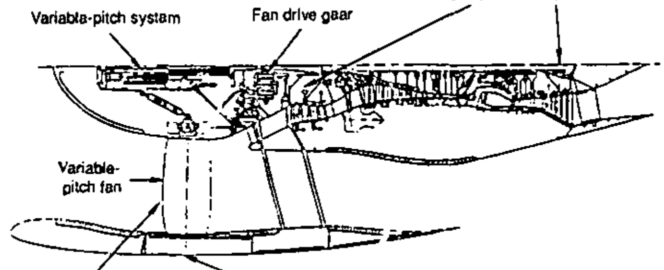

FIGURE 1. PRATT & WHITNEY ADVANCED DUCTED ENGINE

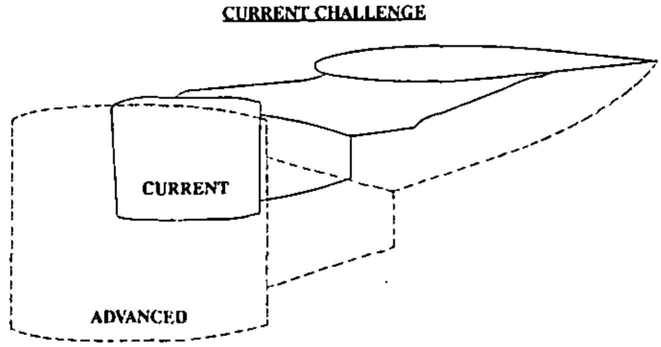

FIGURE 2. SUBSONIC AERODYNAMICS TECHNOLOGY

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Current development efforts are driven by thrust and fuel efficiency requirements. The promise of thrust improvements on the order of 20 percent and efficiency improvements on the order of 12 percent have made integration with the airframe a pivotal issue.

Multiple optimizations will have to be completed in order to incorporate the requirements for performance (thrust, fuel efficiency), emissions, noise, weight, drag, cost, and maintenance.

SUPERSONIC INLET TECHNOLOGY

The propulsion system installation in a supersonic airframe involves many interacting disciplines. One of the primary drivers is the engine/inlet interface. Prior studies sponsored by NASA (Welge et al, 1977 and Douglas, 1979) examined both axisymmetric and rectangular inlets. Also, NASA-sponsored wind-tunnel tests of a complete HSCT airplane model were conducted by Douglas in 1975 (Radkey et. al., 1977). Both mixed- and external-compression axisymmetric inlet nacelles were tested. The effect of wing reflex on wing/nacelle interference was investigated. The Douglas (1979) study was for a high speed civil transport (HSCT) with variable cycle engine (VCE), conducted by Douglas in 1978. At that time Boeing, Douglas, and Lockheed conducted studies that compared 2 mixed-compression axisymmetric inlets, one with a variable-diameter centerbody, the other with translating centerbody.

More recently, the NASA High Speed Research (HSR) Program has been investigating inlet configurations for a HSCT. The Douglas HSCT baseline configuration is shown in Figure 3. The 300-passenger aircraft has a design-mission range of 5500 nm. The over-water supersonic-cruise Mach number is 2.40, with 25-percent of the range over land at a subsonic-cruise Mach number of 0.95. The design mission was defined after 250 possible city-pair missions were considered.

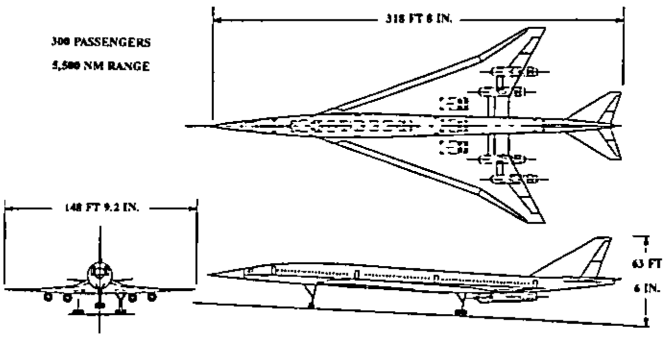

FIGURE 3. DAC HSCT CONFIGURATION

One of the engines used for HSCT trade studies is a General Electric VCE (variable cycle engine) surrounded by a FLADE (fan on blade) bypass duct, Figure 4. The FLADE duct contains a single fan stage made up of extended VCE fan blades, and variable inlet guide vanes and variable exit area. FLADE air is ducted to and exhausted from the lower 200-degree portion of the nacelle, for attenuation of airplane-to-ground jet noise. The FLADE engine provides low noise levels at takeoff and transonic-climb conditions, and low SFC at subsonic-cruise conditions.

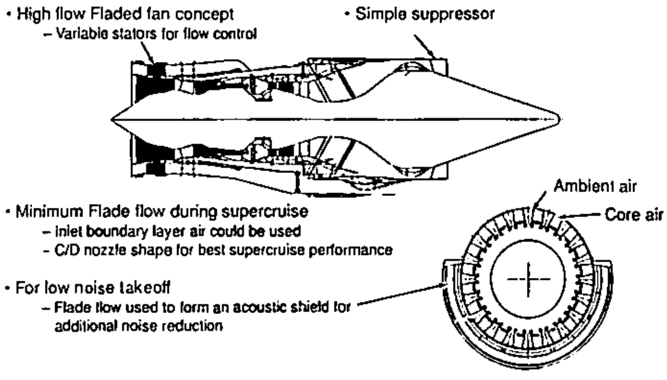

FIGURE 4. GENERAL ELECTRIC FLADE ENGINE

In order to provide the airflow variations at takeoff, climb, and cruise, an efficient variable inlet is required. Several types of inlets are being evaluated, including the variable diameter centerbody inlet (Figure 5).

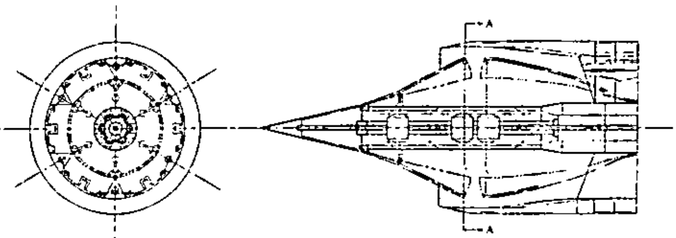

FIGURE 5. VARIABLE DIAMETER CENTERBODY INLET FOR VARIABLE CYCLE ENGINE

A modified version of this design will provide the high airflows at takeoff and climb that may be required for noise suppression and also the lower airflows at cruise conditions.

Inlet studies have focused on mixed-compression inlets in single-engine nacelles. Previous Douglas studies had shown significant performance penalties for external-compression inlets and for multiple-engine pods. The external compression inlets had high initial cowl angles with high wave drag. In the multiple-engine pods the inlets and engines could not be staggered for a low-wave-drag area distribution.

The method currently in use for determination of nacelle wave drag and airplane characteristics with nacelles installed will be further evaluated and modified if necessary, since external-aerodynamic characteristics has a significant effect on the results. This can be done using existing wind-tunnel data for a $M = 2.2$ HSCT configuration (Radkey et al, 1977) with nacelles installed, and with appropriate Euler and Navier-Stokes calculations.

INTEGRATED FLIGHT AND PROPULSION CONTROLS

One of the key features of an integrated control system is the integration of propulsion and flight controls. Not only is this an avenue for design optimization to achieve performance, weight, and cost benefits, but also to implement reconfigurable control concepts as envisioned in the McDonnell Douglas Propulsion Controlled Aircraft (PCA) concept.

The PCA system uses engine thrust to control roll and pitch in the event of a failure of the conventional control system. In addition, thrust control concepts are under study that would be used in parallel with conventional control surfaces to augment the airplane control performance. In this case, there is a full-time augmented propulsion/airframe integrated system that isn't dependent on a failure to trigger operation.

The feasibility of this concept has been studied at Douglas and McDonnell Aircraft Co. for several cases of interest. Figure 6 shows a conceptual scenario for transport aircraft control reconfiguration following control system damage during flight.

An integrated control law design also provides the pilot with the capability to control airspeed in addition to flight path angle and bank angle control. A fully integrated approach employs both fuel transfer and thrust modulation regulated by the control system in response to pilot commands.

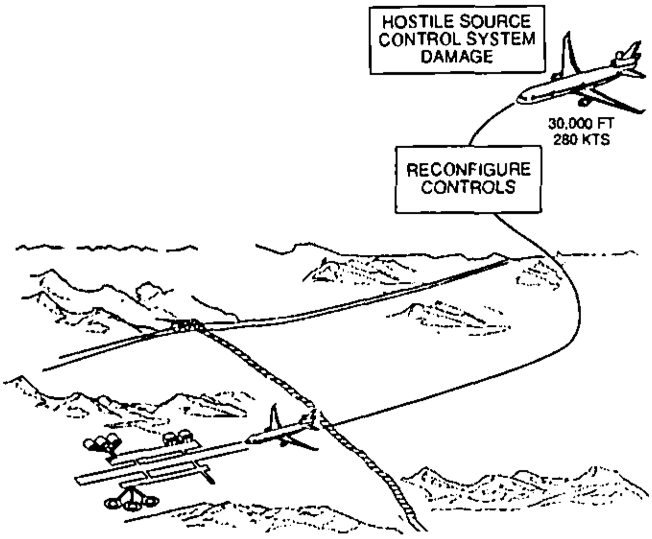

FIGURE 6. FEASIBILITY OF PROPULSION CONTROL FOR TRANSPORT AIRCRAFT

In recent studies of the feasibility of applying propulsion controlled aircraft concepts to civil transports, linear three-degree-of-freedom analysis at low speed flight conditions were performed for an MD-11 configuration. PCA for an MD-11 type aircraft appears to be feasible, but further study is required to resolve some questions concerning the differences between the linear results and results seen in nonlinear six-degree-of-freedom MD-11 simulations.

LAMINAR FLOW CONTROL (LFC)

In the development of aircraft configurations for supersonic cruise, large potential benefits have been identified for laminar flow surfaces. An integrated design approach, however, must evaluate the propulsion system penalties associated with providing the suction power in order to determine the true cost/benefit relationships of LFC.

Previous studies (Powell et. al., 1989) have shown that LFC technology is applicable to supersonic cruise airplanes of the Mach 2+ flight regime. While no intractable aerodynamic problems were identified, several key issues -- such as contamination avoidance and high-lift system integration -- were identified and research objectives were established.

The above-referenced study showed a benefit of up to 15% in L/D for complete LFC. Concomitant with this benefit are the challenges and economic risk of weight, cost, and maintenance requirements for the LFC suction system, which is the highest risk factor to be considered. These risks are minimized when suction airflow is minimized, which requires careful and precise control of the wing pressure distribution. This requires control of low levels of boundary layer crossflow and may imply precision control of the suction distribution.

The propulsion system, then (if it is used as the LFC suction system energizer) becomes a critical partner in the integration of a viable supersonic LFC airplane.

The lower surface of the wing offers a larger potential for drag reduction due to laminarization than the upper surface. The ratio of contributions to L/D improvement from the lower and upper surfaces is on the order of 4 to 3. However, this is calculated for a lower wing surface without engines. Obviously then, engine integration into the lower surface of the wing is important, although more difficult. Additional challenges due to this integration are:

- Loss of laminarizable wing area.
- Potential to laminarize nacelle or cowl.
- Termination of laminar flow due to impingement of the inlet spill shock on the wing surface.
- Structural integration of ducting and wing/engine integration.
- Location of fuel: there is a potential for natural laminar flow on the lower surface if the fuel can be used to cool and stabilize the boundary layer.
- Location of aero break station.
- Optimization of active suction or "pumping" system and integration with engines.
- Type of drive for suction system.
- Nozzle thrust recovery from compressor.
- Source of heat for ice protection if required by laminar flow application.
- Potential turbulent skin friction and pressure drag reduction aft of control surface hingeline for low-speed slot injection of suction air.

CONCLUSIONS

Many technologies must be integrated to achieve a viable multidisciplinary design. Several key areas have been shown to present unique challenges in the civil aircraft design process. In addition to the conventional considerations of inlet/engine and nacelle/airframe integration, features such as LFC, HBPR nacelles, and integrated controls can be important drivers in multidisciplinary designs.

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