Low-Cost Demonstrators for Maturing Technologies

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The use of low-cost demonstrators has been evaluated and found to be an effective tool to supplement wind tunnel, numerical, and empirical data in the development of new aircraft and the maturation of technologies. Through the use of the modular aircraft concept, one basic core vehicle can be used to simulate a wide range of air vehicles for minimal additional costs. Using this approach, a modular demonstrator can be developed for well under $1 million.

Introduction

THE progress of aeronautics has relied heavily on actual flight experience. In fact, the only reliable design information available in the early years of aeronautics was that gained from flight. After powered flight became a reality, the theoretical analyses and ground-based experimental capabilities slowly evolved to supplement flight-test data.

As the performance capabilities of aircraft increased, so did their development costs. As a result, the need to reduce the technical and financial risks in a new project has grown significantly. Figure 1, reproduced from Ref. 1, shows the estimated relative costs required to make a significant configuration change to an aircraft during its development cycle. This figure shows that by determining if configuration changes are necessary early in a program, the costs associated with such a change can be minimized. For example, if a demonstrator is used before the start of preliminary design, and a change to the configuration is found to be necessary, the cost is about $1/10^5$ of that if the necessity for configuration change were discovered after first flight. This is the fundamental reason for using low-cost flight demonstrators—the early cost-effective detection of problems and the low-cost verification of fixes for these problems.

From the very earliest days of aviation flight, demonstrators have been used in the development process. A small survey of aviation literature resulted in a list of some 50 such demonstrators.

Several flight demonstrators for specific aircraft are notable. Among these are the one-half-scale demonstrator of the Short Stirling,[2] the one-fourth-scale demonstrator of the Martin PBM,[3] the Boeing 370-80[4] predecessor to the KC-135 and 707 transport series, the Fairchild Republic Next Generation Trainer (NGT) demonstrator,[5] and the Rutan/Beech Starship demonstrator.[6] These aircraft all were used to determine the handling characteristics in flight and/or during takeoff and landing prior to completion of the full-scale vehicle.

Another group of demonstrators consists of those specifically developed to explore flight conditions previously unattainable by conventional means. This group of demonstrators includes the Bell X-1 and X-2 series and the North American X-15, which were dedicated to the exploration of supersonic and hypersonic flight, and the Bell X-13, X-14, and X-22, the Hiller X-18, and the Curtiss Wright X-19 demonstrators which explored V/STOL flight (see Ref. 7).

A number of other demonstrators were used to explore applications of specific technologies. For example, the Northrop X-21[7] demonstrated the use of boundary-layer suction to stabilize laminar boundary layers at high Reynolds numbers. Both the AVRO 707 and MiG-21-SST[8] demonstrators were used to gain flight experience with thin, highly cambered, and twisted wings for supersonic transports. The French Leduc series of demonstrators[9] investigated the use of highly integrated manned ramjet-powered vehicles. The General Dynamics F-111 TACT aircraft was used to test the high-speed characteristics of supercritical airfoil sections. The F-8 SCW aircraft was fitted with an entirely new supercritical wing to demonstrate near-sonic cruise capability.

Note that most of the demonstrators listed above were not low-cost aircraft. Only recently has it been possible to build truly low-cost demonstrators through the use of inexpensive composite construction and small inexpensive turbine engines. The Fairchild Republic Company (FRC) subscale NGT demonstrator, the NASA AD-1 skew wing aircraft, and the Beech/Rutan Starship are examples of the possibilities now available.

FRC used the low-cost demonstrator approach to reduce the risks inherent in the USAF Next Generation Trainer program. The FRC 62%-scale NGT demonstrator shown in Fig. 2 was designed, built, and flown to investigate the handling characteristics and configuration aerodynamics prior to the submission of the proposal for full-scale development of the T-46A.

The fact that FRC is today producing the T-46A aircraft is due in part to the excellent technical validation of the basic aircraft concept provided by this demonstrator. The flight demonstration program, which required only a total of ten calendar months (including two months of flight testing with 23 flight-test hours), showed that the stability levels and basic response of the air-frame closely matched the predictions. In addition, the general handling and stalling characteristics of the configuration were explored and refined to the satisfaction of the pilot community who flew it.

The flight-test data received by telemetry during the FRC tests proved to be of high quality, and comparable to data normally obtained from well-instrumented conventional

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flight-test aircraft. Of particular importance was the generation of control force and handling qualities data for the aircraft with one engine inoperative. This type of data can be estimated analytically prior to flight, but early in-flight verification of such data can be of immense help early in the life of a project.

Benefits and Limitations of Using Low-Cost Demonstrators

All model tests entail some compromises. Wind tunnel data must be corrected to account for many factors, such as the effects of the wind tunnel walls and the model support systems. The magnitude of these corrections may approach that of the measured data when the ratio of model span to tunnel width and/or tunnel blockage is large. In addition, sting mounts may require significant distortion of the rear of the model fuselage, which may induce unknown secondary effects. Wind tunnel data must also be corrected to full-scale Reynolds number when applied to the full-scale vehicle. Less well known are the effects of noise and tunnel turbulence. Thus, wind tunnel results are not without shortcomings.

The computational capability of the aerospace industry is growing rapidly. Many aerodynamic, aeroelastic, and structural problems can be analyzed using new methods and approaches. While much progress has been made in the analysis of the combined viscid and inviscid flows over real aerodynamic shapes, current numerical methods are far from capable of treating the real flow around a complete real aircraft due to a general inability to successfully treat the problem of large-scale separations which occur at large angles of attack. In addition, the costs of these calculations are nontrivial. Hence, the usefulness of numerical methods is technically limited in spite of a promising future.

The low-cost demonstrator approach provides a means of flight testing relatively large-scale models of proposed aircraft and technologies with minimal distortion of the external lines. For example, the FRC NGT demonstrator was 62% of the full-scale vehicle size. Thus, Reynolds number dependent data need to be extrapolated only from 62 to 100%.

The benefits from using low-cost subscale demonstrators are: the large test Reynolds number available; ease of configuration modification; little configuration compromise; excellent representation of the vehicle flowfield; excellent simulation of special flight conditions (such as one engine out); more realistic data before, during, and after the stall; and excellent representation of nonsteady effects. These benefits are discussed below.

Through the use of low-cost demonstrators, flight-test data can be obtained both at relatively large Reynolds numbers and at reasonable Mach numbers. This means that only modest extrapolation to full scale is required. A significant increase in the realism of the data is then possible. In addition, some instrumentation problems, such as plumbing for measurement of local pressures, are greatly reduced due to the relatively large size of the test vehicle.

Configuration variations can be accomplished easily. Removal and replacement of major portions of the airframe can be done quickly and economically. A modular method of designing and constructing low-cost demonstrators, which is discussed below, supports this ability to quickly modify configurations at modest cost. The fairly large scale of flight demonstrators also allows detailed representation of the aircraft configuration and changes thereto.

The aircraft configuration is not compromised, as is the case for many wind tunnel models. As noted above, sting mounting of wind tunnel models often results in distorted rear fuselage lines. This distortion then must be accounted for when evaluating test data and extrapolating the data to full-scale conditions. Low-cost demonstrator data will not require this type of correction.

The demonstrator provides an excellent representation of the flowfield around the full-scale vehicle. Thus, the demonstrator can be used to determine the trajectory of solids, liquids, or gases ejected from the full-scale aircraft. In particular, this type of testing can be used to check/verify the launching of unusual store shapes from the aircraft.

Excellent simulation of unusual flight conditions, such as one-engine-inoperative flight, can be carried out. The results from this type of flight test are far more meaningful than the results based only on wind tunnel data and analytic estimates. Early verification of the ability of an aircraft to be flown safely in these unusual flight conditions provides increased confidence in the configuration early in the project.

Stall progressions and associated buffeting are modeled more realistically using a low-cost demonstrator rather than a wind tunnel model. The noise, turbulence, and finite extent of a wind tunnel test section have a significant influence on the stalling characteristics of a model. It is not unusual for the free-flight maximum lift coefficient and the stall characteristics of an aircraft to differ radically from those measured in the wind tunnel. Thus, demonstrator flight tests can provide far more meaningful secondary data than can be gathered using mechanical sensors on wind tunnel models.

Non-steady aerodynamic effects, which are extremely difficult to estimate accurately, are included automatically in the forces and moments acting on the vehicle. Damping in pitch, roll, and yaw can only be approximated analytically or determined by sophisticated wind tunnel tests. These data can be derived with reasonable confidence from demonstrator flight tests.

The low-cost demonstrator approach has some limitations: problems flying beyond the stall angle of attack, limited velocity range, engine-airframe mismatch, altitude limitation without pressurization, and the difficulty of scaling vehicle inertias.

Flight-test data beyond the stall are difficult to obtain and generally represent unsteady flight conditions. It is difficult to hold a desired angle of attack or yaw in this condition unless special automatic control systems are used.

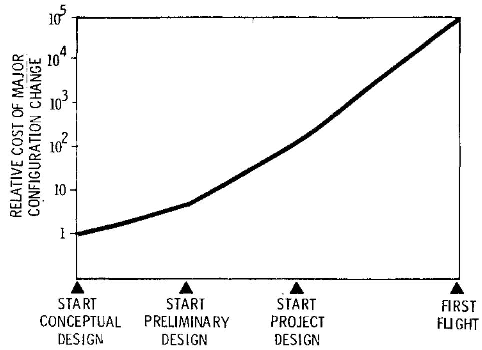

Fig. 1 Relative cost of major aerodynamic configuration change during the development of an aircraft (from Ref. 1).

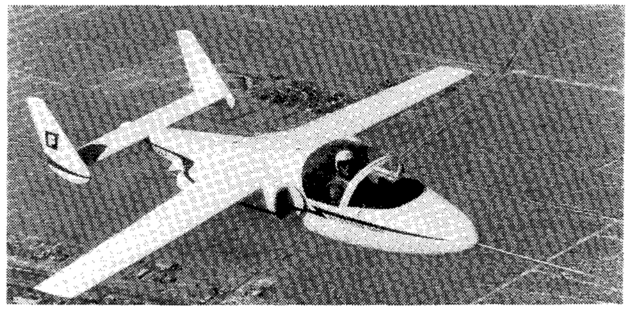

Fig. 2 FRC 62%-scale NGT demonstrator.

The velocity range (and associated Reynolds number range) may be limited if low-thrust engines are used. Some limited increase in speed can be achieved by diving the demonstrator, but the resulting non-steady conditions give rise to larger-than-desirable errors in the flight-test data.

Engines of the proper scaled size are not always available. This means that the mass flow and associated effects may not be modeled properly. This, in turn, makes it difficult to measure meaningful drag coefficients in flight using low-cost demonstrators.

To maintain low costs, the test aircraft must operate below 25,000 ft in order that the aircraft be unpressurized, and preferably below 15,000 ft in order to remove the requirement for an oxygen system. Pressurization leads to more complex systems, a heavier structure, more maintenance and, hence, additional costs. The simplicity of an unpressurized aircraft makes it possible to build truly low-cost test aircraft.

Full-scale structure and moments of inertia distributions are difficult to scale. The moments of inertia have a significant influence on the vehicle performance during nonsteady maneuvers such as stall/spin departures. In many cases, the ratios of the moments of inertias can be matched but not the absolute values. In general, analytical methods can be applied to transfer the test results to full-scale conditions.

The Modular Aircraft Approach

Development of the Concept

Early flight vehicles were constructed using mostly an internal framework of struts and ties which provided simple, direct, and predictable load paths. The aerodynamic forces induced by flight were resisted by fabric stretched over the structural framework.

About 50 years ago, monocoque and semimonocoque metal construction techniques which use contoured aerodynamic skins as major structural elements were introduced into aircraft design. Until recently the outer contours were generally composed of single curvature and straight-line elements. For sound structural reasons the largest possible shell cross sections were used.

In recent years, the external shapes of high-performance vehicles have become increasingly complex with increased use of double and re-entrant curvature. Shells of this type require extensive internal support in order to develop reasonable stress levels before buckling. For these complex aircraft shapes, the structural shell method does not result in low-cost fabrication due to the costs of tooling and fixtures.

An alternative approach for fabricating demonstrator aircraft has been developed which is conceptually similar to the early construction method of using simple geometry internal structures. An arrangement of flat-sided boxes provides the structural basis for mounting aerodynamic contour modules. These aerodynamic modules provide the external shape while the internal box structure provides the strength.

The concept, as developed by FRC, is especially compatible with low-cost demonstrator designs in that it allows extensive tailoring and modification of the external configuration without changing the basic core airframe. Almost any part of the airframe can be modified or replaced to test different aerodynamic components.

The FRC Low-Cost Flight Vehicle Concept, directed at the design and construction of low-cost technology demonstrator aircraft, consists of the following elements: 1) core vehicle, 2) aerodynamic modules, and 3) flight surfaces.

Core Vehicle

The core vehicle (Fig. 3), provides the basic structural system for the demonstrator aircraft. The fundamental assemblies are a longitudinal box for the fuselage strongback and a transverse box for the wing which also supports the engines. The fuselage structure includes the cockpit enclosure, canopy support, and the retractable nose and main landing-gear systems. The fuselage structure thus formed stands on its own landing gear without additional support.

The fuel and hydraulic/electric lines and the control system pushrods/cables are all located externally on the strongback. The fuselage box structure acts as the assembly fixture for these systems. The hydraulics, electrical system, and control runs may be checked out and adjusted on this core vehicle just as they would be on an "iron bird." The principal difference is that the core vehicle can actually be flown when the system checkouts are complete and the aerodynamic modules and flight surfaces are added.

Wing Box

The wing box mates with the fuselage box beam immediately aft of the main gear trunnion support. The wing box structure is a multispar system with intercostal chordwise ribs. The spars and ribs are nontapered, constant height components. The wing box dimensions are defined by the basic wing section. The outboard ends of the wing box support the engine pylons, vertical stabilizers, and outer wing panels.

The transverse box structures for the wing and canards are installed on the fuselage strongbox using fittings installed during the flat-panel construction phase. Note that movement of the wing along the fuselage is then merely a matter of changing the fuselage/wing fittings. Podded engines are installed on the outboard extremities of the wing box where provisions are also made for supporting the vertical stabilizer and outer wing panel.

Aerodynamic Modules

The aerodynamic modules are shown in Fig. 4. These modules are attached to the core structure to provide the areodynamic shape of the vehicle. The aerodynamic module-to-structural box interface is a flat or, at most, a single curved surface. This simple interface eliminates assembly complexities. The aerodynamic forces generated on these

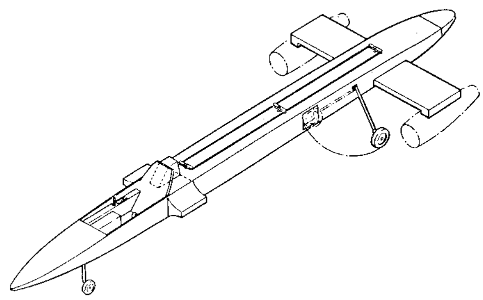

Fig. 3 Isometric view of the low-cost demonstrator core vehicle.

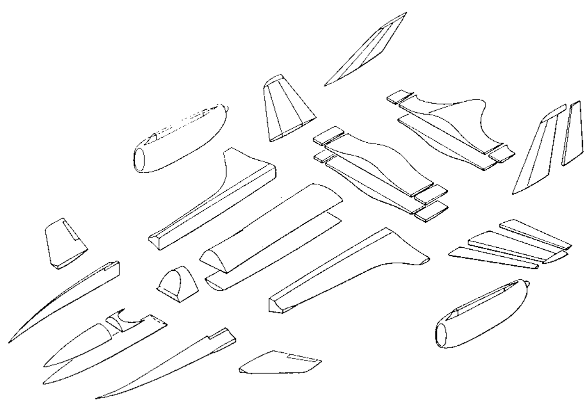

Fig. 4 Low-cost demonstrator aerodynamic modules and flight surfaces.

aerodynamic modules are transmitted directly to the core structure.

The complex aerodynamic contours are created by carving core material to shape using computer-generated templates. The core and templates are easily set up on flat or draped surfaces. The modules are skinned by using prepreg nonmetallic layups over the carved core and cured under pressure.

The aerodynamic modules have open channels built into their bases to provide conduits through which these control runs and systems are routed. Temporary removal of one or more aerodynamic modules then lays bare the control circuits and systems to permit adjustment, repair, and/or modification.

The aerodynamic modules as shown in Fig. 4 are attached to the core vehicle by use of overhanging flaps that are extensions of the aerodynamic module skins. These flaps are secured to the fuselage strongback using a series of bolts. The bolts are intended to take out a portion of the bending loads on the aerodynamic panels by shear. The remainder is taken out by compression of the inner face of the aerodynamic module. A shear pin is provided to transfer the shear loads. See Fig. 5.

Wing/Canard/Vertical Stabilizers

The outer wing panels are mounted on the outboard end of the wing box. The wing panel is constructed of structural foam, hot wired to contour, and covered with fiberglass using a low-temperature cure resin. The spar webs are embedded into the core and adhesively attached. The caps may be reinforced by the use of unidirectional graphite fibers if required. The wing is attached to the core vehicle wing box at discrete moment connections located at the front and rear spars. The rear spar is provided with bolt-on hinge fittings and reinforced where necessary. The aileron hinges and actuation fitting are bonded and encapsulated during the aileron layup. The canard and vertical stabilizers are similar to the wing panel in structural arrangement and fabrication procedure.

Using the methods described above, demonstrators can be built cheaply and quickly. Significant configuration changes to these demonstrators can also be made at modest cost. Individual aerodynamicmodules can be removed and replaced by others that have additional systems built into them.

Because the sytem is largely self-tooling, there is a minimal requirement for subassembly and final assembly fixtures. These items typically represent 20% of the cost of a new aircraft program and, hence, by reducing the number and complexity of these jigs and fixtures, a sizable cost reduction can be achieved.

Demonstrator Adaptability

The potential for a modular demonstrator vehicle design is illustrated in Figs. 6-8. The core system illustrated provides a basis for twin-engined designs using podded or under wing-fuselage installations. Other engine arrangements can be treated similarly. Figure 6 shows the baseline canard-wing configuration. Figure 7 shows the core vehicle with a arrow-wing configuration. Figure 8 shows the core vehicle with a forward-swept wing configuration. Thus, one core vehicle is capable of accommodating several radically different external configurations.

Modules to test technologies one at a time or in combination can be developed quickly and fitted easily to the core vehicle. For example, since the standard modules are merely aerodynamic fairings, one or more fairings may be replaced by fairings containing active flap systems, or by fairings carrying external stores.

If multiple aerodynamic configurations are to be demonstrated, the utilization of a common core vehicle yields large cost savings. This option requires that the core vehicle structural requirements encompass all proposed usage. From this study it appears that sufficient performance is available through the use of J85-type engines so that the weight increase due to the more demanding structural requirements can be accepted without a performance penalty.

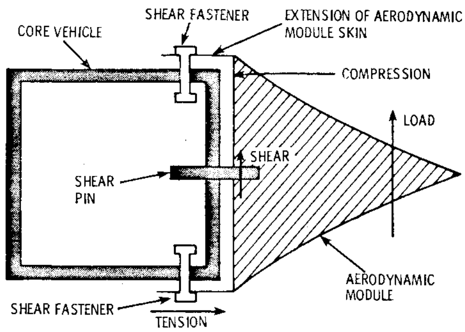

Fig. 5 Schematic diagram showing how loads are transferred from aerodynamic module to core vehicle.

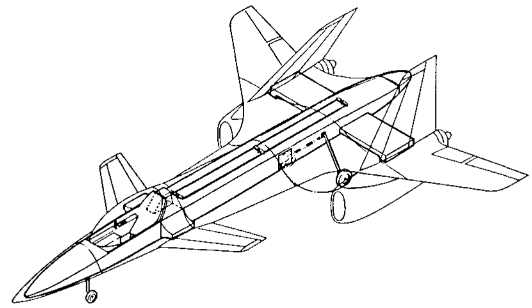

Fig. 6 Canard configuration buildup on the core vehicle.

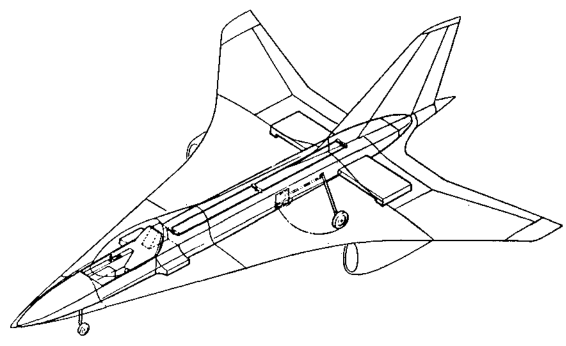

Fig. 7 Arrow-wing configuration built up on the core vehicle.

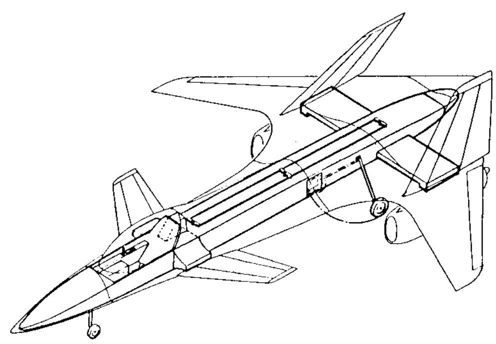

Fig. 8 Forward-swept wing and canard configuration built up on the core vehicle.

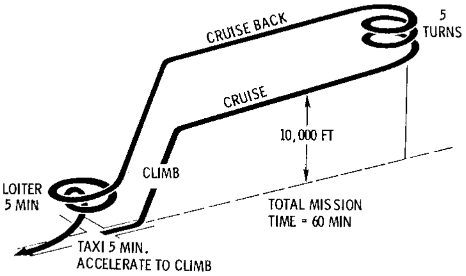

Fig. 9 Baseline design mission.

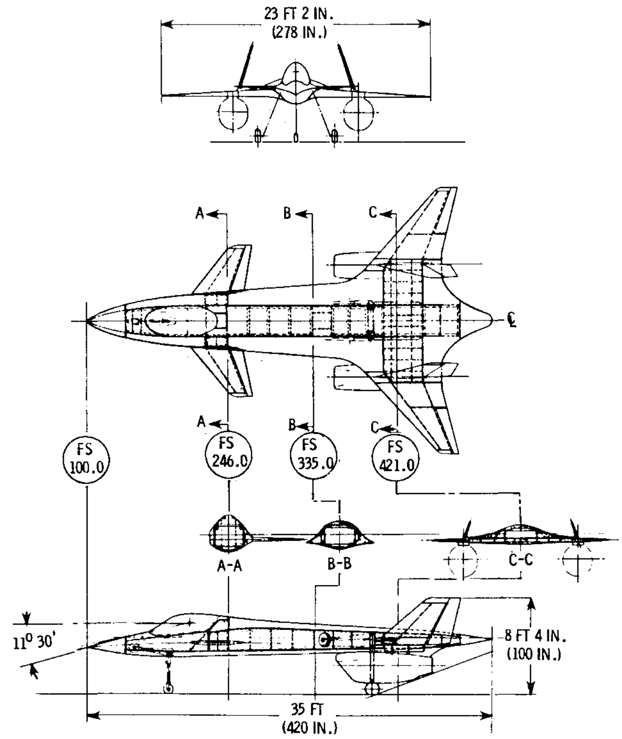

Fig. 10 General arrangement of fighter demonstrator.

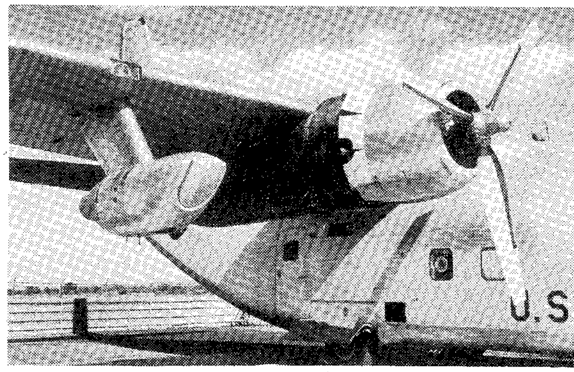

Fig. 11 Booster engine on C-123K.

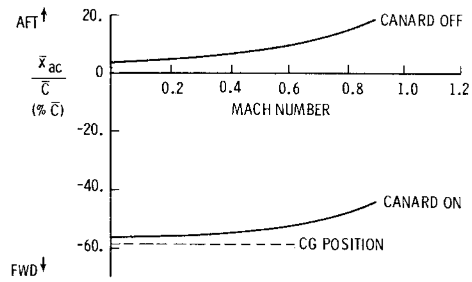

Fig. 12 Variation of aerodynamic center location with Mach number.

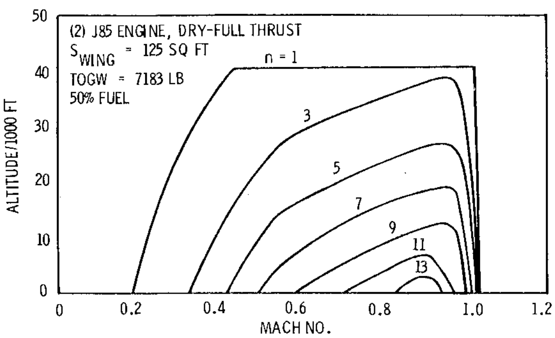

Fig. 13 Full thrust maneuvering envelope.

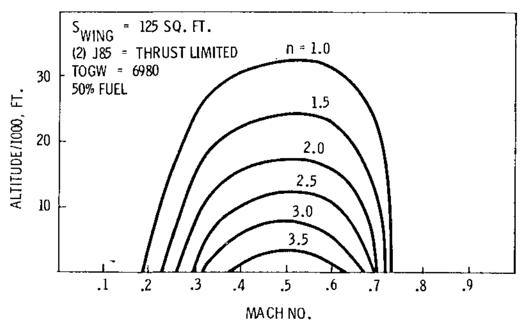

Fig. 14 Limited thrust maneuvering flight envelope.

Conceptual Design of a Flight Demonstrator Vehicle

The conceptual design of the low-cost demonstrator of an advanced fighter configuration has been carried out. The purpose of this demonstrator was the verification of the subsonic handling characteristics of the unaugmented airframe. The costs and schedule required for contruction and flight test were estimated.

The basic sizing mission for this low-cost demonstrator is shown in Fig. 9. This mission provides up to 50 min of testing time if both of the cruise legs are used, as well as the turning flight phase.

Size and General Arrangement

A general arrangement drawing of the low-cost demonstrator conceptual design is given in Fig. 10. The configuration consists of a blended wing-body controlled by a canard. The vehicle is 35 ft long, has a wing span of 23 ft, and is over 8 ft in height. The takeoff gross weight is 6980 lb, including 1750 lb of fuel. The canard main surface is fixed, and control is effected through plain flaps fitted to the trailing edge. The wings are fitted with conventional ailerons. The twin vertical fins are fitted with rudders.

The pilot is reclined at 45 deg beneath a plexiglass canopy. His flight controls consist of a side-arm controller and rudder pedals. A central pedestral contains the primary flight instruments, while secondary instruments are mounted on either side of the leg tunnels. Emergency escape from the vehicle is provided by a Stencel/Talley (Ranger) Yankee extraction system. This is a gas-ejected, tractor rocket system that pulls the pilot out through the prima-cord disrupted canopy via his parachute harness.

The aircraft is supported on the ground by a tricycle landing gear that retracts forward in flight. A hydraulic-powered

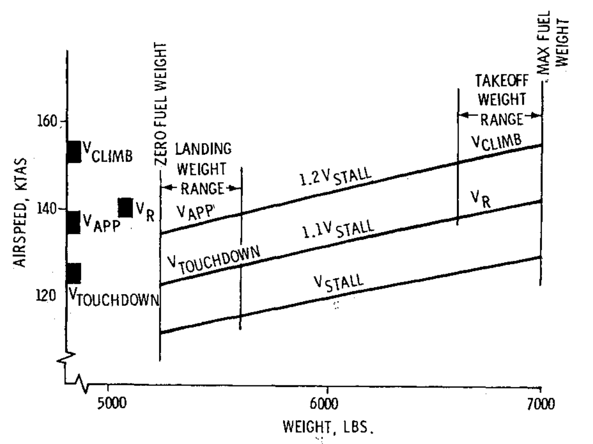

Fig. 15 Low-cost demonstrator takeoff and landing performance.

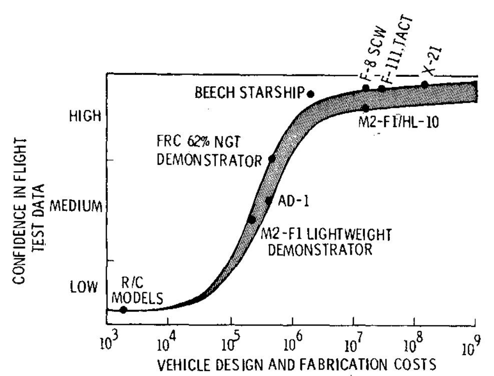

Fig. 16 Confidence level vs vehicle design and fabrication costs (1984 \$).

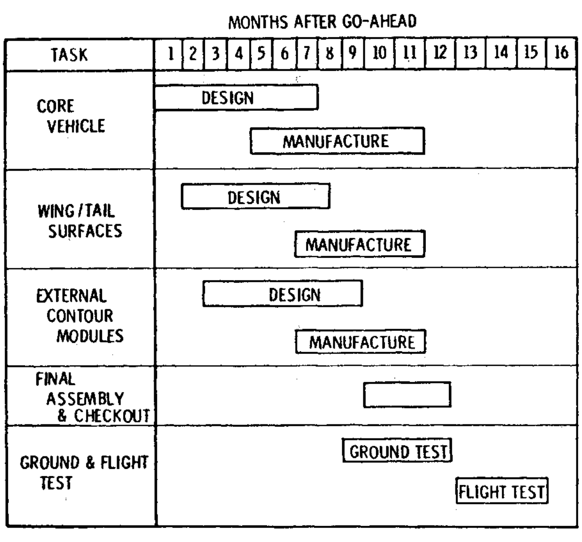

Fig. 17 Development schedule.

retraction system was selected based on the use of off-the-shelf pumps, actuators, and accumulators. The nose wheel is not equipped with steering or brakes. Directional control on the ground is accomplished by differential braking of the main wheels.

Provisions for 100 lb. of avionics/flight-test instrumentation are incorporated into the fuselage aft of the cockpit. The fuel is contained within a single bladder-type fuel cell located within the core vehicle. The fuel supply is located close to the center of gravity so that little or no movement of the center of gravity occurs as the fuel is consumed.

The vehicle structure was modeled on NASTRAN.[10] Examination of the detailed loads generated by a 6*g* symmetric pullup and a 4*g* rolling pullup, as well as other critical maneuvers, showed that the structure was capable of carrying the flight induced loads.

The demonstrator aircraft is powered by two non-augmented General Electric J85 engines. These engines, currently in USAF storage, are used for booster engines for the C-123K transport, as shown in Fig. 11. The wing-mounted pod incorporates an inlet blocker door that inhibits airflow through the engine when the engine is inoperative. Although the blocker function is not normally required for the low-cost demonstrator, the blocker door must be retained because the door becomes the upper wall of the inlet duct when the door is open.

The pod/engine combination was found to provide numerous advantages. Inlet and exhaust ducts are proven assemblies requiring no development testing. Engine and component accessibility, maintainability, and reliability are known and documented, and require no additional development. Control system and support lines are already installed in the pod. Only the interface to the demonstrator aircraft needs to be developed and fabricated. The engine mounts and pylon pickup points are clearly defined and stressed. Thus, no development costs need be incurrred for the pod and pylon if they are made available from USAF storage.

Aerodynamic/Performance of the Demonstrator

Figure 12 shows the location of the aerodynamic center with and without the canard. The center of gravity is located at approximately −59% mac (mean aerodynamic chord). Therefore, the aircraft is 5% stable at low Mach number.

Figure 13 shows the flight envelope for the demonstrator using the full thrust available for the J85 engines. This engine/aircraft combination has the ability to generate sustained load factors beyond the design load factor limit of 9.

Figure 14 shows the corresponding maneuvering envelope when the thrust is limited by a throttle stop to 1500 lb of thrust at sea-level-static conditions. This results in a more reasonable flight envelope. Performance levels between those shown in Figs. 13 and 14 can, of course, be achieved by changing the throttle stop.

Takeoff and landing speeds are shown in Fig. 15. The solid bars on the left side of this figure represent the probable ranges of the climb, rotation, approach, and touchdown speeds. These speeds are fairly high, but are well within the capability of an experienced test pilot, and do not represent a flight hazard.

Prior Demonstrator Costs

With the assistance of the NASA Ames/Dryden Flight Research Center, some cost and schedule data on recent flight-test programs were acquired. These data are summarized below. Table 1 gives the time frame and vehicle acquisition costs, adjusted to 1984 dollars, for each project. Program costs such as in-house flight-test costs, administrative costs, and associated technical investigations are not included here due to the difficulty of comparing austere low-cost demonstrator programs with full-scale test programs.

These data clearly show the vast financial gulf separating the two lowest cost demonstrators, the M2-F1 Lightweight and the AD-1, from the remainder of the flight-test vehicles. These results are presented in Fig. 16 in the form of "Confidence in Flight-Test Data" plotted against "Vehicle Design and Fabrication Costs." Also included on these plots are the FRC subscale NGT demonstrator, and an estimate of the Beech/Rutan Starship costs. The rating of the confidence in the applicability of the resulting flight-test data was developed from a consensus of experienced preliminary design personnel in the FRC Advanced Product Development Department.

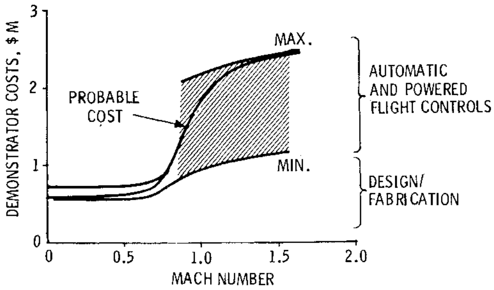

Fig. 18 Projected demonstrator cost vs design Mach number.

Included in this figure is an estimate of the cost of radio control models when used as a research approach. A low-cost radio control model can offer results of limited value at a cost of only a few thousand dollars. The low-cost demonstrator approach can provide medium-to-high-confidence test results for several hundred thousand dollars. However, a high-confidence level requires multimillions of dollars (and the associated elaborate test program). The Beech/Rutan Starship shows up on this curve as a particularly cost-effective tool in the development of a new configuration.

It can be seen that a series of small demonstrators, each "tuned" to investigate certain specific aspects of a new project, may result in a significant savings in project money. As discussed previously, early demonstration of the adequacy of technical solutions results in large savings due to the reduced need for changes to prototype and production aircraft.

Cost Estimates for the Conceptual Design

Figure 17 shows the schedule for design, fabrication, and testing of the conceptual demonstrator. The first flight occurs just over one year from go-ahead. Note that it was assumed that a complete geometric description of the full-scale aircraft was available on a CAD/CAM system at the outset of the program and that estimated loads on the vehicle were available at program start. In addition, the J85 engine pods were assumed to be government furnished equipment (GFE). These program costs are based on the assumptions that the demonstrator aircraft would be designed to reasonable and prudent standards (but not full Mil-Spec qualified); that the flight-test program is to be managed, staffed, and flown by contractor personnel; and that only limited formal reports would be prepared.

During the costing of the demonstrator, the effects of design Mach number on the vehicle costs were investigated parametrically. Figure 18 shows the results. Insofar as the structure itself is concerned, an increase in cost occurs above a Mach number of approximately 0.7 due to the increased dynamic loads on the airframe and the necessity for maintaining a stiff structure. Supersonic flight with its more demanding stiffness and load requirements causes still further increases in structural costs. The major cost increment, however, lies in the necessity for including automatic and powered flight controls at high subsonic and supersonic speeds. It is estimated that such a system would add approximately $1 million to the cost of a demonstrator. This increase is shown in Fig. 18 as the upper limit of the cross-hatched area. A probable cost line for a more or less conventional aircraft has been included to show the progression with Mach number.

The cost estimates for this type of construction were difficult to make since a completely new approach to design and construction is proposed and, thus, the conventional costing data base no longer applies. Several shop construction estimates were solicited from both Fairchild Republic and outside vendors. The estimated man hours required were essentially in agreement. The resulting cost estimate for the design and fabrication of the demonstrator is given in Table 2.

Table 1 Summary of some NASA flight demonstrator costs

Program	Time frame	Vehicle costs, 1984 $
X-21	1961-1969	128,000,000
M2-F1 Lightweight	1961-1969	224,000
M2-F2/HL-10	1963-1968	15,400,000
F-8 SCW	1968-1977	15,500,000
F-111 TACT	1971-1976	25,800,000
AD-1	1975-1981	415,000

Table 2 Design and fabrication cost estimates

Engine/pods assumed to be GFE	
Engineering design	$200,000
Manufacturing design	150,000
Fabrication	350,000
	$700,000

Table 3 Test and reporting cost estimates

Ground tests	500,000
Airworthiness tests	750,000
Program Management	72,000
Reports	48,000
	$1,370,000

It is estimated that a reasonable six-month flight test program of this demonstrator aircraft would cost approximately $1,370,000, as shown in Table 3, for a total program cost of approximately $2 million.

Conclusions

A low-cost flight demonstrator vehicle can save significant costs and schedule time when used to verify aircraft configuration aerodynamic in the early development stage.

Such low-cost demonstrators should be limited to a maximum Mach number of approximately 0.7 to maintain low demonstrator cost. Figure 16 shows a plot of estimated demonstrator fabrication cost vs Mach number. The knee of the curve occurs at approximately $M=0.7$. Demonstrator aircraft designed for transonic and supersonic flight will incur added costs ranging up to $1 million for the development and installation of an automatic flight-control system.

The low-cost demonstrator approach offers the opportunity to explore a wide variety of aerodynamic technologies as well as novel methods of construction for a very low price. Coupled with a modular construction approach involving a common core vehicle, it is possible to conduct a series of demonstrator programs with a savings of approximately 65% per program because of the common core.

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