Designing Jet Aircraft Wind-Tunnel Test Programs with Propulsion System Simulation

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This paper discusses the design of wind-tunnel force test programs for jet aircraft configurations where propulsion system aerodynamic effects must be evaluated in the testing. The simulation requirements of present day jet aircraft are discussed, as are the simulation problems. The potential tradeoff between individual model engine simulator complexity and test program complexity that will provide the required simulation is introduced. Various model support techniques and engine simulation techniques that might be used are described. Test program designs that could yield aircraft force coefficient data are presented, and finally, the choice of an engine simulator and test program design is considered for three specific aircraft configurations.

1.0 Introduction

THIS article deals with the problems of designing test programs for obtaining aerodynamic coefficient data on jet aircraft configurations. It is intended to provide guidelines for those who must obtain aircraft force coefficient data for a particular aircraft. Test program design has become a complex problem for many jet aircraft configurations because of the need to simulate the aircraft propulsion system. Texts on wind-tunnel testing, such as Refs. 1–3, illustrate methods for propulsion system simulation and model support but do not adequately cover the problems of combining these techniques in a test program.

1.1 The Importance of Propulsion System Simulation

Propulsion simulation has become important for today's aircraft designs partly because customers are providing the manufacturers with more complete and more strict definitions of required aircraft performance. In addition, propulsion system effects with today's jet aircraft are more significant than they have been for aircraft designs of the past. For supersonic jet aircraft (see Ref. 4) the range of exhaust pressure ratios is greater. At low nozzle pressure ratios, the external flow may influence the exhaust nozzle internal pressure distribution and at high-nozzle pressure ratios, the pluming exhaust can change the boattail pressure distribution. Closely spaced, twin-jet engines can produce complex interference effects and the pluming jet may impinge on the fuselage. Nor are the propulsion system effects limited to the region of the exhaust nozzle. Sharp-edged inlets, required for low supersonic drag, cause high spillage drag when operated at capture ratios below 1.0. The low-energy spilled flow can change afterbody drag. High-bypass ratio turbofans are a somewhat different problem. The tendency of the aircraft designer to position wing-mounted engine centerlines close below the wing introduces the possibility of interference between the wing, pylon, engine pod and propulsive stream tube.

The importance of propulsion system effects is also related to the problem of defining where the propulsion system begins and ends. Once it was a clearly defined interface between a mechanical piece of hardware called the engine and an aircraft structure. Now the propulsion system may include an extensive inlet and nozzle system for which both the airframe and engine manufacturer have responsibility. It becomes both a technical and political requirement that propulsion system effects be sorted out during model testing so that responsibility for deficiencies can be assigned and performance improved where required.

1.2 The Problem of Designing a Test Program Which Includes Adequate Propulsion System Simulation

In designing a wind-tunnel test program with propulsion system simulation, one must first decide what extent of simulation is needed. This will depend on the aircraft, Mach number range, inlet geometry, etc., and is discussed in Sec. 2.0. When this decision has been made, the test program design may be either easy or difficult, depending on how much simulation is required and what the airplane and propulsion system configuration is. If relatively complete simulation is required it becomes necessary to consider tradeoffs in engine simulation cost, complexity, and flow requirements; model support techniques; and the complexity of test program design. Various engine simulation techniques are discussed in Sec. 3.0.

Selection of suitable model support is also important in designing a test program. The decision as to the best way to support the model becomes dependent upon the aircraft design and the location of the engines as well as the amount of flow which must be carried to and from the model. Different model support techniques and their limitations are discussed in Sec. 4.0.

Ideally, aircraft configuration force coefficient determination would be done with one model containing adequate propulsion-system-simulation in a wind tunnel big enough to minimize wall interference. This has been done successfully with models of propeller-driven aircraft. It is currently being done with models of some aircraft powered by high bypass ratio turbofans through the use of turbine-powered engine simulators. Often, though, it is uneconomic or impossible to obtain complete aircraft force data with propulsion system simulation in one test. In such cases, getting aircraft force coefficient data will best be attained by utilizing a more complicated test program design. This involves testing more than one partially complete model and adding up the results to get complete force data. This kind of testing involves the use of "reference configurations" to provide a common zero-point for adding results. At times the choice of a multimodel test program design will be dictated by engine simulation problems or by model support problems. At other times, the choice will be made on the basis of a cost tradeoff between a single model program requiring an expensive model-engine simulator package and a multimodel program requiring two or more simpler models. Typical test program designs which might be useful are presented in Sec. 5.0. Wind-tunnel test

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Table 1 Engine simulation techniques and their characteristics

		Inlet flow removal and exhaust flow supply requirements for proper propulsive stream tube simulation					
		Turbofan		Turbojet		Afterburning turbojet	
Simulation technique	Peculiarities	% Inlet flow removed	% Exhaust flow supplied	% Inlet flow removed	% Exhaust flow supplied	% Inlet flow removed	% Exhaust flow spplied
Small-scale engine	Near 100% simulation Not developed yet	0	Negl.	0	Negl.	0	Negl.
Turbine-powered engine simulator	T_{exh} not simulated	20–25	20	30–40	30	0–20	20
Ejector-powered jet	T_{exh} not simulated	35–40	Over 50	50	Over 50	0	Over 50
Supplied-air jet-pumped inlet	T_{exh} not simulated	100	100	100	100	100	100
Flow-thru nacelle	T_{exh} not simulated $P_{T_{exh}}$ not simulated	0–75	0	0–75	0	0–75	0
Solid nacelle	No simulation of propulsive stream tube	...	...	...	...	...	...

program designs for three specific jet aircraft types are discussed in Sec. 6.0.

2.0 Choosing the Extent of Propulsion System Simulation

In jet aircraft the operation of the propulsion system can have a variety of effects on the aircraft aerodynamics. The following list suggests some of the ways the propulsion system and aircraft interact to influence aircraft force coefficients: a) the amount of inlet spillage in the presence of the aircraft flowfield and the associated drag; b) the net drag of bypassed flow and bleed flow; c) exhaust nozzle internal performance in the aircraft flowfield; d) engine nacelle afterbody drag and base drag at various nozzle pressure ratios and with various amount of inlet spillage; e) the effect of inlet and exhaust flows on aircraft trim. The extent of propulsion system simulation that is needed will depend upon which of the possible interactions are significant for the test being considered. This is a function of one or more of the following factors: 1) the range of attitudes for which test data are desired; 2) the range of test Mach numbers required; 3) the range of propulsion system operating conditions associated with the flight conditions encompassed by the tests; 4) the characteristics of the propulsion system; 5) vehicle-propulsion system geometry; 6) the required test accuracy.

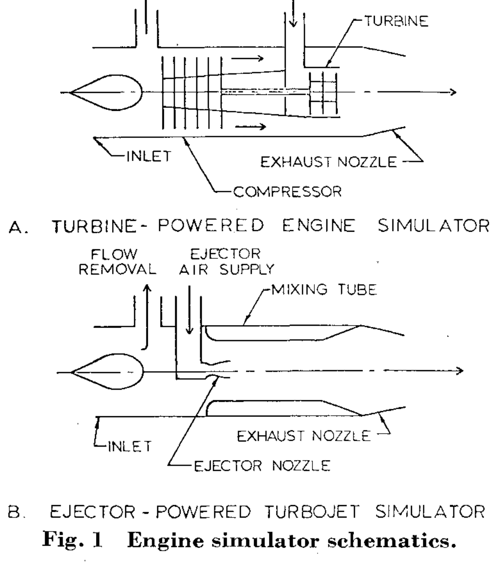

Fig. 1 Engine simulator schematics.

The peak Mach number at which an aircraft is designed to fly probably has the greatest influence on the extent of propulsion system simulation needed through its effect on the inlet design, on the test Mach number schedule, and on the range of engine operating conditions (exhaust pressure ratio). Subsonic aircraft have round inlet lips which retain low-spillage drag throughout most of the normal engine operating range. Ram compression is relatively small so that exhaust pressure ratio is low, the exhaust nozzle design is simple, and interactions between the exhaust flow and external flow do not produce large changes in thrust and drag. In many instances a flow-through-nacelle provides adequate simulation. The final choice will depend upon details related to the particular aircraft.

Supersonic aircraft, on the other hand, have sharp inlet lips and a large range of exhaust pressure ratios. The sharp inlet lips contribute to high-spillage drag at low and intermediate Mach numbers and possible interference between the spilled flow and freestream flow aft of the inlet. With the greater range of exhaust pressure ratios there exists more of the flight spectrum where interactions between the external flow and exhaust flow can occur. The effects of bypass flow on inlet-engine matching may also be significant. With supersonic aircraft it becomes almost imperative that, somewhere in the development, wind-tunnel tests be conducted with nearly complete simulation of inlet spillage, exhaust pressure ratio, etc. If aircraft force data are the only thing desired, it is not necessary to duplicate the inlet internal aerodynamics.

3.0 Engine Simulation Techniques

The main aim of propulsion system simulation is to provide adequate simulation of the inlet and exhaust stream tubes. An engine simulator can create a high level of simulation by taking the inlet flow and properly conditioning it so that it can be ejected to simulate exhaust flow, or by taking in the inlet flow and ducting it from the model while ducting in flow to simulate the exhaust, or perhaps by a combination of ducting and conditioning. In almost every case, some flow must be ducted to or from the engine simulator.

A number of simulator attributes, in addition to the available level of simulation, will determine the choice of an engine simulator for a particular model test program: 1) cross-sectional area of piping, etc., required for inlet flow removal, exhaust jet gas supply, power supply, or fuel supply (as space available in model); 2) potential accuracy of flow and thrust measurement; 3) reliability; 4) cost or availability.

Table 1 lists propulsion system simulation techniques and matches them with various engine types on the basis of the percent of inlet flow that must be ducted away for inlet simulation and the percent of exhaust flow that must be supplied. The techniques are arranged from top to bottom in the order of decreasing cost and complexity, and they range from a small-scale engine that is the most expensive to a solid nacelle contour that is the least expensive. Certain peculiarities of each simulator type have also been listed. In some cases the amount of inlet flow that must be dumped might be reduced by installing an internal heat exchanger and supplying it with refrigerant. The turbine-powered engine simulator and the ejector-powered jet are illustrated in Fig. 1 so that there will be no question about their function.

Table 1 shows that the more costly engine simulators have an advantage when complete propulsion system simulation is required in that they require less flow to be ducted to and from the model. For simulation of afterburning engines, the ejector-powered jet is attractive for the same reason. The total piping cross section for ducting flow can be calculated if the simulator characteristics and the inlet flow are known. This cross section can be compared to the cross-sectional area of the model support to see if the flow can be piped through it.

Accurate measurement of aircraft model force coefficients usually requires accurate force measurement, accurate inlet and exhaust flow measurement, and accurate measurement of thrust-related engine simulator parameters. Accuracy may not be easily attained. Force measurement may have to be made with fluids being ducted in and out of the model. Flow measurements may have to be made in a confined space. Accuracy of measurement of thrust-related parameters for jet simulators is easier when pressures and temperatures are uniform and their values nominal. The gross thrust accuracy for the supplied-air jet is probably $\pm\frac{1}{4}\%$. Turbine-powered simulators introduce temperature extremes as well as spatial nonuniformities at the measuring station and gross thrust accuracy is limited to $\pm\frac{1}{2}\%$. Accuracy, of course, requires adequate simulation of inlet and exhaust nozzle flowfields.

The reliability of simulators with rotating parts is lower than the reliability of stationary hardware. Current turbine-powered engine simulators run at rotational speeds up to 80,000 rpm and bearing lubrication is critical. Furthermore, the instrumentation required for interpreting the data from these simulators is extensive and can be a source of trouble.

There is a large jump in cost when one includes precision moving parts. The cost of turbine-powered engine simulator cores used for modeling fan jet engines is in the five-figure range. An advanced powered simulator for jet aircraft yielding higher pressure ratios will cost still more. A small-scale engine, if feasible, might cost well over $100,000.

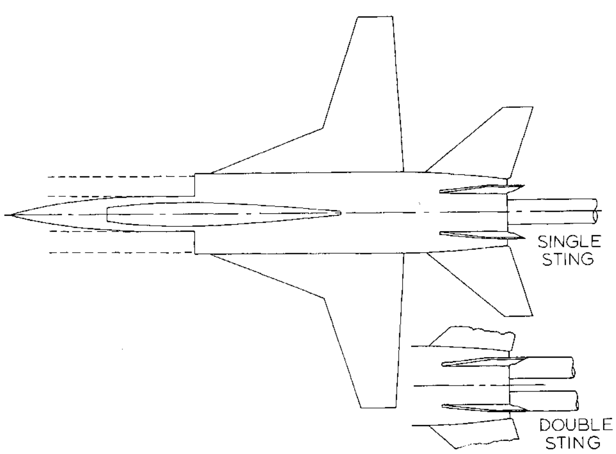

Fig. 2 Aft sting mounting.

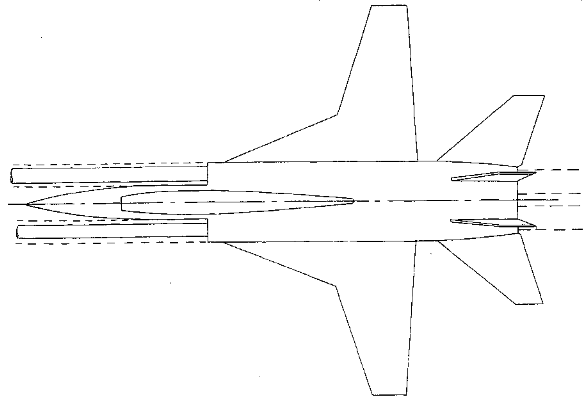

Fig. 3 Inlet stream tube mounting.

In the final selection of a test program logic and engine simulator, it will be necessary to weigh each of the foregoing factors on the basis of how important it is for the particular test program and aircraft configuration. One may have to adopt a scoring system to evaluate which simulator and methodology best suits the requirements within the economic and schedule limitations.

4.0 Model Support Techniques

The design of a suitable, economical test program for an aircraft configuration may depend strongly upon finding one or more model-mounting techniques that permit the generation of aircraft configuration force data that are free of support interference effects (Ref. 1, pp. 141–154). Very often models are mounted as shown in Fig. 2 on a sting attached at the downstream end of the fuselage. With this type of mounting, the sting attachment may have a small effect on the aircraft model flowfield and the effect can be corrected for. This mounting is feasible for conventional aircraft which fly at low angles-of-attack and where the engines are mounted forward of the tail. It is possible to use this technique with single-engine jet aircraft model testing where the sting substitutes for all or part of the exhaust jet blockage. Some simulation is lost when doing this, however, because jet aspiration is not simulated. This technique loses more of its appeal for aircraft with twin, fuselage-mounted jet engines since the interference between the two jets and the fuselage aft end would not be simulated. Still, this idea can be extended to one model of a twin-jet configuration in a multimodel test methodology by using a double sting (Fig. 2), again substituting the sting blockage for all or part of the jet blockage. The sting can serve as a duct for exhausting engine inlet air from the model.

The idea of occupying part of the propulsive stream tube blockage with the model support can also be applied to the engine inlets for low angle-of-attack testing as illustrated in Fig. 3. Here, the support tubes can be used to supply jet simulation flow. If they occupy only part of the inlet stream tube it may still be possible to evaluate the effects of inlet spillage.

Another mounting technique that has been used for determination of propulsion effects with fuselage-mounted engines Ref. 5) is wing mounting (Fig. 4). Sometimes it may be possible to mount the wings to the tunnel walls. Wing mounting does not provide much potential for ducting air to or from the model, however. Furthermore, it may introduce interference effects that are difficult to evaluate in reference configuration testing.

Strut mounting from the forward part of the fuselage (Ref. 6, p. 18) may also be useful for fuselage-mounted engine configurations (see Fig. 5). This technique sometimes provides more room for ducting than wing mounting, but it also introduces interference effects that are difficult to evaluate.

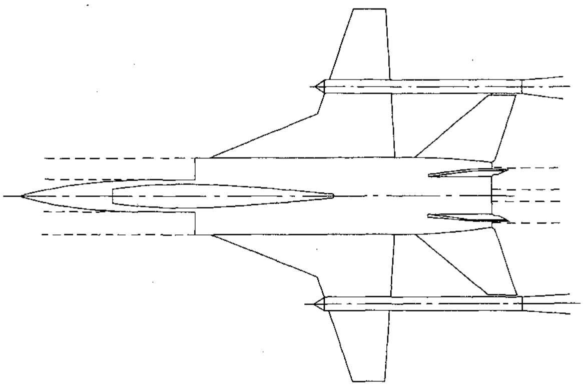

Fig. 4 Wing mounting.

The problems of propulsion system simulation for fuselage-mounted engine configurations may be simplified by reflection plane mounting of a half model as portrayed in Fig. 6. Ducting from the inlet and to the exhaust nozzle can go directly through the tunnel wall into the model. Although it seems that interference-free test data should be obtainable from reflection plane testing, there remains some question about the reliability of the absolute values obtained therefrom (Ref. 2). Consequently, reflection plane testing usually constitutes only one part of a multimodel methodology where it is assumed that changes in performance due to differences in test conditions are accurately revealed by the reflection plane test. Absolute levels of performance are obtained by using the reflection plane results to permute complete model results obtained with a common reference configuration.

Magnetic suspension of wind-tunnel models is being attempted. It offers complete elimination of sting interference. However, magnetic suspension prohibits propulsion system simulation since it is not possible to duct gases to and from the model. Also, the accuracy of force measurement may be limited.

5.0 Typical Test Program Designs

This section is devoted to a review of test program designs which are applicable to wind tunnel aerodynamic model testing. Various methodologies are categorized below to make the discussion which follows simpler: a) a one-model test program; b) test programs using two or more essentially complete airplane models; c) test programs using a reflection plane mounted half model as one model in a multimodel test.

For simplicity of methodology, as we have noted, a one-model test program represents an ideal. This ideal usually can be achieved where propulsion system effects are small or when suitable simulators are available and convenient model support points exist. For complete propulsion system simulation, the one-model test program usually requires a more complex engine simulator than multimodel programs.

Propulsion system simulation for multimodel programs can usually be attained by using the supplied-air jet, pumped inlet flow engine simulation technique. We will now discuss two methodologies involving more than one essentially complete airplane model. The first of these is illustrated in Fig. 7 and consists of at least two models split circumferentially at the same fuselage station into metric and nonmetric sections. One model has the front portion metric and operating inlets. It is sting supported at the rear. The second model must be wing supported or forward fuselage supported and has faired inlets with a metric aft portion and exhaust flow. The thrust-minus-drag of the complete configuration is the sum of the corrected stream-wise forces measured on the two models. This method suffers in that one cannot measure effects of inlet spillage on aft end drag. When a model is split in half circumferentially like this, accurate force determination requires correction for the pressure acting across the metric-nonmetric gap. If the circumferential pressure variations are small, the gap can be left unsealed, but if they are large a flexible circumferential seal may be necessary and account must be taken of the seal tare forces.

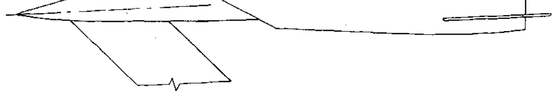

Fig. 5 Forward fuselage strut mounting.

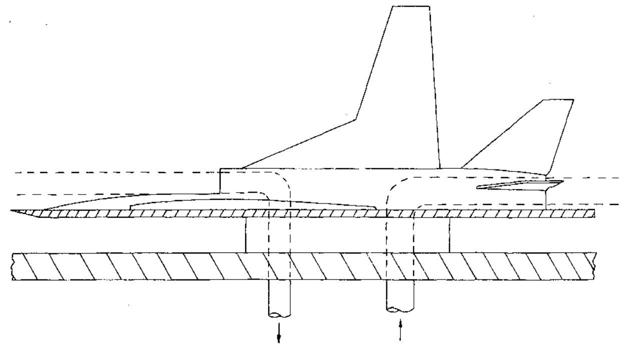

Fig. 6 Half model wall mounting.

The second of the two complete model methodologies, shown in Fig. 8, does permit direct measurement of inlet spillage effects on aft end drag. Here, the first model is mounted on an aft sting which occupies the propulsive jet blockage and serves as an exhaust duct for the inlet flow. The second model is wing or forward fuselage mounted and has jet flow but faired over inlets. Application of this method requires the use of reference configurations. For example, model one would be tested with faired over inlets and model two would be tested with a simulated aft sting support. The measured drag of model one with the ram drag substracted out will be very close to the actual configuration drag if the sting actually duplicates the jet blockage. The test results on the second model will serve as a small correction for jet effects at different exhaust pressure ratios.

Figure 9 illustrates a methodology employing a half model as one of two models. This methodology may simplify the

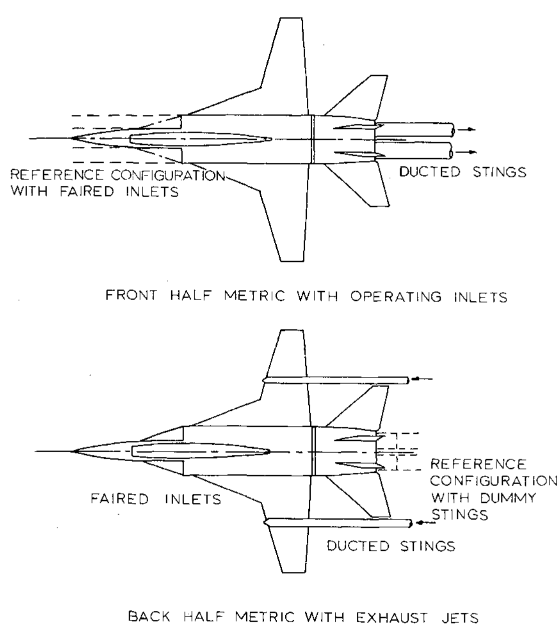

Fig. 7 Split model test program.

propulsion simulator requirements for an aircraft configuration having twin, fuselage-mounted engines because the inlet and exhaust flows for the half model can be ducted through the sidewall area and the second, centerline-mounted model, needs no propulsion simulation provided that reference configuration tests (faired inlet, simulated aft sting) are run on the half model. The drag of the complete aircraft is then formed from the centerline model drag and corrections for propulsion system effects found on the half model.

$$D = D_{\mathbb{C}} + \Delta D_{\substack{\text{spillage} \\ \text{half model}}} + \Delta D_{\substack{\text{jet} \\ \text{half model}}}$$

When an engine simulator is used, it is usually necessary to calibrate it so that the gross exhaust thrust is known as a function of nozzle pressure ratio, etc. For turbine-powered engine simulators the calibration usually involves a so-called direct connect test wherein the flow handling capacity of the fan passage and the gross exhaust thrust are defined as a function of engine pressure ratios, turbine flow, etc. It is then assumed that the reference gross exhaust thrust and fan flow during the model tests can be accurately calculated from the calibration data. The airplane drag with jet engine simulation is then equal to:

$$D = T_{\text{gross}} - (T - D)_{\substack{\text{airplane model} \\ \text{with engine simulators}}} - \dot{m}V_0$$

or, i.e., Drag = (simulator gross exhaust thrust) − (measured airplane model thrust-minus-drag) − (ram drag). For a more complete development of these equations, see Ref. 7.

In designing a test program, it is well to keep in mind the possibility of obtaining subsidiary data with a small increase in test complexity. This possibility has been realized in the case of model testing of turbofan powered transport aircraft. It has become customary to make a wind tunnel calibration to get the net thrust, (*T-D*), of the turbine-powered engine simulators with the correct pylon configuration. Proper application of these data permits the isolation of engine-pylon-wing interference effects.

$$\Delta D_{\text{interference}} = (T - D)_{\substack{\text{simulators} \\ \text{with pylons}}} - (T - D)_{\substack{\text{airplane model} \\ \text{with engine simulators}}} - D_{\substack{\text{airplane model} \\ \text{without nacelles} \\ \text{and pylons}}}$$

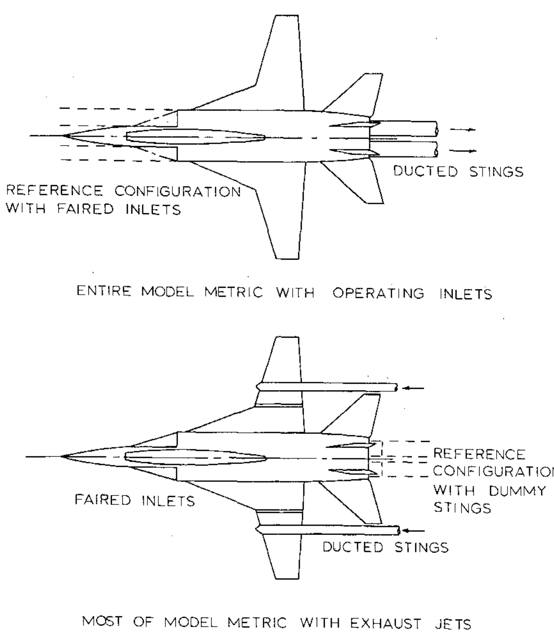

Fig. 8 Two complete model test program.

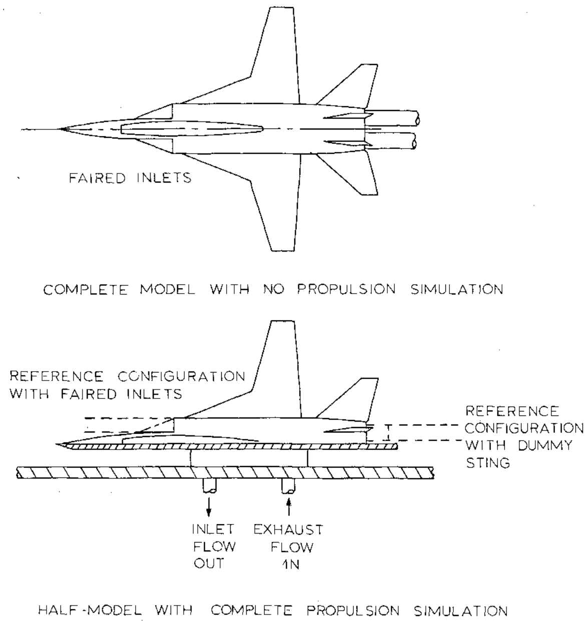

Fig. 9 Test program utilizing a half model.

Equations for obtaining interference drag from wind tunnel tests are also presented in Ref. 8.

6.0 Choosing a Test Program Design

In summary, the choice of propulsion system simulation techniques and the development of a test program design for a jet aircraft configuration requires a decision as to the extent of simulation required and will then be a tradeoff based on a number of factors, including: a) the range of model attitudes for which test data are desired; b) the range of test Mach numbers required; c) the range of propulsion system operating conditions to be simulated; d) the characteristics of the propulsion system; e) the vehicle-propulsion system geometry as it relates to effects of the propulsion system on the vehicle force coefficients; f) the vehicle-propulsion system geometry as it relates to finding a suitable model mounting point; g) the accuracy required from the test; h) the amount of subsidiary data that is desired; i) cost.

The choice of a test methodology and propulsion system simulation techniques will now be reviewed for three jet aircraft configurations: a) a subsonic, turbofan powered aircraft with rounded engine inlet lips giving low-spillage drag over a wide range of capture ratios; b) a supersonic, afterburning, turbojet aircraft with twin fuselage-mounted engines having sharp lip inlets giving low wave drag at supersonic speeds but high spillage drag; c) a supersonic transport aircraft powered by afterburning turbojets pylon-mounted on the wings.

Complete inlet simulation or exhaust pressure ratio simulation may not be necessary for modeling a subsonic turbofan installation when testing at subsonic cruise conditions below the critical Mach number. Consequently, one might use a solid nacelle although the flow-through nacelle is attractive for better inlet simulation. For evaluation of inlet drag at reduced capture ratios or when wing-pylon-engine-propulsive stream tube interference effects are important, it may be necessary to consider a more sophisticated simulation technique such as the turbine-powered engine simulator or the ejector-powered simulator that is less expensive but offers less complete simulation. The turbine-powered engine simulator has been used successfully for modeling high-bypass ratio turbofan engines. Under these circumstances, it has been used with no excess inlet flow removal, and it has been assumed that adequate inlet simulation was obtained by using

Fig. 10 Model with flowing inlet and jet.

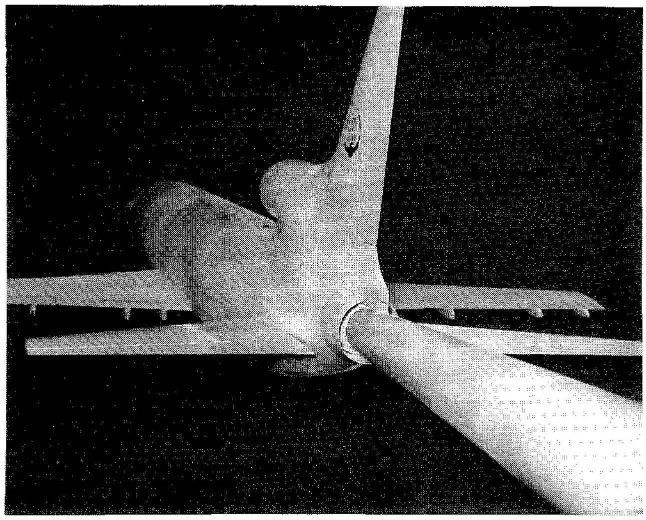

Fig. 12 Model with dummy sting.

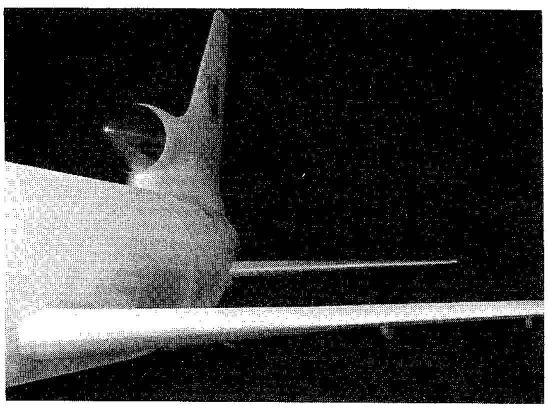

Fig. 11 Model with faired inlet.

a slightly undersized inlet area to give the correct capture ratio. For subsonic turbojets or turbofans, the requirements of engine simulation do not themselves dictate a complicated test program design. With a configuration having all engines mounted on the wings, the aft end of the fuselage forms a convenient model attachment point. In such a case, a one-model test program can be realized. If a tri-jet configuration with one tail-mounted engine were being modeled, a more complicated methodology would be necessary. Such a configuration does not lend itself to half-model testing so one would have to adopt a methodology similar to that shown in Fig. 8. An aft sting support would substitute for the rear engine in one model and the second model would be used to evaluate the effect of having an operating engine at the rear of the fuselage instead of a sting. The first model would probably have the aft engine inlet faired over while the second model would have an operating inlet as well as exhaust flow. Probably, the entire aircraft need not be simulated by the second model so one could duct adequate flow through the fuselage to permit the use of a supplied-air jet and pumped inlet propulsion system simulation technique. Figures 10–12 illustrate such a test conducted in Flui-Dyne Engineering Corporation's large transonic wind tunnel on a $\frac{1}{20}$th scale model of the Lockheed 1011. In this study of the center engine performance, the model was tested with flowing inlet and jet, with a faired over inlet and with a dummy wind tunnel sting.

For current twin-jet supersonic fighter aircraft such as the F-15, the requirement for complete simulation of the propulsion system combined with the lack of a suitable aft model support point makes a multimodel methodology necessary. One can substitute aft stings for the exhaust jets on one of two models in a two-model metholology, but the second model must have correct aft end geometry and jet simulation. The two complete model methodology illustrated in Fig. 8 and the half-model methodology shown in Fig. 9 are both attractive obtaining aircraft force coefficients. For the two complete model methodology, one model will have inlet simulation and other exhaust simulation. For the half-model test program, the sting-mounted model will have no propulsion system (i.e., faired over inlets, etc.) and the half model will have both inlet and exhaust jet simulation. The half-model methodology has the advantage of somewhat better total simulation since concurrent inlet and exhaust effects can be evaluated. Neither of the two methodologies requires exotic engine simulators because the mounting systems provide adequate ducting area in every case. Adoption of a costly turbine-powered engine simulator provides nothing of value because it does not eliminate the model support problem which dictates a multimodel test program design.

Model testing of a supersonic transport aircraft having engine pods mounted on the wings represents a difficult case for obtaining data with propulsion system simulation. The requirement for coincident simulation of inlet spillage and exhaust pluming is more important for this configuration than it is on the others because the nacelles will be mounted close under the wings and there will be interaction between spilled flow, the wing, and the exhaust jet. Consequently, a methodology such as the one shown in Fig. 8 may not provide adequate interaction data. Since the engines will be pylon mounted and out on the wing, resorting to a half model would not solve the ducting area problem. On the other hand, the aft end of the fuselage is uncluttered and can be used for model mounting. In this case, the problems of flow ducting for propulsion system simulation with the absence of model mounting problems tend to squeeze one back to a one-model methodology with either a high-performance turbine-powered engine simulator or, for the afterburning case, an ejector-powered jet simulator since these simulators require less flow to and from them.

Seemingly suitable test program designs have been outlined for the three configurations. The resulting test program design depended upon the particular aircraft characteristics. There may be cases where the aircraft configuration, flight profile, etc. make it impossible to get wind-tunnel data with adequate propulsion system simulation.

7.0 Conclusions

1) It has become increasingly important to simulate propulsion system operation during wind-tunnel tests of jet aircraft configurations. 2) Designing a wind-tunnel test program which yields engine-on aerodynamic data can be

complex depending upon the particular simulation requirements, aircraft configuration, etc. 3) Before considering the test program design, it is necessary to decide what extent of simulation is desired, and this is primarily a function of the design Mach number of the aircraft and the Mach number range of the tests. 4) After the extent of simulation has been decided upon, the development of a test program design can become a tradeoff between engine simulator cost, complexity and ducting requirements; available model support techniques; and the complexity of the test program design. 5) Test program design is strongly dependent on the particular aircraft configuration to be tested and for some configurations it may be impossible to find a test program design which provides complete propulsion system simulation.

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Optimizing the Propulsion/Lift System for Turbofan STOL Aircraft

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A methodology has been developed in which aircraft configurations are optimized and systems are compared with cost effectiveness included in the initial stages of analysis. This method is applied to a comparison of propulsive high-lift systems for a STOL configuration with high bypass ratio turbofan engines. Three basic propulsive lift systems are considered: 1) external blowing of the trailing edge flaps, 2) blowing from the interior of the wing at both the knee and trailing edge of the flap (jet flap concept) combined with thrust vectoring, and 3) blowing from the interior of the wing at the flap knee (BLC concept) combined with thrust vectoring. These systems are optimized for a fixed takeoff distance and then incorporated into a parametric mission-sizing computer program which recognizes the weight aspects of each system. The results of this program are costed and minimum cost configurations are selected and compared.

I. Introduction

THERE is now and will be a continuing need for cost effective STOL aircraft suitable for either cargo or passenger transportation. This need exists within the environs of both military and commercial operations. There have been successful STOL aircraft designed using turboprop propulsion combined with a deflected slipstream high-lift system. However, the development of an aircraft which integrates the thrust and economical fuel consumption characteristics of a high bypass ratio turbofan engine with an efficient high-lift system remains as a goal for the aircraft and propulsion industries. It is generally agreed that high bypass ratio turbofan engines must be considered for new STOL aircraft especially when high-thrust levels, high-altitude, and high-speed cruise are required. It is the primary purpose of this paper to present the results of a comparison of three STOL high-lift concepts which have been integrated with high bypass ratio turbofan engines. Transport aircraft configurations have been optimized using these concepts and will be compared along with significant characteristics of each system. This comparison should provide guidance for further study and direction for future research and development expenditures. None of these systems have been subjected to a highly detailed analysis and do not represent completely optimized concepts. Every effort has been made to make the comparison as consistent as possible.

In the highly competitive environment of both commercial and military markets it has become necessary to consider cost effectiveness even in very preliminary design studies. A secondary purpose of this paper is the discussion and demonstration of a study methodology which has been developed to integrate cost effectiveness into the early technical development of new airplane concepts.

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