NASA TECHNICAL MEMORANDUM

NASA TM X-73,231

NASA TM X-73,231

LARGE-SCALE V/STOL TESTING

David G. Koenig, Thomas N. Aiken, Kiyoshi Aoyagi
Ames Research Center
Moffett Field, Calif. 94035

and

Michael D. Falarski
Ames Directorate, USAAMRDL
Ames Research Center
Moffett Field, Calif. 94035

(NASA-TM-X-73231) LARGE-SCALE V/STOL TESTING (NASA) 16 p HC A02/MF A01 CSCL 01C

N77-23091

Unclas
G3/05 26131

May 1977

1. Report No. NASA TM X-73,231	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LARGE-SCALE V/STOL TESTING		5. Report Date
		6. Performing Organization Code
7. Author(s) David G. Koenig,* Thomas N. Aiken,* Kiyoshi Aoyagi* and Michael D. Falarski**		8. Performing Organization Report No. A-7002
9. Performing Organization Name and Address *Ames Research Center, NASA and **Ames Directorate, USAAMRDL Ames Research Center, Moffett Field, CA 94035		10. Work Unit No. 505-10-41
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546 and U.S. Army Air Mobility R&D Laboratory, Moffett Field, Calif. 94035		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Several facets of large-scale testing of V/STOL aircraft configurations are discussed with particular emphasis on test experience in the Ames 40- by 80-Foot Wind Tunnel. Examples of powered-lift test programs are presented in order to illustrate tradeoffs confronting the planner of V/STOL test programs. It is indicated that large-scale V/STOL wind-tunnel testing can sometimes compete with small-scale testing in the effort required (overall test time) and program costs because of the possibility of conducting a number of different tests with a single large-scale model where several small-scale models would be required. The benefits of both high- or full-scale Reynolds numbers, more detailed configuration simulation, and number and type of onboard measurements increase rapidly with scale. Planning must be more detailed at large scale in order to balance the trade-offs between the increased costs, as number of measurements and model configuration variables increase and the benefits of larger amounts of information coming out of one test.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
Aircraft Design Testing		Unlimited STAR Category - 05	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 15	22. Price* $3.25

*For sale by the National Technical Information Service, Springfield, Virginia 22161

LARGE-SCALE V/STOL TESTING

David G. Koenig,* Thomas N. Aiken,** and Kiyoshi Aoyagi*
Ames Research Center, NASA, Moffett Field, California
and
Michael D. Falarski
U.S. Army Aviation Systems Command
Air Mobility R&D Laboratory
Ames Directorate
Ames Research Center, Moffett Field, California

Abstract

Severa' facets of large-scale testing of V/STOL aircraft configurations are discussed with particular emphasis on test experience in the Ames 40- by 80-Foot Wind Tunnel. Examples of powered-lift test programs are presented in order to illustrate trade-offs confronting the planner of V/STOL test programs. It is indicated that large-scale V/STOL wind-tunnel testing can sometimes compete with small-scale testing in the effort required (overall test time) and program costs because of the possibility of conducting a number of different tests with a single large-scale model where several small-scale models would be required. The benefits of both high- or full-scale Reynolds numbers, more detailed configuration simulation, and number and type of onboard measurements increase rapidly with scale. Planning must be more detailed at large scale in order to balance the trade-offs between the increased costs, as number of measurements and model configuration variables increase and the benefits of larger amounts of information coming out of one test.

Nomenclature

A_E = nozzle area

A_L = $n\,(\pi D_L/4)^2$, area of powered lifting area; fully expanded

A_m = $\Pi b^2/4$, momentum area of aircraft

A_N = nozzle area

A_T = cross-sectional area of wind-tunnel test section

b = wing span

b_T = width of test section

C_D = drag/qS

C_d = discharge coefficient

C_L = lift/qS

C_m = pitching moment/$qS\bar{c}$

C_T = thrust/qS

C_V = velocity coefficient

$\bar{c}$ = mean aerodynamic chord

D_L = diameter of lifting element

d = fan diameter

F_X = axial force

L = lift

n = number of lifting elements

PNL = perceived noise level, dB

P_o = atmospheric pressure

P_T = total pressure

q = dynamic pressure

S = wing area

T_c = total thrust (fan at $\alpha = 0°$)/$q(\Pi d^2/4)$

V = airspeed, m/sec (knots)

V_j = jet velocity, m/sec (ft/sec)

α = angle of attack

β_V = deflector vane setting

δ = flap deflection

I. Introduction

Development of V/STOL aircraft is becoming more dependent on large-scale wind-tunnel test programs than has been the case for the development of conventional aircraft. Interaction of the powerplant and the airframe introduces additional test parameters, and analytic tools in the process of being developed to handle the effect of this integration have not yet been proven. Because of the complexity and costs of some V/STOL models and their components as well as costs of flight testing, it is felt that large-scale testing at low speed must become a more significant part of aircraft development. It is, therefore, the objective of this paper to give the reader some insight into the major considerations associated with large-scale V/STOL testing.

The paper is divided into two parts: reasons for testing at large scale, i.e., scale effects, detail, and acoustics; and test considerations, i.e., planning, sizing, model construction, and operations. The presentation makes use of as many examples as possible from test results and from experiences in testing large-scale powered-lift models. Most of the examples are from programs at the Ames 40- by 80-Foot Wind Tunnel and the static test sites nearby. It is felt, however, that many of the considerations discussed are applicable to other large-scale testing facilities where powered models are involved.

---

*Research Scientist, Member AIAA.
**Research Scientist.

II. Reasons for Large-Scale Testing

The reasons for testing at large scale are many, but much of the justification can be placed within the objectives of obtaining close to full-scale Reynolds numbers, requirements for detailed representation of model configurations, and the possibility of obtaining a large variety of information from one model, including noise evaluation. To minimize the costs and time required for testing both large- and small-scale models, these reasons must be closely evaluated. To help in evaluation, brief examples follow.

Scale Effects

In much of the work that has been done in analyzing scale effects on the characteristics of lift-propulsion systems, there has been difficulty in separating the combined effects of going from one model and test installation to another model and test installation. For V/STOL aircraft model testing, this is a continual problem because of the strong effect of the simulated propulsion system on the aerodynamic characteristics involved. Examples of comparisons which indicate such scale effects are presented in Figs. 1, 2, and 3 for components of lifting systems which are documented in Refs. 1 and 2, and unpublished data,† respectively. Even for these correlations there are always questions: How accurate are the surface contours for the inlet tests? Was the grit large enough and applied far enough forward on the slat for the case in Fig. 3? But for testing complete powered-lift configurations, documenting such things as similarity in contour, similarity in flow conditions, or deflections under load can be an order of magnitude more difficult.

Problems in correlating test results for complete configurations may be illustrated by the investigation of an externally blown flap STOL configuration completed by NASA 4 years ago.[3,4] Two models were built, the larger being six times the size of the smaller, with tests being performed in the Ames 40- by 80-Foot Wind Tunnel and the Langley V/STOL Tunnel, respectively. The test installations are shown in Fig. 4. The small model was powered by ejector propulsion simulators and the large one by JT15D-1 turbofan engines. The small model is shown mounted within the liner installed in the 15- by 22-ft test section of the V/STOL tunnel to simulate the 40- by 80-ft test section. Although the essential purpose was not to look at Reynolds numbers or size effects as both wind-tunnel programs had other specific objectives, the effect of scale was an incidental result of the program. As can be seen by the three-component data of Fig. 5, the comparison in the performance of the two models was less than satisfactory. With the power off, the lift was less for the large model; with the power on, the lift was greater. This was the case even though the flap geometry was similar for the two cases, indicating a Reynolds number effect in flap effectiveness for both power off and on or different propulsion effects. Strong scale effects had been noted in past investigations of slotted flap configurations, but these occurred primarily with the power off. Here, with a blown flap system, even though instrumentation was complete for both models, at least toward meeting the objectives of the respective tests, there still was not enough documentation to show why the differences in lift occurred. The principal complications were probably the scale effect on the reaction of the jet with the flap system, combined with the use of two different power systems for the two models. These effects and similar ones have to be separated and well defined if results from small-scale powered models are to be used.

Even though with small size it is difficult to provide sufficient instrumentation to document scale effects, it is continually being attempted. One program where good correlation between large and small scale was obtained was in the development of the Advanced Harrier and is the subject of two other papers in this conference.[5,6] To a certain extent, that case was more straightforward in that full-scale results were used as verification of the small-scale results in order to quantify such things as flap lift increments and pitch control. Furthermore, the flap and propulsion systems were not completely integrated as was the case for the external blown-flap (EBF) models of Fig. 4, and small-scale flap performance was not influenced by small differences in the simulation of the engine efflux.

Model Detail

The comparison in slat effectiveness shown in Fig. 3 is believed to demonstrate the effect of Reynolds number; however, there is a chance that slat details such as the mechanical representation of the slat nose and wiper plate thickness may have an effect on slat performance.

For powered-lift models, there have been cases of externally blown flap tests where bracket thickness and placement have affected flap position and slot gap optimization. Another example of the effect of brackets occurred in the development of the NASA C8A flight test vehicle.[7] The aircraft was a C7A Buffalo modified to incorporate direct thrust and a thrust augmentor flap. During the development, a 0.7 scale model of the augmentor flap was statically tested, and the results are reported in Ref. 8. A section of the augmentor is shown in Fig. 6. Early in the tests, the upper part or shroud was held on by the turnbuckles to allow adjustment of slots for optimization runs. As the design of the aircraft proceeded, a final attachment plan, adaptable to the airplane, was developed, and the static model was tested with several configurations of these brackets. It was found that refinement of the design improved the performance of the system by 12%, based on the thrust of the primary nozzle. The width of the turnbuckles was the same as that of the aircraft brackets so that, in this case, it was evident that the large-scale model was needed to confidently evaluate all the details of the flap mounting structure.

Variety of Information

Large-scale models can provide a wider range in the types of measurements obtained in one test than small-scale models. Measurements possible

†Barrack, J. P., Hall, L. P., and Kirk, J. V., "Full-Scale Investigation of the Low-Speed Aerodynamic Characteristics of the F-111B Aircraft," NASA Ames Working Paper 249, Sept. 1969.

using large models are illustrated in the upper left of Fig. 7 for a complete aircraft configuration. Most of these can be made at small scale, but they would probably require several models. Using smaller scale models, either components or complete aircraft configurations, the test items on the right of Fig. 7 are possible. Acoustic studies require special model design and testing considerations which, for both large and small scale, may require separate tests. Measuring noise of large-scale models is discussed in Ref. 9, and special techniques for acoustic research in tunnels are treated in Ref. 10. If acoustics can be studied in the same tests, however, significant cost savings should be possible.

For complete acoustic models, the typical problems at small scale continue to be such things as suppression of noise of propulsion simulators, high-frequency measurements, and simulation of detail. As scale goes to full size, noise measurements in the 40- by 80-ft wind tunnel must be made in the near field. Ref. 11 describes an empirical technique for correcting results for near-field effects and compares jet noise measurements with flight tests (Fig. 8). Wind-tunnel and flight measurements agreed within 2 dB. With this program and others such as that of Ref. 12 for establishing the validity of wind-tunnel acoustic measurements, size can be used to good advantage to simulate both detail in the location of the sensors and the complete aircraft configuration. This was true for the large STOL model shown in Fig. 4.[13] At somewhat smaller scale for jet noise studies such as that shown in Fig. 9,[14] size of the installation helped to refine the survey of the noise field of hot high-velocity jets at several freestream velocities.

Costs

Once the need for large-scale tests has been formulated, limits on the use of such tests have often been placed because of high cost estimates for the proposed programs. The alternatives are to use smaller models and do more testing of aircraft components. Since, for the latter case, the lack of large-scale test results might jeopardize predictions of aircraft flight characteristics, it was felt that a study of comparative costs of large- and small-scale test programs was justified. Cases were studied which were either completely large scale or completely small scale but had common final objectives. One of these cases is described below and is based on the author's experience with test programs of a large variety of aircraft configurations. The results must be considered approximate because of the following: difficulty in evaluating the impact of computer-controlled machining and forming on model making; wide variation in costs of the smaller wind tunnels; no distinction in labor rates for different skills; variations in possible combinations of the relative effort used in component and complete configuration testing.

A comparison was made of costs of two test programs, one at large scale and one at small scale, each producing the same variety of information as listed for the small model in Fig. 7. It was assumed that all the small models were still large enough to justify use of the test data directly to predict stall and maximum flap performance; i.e., no additional testing time was assumed necessary for grit checks and flow studies to detail any local flow separation. It was also assumed that the 40- by 80-ft wind tunnel was used for the large-scale tests at $570/hr, and a typical V/STOL tunnel of 5 m by 8 m, such as at Langley or Lockheed, was used for small-scale tests at $450/hr. These values represent direct costs plus overhead. The comparison can only be qualitative since hourly rates can vary from one facility to another, and, whereas we assume that both static and wind-tunnel costs are the same, static test rates are likely to be lower. To further simplify the comparison, cost of materials, power plants, equipment, model repair, per diem and travel expenses were neglected. This does not invalidate the comparison since, generally, the equipment and power plants are already available for incorporation into the model and test installation, and the cost of installation refurbishment, etc. is less than 10% of total program costs.

For the large-scale tests, there was one static and one wind-tunnel test. The small-scale program was divided into four sets with the component models tested statically and the complete models tested in the wind tunnel. A summary of the cost comparison is presented in Fig. 10 which shows that total program costs are approximately the same for the two programs.

Other cases in which test effort was organized in a slightly different way than that shown in Fig. 10 showed that the relative costs could vary as much as 25%, particularly when a component test such as that for a thrust deflector was added to the large-scale test program. However, regardless of this and the previously mentioned qualifications of the study, it seems evident that the large-scale costs do not have to be much more than those required for small-scale tests if the large-scale model is designed to combine several different types of measurements during a single series of tests. If this can be programmed, the large-scale advantages of high Reynolds number, Strouhal number, detail of geometry, and measurement accuracy can be obtained while costing little more than the equivalent small-scale testing effort.

III. Test Considerations

Even though the costs of small- and large-scale testing can be equivalent, a major problem is the shortage of large test facilities. The wind tunnels capable of accepting some complete aircraft, located in the United States, are listed in Table 1.

Table 1 Wind-tunnel locations

Facility, m (ft)	Maximum speed, m/sec (knots)
9.1 x 18.3 (30 x 60) (Langley)	51 (100)
12.2 x 24.4 (40 x 80) (Ames)	92 (180, will be 300)
24.4 x 36.6 (80 x 120) (Ames, design in progress)	51 (100)

Each of these facilities has open static test sites nearby so that models can be transported between facilities without complete disassembly. The following discussion will consider tests in and near the 40- by 80-ft wind tunnel, but much of the discussion could be applied to planning test programs in other test facilities. In recent years there have been two very active open-field test sites at Ames which have been used for both testing of model or aircraft components as well as complete aircraft configurations.

Planning and Organization

Experience with recent V/STOL test programs in the 40- by 80-ft wind tunnel has shown that to reduce costs and testing time, advanced planning and organization cannot be over emphasized. Service organizations, contractors, and NASA offices must be all coordinated and briefed. Figure 11 shows the organization of three recent projects in order of increasing cost and extent of organization. They represent examples of 1) an in-house research project (Fig. 11a), 2) a joint service-NASA R.& D. program (Fig. 11b), and 3) a service-oriented development program supported by NASA (Fig. 11c).

Project 1 test results are reported in Refs. 15 and 16. This was an internally managed, basic research project with the objective of studying stability and control, high angle-of-attack characteristics through the stall, and acoustics. Project management came from the Ames Large-Scale Aerodynamics Branch (LSAB) with both an engine and an airframe manufacturer acting as consultants. Final reporting was done by the LSAB.

Project 2 test results are reported in Refs. 17, 18, and 19. This was a Navy-NASA jointly funded program, managed by NASA, with the objective of obtaining static (in and out of ground effect) and wind-tunnel data for loads, stability and control, and performance. The model was heavily instrumented to document propulsion and external surface pressures. The test management came from the Ames Aircraft Project Office, with the LSAB serving as advisors. The airframe contractor supported the tests with design, test support, data analysis, and reporting.

Project 3 test results are reported in Ref. 6. This was Navy-funded with test management coming jointly from the LSAB, the contractor, and the Navy. The model was equipped primarily for full-scale stability, control, and performance checks with the instrumentation required to document power settings together with a few loads. The cost of the model was an order of magnitude higher than the foregoing projects because the model combined a fuselage flight structure with the Rolls Royce F402-R-402 engine and a boiler plate wing-flap system. In addition, since the tests were part of an aircraft development program on a tight schedule, it was highly "visible," and a large number of contractor personnel were required to support the operation of the tests and correlate test results on a daily basis.

The test programs of both Figs. 11b and 11c proved not only to include and require extensive coordination between groups, but they were also expensive. This was true in spite of their use of some of the following considerations. High costs can sometimes be cut by the following: 1) use of boiler plate construction for models, 2) careful evaluation of trade-offs in complexity and cost, 3) use of increased tolerances where at all possible, 4) use of analytic methods and algorithms in planning the test procedure, 5) coordination with small-scale programs to minimize duplication, and 6) borrowing or leasing equipment and model parts where possible. Measurements to be made are major planning items. For V/STOL wind-tunnel testing at large scale, the types of measurements are many and could include all or some of the following in one test:

1) Stability and control
2) Aerodynamic performance,
3) Propulsion performance, inlet and nozzle
4) Loads on flaps and control surfaces
5) Surface pressure measurements on all components
6) Boundary-layer surveys
7) Acoustic studies, near and far field
8) Wake surveys, downwash, sidewash
9) Flow surveys near tunnel walls to evaluate wall effects
10) Flow visualization
11) Structural static and dynamic loading
12) Aircraft systems checks

A principal problem in program management is to avoid attempting so many measurements that the primary goals of the experiment are jeopardized through complex equipment malfunction, but, at the same time, to take full advantage of the test installation, and testing time.

Model Sizing and Construction

During the early development stage of powered-lift aircraft, components such as deflectors, thrust reversers, or blown flaps can be studied, but eventually, the complete lifting system must be represented making tests on complete aircraft configurations essential. In either case, consideration of cost means resorting to simplifying model construction, adapting model size to existing surplus engines, or minimizing test configuration changes.

Sizing

For model scales which make full use of the capacity of the 40- by 80-ft wind tunnel, our experience has been that size is dictated by available energy sources such as compressed air capacity and electrical motor and gas turbine sizes available. As will be discussed, the size of gas turbine engines which have been developed for business jet aircraft adapts well to model scales of 0.3 to 0.7. For larger models, there is a jump in thrust to the 10,000 class which will force the aerodynamic size limits and result in large wall interference effects. The estimation of these effects then becomes vital. Reference 20 relates aircraft and wind-tunnel geometry to model-tunnel sizing parameters in order to establish tentative sizing criteria for V/STOL wind-tunnel testing. Correlation plots from that reference are presented in Fig. 12 and have been updated with the models of Refs. 6, 15, and 19. The lines have been somewhat arbitrarily drawn in the figure to represent guidelines of good wind-tunnel flight correlation. The wall effects for the large configurations and for decelerating flight can be significant as shown in Refs. 21 and 22, and the ranges of Fig. 12 might well be lowered for these cases. However, it is felt that as more detailed correlation techniques are developed, particularly for VTOL configurations, the ranges can be expanded.

Currently, the most practical of the energy sources available for 40- by 80-ft wind-tunnel model use is the small turbojet or turbofan engine. The engines available are shown in Fig. 13 together with the operating parameters for maximum continuous performance. Ames attempts to maintain a sufficient number of each to power model configurations having from four to six engines. These engines, plus other gas power sources, have been placed on the thrust-pressure ratio map of Fig. 14. The T58 and J85 are used to drive the LF376 and LF336 tip-driven fans, respectively [0.91 m (3 ft) diameter]. The LF376 fans were used in the model shown in Fig. 15 (the model used in the program of Fig. 11b). The J85 has also been used as a lift engine oriented in a vertical thrusting position for the program of Ref. 23. In addition, this engine has driven the turbines of modified Viper engines for which the compressor output is used to power blown flap models such as that reported in Ref. 22 or for the blown semispan installation shown in Fig. 16.

Additional sources of energy such as high-pressure air and electric power have been considered only as auxiliary power for large-scale models, except for the electric motors driving rotary-wing or propeller-driven models. As the high-pressure air source capacity is increased at the wind tunnel, it could be practical energy source for medium-sized static or dynamically similar models, 12-in.-diameter tip-driven fan installations, and boundary-layer control (BLC) systems for large-scale models. Target capacity for the air supply is 32 kg/sec (70 lb/sec) at 2000 psi maximum with a continuous rating of 11 kg/sec (25 lb/sec). For information on available electric motors and maximum load, the reader should consult Ref. 24.

The foregoing has been a very brief discussion of the practical constraint on sizing large-scale models, the power plant. A major need is for a small or medium-sized, high-bypass-ratio turbofan or a practical scheme to simulate it. It is hoped that further development of the business jet will bring about such an engine. The closest to this is the LF376. Determining the availability of these and other possibilities, such as the engines listed in Figs. 13 and 14, as well as electrical and high-pressure air sources, becomes an essential consideration in the planning of a proposed powered-lift program.

Construction

Experience in construction of large-scale models has shown that, for most cases, so-called boiler plate construction is adequate and no more expensive for a given aircraft configuration than for smaller models requiring machining, advanced casting techniques, and many man-hours of finishing. However, to profit from the advantages of "boiler plating," expensive forming, casting or machining are not utilized, unless these methods are absolutely required to accurately simulate performance items such as inlet, slots, or wing leading-edge contours. To illustrate trade-offs, examples follow.

The housing for the JT15D used on the upper surface blown-flap (USB) model of Ref. 15 is shown in Fig. 17. Since the model was to be used to investigate aircraft stability, control, and stall characteristics, it was decided that the weight of the nacelle could be supported from below with an oversized and stiff pylon beam. Rather than use an expensive shell mount to minimize overall nacelle width, the engines were moved outboard on the wing to maintain a required length of exposed wing leading edge between the nacelles and the fuselage. In terms of percent span, this was less than 1% span further out on the wing. For this case, the maximum nozzle pressure ratio and optimum duct performance were not needed, so the internal nozzle contours were not critical as long as the surfaces were continuous and smooth in a streamwise direction. To ease this situation, the nozzle was made overly long to reduce curvature. This made it possible to use segmented, welded construction of both the hot and cold nozzle ducts with external formers as shown. The forward skin was rolled sheet steel with access panels placed to ease servicing and engine checks (no compound curves). The skin on the nozzle had to have a compound curvature, but it was covering the outer duct and could be fiberglass. The inlet was spun-formed for previous test programs and was readily adapted to the nacelle framework and cowling. After the first test, the lower nacelle contour was modified economically by adding foam and fiberglass for all four nacelles. This involved approximately 100 man-hours.

The second example is that of the complete VTOL method used for the program of Fig. 11b. The model is shown in Fig. 18 (during its construction) and in Fig. 15 (fully completed). Three T58's needed to power the LF336 fans were housed in the fuselage and ingested air from the two side inlets (one is shown installed). The hot ducting was well insulated and bay cooling was an essential part of the design, making it possible to form most of the compound surfaces from fiberglass, particularly the simulated canopy and the inlets. Most of the surfaces were defined by 1/8- to 1/4-in. steel ribs or bulkheads, precut to a computed curvature for that particular cross section and welded in place to a base framework. In hot areas, stringers were installed, and steel skin was plug-welded or screwed to these formers which became an integral part of the structure. In cool areas, foam and fiberglass were installed between the formers. The wing and flaps had a steel spar and were covered with wood and a single layer of fiberglass. Small-tolerance areas were held to the outer wing, flaps, and inlets. Construction setup time was considerably reduced by increasing tolerances in other areas where possible.

A very significant note must be made about locating instrumentation on models such as that just described. The scanivalves and miscellaneous transducers which are located on the model must be accessible and compatible with cooling requirements. For the above model, it was difficult to find a cool area in which to install these units (an area centrally located to minimize pressure tubing length). The final position was between the outer wing and the gas generator inlet duct. The problem was recently made significant when an onboard data acquisition system was made optional for 40- by 80-ft wind-tunnel models. This system requires locating Remote Multiplexing Distribution Units (RMDU's) on or near the model, preferably near the scanivalves. Although use of the RMDU's will not be required, they will greatly reduce hookup and pressure check time.

Operations

The limited availability of large-scale wind tunnels makes it imperative that the complete test procedure evolve from trade-offs in tunnel time and model complexity such as the number of onboard measurements or the number of configuration variables. For powered-lift programs, the expense of the model and justification for starting the program in the first place seem to bring pressure from all participants to increase the number of measurements and test variables. The following comments are designed to help with judging the impact of increasing complexity on wind-tunnel time.

Figure 19 shows the ratio of total down time to on-site time as a function of the number of model configuration variables. The vertical scale is sliding since the actual ratio can depend on too many factors beyond our control. A good number for zero changes with power off is 30 as a start. The estimations or faired curves are based on 350 onboard measurements. The test cases have approximately this number of measurements. Some of the results come from the author's experiences and are qualitative, but the curves are primarily derived from the USB tests,[15] lift-cruise fan model tests,[19] and augmentor wing tests.[21] The effect of power is shown on the plot at zero configuration changes and should be typical of the penalty paid for engine maintenance, time required to purge the tunnel of exhaust gases, and cooling of the air in the tunnel. The steeper slope with the first two configuration changes reflects the assumption that these two are major changes (such as tail installation or removal which can take 2 to 4 hrs in the 40- by 80-ft wind tunnel).

Figure 20 shows the variation in time required to record each data point as a function of the number of onboard measurements. No accounting is made of power changes which at times must be made to keep up with changes in tunnel air temperature and which can add an additional 30 sec to some data points. These minor throttle adjustments can usually be done during changes in other settings such as angle of attack or sideslip. It has been assumed that the first 1-1/2 min consist of: setting the test conditions such as angle of attack, sideslip, or power; letting the tunnel airspeed steady out; and recording the data from the scale system. After a 12- to 15-sec scanning period, recording with the model data system is started. Although, as the system itself is refined in the future, the slope of the curve could decrease slightly, the penalty in testing time because of onboard measurements is significant enough to warrant inclusion in the initial planning of the program. In arriving at the 1-1/2-min period shown in Fig. 20, it was assumed that any thrust changes would be only those required to compensate for temperature changes, and tunnel power would have to be changed in small increments between data points.

Figure 21 illustrates the problems encountered in estimating the settling time required after a rapid thrust or drag change is made in the test section. The cross-hatched area represents an estimate of the minimum required time, assuming that wind-tunnel drive power is changed to compensate the thrust change at the same time. Since the tunnel speed is adjusted manually, this requires good coordination between the wind-tunnel and engine operators (or model controller). Lines representing the wind-tunnel characteristics with the model out are also shown for reference. The values of Δq were chosen to bracket the equivalent wind-tunnel power change required to compensate for the thrust change in the test section. The problems with wind-tunnel size are illustrated by the large air circulation time of 80 sec for 60 knots, a commonly used test airspeed for V/STOL transition. In practice, in order to be assured that airspeed has stopped varying, the time taken is about twice that indicated for the 50- to 60-knot range, about 2 min, the last minute is generally consumed by fine adjustments to airspeed. A computer-controlled speed adjustment now being considered for the new 40- by 80-ft/80- by 120-ft test power system may eliminate the need for this latter period of adjustment. However, in spite of inputs from model power conditions, angle of attack, or air temperature, such a speed control system will still have difficulty in reducing the time indicated in the figure simply because of the large volume of air circulating in the tunnel.

A major problem in operating with gas turbine engines results from the lack of a positive ventilating system and a practical operating limit of 130°F in the test section. As shown in Fig. 22, the use of gas turbine engines results in a certain maximum running time. After this, the engines must be shut off, the appropriate doors opened, and the tunnel run at low speed for purging or for reducing air temperature. Currently, this takes 20 min to 1 hr. To reduce this time, which is essentially lost for test purposes, an attempt is usually made to schedule V/STOL testing with engines in the cool months and/or restricting operation to evening and early morning hours. Note that the choice of power plant and sizing of the model have a strong influence on this time. The problem will certainly be eliminated in operating the 80- by 120-ft test section.

In summary, the major factors to consider in attempting to minimize wind-tunnel time for large-scale V/STOL models are, to a certain extent, similar to those of other powered models. In both cases, power and instrumentation calibrations should be done prior to model testing, model parts should be fitted, and run procedures planned in detail. The major differences appear in operations where, for the larger tunnels, settling times are large; for closed-return tunnels, gas generator operation brings the need for purging time. Another factor which has not been mentioned is that the logistics of making model changes in the larger wind tunnels are completely different since the model is 15 to 40 ft above the wind-tunnel floor. To take advantage of the larger size in order to get many types of data, this difference must be recognized, and accessibility problems must be anticipated at the inception of the program.

IV. Concluding Remarks

Large-scale V/STOL wind-tunnel testing results in benefits of both high Reynolds numbers and more detailed configuration simulation, and the number and type of possible onboard measurements increase rapidly with scale. Large-scale testing can sometimes compete with small-scale testing in terms of the effort required (overall test time) and program costs because of the possibility of conducting a number of different tests that would require additional small-scale models. Planning must be more detailed at large scale in order to balance the trade-offs between the increased costs, as number of measurements and model configuration variables increase, and the benefits of larger amounts of information coming out of one test. To help in evaluating these trade-offs, several facets of large-scale testing have been presented with particular emphasis on test experience in the Ames 40- by 80-ft Wind Tunnel.

References

[1]Mort, K. W., "Summary of Large-Scale Tests of Ducted Fans," Paper 8, Conference on V/STOL and STOL Aircraft, Ames Research Center, Moffett Field, Calif., 1966, NASA SP-116.

[2]Hickey, D. H., "V/STOL Aerodynamics: A Review of the Technology," AGARD Conference Proceedings 143, Paper 1, Delft, the Netherlands, 1974.

[3]Aoyagi, K., Falarski, M. D., and Koenig, D. G., "Wind-Tunnel Investigation of a Large-Scale 25° Swept-Wing Jet Transport Model with an External Blowing Triple-Slotted Flap," NASA, TM X-62,197, Nov. 1973.

[4]Gentry, C. L., Jr., "Wind-Tunnel Investigation of an Internally Blown Flap STOL Transport Model Including an Investigation of Wall Effects," NASA TM X-3009, Sept. 1974.

[5]Miller, K. and Lacey, T. R., "The AV-8B Wing: Aerodynamic Concept and Design," AIAA Paper 77-607, Moffett Field, Calif., 1977.

[6]Hollingsworth, E. G., Aiken, T. N., and Ragget, J., "Validation of AV8-B V/STOL Characteristics of Full-Scale Static and Wind-Tunnel Tests," AIAA Paper 77-597, Moffett Field, Calif., 1977.

[7]Quigley, H. C. and Vomaske, R. F., "Preliminary Results of Flight Tests of the Augmentor-Wing Jet STOL Research Aircraft," STOL Technology Conference, Paper 20, Ames Research Center, Moffett Field, Calif., 1972.

[8]Harkonen, D. L., Wintermeyer, C. ?., and Wright, F. L., "Static Tests of a 0.7 Scale Augmentor Wing Flap for the Modified C-8A Airplane Test Results and Analysis," NASA CR-114315, 1971.

[9]Falarski, M. D., Koenig, D. G., and Soderman, P. T., "Aspects of Investigating STOL Noise Using Large Scale Wind Tunnel Models," Canadian Aeronautics and Space Journal, Vol. 19, Feb. 1973, pp. 61-69.

[10]Soderman, P. T., "Instrumentation and Techniques for Acoustic Research in Wind Tunnels," 6th International Congress on Instrumentation in Aerospace Simulation Facilities, IEEE Publication 75 CHO 993 6 AES, 1975.

[11]Strout, F. G. and Atencio, A., "Flight Effects on JT8D Engine Jet Noise as Measured in the NASA Ames 40- by 80-Foot Wind Tunnel," AIAA Paper 76-556, Palo Alto, Calif., 1976.

[12]Atencio, A. Jr., "The Effect of Forward Speed on J85 Engine Noise from Suppressor Nozzles as Measured in the NASA-Ames 40- by 80-Foot Wind Tunnel," NASA TN D-8426, Feb. 1977.

[13]Falarski, M. D., Aiken, T. N., Aoyagi, K., and Koenig, D. G., "Comparison of Acoustic Characteristics of Large-Scale Models of Several Propulsive-Lift Concepts," Journal of Aircraft AIAA, Vol. 12, July 1975, pp. 600-604.

[14]Jaeck, C. J., "Static and Wind Tunnel Near-Field/Far-Field Jet Noise Measurements from Model Scale Single-Flow Baseline and Suppressor Nozzles," Vol. I: Noise Source Locations and Extrapolation of Static Free-Field Jet Noise Data, NASA CR-137913, Sept. 1976. Vol. II: Forward Speed Effects, NASA CR-137914, Nov. 1976.

[15]Aoyagi, K., Falarski, M. D., and Koenig, D. G., "Wind Tunnel Investigation of a Large-Scale Upper Surface Blown-Flap Transport Model Having Two Engines," NASA TM X-62,296, Aug. 1973.

[16]Koenig, D. G. and Aoyagi, K., "Maximum Lift of Upper Surface Blowing STOL Aircraft with Swept Wings," AIAA Paper 75-868, Hartford, Conn., 1975.

[17]Gambucci, B. J., Aoyagi, K., and Rolls, L. S., "Wind Tunnel Investigation of a Large-Scale Model of a Lift/Cruise Fan V/STOL Aircraft," NASA TM X-73,139, May 1976.

[18]Gambucci, B. J., Aoyagi, K., and Rolls, L. S., "Wind Tunnel Investigation of a Large-Scale Model of a Lift/Cruise Fan V/STOL Aircraft with Extended Lift/Cruise Nacelles," NASA TM X-73,164, Aug. 1976.

[19]"Wind Tunnel and Ground Static Investigation of a Large Scale Model of a Lift/Cruise Fan V/STOL Aircraft," NASA CR-137916, Oct. 1976.

[20]Hickey, D. H. and Cook, W. L., "Correlation of Wind Tunnel and Flight-Test Aerodynamic Data for Five V/STOL Aircraft," presented at the Flight Mechanics Panel Meeting of AGARD, Rome, Italy, Oct. 1965.

[21]Koenig, D. G. and Corsiglia, V. R., "Aerodynamic Characteristics of a Large Scale Model with an Unswept Wing and Augmented Jet Flap," NASA TN D-4610, June 1968.

[22]Heyson, H. H., "Rapid Estimation of Wind Tunnel Corrections with Application to Wind Tunnel and Model Design," NASA TN D-6416, Sept. 1971.

[23]Tolhurst, W. H. and Kelly, M. W., "Characteristics of Two Large-Scale Jet-Lift Propulsion Systems," Conference on V/STOL and STOL Aircraft, Ames Research Center, Moffett Field, Calif., 1966, NASA SP-116.

[24]"Guide for Planning Investigations in the Ames 40- by 80-Foot Wind Tunnel," Ames Research Center, Moffett Field, Calif., June 1975.

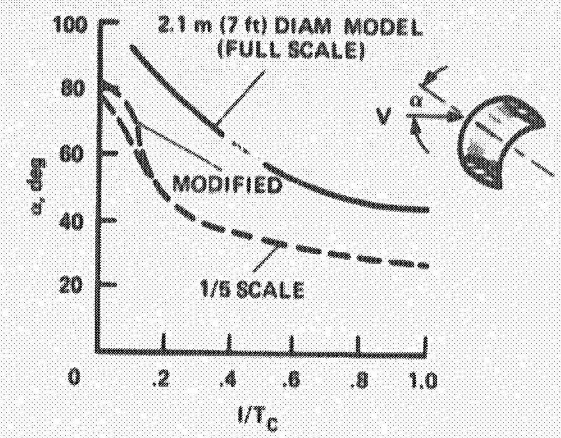


Fig. 1 Effect of scale on duct inlet stall boundary (see Ref. 1).

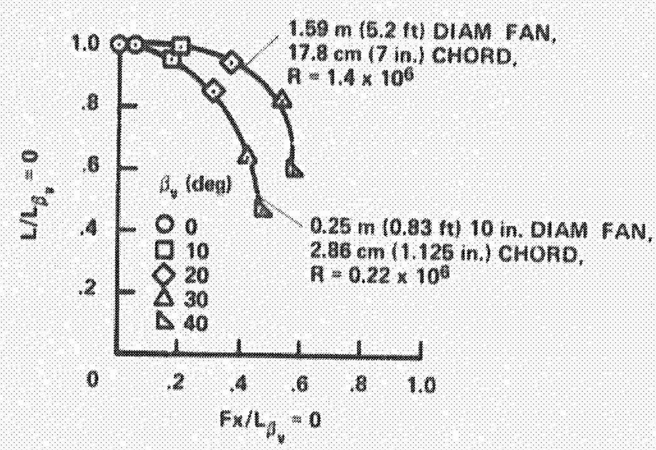


Fig. 2 Performance of large- and small-scale exit vane systems (see Ref. 2).

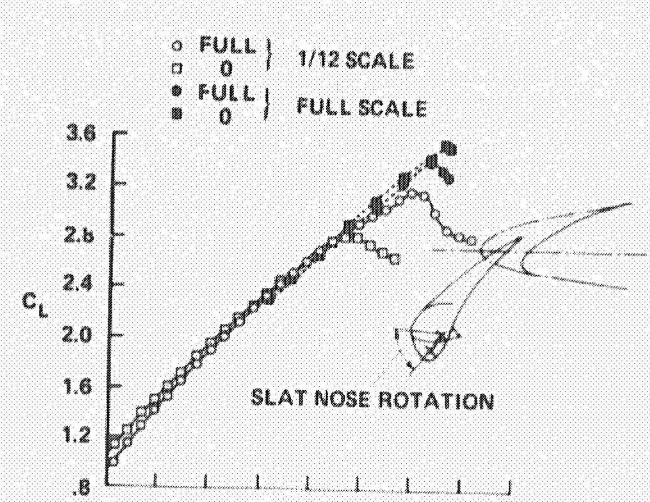


Fig. 3 Effect of scale on the lift characteristics of the F-111A airplane landing configuration (see footnote page 2).

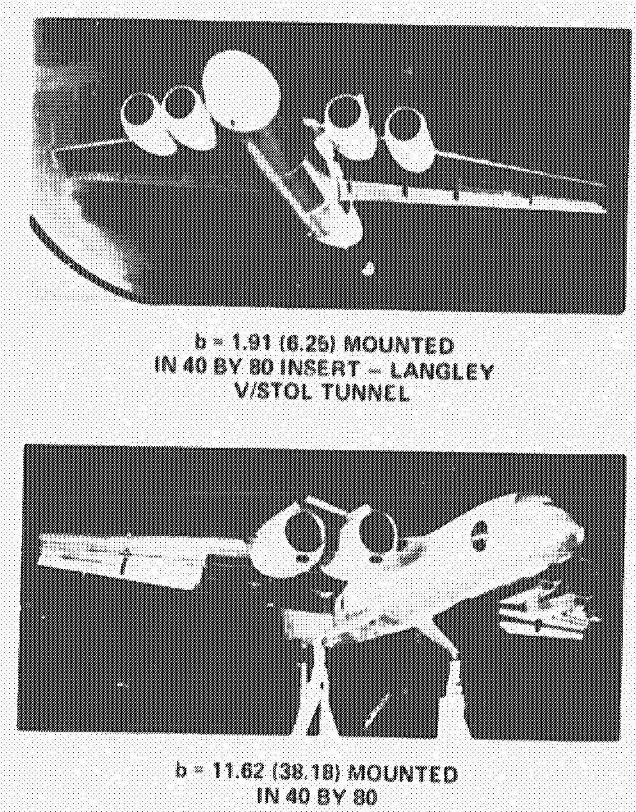


Fig. 4 EBF models with the same wing-flap geometry.

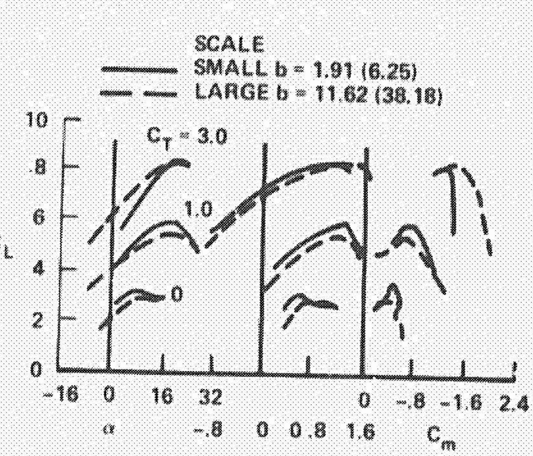


Fig. 5 Comparison of wind-tunnel tests of a triple-slotted external blowing configuration.

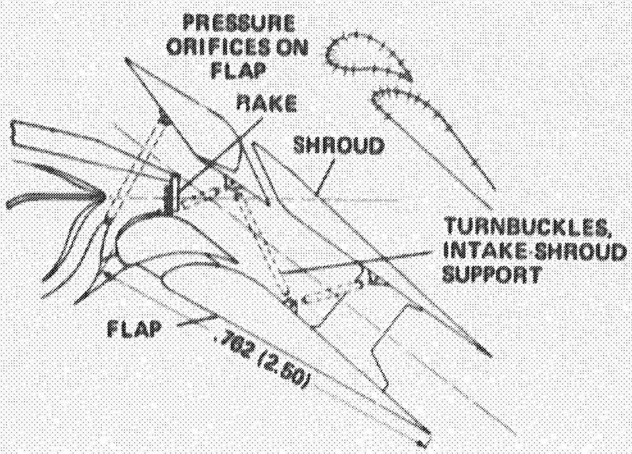


Fig. 6 Augmentor flap for 0.7 scale test (see Ref. 8).

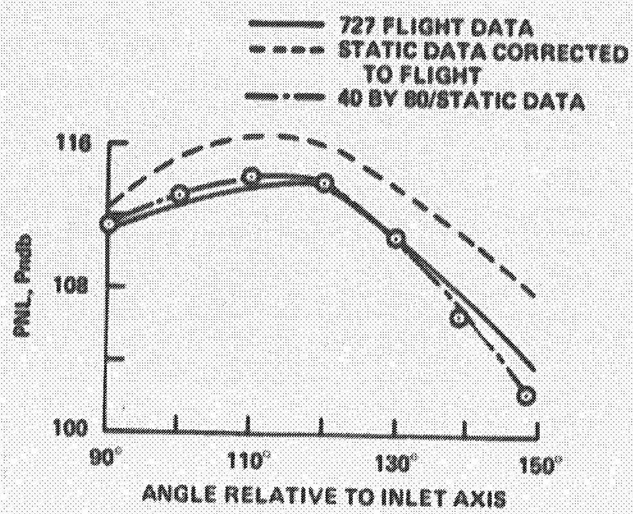
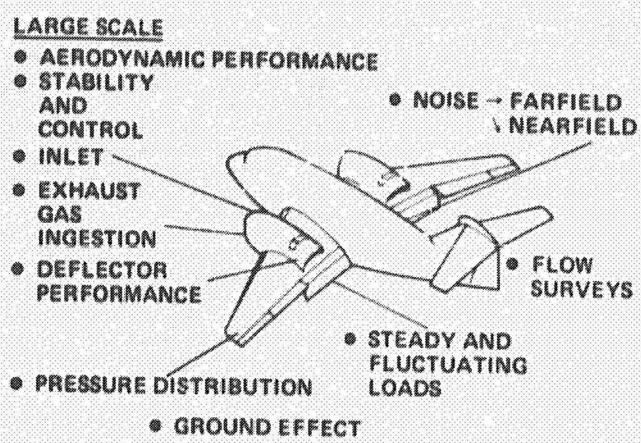


Fig. 8 Comparison of 40- by 80-ft wind tunnel and flight stand data with the 20 lobe ejector suppressor on a JT8D-17 turbofan engine (see Ref. 11).



SMALL SCALE
COMPONENT TESTS
- INLET
- INGESTION
- DEFLECTOR PERFORMANCE
- LOADS

COMPLETE MODEL TESTS
- PERFORMANCE
- STABILITY AND CONTROL
- PRESSURE DISTRIBUTION
- INGESTION

Fig. 7 Measurements using large- and small-scale models.

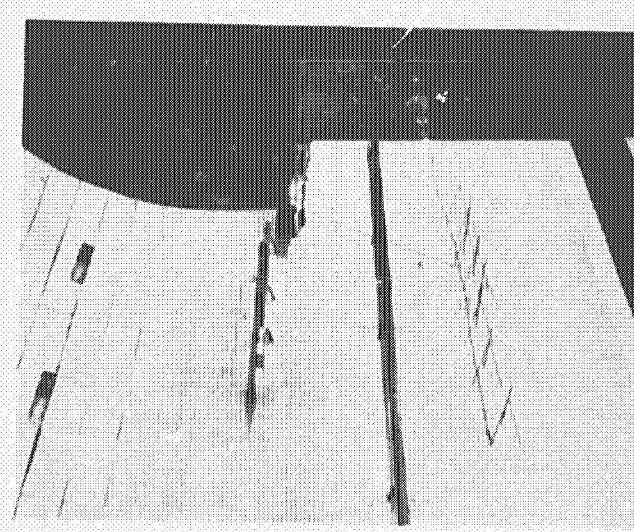


Fig. 9 Wind-tunnel (40- by 80-ft) test installation of hardware used in high-velocity jet noise studies.

LARGE SCALE

*• MODEL	$784K	
WIND TUNNEL TIME	228	
STATIC TEST TIME	91	
	$1003	

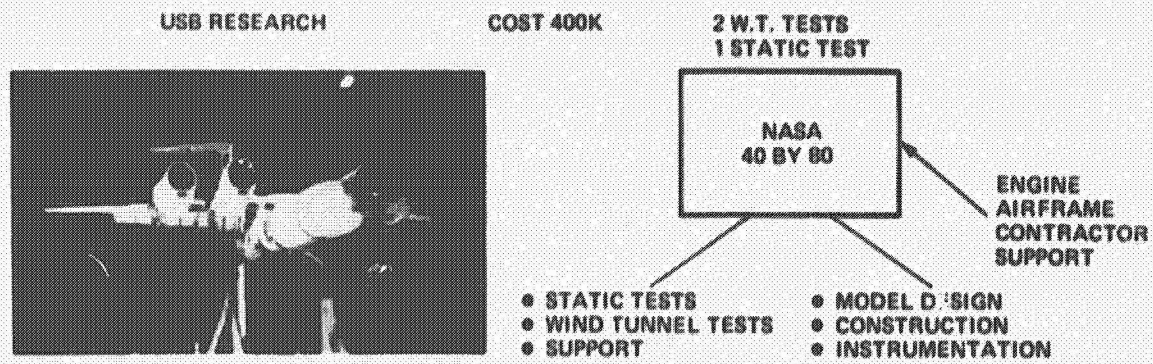
–MODEL COST = 28 x MAN HOURS (LARGE & SMALL SCALE)
–WIND TUNNEL:
COSTS
LARGE SCALE, COSTS = 570 x HRS
SMALL SCALE, COSTS = 450 x HRS

*COMPLETE MODEL

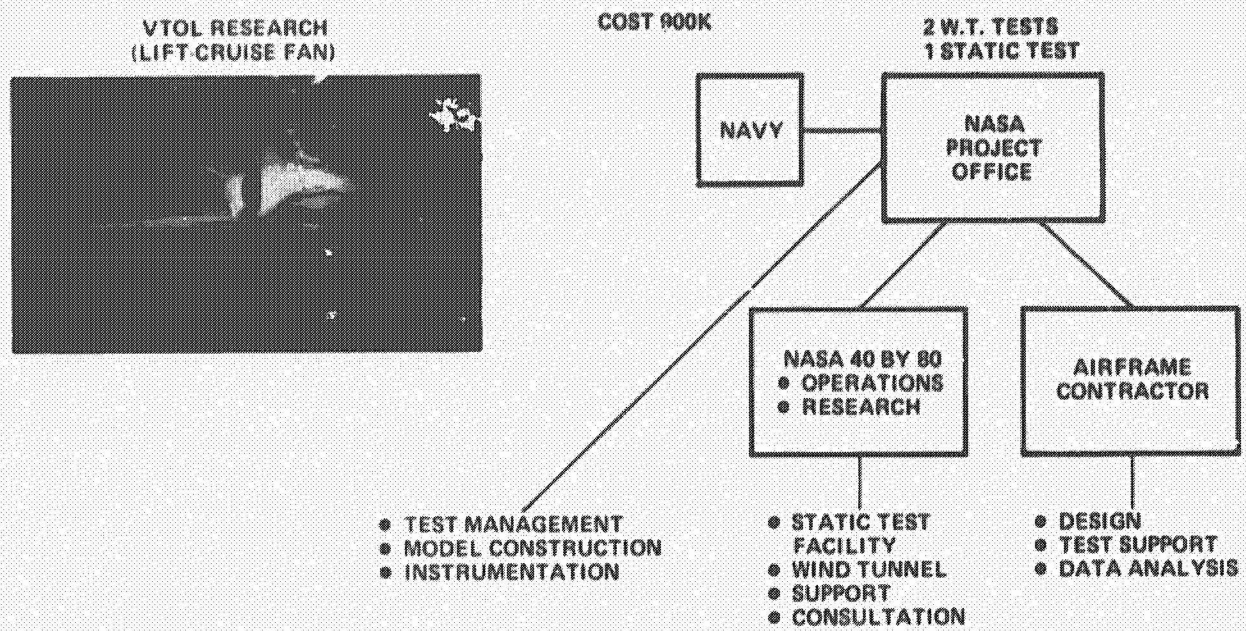
SMALL SCALE

• INLET-INGESTION		
MODEL	$56K	
STATIC TESTS	45	$101K
• DEFLECTOR LOADS (STATIC)		
MODEL	112	
STATIC TESTS	54	166
*• STABILITY AND CONTROL INCLUDING SURFACE PRESSURES		
MODEL (COMPLETE)	224	
WIND TUNNEL	144	368
*• INGESTION-WIND ON WITH SIMULATION OF THRUST REVERSERS		
MODEL (COMPLETE)	336	
WIND TUNNEL	108	444
		$1079K

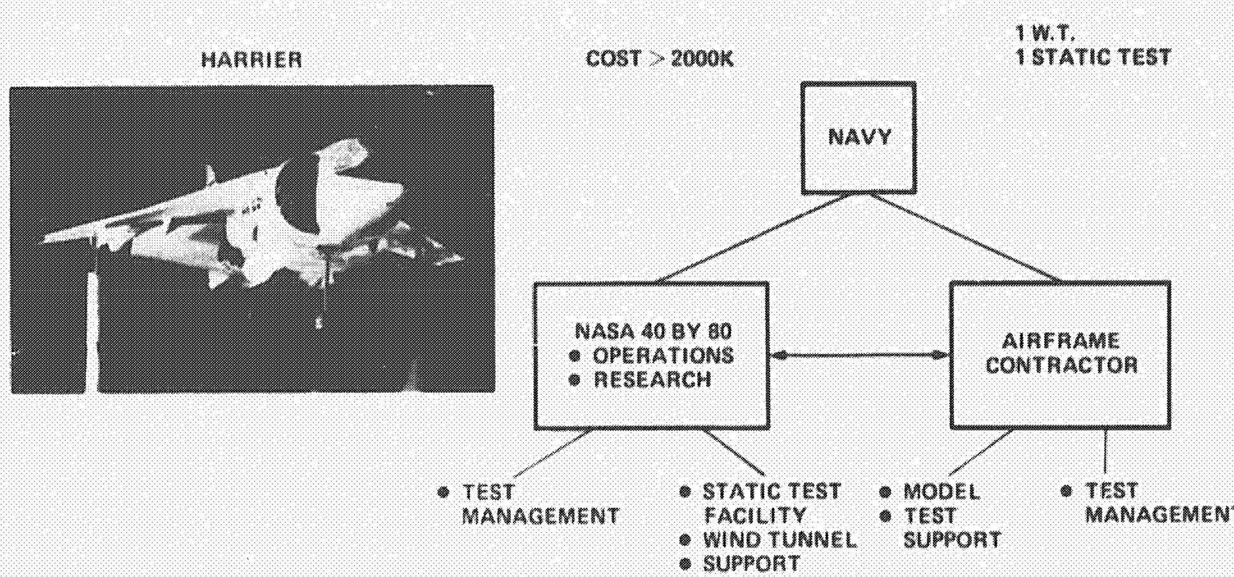
Fig. 10 Large-scale versus small-scale cost — a qualatitative comparison.



a) An in-house basic research project.

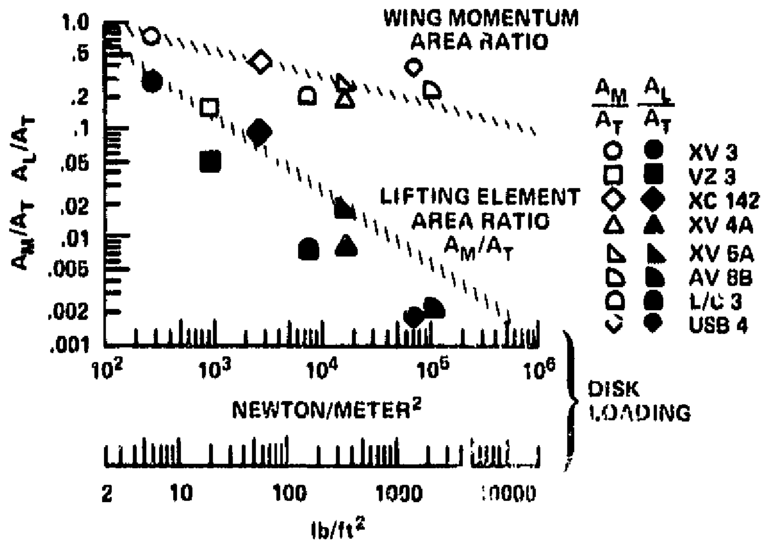


b) A joint service R.& D. project.

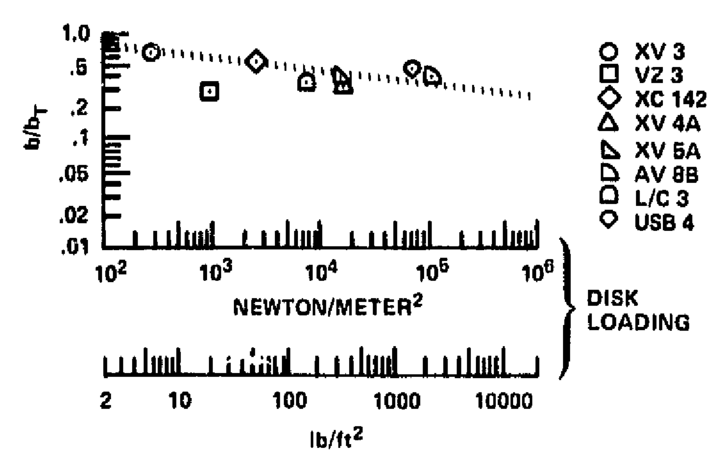


c) A military development program.

Fig. 11 Organization of recent test programs.



a) L..t and momentum area sizing.



b) Wing span sizing.

Fig. 12. Sizing parameters.

	THRUST N	THRUST (lb)	W kg/sec	W (lb/sec)	P_T/P_O	A_e m^2	A_e in^2
J85-5	11,560	(2600)	19.28	(42.5)	2.24	.0742	(115)
T58	2,670	(600)	5.67	(12.5)	2.1	.0188	(29.2)
J97	20,020	(4500)	31.75	(70)	3.0	.0839	(130)
JT15-D	8,450	(1900)	34.02	(75)	1.35	.1419	(220)

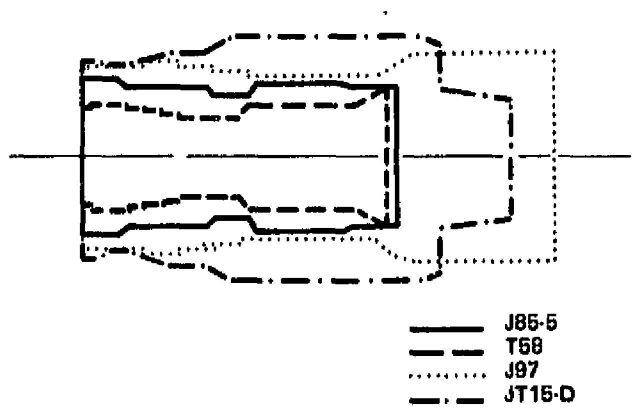


Fig. 13 Small turbofan or turbojet engines available for use in large-scale V/STOL testing.

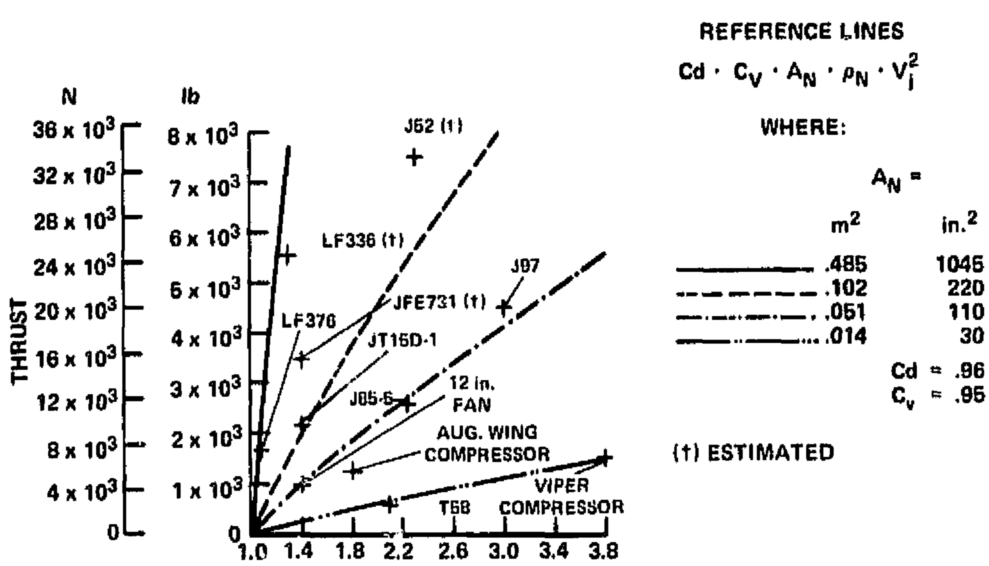


Fig. 14 Summary of possible gas energy sources (continuous running limits unless otherwise noted).

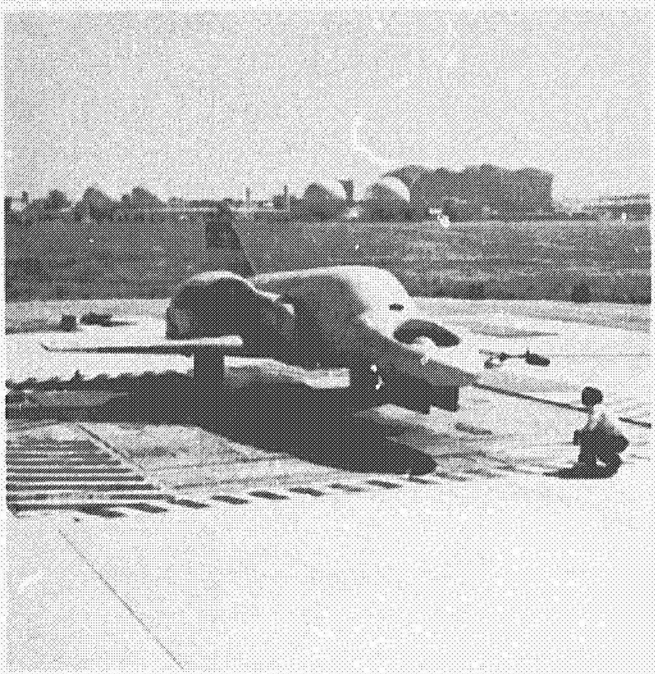
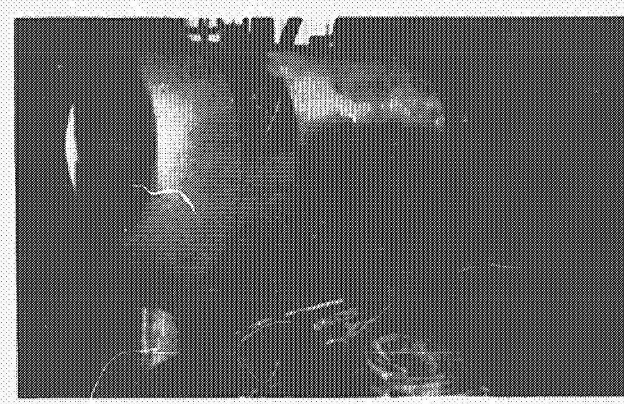
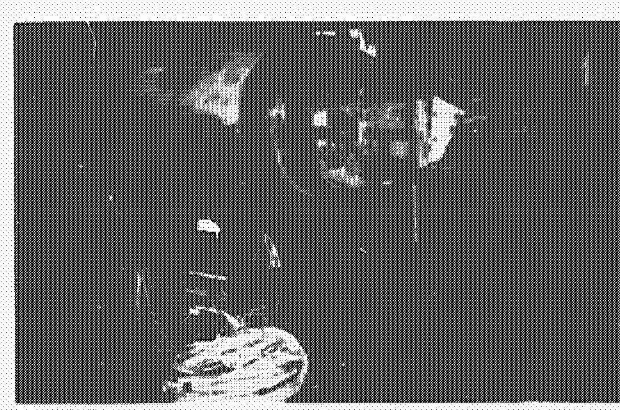


Fig. 15. Model of lift-cruise fan aircraft.



a) 3/4 front view.



b) 3/4 rear view.

Fig. 17. JT15D nacelle for USB model.

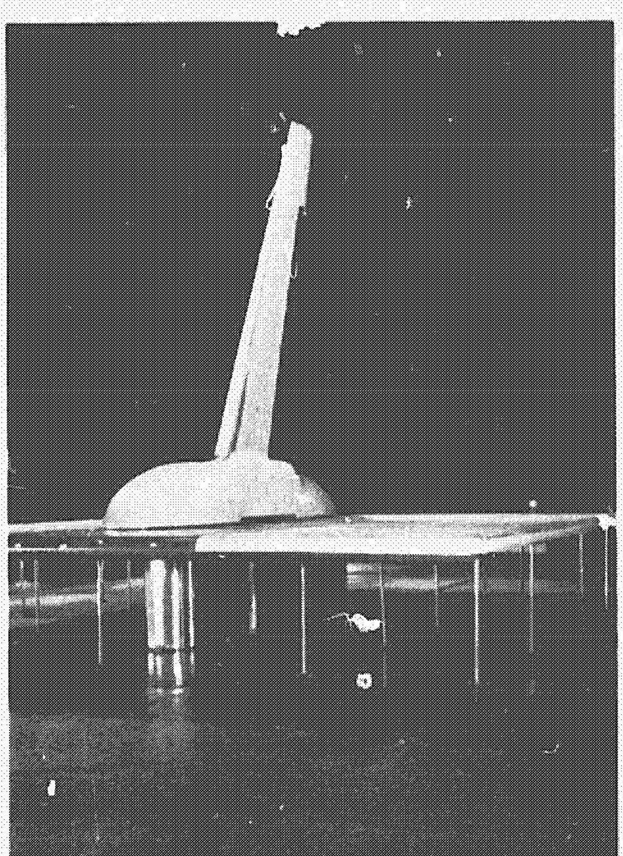


Fig. 16. Semispan mount in the 40- by 80-ft wind tunnel.

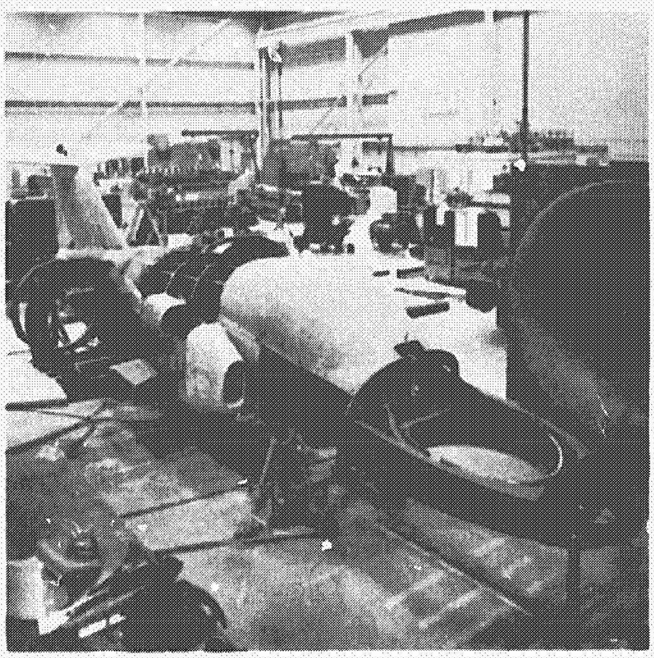


Fig. 18. Partially completed boiler plate VTOL model.

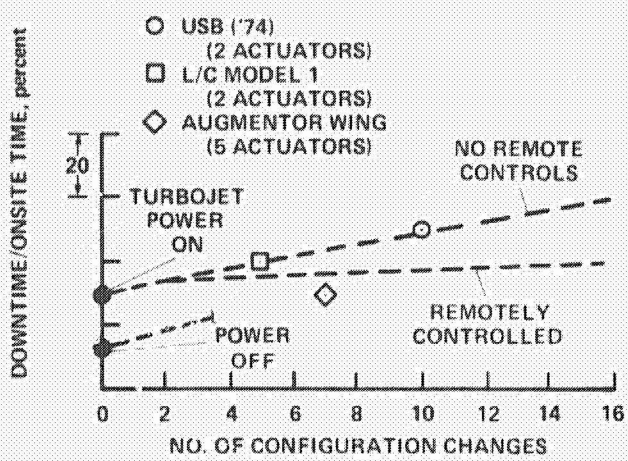
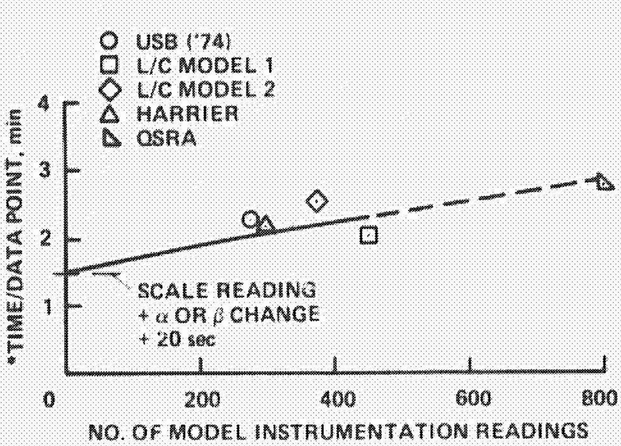


Fig. 19. Variation of down time with number of configuration changes in the wind tunnel.



*ACTUAL TIME PER DATA POINT DURING TYPICAL POLAR OR YAWLER

Fig. 20. Time required for a data point for powered models.

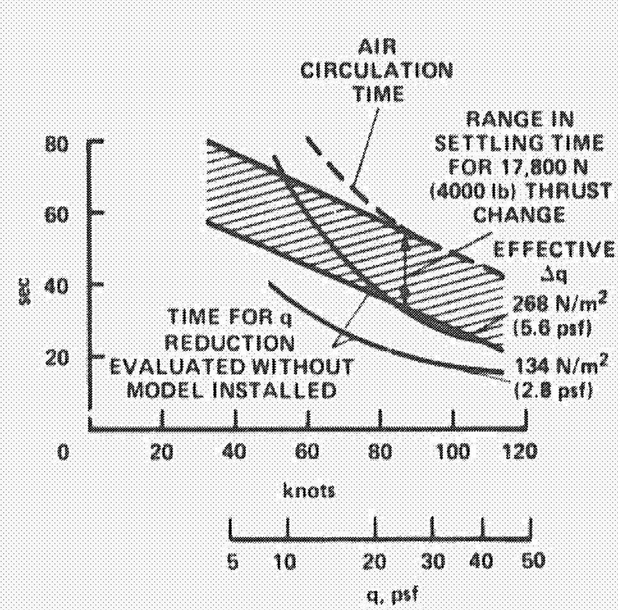


Fig. 21. Settling time recommended after a rapid thrust change of 17,800 N (4,000 lb).

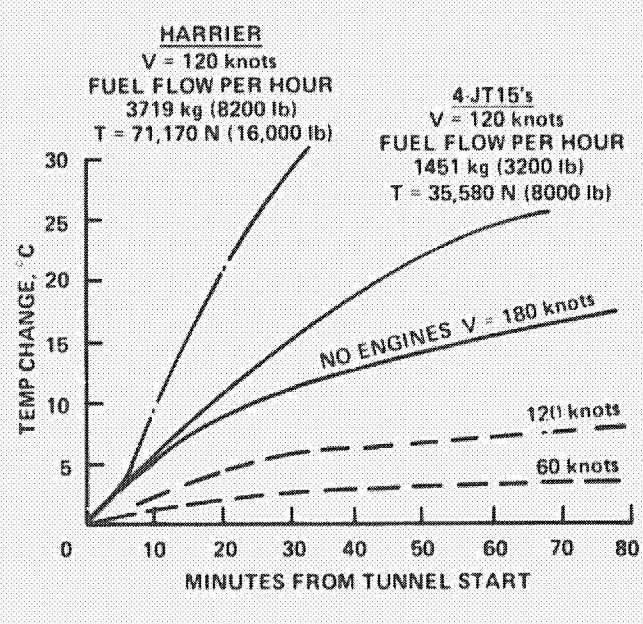


Fig. 22. The variation of test-section temperature with test duration.