REPORT OF THE PANEL ON PROPULSION AERODYNAMICS

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INTRODUCTION

Effort allocated to wind-tunnel investigations of propulsion-system installations has increased in recent years because of the dramatically increasing impact of these installations on overall airplane performance and on the cost and duration of flight-test programs. Unfortunately, the effectiveness of this effort has been seriously limited by a lack of knowledge of the degree of accuracy with which wind-tunnel data can be used to predict propulsion-system installation performance under actual flight conditions. Experience to date has been spotty, the degree of agreement between wind-tunnel-derived results and flight results ranging from excellent to very poor.

The discrepancies noted between propulsion aerodynamic characteristics as predicted from wind-tunnel tests and as measured in flight appear to arise from four basic sources:

(1) Difficulties involved in obtaining accurate wind-tunnel data: The models used tend to be much more complex than the usual external aerodynamics models because of the necessity for simulating and modulating engine and auxiliary airflows, for representing inlet and exit geometries in extensive detail, for providing an unusually large amount of instrumentation (sometimes including separate force measurements on inlet and nozzle components) and for using nonstandard types of model support systems

(2) Uncertainties in the corrections applied to the wind-tunnel data to allow for sting tares, blockage, wall effects, etc.

(3) Uncertainties involved in extrapolating the corrected wind-tunnel data from tunnel conditions to full-scale flight conditions

(4) Difficulties involved in obtaining comparable and accurate flight data.

Propulsion aerodynamic data obtained in the National Transonic Facility (NTF) at subflight Reynolds numbers will be subject to all these problems. The variable Reynolds number capability of this facility, however, will for the first time provide the analyst a tool for understanding and quantifying the factors involved in item (3) - the process of extrapolating the model data to full-scale conditions. This capability is believed to be a very important contribution.

FOCUS

There was a consensus that the NTF would be of outstanding value as a propulsion aerodynamics research facility. The discussion of the panel was focused in the following areas related to such usage:

(1) Identification of research emphasis and primary objectives

(2) Identification of special provisions, equipment, instrumentation, etc. considered either necessary or desirable

(3) Identification and prioritization of specific propulsion aerodynamics problems believed to merit investigation in the facility at Reynolds numbers extending beyond present facility capabilities

(4) Identification of precursor research and studies which can and should be undertaken prior to utilization of the facility for this type of research.

PROPULSION AERODYNAMICS RESEARCH EMPHASIS AND PRIMARY OBJECTIVES

The panel was in general agreement that emphasis in propulsion aerodynamics investigations in the NTF should be placed on the study of Reynolds number sensitive phenomena. It was felt that in addition to helping to clarify data extrapolation problems, the data obtained would be of direct use to the designer. Further, by permitting checks of theory against experiment at realistic conditions, the data would lead to the development of greatly improved analytical and theoretical methods. An important consensus of the group was that one of the primary services of the tunnel will be that of providing a standard for judging the capabilities and limitations of other propulsion aerodynamics research facilities. There is no question but that facilities other than NTF will have to carry the large bulk of propulsion aerodynamics research for the foreseeable future; hence, it was emphasized that the capabilities and limitations of these other facilities must be established reliably.

FACILITY AND EQUIPMENT CONSIDERATIONS

The panel was in agreement with the other panels and with the NTF program personnel in the belief that the first order of business in the NTF is research on the tunnel itself. In addition to the establishment of the operating envelope, considerable effort must be devoted to achieving a high-quality test-section flow (flow uniformity, turbulence and noise levels, etc.), to insuring that the various tunnel interference and blockage effects have been minimized adequately in the design and are predictable, and to achieving a very precise tunnel calibration. In addition, the boundary-layer development at the cryogenic condition must be compared with boundary-layer development in flight at similar Reynolds numbers. Transition, turbulence spectrum, separation, reattachment, etc., all need to be studied in order to verify that the viscous flows are similar at wind-tunnel and flight conditions. The panel was emphatic on the need for this effort inasmuch as the forces, pressures, and viscous flow development for some propulsion models (especially jet nozzle-afterbody models) seem to be very sensitive to these factors.

Up to the present time, only limited attention has been given to utilization of the NTF as a propulsion aerodynamics research facility. The only pertinent feature noted specifically in the workshop presentations was the allocation of 50 cm^2 (7.8 in^2) of flow area in the standard sting for the piping of internal flow gases at a pressure of 41.4 MN/m^2 (6000 psi). This and many other features require detailed study. Concern was expressed, for example, relative to the time required for model changes in the tunnel. Propulsion aerodynamics studies, especially jet-exit-afterbody investigations, characteristically require much more frequent tunnel entries than do more straightforward aerodynamic tests. Unless tunnel entry time can be decreased to a major extent or the models can be automated to an as yet unprecedented degree (or both) only very basic propulsion tests with very simple models will be practicable.

Certain equipment, in addition to that currently planned, was identified by the panel as necessary to permit utilization of the NTF for propulsion research. This equipment as an initial minimum included:

(1) Jet and secondary-flow gas supply systems

(2) Special support systems (for example, a "double hockey, flow-through sting")

(3) "Flow-through" and other special propulsion balances

(4) Boundary-layer measurement instrumentation

(5) Surface flow visualization equipment

Other equipment such as high-angle-of-attack stings or sting knuckles (up to an angle of attack of 70° for fighter models), flow-field visualization equipment, and dynamic-flow measurement instrumentation obviously is desirable and should not be forgotten in equipment planning.

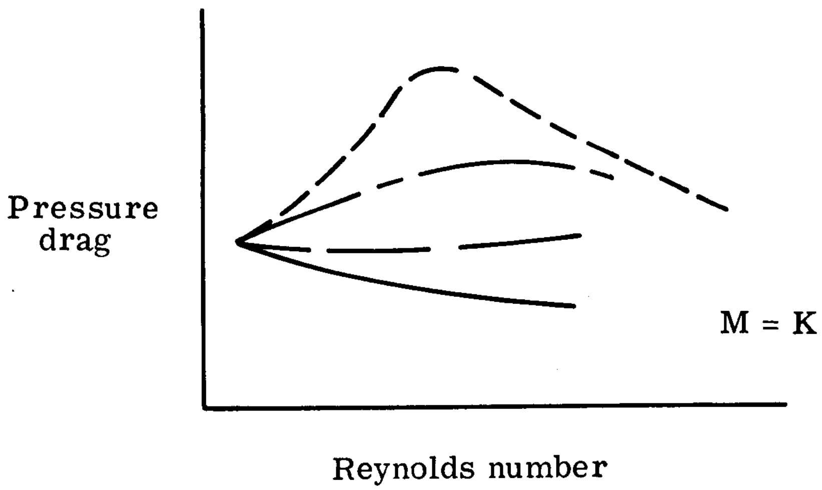
Provision of some of the listed items will necessitate rather extensive research and development activities in their own right. Inherent in the gas supply systems, for example, is an extensive research program needed to determine and validate jet-simulation techniques for the special conditions encountered in the NTF. A similar effort may also be needed to establish techniques for controlling and measuring internal model flows. It is understood that research is either under way or planned to examine model surface finish requirements (hopefully, including effects of roughness, gaps, and steps) and to establish pressure-orifice size requirements. Such information is necessary to the efforts of the propulsion model designer.

INITIAL PROPULSION AERODYNAMICS STUDIES PROPOSED FOR THE NTF

The three propulsion aerodynamics studies considered by the panel to be of greatest interest for early implementation in the NTF are now discussed in descending order of priority.

Effects of Reynolds Number on Drag of Simple Afterbody Models Incorporating Simulated Jets

As illustrated by sketch (a), current data from various facilities on the effects of Reynolds number on the drag of a given afterbody shape are often inconsistent.



Sketch (a)

The objective of the research would be to clarify the situation with consideration given to such factors as body shape, exhaust-plume characteristics, and effects of adjacent airframe components. The model proposed for investigation is illustrated in the upper left corner of figure 1.

The single jet model would be a simple body of revolution with an ogival nose and with several afterbody shapes, including boattails with and without flow separation. Provision would be made for the addition of tail surfaces. Instrumentation would be provided to determine afterbody forces and surface pressure distributions, forebody pressure distributions (to detect forebody drag changes which might offset observed afterbody drag changes), and boundary-layer separation and reattachment locations. Subsonic and transonic testing, first as a pressure model and then as a force model, would be conducted jet on, jet off, and with solid jet simulators. Test results would be compared with theory and with test results for the same models in other facilities. Such comparisons would be of assistance in studying the wall-interference and blockage-correction problems of the NTF and would provide some insight regarding flow quality effects. A further objective of the tunnel-to-tunnel comparison testing would be the establishment of criteria for facility selection for propulsion aerodynamics testing. It is anticipated that one of the boattailed body configurations eventually would be chosen as a reference standard calibration model similar to the current Supersonic Tunnel Association standard nozzle.

For later testing, after the highest priority tests have been completed, the single-jet model could be modified into twin-jet and nonaxisymmetric models, as illustrated in the center and bottom right of figure 1. The conventional twin-jet model would be used to study base and interfairing problems and jet-to-jet interference problems. The nonaxisymmetric twin jet, in addition to providing jet-shape-effects data, also would be used to study thrust-vectoring and induced-lift effects.

Correlation of Propulsion Aerodynamics Test Data From Wind Tunnel and Flight Tests At or Near Flight Reynolds Number Conditions

The preceding recommended program would be expected to clarify the basic effects of test Reynolds number on the wind-tunnel to wind-tunnel propulsion aerodynamics data correlation problem. It still will be necessary, however, to close the loop by extending the study to a comparison of wind-tunnel and flight data. This extension will require investigation in the NTF of propulsion models of complete aircraft. As an initial step, it is proposed that some 1980-era fighter be selected because, by then it will already have been subjected to extensive propulsive aerodynamics tests in other wind tunnels and in flight. A fighter configuration is believed to be a better choice for the study than either a bomber or a commercial transport because the model size of its propulsion system for a given permissible model frontal area is much greater than those for the other two classes of aircraft.

The first objective of the model tests in the NTF would be to obtain pressure-distribution data in model regions near the inlets and exits for the exact configurations and the exact subsonic and transonic operating conditions that have been explored previously in flight. Boundary-layer profiles at critical points on the configuration should also be compared. It is believed that it would be satisfactory to delay very high angle-of-attack studies and the procurement of overall drag correlation data to later phases of the program. Pressure-distribution data would be obtained at lower than flight Reynolds numbers for wind-tunnel to wind-tunnel data correlation purposes.

Effects of Reynolds Number on Inlet Transonic Drag

No data concerning the effects of Reynolds number on inlet spillage drag exist for either conventional or supercritical lip shapes. This is an important deficiency inasmuch as all supersonic aircraft are being designed currently with rounded rather than with sharp inlet lips. This information deficiency will extend to the case of subsonic aircraft as progressive thinning of the inlet lips accompanies extension of the subsonic design cruise Mach number to values beyond about 0.9. The possibility exists that important performance gains can be attained by optimizing the inlet-lip and afterbody shapes. Such optimization requires experimental design data over a wide range of flight-level Reynolds numbers. An isolated drag model of a rectangular supersonic inlet is proposed for the initial study. Drag tests would be conducted over the Mach number range from 0.7 to 1.2, over the Reynolds number range from current wind-tunnel levels to NTF maximum values, and over appropriate ranges of mass-flow ratio and angle of attack. Pressure-distribution and flow-visualization measurements would be conducted separately at appropriate stages of the investigation to study flow phenomena and to guide the inlet-lip development effort. A circular inlet also would be studied in a later stage of the investigation. Special requirements for the investigation are: the development of accurate flow through balances to function in the cryogenic high-dynamic-pressure environment, definition of model surface finish requirements, and accommodation of a large number (approximately 200) of pressure measurements.

Additional Propulsion Aerodynamics Problems

Additional propulsion aerodynamics problems considered by the panel to have merit for future investigation in the NTF were:

(1) Effects of Reynolds number on inlet-flow distortion (consideration given to forebody flow fields, inlet lip shapes, internal contours, etc.)

(2) Exploration of propulsive lift concepts (cruise and maneuver cases with wing in influence of jet)

(3) Study of effects of Reynolds number on jet-flow-field interactions

(4) Study of close-coupled inlet-exit systems.

PRECURSOR EFFORT

It was the strong opinion of the panel that a large amount of precursor research and engineering development work needs to be undertaken now so that the NTF can be utilized for propulsion aerodynamics research within a reasonably short time after it is placed in research operation. A good example is the need for studies to determine the requirements for achieving valid jet simulation. Other examples are mentioned in the foregoing discussion. The consensus of the panel was that if such work cannot be done in-house within a suitable time frame, outside assistance should be enlisted through the medium of suitable contracts or grants.

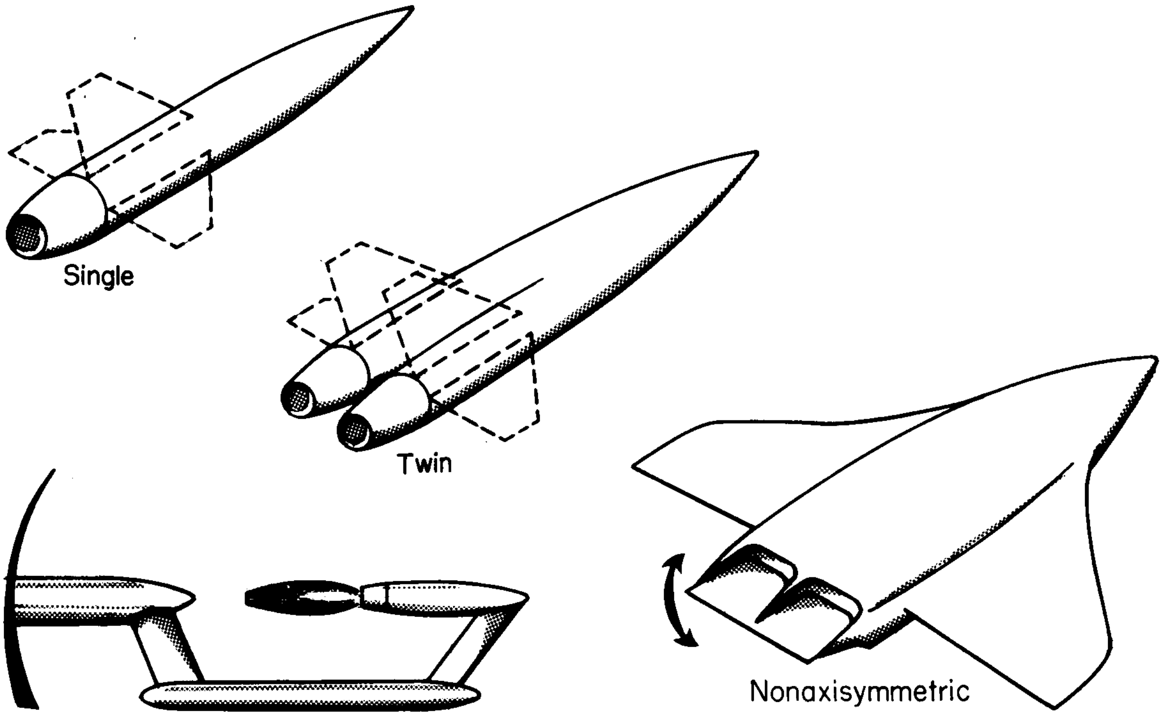


Figure 1.- Basic research models.