AD HOC SUBCOMMITTEE REPORT TO THE
CONGRESSIONAL COMMITTEE ON AERONAUTICS

ASSESSMENT OF THE ALTITUDE WIND TUNNEL AT NASA LEWIS RESEARCH CENTER

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INTRODUCTION

The Ad Hoc Altitude Wind Tunnel Advisory subcommittee was formed at the request of H. Harvey Album, Chairman of the Congressional Advisory Committee on Aeronautics, to accomplish a detailed review of the proposed rehabilitation of the AWT.

The subcommittee members are H. R. Bankhead, R. H. Johnson, H. A. Morse, Dr. K. M. Rosen, B. A. Robideau, J. F. Stroud, A. A. Stewart and T. F. Donohue. The members are a cross section of the aero-propulsion community, representing large transport aircraft, rotorcraft, high performance military aircraft, propulsion systems, and government activities.

NASA has provided the subcommittee with briefing material and presented a review of the objectives, plans and progress of the AWT at a meeting at NASA LeRC on 30 January and February 1, 1985.

The information provided by NASA combined with the knowledge and experience of the committee members is the basis for the assessment.

NASA PROPOSED REQUIREMENTS FOR THE ALTITUDE WIND TUNNEL

NASA has stated that a new test facility should satisfy the following requirements.

(1) Large/Full Scale Test Articles

(2) Wind Tunnel Configuration - Aerodynamics/Acoustics

(3) Propulsion System Operation/Simulation

(4) Concurrent Pressure and Temperature Simulation of Altitude

(5) Full Subsonic Speed Range

(6) Icing and Heavy Rain Capability

The subsequent discussions on Capabilities and Alternate Facilities follow the item numbers and subjects as shown above.

COMMITTEE EVALUATION OF AWT CAPABILITIES RELATIVE TO THE REQUIREMENTS

NOTE-There is a diversity of opinion among the committee members as to the amount of test section blockage that will produce meaningful data. 1.5% blockage is accepted as the standard for precision transonic aerodynamic force and pressure data. The committee's opinion on blockage for propulsion systems and aero/propulsion integration testing varies from 1.5% to 10%. The committee feels that NASA should establish an R&T program that would assess the effects of blockage on the quality of the results for the various types of tests that are proposed for the AWT.

(1) TESTING OF LARGE/FULL SCALE TEST ARTICLES WILL YIELD QUESTIONABLE DATA.

NASA is claiming that accurate data (in terms of force and pressure) can be obtained with test section blockage of approximately 10 to 12 percent, which is contrary to expert opinion that blockage must be limited to 1.5 percent or less for precision transonic aerodynamic force and pressure data.

A 1.5% blockage limitation would exclude large full scale fighters (F-15), and high by-pass engines such as CF6, JT9, RB.211, and full scale turboprops (greater than about 8 feet in diameter). NASA needs to develop test data to show the effect of test article size, shape and orientation on: 1) external force and pressure measurement, 2) engine inlet performance, 3) propeller performance and 4) propulsion system integration.

(2) AERODYNAMIC TESTING HAS SIZE LIMITATIONS

The size of wind tunnel (20' octagonal - 314 ft^2) is well suited to small integrated propulsion systems such as advanced V/STOL, advanced systems such as JVX, X-Wing, ABC and Grumman 698, rotorcraft, small executive jets and general aviation. Again, the rationale is based on utilizing reasonable blockage for performance and pressure measurements. In our judgement, slotted walls with a plenum evacuation system will not be adequate for blockage of 10 to 12 percent. Compartmentation of the plenum evacuation system or adaptive walls are not practical solutions.

ACOUSTIC BACKGROUND NOISE NOT DEFINED AT LOW SPEED

Tunnel background noise is estimated at 120 dB. This may be acceptable at .8 Mach, but what is it at low speed where far field noise assessment data is required.

(3) PROPULSION SYSTEM OPERATION/SIMULATION HAS SIZE LIMITATION

Inlet/engine compatibility testing is feasible with smaller engines such as V/STOL, advanced systems, rotorcraft, small executive jets and general aviation. The facility is not suitable for large propulsion systems.

(4) CONCURRENT PRESSURE AND TEMPERATURE SIMULATION OF ALTITUDE IS CONSTRAINED TO MAXIMUM MACH NUMBER CAPABILITY

The proposed facility will provide concurrent temperature and pressure simulation over a range of altitudes to 55,000 feet. However, this occurs at reduced Mach number at lower altitude as shown in the following item.

(5) MACH NUMBER IS LIMITED AT INTERMEDIATE ALTITUDES

Although the facility will provide near zero to Mach 0.9, the Mach number is restricted over a part of the aircraft operating regimes as shown below.

Mach Limitation as Function of Blockage (with plenum evacuation).

Altitude (Feet)	NASA Estimate of Limit Mach Number with 6% Blockage
35,000	0.95
30,000	0.95 (342 Keas)
25,000	0.88 (354 Keas)
20,000	0.78 (350 Keas)
15,000	0.68 (337 Keas)
10,000	0.61 (334 Keas)

It is likely that a facility comparable to AWT will be needed for full scale development of propfans or their derivatives. The AWT must be capable of clearing the flight envelope for a .82 Mach system. This means that it must be capable of operating at .9M at approximately 25,000 ft., at least transiently.

(6) ICING, HEAVY RAIN TESTING MAY BE LIMITED TO SMALL SIZE PROPULSION SYSTEM/AIRFRAME COMPONENTS

In AWT it should be possible to test smaller commercial podded engines (JT8D), at low Mach numbers, executive jets, general aviation, V/STOL, advanced systems, and rotorcraft systems/components.

AWT offers potential for testing larger wing sections and larger components (inlets) and offer more altitude capabilities than the LeRC 6x9 icing research tunnel.

Previous experience with large commercial transports was that a full scale section of the wing was tested successfully in the NASA-Lewis 6 ft. x 9 ft. icing tunnel. In addition, sub scale models of the engine inlet/ducting were tested in that facility and scaling laws worked satisfactorily.

ALTERNATE FACILITIES

It is clear that none of these alternate facilities by itself offers the utility for integrated aero-propulsion testing and ambient temperature control. They are suitable for development and qualification in a segmented test program.

NOTE-While the propulsion testing facilities at AEDC (16S, 16T, ASTF, etc.) are offered as alternatives to the AWT, these facilities are considered to be generally unavailable for testing of non-military propulsion systems.

(1) FULL/LARGE SCALE TEST ARTICLES

AEDC, (16T, and 16S) could be used for large scale propulsion airframe integration tests with flowing propulsion systems. Full scale engine development could be accomplished in ASTF and other direct connect facilities. Inlet and inlet-engine compatibility evaluations could be conducted at full scale over a wide range of angle of attack in the planned ASTF freejet facility.

(2) WIND TUNNEL CONFIGURATION - AERODYNAMICS/ACOUSTICS

Numerous high Reynolds number wind tunnels are available, as shown in the Attachment, where propulsion airframe integration and aerodynamic testing can be conducted. These would include the AEDC 16T and 16S, LaRC 16 foot, Ames 11 foot and Ames 14 foot.

(3) PROPULSION SYSTEM OPERATION/SIMULATION

The primary testing of inlet/engine compatibility and basic engine testing could be conducted in ASTF. However, the ASTF facility, while providing internal aerodynamic evaluation would not provide total external aerodynamic simulation or integrated propulsion system subsonic testing available with AWT. Inlet/engine compatibility testing would involve the freejet operation whereas the basic engine testing would be conducted in the direct connect portion of ASTF.

(4) CONCURRENT PRESSURE AND TEMPERATURE SIMULATION OF ALTITUDE

In fighter propulsion system development, one area of importance is operation in the high altitude, low Mach regime where experience indicates potential adverse engine operation. This can be simulated with concurrent pressure and temperature in ASTF, over the operating regime of current and future fighters, in the planned freejet at angles of attack up to 55°.

Concurrent altitude and temperature in the AWT will be of value for full scale prop-fan and engine similarity testing.

(5) FULL SUBSONIC SPEED RANGE

Numerous existing wind tunnels will provide high Reynolds numbers over the full subsonic Mach range as indicated in the Attachment. AWT, on the other hand, is limited in Mach number below 30,000 feet and, accordingly, results in lower Reynolds numbers at the intermediate altitudes.

(6) ICING, HEAVY RAIN CAPABILITY

The NASA/Lewis 6 ft. x 9 ft. icing tunnel represents a satisfactory alternative for testing full scale sections of the wings of large aircraft as well as testing inlet segments of these aircraft. It has been used by executive/commercial jets and general aviation.

AWT will provide a larger test section for integrated propulsion and icing testing for this class of vehicles and it will provide increased altitude and Mach number capability.

AEDC has existing icing capabilities for development and demonstration.

PARTICULAR TEST APPLICATIONS

PROPULSION SYSTEMS

The AWT could be utilized in the development of smaller full scale propulsion systems (executive/general aviation, rotorcraft, V/STOL, etc) and in research of propulsion concepts using sub scale models of larger systems and full size smaller systems.

Blockage of tunnel test section area and angle of attack limitations preclude full scale testing of large propulsion systems (CF6, TF39, JT9D) in AWT.

The AWT has limited applicability to high performance supersonic propulsion systems. Testing of this type of propulsion system is better accomplished in a direct connect or freejet altitude test facility.

Turboprop (propfan) propulsion system testing appears to be limited to isolated propfans of about 8 feet in diameter in AWT, yielding aeroelastic data of limited value, because of absence of airframe interactions.

PROPULSION SYSTEM INTEGRATION

The advantages of the AWT for propulsion system airframe integration are applicable to subscale models of large systems.

Of particular interest is the internal/external aerodynamic testing capability which could allow for integrated testing of inlets, nozzles/diffusers, IR suppressors consistent with tunnel size limitations delineated above.

ROTORCRAFT

The AWT as currently proposed does not provide a facility for controlled rotorcraft icing development and demonstration. However, the AWT would allow testing of larger systems and components than the 6x9 LeRC Icing Research Tunnel.

A significant rotorcraft test capability deficiency exists for large scale rotating blade icing experiments. A facility is desired which will allow rapid system development and possible certification. A test facility should allow rotor rotation, provide electrical drive power, operate to 150 kts, and have a large test section.

ADVANCED TURBOPROPS

The AWT appears to be limited to 8 foot diameter propeller or subscale models. Aeroelastic scaling is not yet feasible for complex structure propellers.

APPROACH

PLANNING

The committee has some concern regarding the scheduling of the modeling efforts relative to the actual design and construction of the AWT. Specifically, the completion of the aero/thermo modeling in mid-1986 and the icing system in later 1987 occur late in the tunnel design phase and after the start of construction. NASA must determine the maximum section blockage that can be used and still obtain accurate force and pressure measurements. The success of these elements is a prerequisite to the performance of the AWT and should be completed earlier in the facility design and construction phase to avoid potential schedule delays and/or a significant increase in CofF.

NASA needs to present a comprehensive, technical view of the AWT (strengths, weaknesses and limitations), and the problems that must be overcome or improvements in current state-of-the-art test capability that must be achieved for the AWT to fully attain advertised capability.

FACILITY OMISSIONS

NASA has omitted several facility features that would enhance the utility of the AWT.

1. Load absorber for convertible engine and turboshaft system evaluation.

2. Direct and immediate access to test section for ice accretion viewing and measurement.

3. Heat exchanger de-icing may be required for prolonged use.

4. Ability to develop small (less than 5 microns) droplets for scale model icing testing.

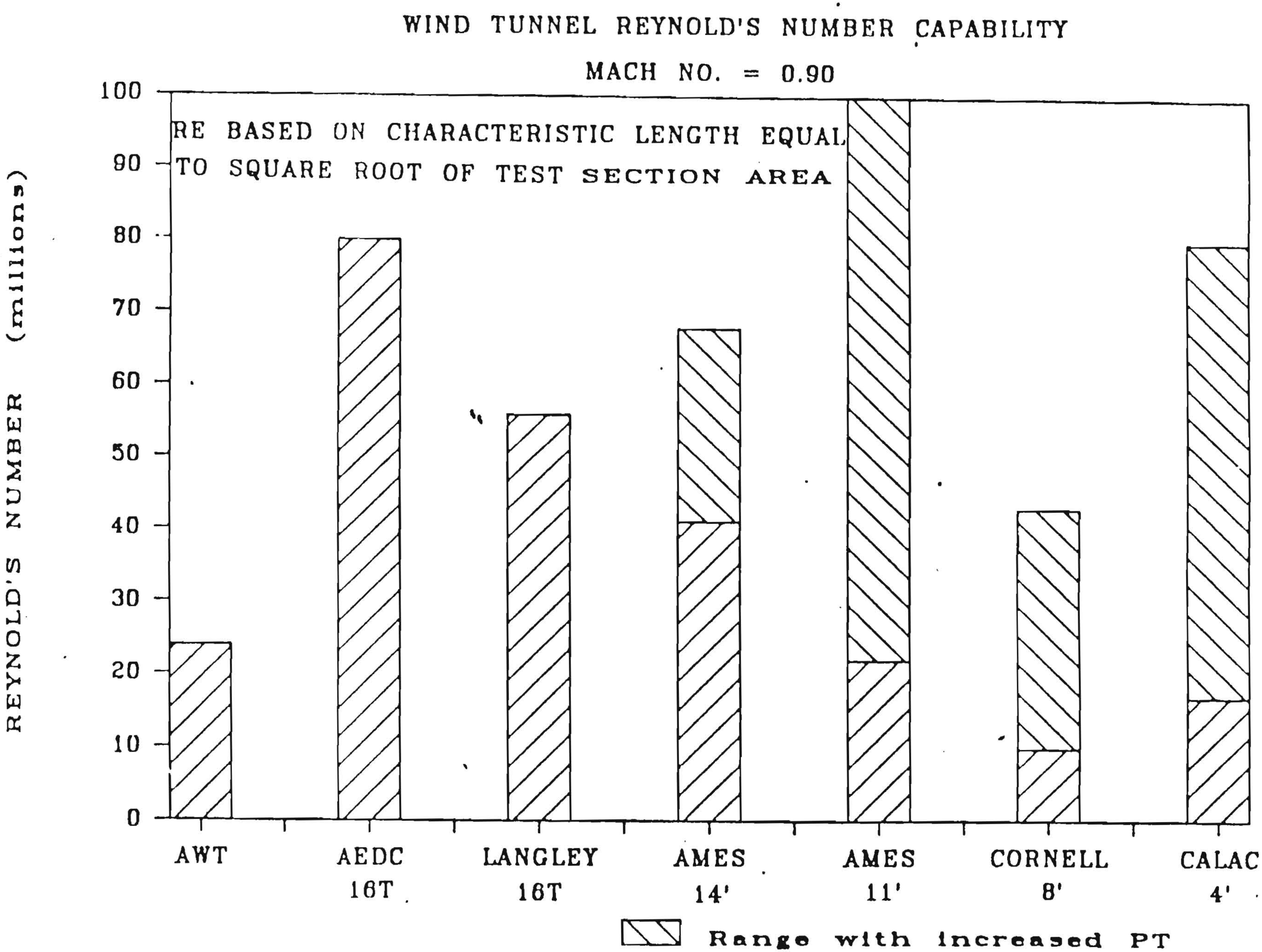
COSTS

The committee was unable to evaluate the cost of the facility and the cost of the supporting work due to unfamiliarity with these expenditures.

The proposed $160M AWT CofF budget was described by NASA as being completely independent of both the NASA R&PM and R&T budgets planned for LeRC. The committee has a concern that the $160M CofF funds budgeted for the AWT may be diverted from programs that may be of greater national importance.

NASA has estimated that the yearly operating costs of the AWT will be $5M. This $5M cost must not adversely impact the LeRC commitment of Aero-propulsion R&T.

Congressional approval of CofF resources for the AWT has not been obtained, yet currently several million dollars (actual amount difficult to define) of both R&T and R&PM funds are being expended for modeling, scale testing, design, etc., which would prove to be counterproductive should the AWT rehabilitation be disapproved.


WIND TUNNEL REYNOLD'S NUMBER CAPABILITY
MACH NO. = 0.90
RE BASED ON CHARACTERISTIC LENGTH EQUAL TO SQUARE ROOT OF TEST SECTION AREA
REYNOLD'S NUMBER (millions)
100
90
80
70
60
50
40
30
20
10
0
AWT
AEDC 16T
LANGLEY 16T
AMES 14'
AMES 11'
CORNELL 8'
CALAC 4'
Range with increased PT

National Aeronautics and
Space Administration

Lewis Research Center
Cleveland, Ohio
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J. Abbott

NASA

Reply to Attn of: 2910

JUN 4, 1985

MEMORANDUM FOR RECORD

FROM: 2910/Chief, Altitude Wind Tunnel Research Office

SUBJECT: Response to AdHoc Subcommittee Report Concerning An Assessment of the Proposed AWT Rehabilitation

The subject report was prepared for the Congressional Advisory Committee on Aeronautics. A copy of this report is attached to this memo for reference. The purpose of this memo is to respond to the comments made by the Subcommittee in their report. This memo was contributed to by a number of the AWT Project Office members. The following response is made in the order which the Subcommittee comments appear in their report.

Committee Evaluation of AWT Capabilities Relative to Requirements

The first 3 Subcommittee comments in this section deal with the size of test article that AWT could effectively handle. Accordingly, our response is addressed to all three comments concurrently.

Response - The Subcommittee states that (paraphrasing) "NASA claims that accurate data can be obtained with test section blockages of 10 to 12 percent in the transonic speed range and that this is contrary to expert opinion". We most certainly agree with the subcommittee and it was not our intent to leave this impression. While we did indicate that the AWT is designed to handle blockage as high as 10 to 12 percent, we always felt that there would be some limitations as to what could be done with these high blockages, but that valuable data could nevertheless be obtained as will be discussed below.

For a better view into the subject, which is a rather complex one, approximate transonic tunnel blockage limitations for obtaining good data are shown in Figure 1. Good data is defined as accurate force and external pressure measurements. On the right hand side of the figure a boundary is shown which represents the maximum Mach number up to which good data can be obtained for slotted (or otherwise bled) tunnels. The curve is anchored by Langley data in the low blockage (less than 1 percent) region. This restriction to low blockages here is dictated by the desire to get accurate data and also to obtain this data at as high a Mach number as possible in the transonic region. It is interesting to note that even for these very low blockages ($<$ 1 percent), accurate data is not obtainable at Mach numbers approaching one. Also indicated in the figure is the good data boundary for higher blockages as determined by Mitchell at LeRC and it can be seen that both the LaRC and

LeRC results are generally consistent. It can also be seen, that these results generally follow the unslotted wall tunnel choke limit. An additional data point for a large blockage model from LaRC tests of a V/STOL propulsion system is also shown in the figure. A 1/5 scale model confirmed that for these tests good data was obtained up to a Mach number of .85 at the 6 percent blockage for the full-scale model. Thus, these data indicate that the good data boundary lies somewhere between the unslotted wall tunnel choke limit and LaRC large blockage data as illustrated in the figure. The overall result is that good data can be obtained over a useful and wide range of Mach numbers and blockages in AWT. However, the maximum Mach number level will be more limited as blockage is increased.

Additional information relative to this subject was found in AEDC documentation where they specify blockage limits for the 16T wind tunnel. It was noted that for afterbody performance models good data can be obtained at blockages up to 5 percent. Thus, we have another indication that a 1 1/2 percent limit on blockage as suggested by the Subcommittee is unnecessarily restrictive. For engine/inlet type tests AEDC claims the limit exceeds 10 percent and could be as high as 15 percent. For this case only the flow into the engine is appropriately simulated, because of the general increasing difficulty, as blockage is increased, of preventing wall interference effects from disturbing the flow over the aft end of test article, and thus only good internal engine performance can be obtained. While they do not specify Mach number range at these blockages, we would assume that there would again be some limitations similar to the boundary indicated in Figure 1.

The good data boundary for AWT will be identified more precisely at the high blockage conditions through an extensive test section modeling effort that is currently underway at Lewis Research Center. This modeling program will investigate slotted wall bleed systems for a range of blockages up to about 10 percent. The goal is to develop a slot configuration (with axial tailoring of slots or compartmentalized slot segments) that will provide the least wall interference for a given blockage and thus extend the good data boundary to as high a Mach number as possible. The modeling effort will also include running model fans to assess and improve blockage boundaries with active propulsion devices. In addition to the modeling program, improvement in the AWT blockage boundary is anticipated as a result of the incorporation of wind tunnel wall interference corrections. This concept, which has already met with much success for 2-D wind tunnels, is currently being developed for 3-D tunnels. LaRC and others have extensive efforts underway to develop correction procedures. See for example AIAA paper no. 84-0599 "Wall Pressure Measurements for Three-Dimensional Transonic Tests", by William G. Sewall of LaRC. Discussion with LaRC indicated that in several years these corrective procedures will be developed and should therefore, be available for use in the AWT. Together, the modeling activities and the wall interference corrective procedures should allow the good data boundary to be moved out to the range of .85 Mach number and possible higher at blockage levels of about 5 percent. This will allow quite large propulsion systems to be evaluated in the AWT as will be discussed next.

To illustrate in more specific terms the AWT capability, we have indicated the design Mach number and blockage of several classes of propulsion systems relative to the good data boundary in Figure 2. As can be seen good data can be obtained over the required blockage and operating mach number range for typical full-scale commuter and cruise missile propulsion systems. Additionally, it is highly likely that from a blockage standpoint, attaining good data will be possible with large scale props (in the range of 10 feet in diameter) over the mach number range of interest as indicated by the data plotted for the NASA Large-Scale Advanced Prop (LAP) program. This may require the employment of technically advanced test section bleed systems and wall interference correction techniques as discussed earlier.

For turbofans, the good data limit may allow testing of engines as large as the 36,000 pound thrust NASA Energy Efficient Engine (E^3). Furthermore, for the special case of engine/inlet interaction tests where the external aerodynamics is not of importance, even larger turbofan engines could be tested up to the .8 cruise mach number of interest for commercial transports. It was earlier noted that at AEDC, blockage limits for engine/inlet interaction testing are substantially higher than that for those for external aerodynamic tests.

For wind tunnel testing of props, however, there is another size limiting factor in addition to test article blockage. It concerns the interference of the tunnel walls with the prop aerodynamics. Previous experience concerning wind tunnel prop size limitations is shown in Figure 3. Solid wall wind tunnels were generally limited to props about 1/2 the size of the test section ($D_{Prop}/D_{Tunnel} \approx .5$). However, props were tested to as high as $D_P/D_T = .8$ at LaRC. For vented tunnels, the limit was generally $D_P/D_T = .6$ which is about the same as for the "Glauert criteria" for free-jet facilities. LaRC has had considerable experience in the 1950's testing props in the range of $D_P/D_T = .6$. Future props will probably be of the higher disc loading type and this could influence the size limit for testing in wind tunnels, however, current information does not indicate this is the case. Therefore, for good prop aerodynamics previous experience indicates that AWT can test props up to about 12 feet in diameter.

In summary, AWT will provide for the testing of a highly useful range of propulsion systems sizes and also for a broad range of propulsion system types. Specifically, considering blockage and wind tunnel wall interference effects on prop aerodynamics, previous experience indicates that props at least in the range of 10 to 12 feet in diameter can be effectively tested. Furthermore, considering the extensive AWT test section modeling effort and the advancements in wind tunnel data correction technology possible prior to the initial operation of the AWT, the prospects for increasing the maximum size of propulsion systems that can be affectively tested in AWT is highly likely.

Subcommittee comment (2) pertaining to acoustic background noise at low speed.

Response - Predicted overall sound pressure levels for a range of Mach numbers are shown in Figure 4. These data are estimates made by Sverdrup an architectural and engineering contractor and have been confirmed by NASA. It can be seen that the 120 dB goal is attained at the .2 Mach number, representative of take-off conditions, as well as for the .8 Mach number representative of the cruise case for the larger subsonic aircraft. Further, in the AWT modeling program, the plan is to confirm that the background noise levels will meet the goal at the take-off and cruise conditions as indicated by the predictions. Should any problem arise, adjustments will be made, for example in the acoustic treatment design, to achieve the goals.

Subcommittee comments (4) and (5) are addressed concurrently since they are essentially related comments.

Response - The operational envelop of the AWT is, as the subcommittee points out, limited in the lower right hand corner (high Mach numbers and low altitudes) as shown in Figure 5. This is because of the increasing tunnel power (and accordingly, cost) required to extend tunnel operation into this region. This is generally true for all wind tunnels both subsonic and supersonic. However, as can also be seen in Figure 5, the tunnel operating range covers the requirements for <u>all</u> subsonic classes of vehicles except for cruise missiles. For this special case, where high-speed and low altitude operation are required, it is common wind tunnel practice to employ test section inserts to extend the operational range into this region. Figure 5 shows that by employing 1 foot thick tunnel inserts (reducing test section span to 18 feet) AWT operational capability can be extended to cover most of the cruise missile operational range. This added capability does not require an increase in tunnel horsepower or refrigeration capacity, and it is also within the capability of the fan. Although a sacrifice in tunnel size is necessitated to do this, cruise missiles are generally relatively small and, therefore, tunnel blockage limitations are not compromised. The blockage for typical cruise missiles in an 18 foot AWT test section would be in the neighborhood of 1.5 to 2 percent. This insert concept has already been studied for inclusion into AWT.

Subcommittee comment (6) refers to the value of AWT as an icing facility particularily in regard to research on scaling.

Response - There is considerable opinion that the scaling laws for icing are not well-defined. Different groups have used different scaling laws with varying degrees of success. In reference 1, the FAA cites scaling as an important area of study to establish and verify laws and testing techniques. Although much valuable research and development has been and will be done in the IRT, clearly scaling is a more difficult problem in that facility than it will be in the AWT. The greater the degree of scaling, the greater the uncertainty in the data.

The subcommittee is correct in stating that the IRT has been used successfully for testing and development. The AWT, however, does not represent an "alternate" facility, but rather a "complementary" facility. As the subcommittee noted, the AWT will provide a much larger test section (20' versus 6'x9') and in addition, will have substantially increased altitude and Mach number capability relative to the IRT.

In reference 2 a majority of 43 airlines, aircraft manufacturers and regulatory agencies surveyed indicated a need for a facility such as the Altitude Wind Tunnel for icing research. An FAA study of national needs in icing research facilities (reference 1) identified both the IRT and AWT as being essential elements of a National Icing Facilities system. In fact, of the 11 icing wind tunnels operating in the United States and Canada, only these two were considered to have potential for use in icing certification testing.

Reference 1 includes ASTF at AEDC as an integral part, along with IRT and AWT, of a National Icing Facilities list. ASTF is an engine test facility operated in the free-jet mode, so is not an alternate to the AWT, but rather a complement.

Alternate Facilities

Subcommittee comment (1)

Response - AEDC wind tunnel 16S is a supersonic wind tunnel and does not have capability in the subsonic speed range like AWT. It is, therefore, not a tunnel which could serve as a substitute for AWT. However, AEDC 16T does have subsonic speed testing capability and can be used for subsonic propulsion system and propulsion/airframe integration testing. But, this tunnel does not have a refrigeration system for producing the correct altitude free stream temperatures and, accordingly, engine corrected speeds cannot be simulated without resorting to overspeeding the engine. This limitation will not permit, for example, aeroelastic testing of large props as illustrated in Figure 6. Aeroelastics of the new high-speed, swept props is an important factor in the technology for these new props. A comparison of the operating range with matched altitude temperature for AWT and for other wind tunnels in addition to 16T is shown in Figure 7. It can be seen that the AWT is the only large tunnel with the capability for matching altitude temperature over a wide range of altitudes in the subsonic region.

In the planning stage at AEDC is a modification to ASTF that will permit this facility to operate in a free-jet mode. This will allow inlet/engine interaction testing; however, the free-jet size will be substantially smaller than AWT. At .8 Mach number ASTF has a maximum free-jet cross-sectional area of about 60 sq. ft. ($\approx$ 9 ft. diameter). Using the Glauert criteria for determining the maximum size prop that can be tested in a free jet, ASTF could only test about a 5 1/2 ft. diameter prop. This is less than half the size capability of AWT. Further, in ASTF only prop performance would be attainable since the external nacelle flow is not properly simulated in a free-jet. And of course, external aerodynamics cannot be obtained for other propulsion systems in a free-jet facility. Summarizing, none of the above facilities come close to the capability the AWT offers for propulsion system and propulsion/airframe integration testing.

Subcommittee comment (2)

Response - Yes, there are other facilities in the country that have a higher Reynolds Number (Re) capability than AWT. For "aerodynamic testing", where blockages must be kept quite small ($<$1.5 percent), there is no doubt that higher Re's can be obtained in the large atmospheric or pressurized tunnels like 16T, 16-Foot, 14-Foot, 11-Foot, etc. The AWT, which must operate at altitude for Mach numbers greater than about 0.52, can not provide the high Re's that these other tunnels can for small models. (Even these other tunnels, however, probably don't provide full-scale Re for such small models - only NTF (pressurized and cooled) can do that).

For larger models, however, with blockages ranging from 3 percent to 10 percent, AWT will provide full-scale or close to full-scale Re for a large class of test articles. A full-scale model running in AWT at the proper Mach number, altitude pressure, and altitude temperature will be, by definition, at full-scale Re. (This same size model running in one of the other facilities, say 16T, would be operating at Re's greater than full-scale!)

So, for large or full-scale models, Re is not really an issue in comparing AWT with other facilities. What is an issue is the additional capabilities that AWT has that none of the other mentioned facilities have - specifically, the matched altitude pressure and temperature capabilities. For "aerodynamic testing" (e.g. aircraft or external aerodynamics - lift, drag, pitching moment, etc.) the important aerodynamic parameters that must be matched for proper aero similarity are M and Re. Hence, the rationale behind pressurized tunnels like the Ames 11-Foot and pressurized, cooled tunnels like NTF is to drive the density up as high as possible to get as close as possible to full-scale Re with small test models whose size is dictated by staying at blockages less than 1.5 percent.

In the case of "propulsion system testing", however, matching M and Re is an desireable as it is for "aerodynamic testing", but now additional parameters also become important. We are now talking about rotating machinery and in this case, at least two other parameters become important. The first is corrected speed, $N/\sqrt{T/Tref}$. It is important to match corrected speed (or relative Mach number of rotating components) during a "propulsion system test" for the reasons described in the previous NASA response. If the test objectives include obtaining blade stress and/or flutter data, along with proper blade twist, then all bets are off unless the tests are conducted at the true altitude temperature.

The other parameter that is important to match for "propulsion testing" is actual altitude pressure, as illustrated in Figure 8. As the figure indicates, in an atmospheric (sea-level) tunnel, because of the higher that actual flight density (and hence, pressure), blade flutter characteristics could be completely different from what they would be at the actual altitude density represented by the flight envelope shown in the figure.

The foregoing discussion applies not only to props, but also to future turbofan engines. For reduced specific fuel consumption, the trend in future turbofan engines is to shorten and slim nacelles, increase bypass ratio, remove fan dampers and to sweep fan blades. Thus, future fans will be more like ducted props and will have aeroelastic characteristics closer to those of an advanced prop.

In summary, for "aerodynamic testing" Mach number and Re must be matched as best as possible in order to obtain "good" test results. For "propulsion testing", matching Mach number and Re is not enough. Altitude pressure and temperature must also be matched. AWT is the only facility that will be capable of providing these unique characteristics.

Subcommittee comment (3)

Response - We agree with the Subcommittees statement that the ASTF free-jet facility will not be able to evaluate external aerodynamics of propulsion systems as the AWT could. For engine/inlet compatibility testing or for prop testing, the AWT has over twice the test section size at .8 Mach number than the ASTF does in the free-jet mode of operation.

Subcommittee comment (4).

Response - None

Subcommittee comment (5).

Response - NASA response in comment (2) above, also applies here.

Subcommittee comment (6).

Response - The NASA response in comment 6 above, also applies here.

Particular Test Applications

Subcommittee comment relative to Propulsion Systems.

Response - We agree with the Subcommittee's comment that the AWT could be utilized in the development of smaller full-scale propulsion systems (executive/general aviation, rotorcraft, V/STOL, etc.) and in research of propulsion concepts using subscale models of larger systems. This work is also becoming more important because of the continuing pressure for improved performance and fuel efficiency and also, because of the greater degree of integration of the propulsion system into the airframe for the newer aircraft.

The large propulsion systems mentioned (CF6, JT9D, etc.) would pose problems in AWT at angle-of-attack, however, they could still be tested at moderate angles-of-attack depending on engine size, particularily if only engine/inlet internal performance is desired. The extent to which this can be done will be determined through both the AWT modeling program and the eventual calibration of the AWT.

It is true that the AWT, being a subsonic tunnel, would have limited applicability to support high performance supersonic propulsion systems. However, these systems operating in the subsonic range and accordingly, the AWT could provide an alternate facility, assuming the ASTF free-jet modification occurs, for subsonic performance integration tests including engine/inlet interaction and icing.

In the area of advanced turboprops, we do not agree that the AWT would be limited to 8 foot diameter props. As indicated in an earlier NASA response (see the first response under "Committee Evaluation ---" above) to this general comment, we believe that props in the range of 10 to 12 feet in diameter can be tested and for which good data can be obtained depending on the associated blockage and type of installation. Further, airframe interaction effects are also attainable. These would include simulating wing upwash effects by running the prop at angle-of-attack and strut effects for pusher type configurations to name a few. Of course, where maximum blockage is increased as a result of investigating airframe interactions, prop size will have to be reduced, but it still can be quite large depending on the situation.

Propulsion Systems Integration

Subcommittee comments similar to the ones here have already been made and NASA has provided a response. Therefore, no further response will be made.

Subcommittee comment relative to Rotorcraft.

Response - It is true that the AWT will not accommodate full-size rotating blades for many rotorcraft. However, model rotor testing would be inexpensive and safe way to determine the approximate penalties of ice accretion (reference 3). Such testing would require scaling of the results, but the AWT will need less scaling than any other icing tunnel. For 1/5th-scale testing, it is necessary to provide drop-sizes down to about 5um, and part of the research plan for the AWT is to develop spray nozzles with this capability. Thus, 1/5th and larger scale models of rotors could be tested in the AWT. Reference 3 "strongly endorsed" the AWT as partly filling the gap in the North American rotor blade icing test capability.

Subcommittee comment relative to Advanced Turboprops.

Response - This Subcommittee comment is similar to ones made before and therefore, will not be addressed here.

Approach

Subcommittee comment relative to Planning.

Response - We are in agreement with the subcommittee that the modeling activity should be completed early in the final design of the AWT in order to avoid schedule delays and/or cost overruns. We have structured the modeling program to do this by establishing the requirement that all component model data be available no later than one year into the final design activity of the AWT. The schedule presented to the subcommittee which illustrates this is re-presented in Figure 9. It can be seen that model data on major components and subsystems (such as the icing spray system) would meet this availability requirement. For those items for which model data became available after the start of the final design, such as for the fan for example, the design schedule for these components was adjusted to be compatible with this. While the full loop and high-speed icing modeling results become available later than one year into the design, we do not feel this is critical because all loop components will have been tested by the time the loop is tested and the high-speed icing results are not expected to have a major impact on the AWT design.

NASA feels that the material in this document responds to the general comments/questions raised by the subcommittee.

Subcommittee comment relative to Facility Omissions.

Response -

1. NASA has considered the possibility of needing a power take-off and load absorber for testing special types of propulsion systems such as convertible engines, etc. The tunnel will be designed to accept in a general sense and not preclude this type of installation should the need arise.

2. Test section access.
   Ice accretion viewing will be possible through video monitors. Direct access to the test section will be possible at the completion of a test, although the tunnel will need to be re-pressurized before entry.

3. Heat exchanger de-icing.
   Part of the present modeling effort includes ice accretion testing of the AWT heat exchanger design. It is possible that testing would be limited to 45 to 60 minutes for the severest icing conditions. This would be sufficient time to conduct standard icing tests, however.

4. Small droplet sprays.
   No icing facility currently produces clouds with verified drop-sizes below 10 um volume median diameter. Existing drop-sizing instrumentation is incapable of measurements below this size. To extend the state-of-the-art, the icing modeling plan includes both the development of nozzles capable of producing median drop-sizes as small as 5 um and instrument evaluation and development to provide a measuring capability for these small sizes. Results from this research will benefit not just the AWT, but the IRT and other icing facilities as well.

   A 5 um cloud would provide a 1/5th-scale model with the equivalent of a full-size encounter with a 15 um cloud, the current FAR 25 lower limit. We feel that 5 um represents a current lower limit of achievable drop-size for both spray nozzles and measuring instrumentation. Improved instrumentation may result in reductions in FAR 25 lower drop-size limits. If this occurs or if the need to test smaller scales develops, drop-sizes below 5 um volume median diameter would be needed. Thus, future research might well be directed towards providing cloud with droplets smaller than 5 um. Such a development could be retrofitted to the AWT.

Subcommittee comment relative to Costs.

Response - The CoF (Construction of Facilities) budget is a separate line item in the total NASA budget and is considered separately from the R&PM (manpower) and R&T (technical programs) budget line items. If the AWT were not approved for inclusion in the CoF budget submittal, the funds associated with the AWT would not be made available for R&T activities. The CoF budget would be reevaluated to determine what other proposed facilities would be submitted for AWT in the total CoF budget submittal. The $160M CoF budget for AWT would be incrementally funded over four fiscal years so that the maximum burden on the NASA budget in any one year would be limited to $50M. Monies allocated to the CoF budget do not significantly impact the NASA budget, since they represent only 2 percent of the total. Therefore, any monies in the CoF budget would not adversely impact the NASA commitment to Aero-propulsion R&T.

The estimated $5M yearly operating costs to run the AWT represents less than 3 percent of the LeRC total R&PM operating budget. This estimated operating cost is consistent with the operating costs of other large wind tunnels. Since this operating cost is such a low percentage of total operating costs and is of a magnitude consistent with tunnels already operating at Lewis, there is very little chance that operating the AWT would adversely impact the LeRC commitment to Aero-propulsion R&T.

Concerning the comment that the funds being spent on the modeling program would be counter-productive if the AWT rehabilitation is not approved. Most large CoF efforts are in this position prior to program approval. It is a risk that must be taken, so that on approval, the facility design and construction can proceed in a timely manner and without significant technical risk. Further, much of the modeling program technology will be of a generic nature. This includes for example, low-loss turning vanes, improved aero codes for wind tunnel design, icing spray systems for uniform clouds and very small droplet sizes ($\sim$5 um), instrumentation for measuring small droplets, technology for anechoic wind tunnel test sections, and technology for testing high blockage propulsion systems in wind tunnels. On several occasions, the later technology item was identified by the subcommittee as being deficient.

Concluding Remarks

The following concluding remarks address only the major comments raised by the subcommittee. The comments concerning test article blockage limits and maximum size of prop that can be effectively tested in AWT are not consistent with previous experience and current practices. This information indicates that AWT test article blockage limits for getting good data in the subsonic transport speed range can be significantly higher than the 1 1/2 percent indicated by the Subcommittee. Also, considering blockage and tunnel wall interference on prop aerodynamics, props up to 10 to 12 feet in diameter can be effectively tested in AWT instead of up to 8 feet as suggested by the Subcommittee. In addition, advancing technology in the area of wind tunnel wall interference reduction and wall interference corrections can be expected to increase AWT test article size capability above those indicated above by the time the tunnel becomes operational in the 1990's.

Concerning alternate facilities, existing large propulsion wind tunnels, such as AEDC 16T, do not have the refrigeration capability necessary to simulate true altitude temperature in the subsonic speed range. This requires overspeeding props, for example, in order to obtain the proper corrected speed at altitude and thus prevents good aeroelastic data from being obtained. Aeroelastics is an important technology for the emerging, highly loaded prop fans and may be also important for future very high by-pass turbofan engines. Overspeeding to obtain aerodynamic performance can also be limited by engine structural and/or turbine temperature limits. AEDC's proposed free-jet addition to ASTF can simulate altitude pressure and temperature, but will have a relatively small test section, about half the size of AWT, at nominal subsonic transport cruise speeds. This means that for props, for example, AWT will have the capability for testing about twice the size prop that ASTF's free-jet modification will have. Furthermore, AEDC's facilities are generally not available for non-military testing. Therefore, AWT will provide for a significant extension to the current and planned propulsion wind tunnel testing capability for civilian and also military applications.

Concerning the value of AWT for conducting large scale icing research or developmental testing, a number of committee reports and studies involving a broad cross-section of governmental and industry representatives has indicated a need for AWT as an integral part of the nation's icing research capabilities.

REFERENCES

1. Taylor, F. R.; and Adams, R. J.: National Icing Facilities Requirements Investigation. Report No. FAA-CT-81-35, June 1981.

2. Koegeboehm, L. P.: Commercial Aviation Icing Research Requirements. NASA Contractor Report 165336, April 1981.

3. Rotorcraft Icing - Status and Prospects. AGARD Advisory Status Report No. 166, August 1981.

TRANSONIC WIND TUNNEL TESTING

BLOCKAGE LIMITATIONS

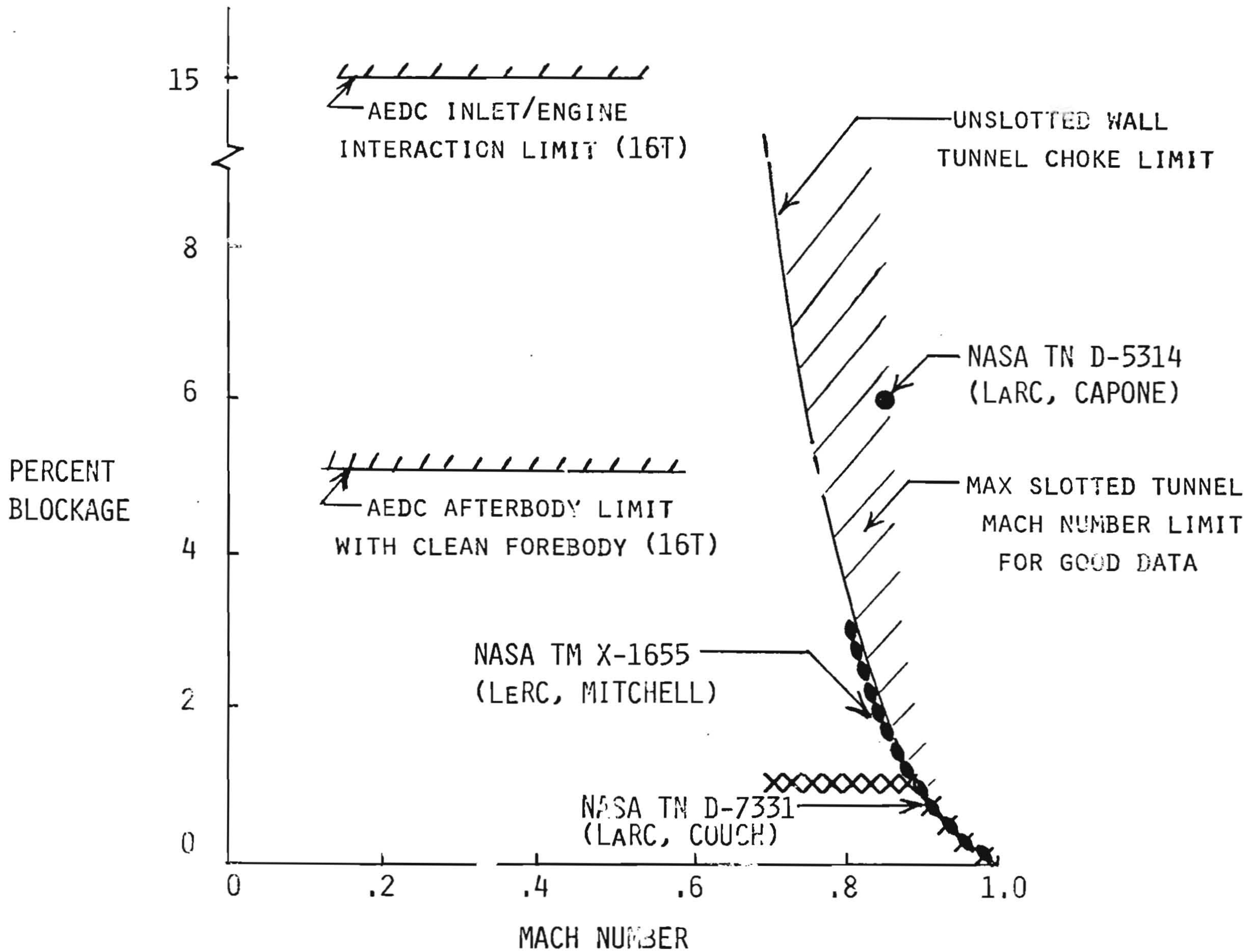


FIGURE 1

TRANSONIC WIND TUNNEL TESTING
BLOCKAGE LIMITATIONS

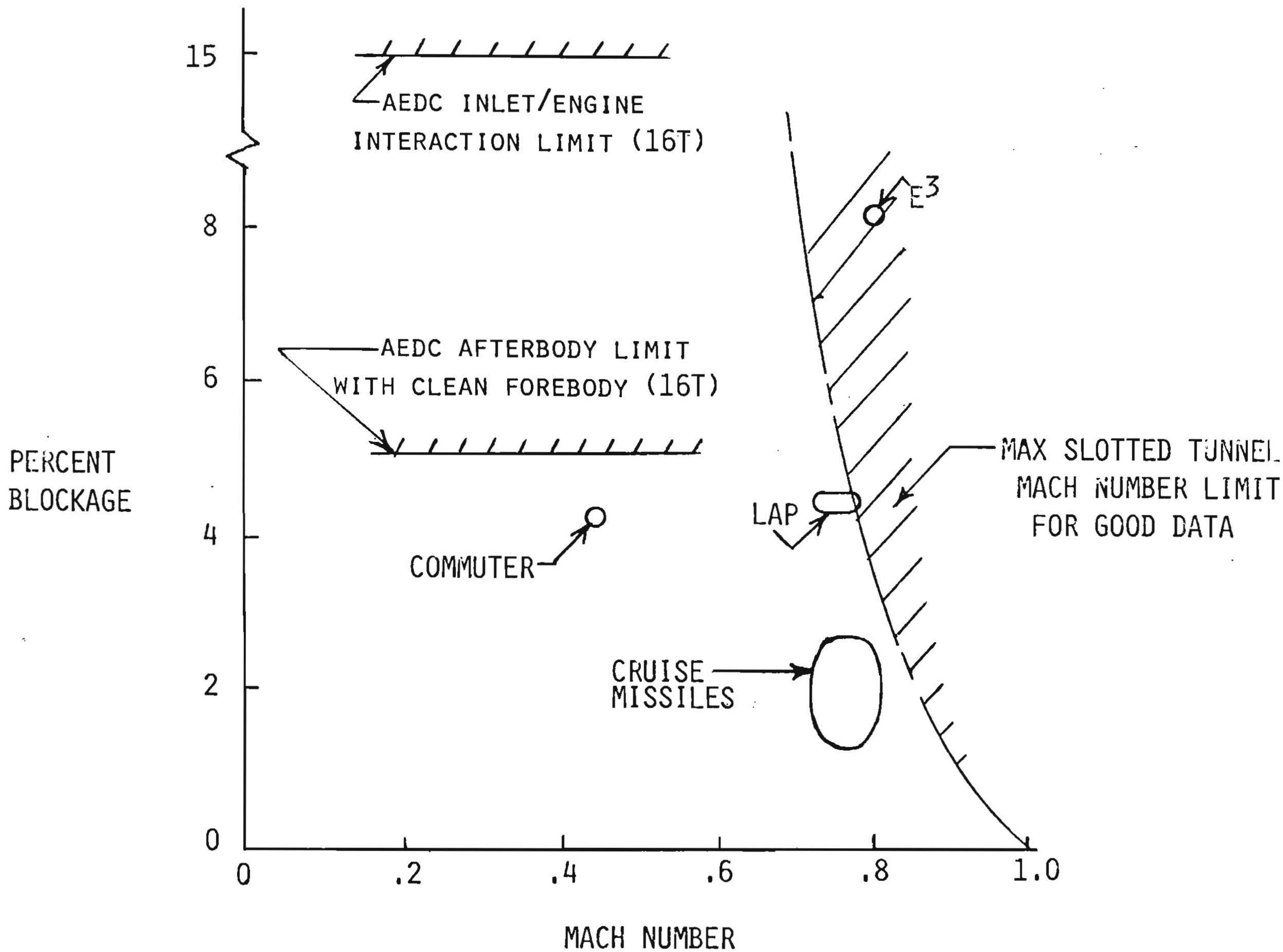


FIGURE 2

PROPELLER SIZE LIMITATIONS TO MINIMIZE INTERFERENCE

"ROUND" TEST SECTIONS

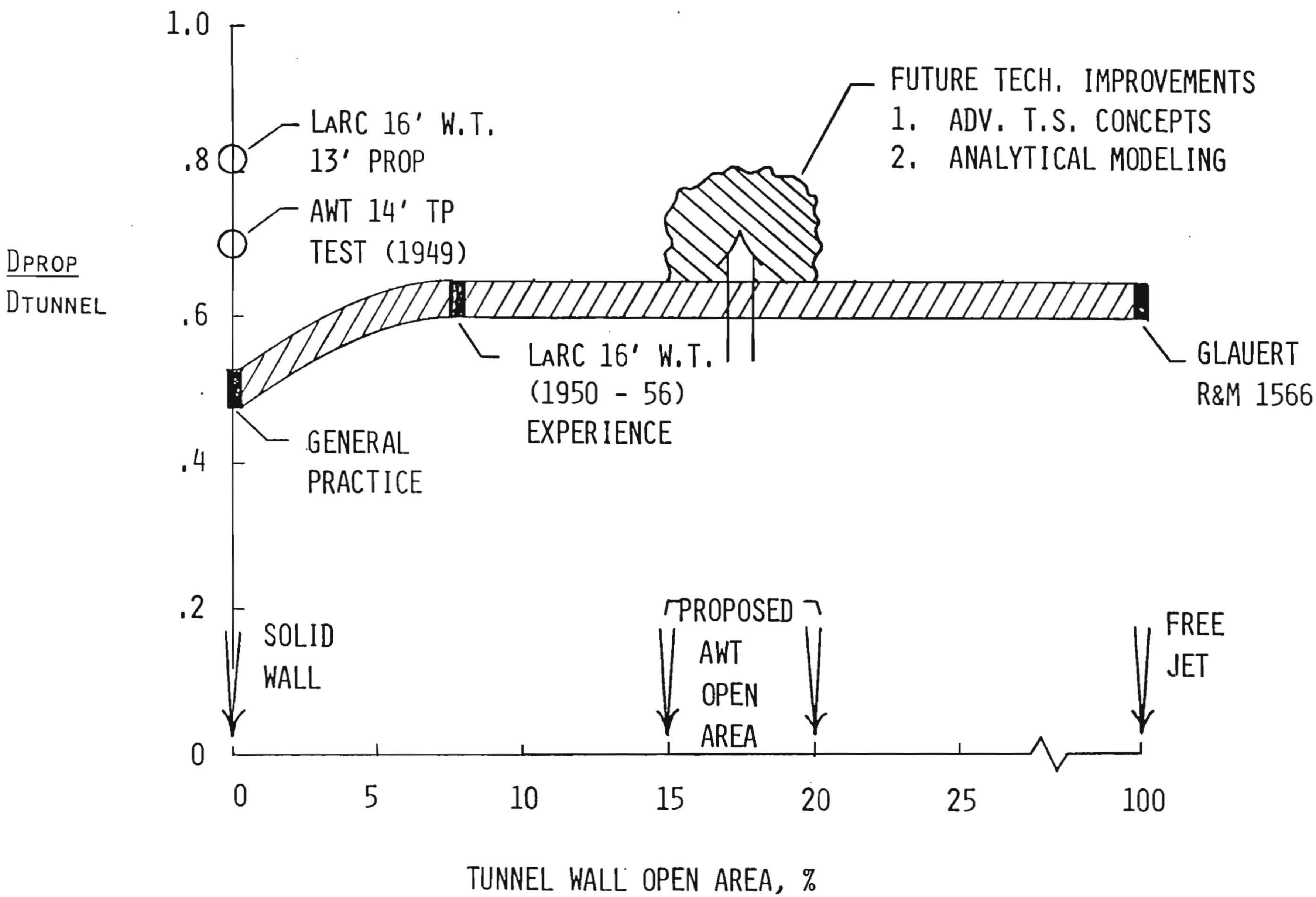


FIGURE 3

ALTITUDE WIND TUNNEL

PREDICTED SOUND PRESSURE LEVEL

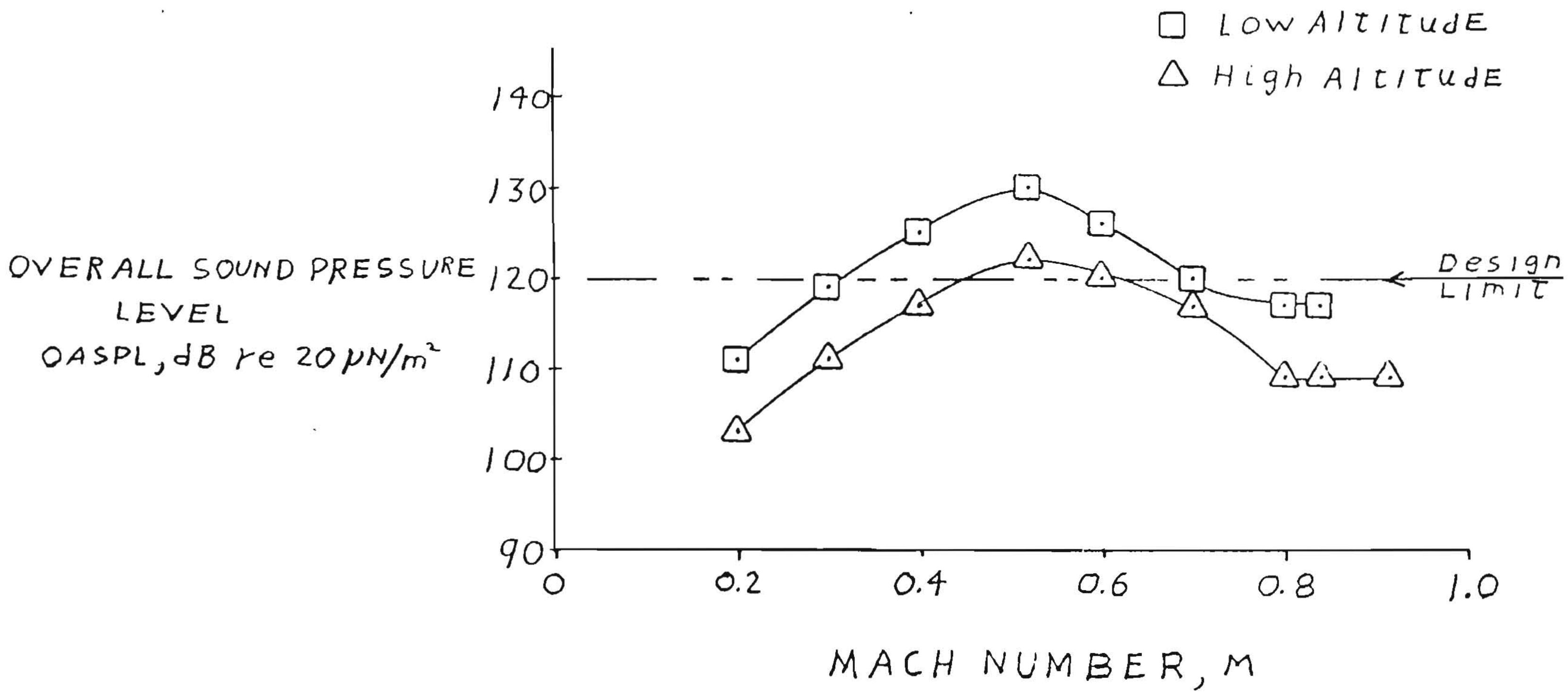


FIGURE 4

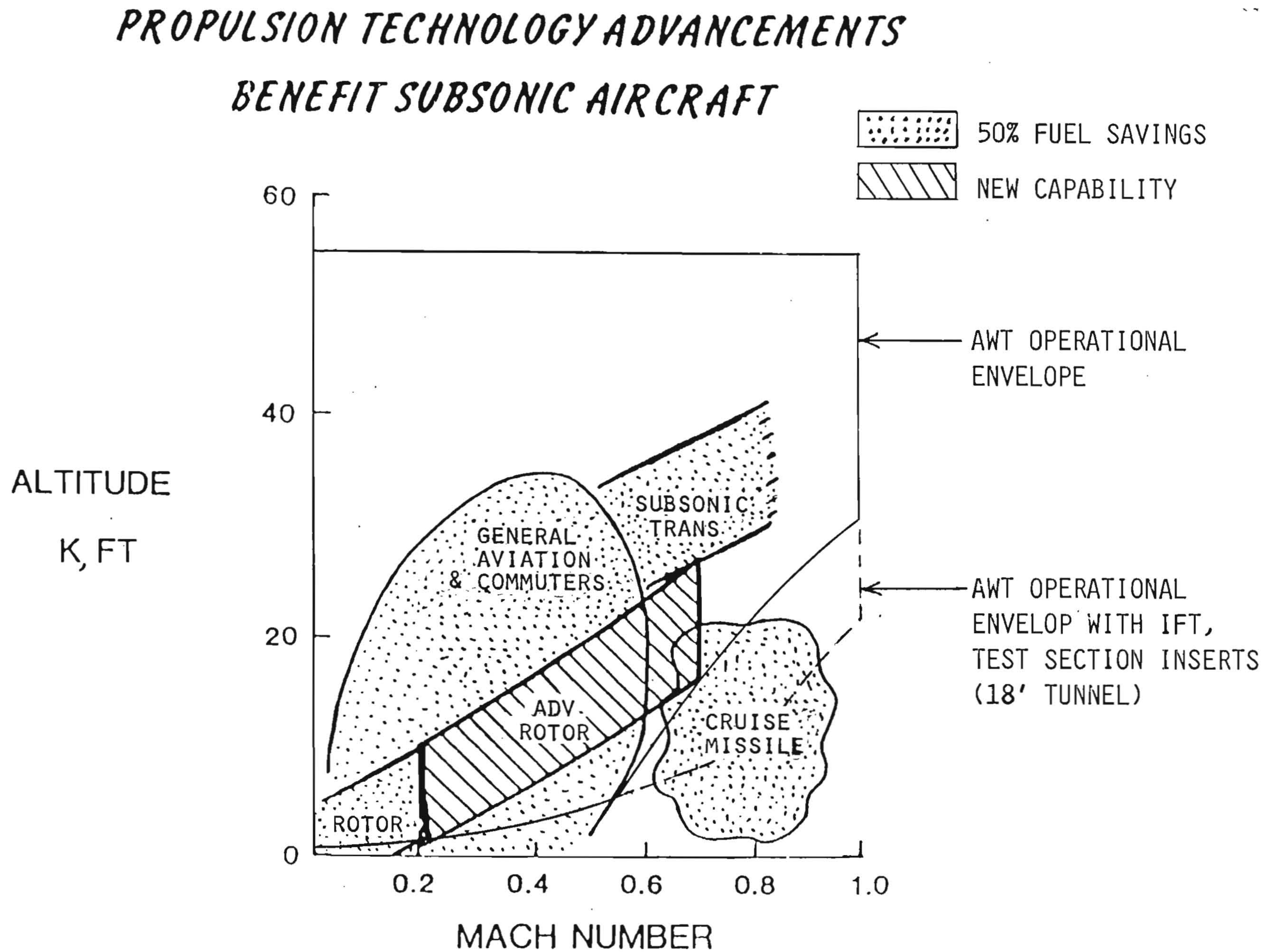
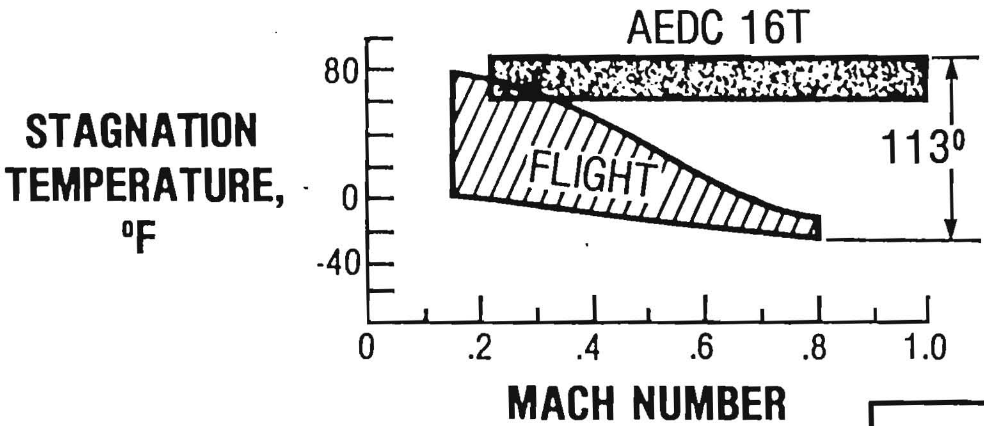

PROPULSION TECHNOLOGY ADVANCEMENTS
BENEFIT SUBSONIC AIRCRAFT
50% FUEL SAVINGS
NEW CAPABILITY
ALTITUDE
K, FT
60
40
20
0
AWT OPERATIONAL ENVELOPE
AWT OPERATIONAL ENVELOP WITH IFT, TEST SECTION INSERTS (18' TUNNEL)
GENERAL AVIATION & COMMUTERS
SUBSONIC TRANS
ADV ROTOR
ROTOR
CRUISE MISSILE
0.2
0.4
0.6
0.8
1.0
MACH NUMBER

FIGURE 5

NASA

ALTITUDE WIND TUNNEL

TURBOPROP TEST REQUIREMENT



AERODYNAMIC SIMILARITY REQUIRES $N/\sqrt{T}$ = CONSTANT

113° TEMPERATURE DIFFERENCE RESULTS IN 10 TO 12% PROPELLER OVERSPEED TO MAINTAIN SIMILARITY

- 25% CENTRIFUGAL OVERSTRESS
- BLADE TIP TWIST ERROR

FLUTTER CHARACTERISTICS SIGNIFICANTLY ALTERED

MISMATCH BETWEEN ENGINE EXCITATIONS & BLADE NATURAL FREQUENCIES

CORRECT AMBIENT TEMPERATURE

CD-84-14364

FIGURE 6

PROPULSION WIND TUNNELS

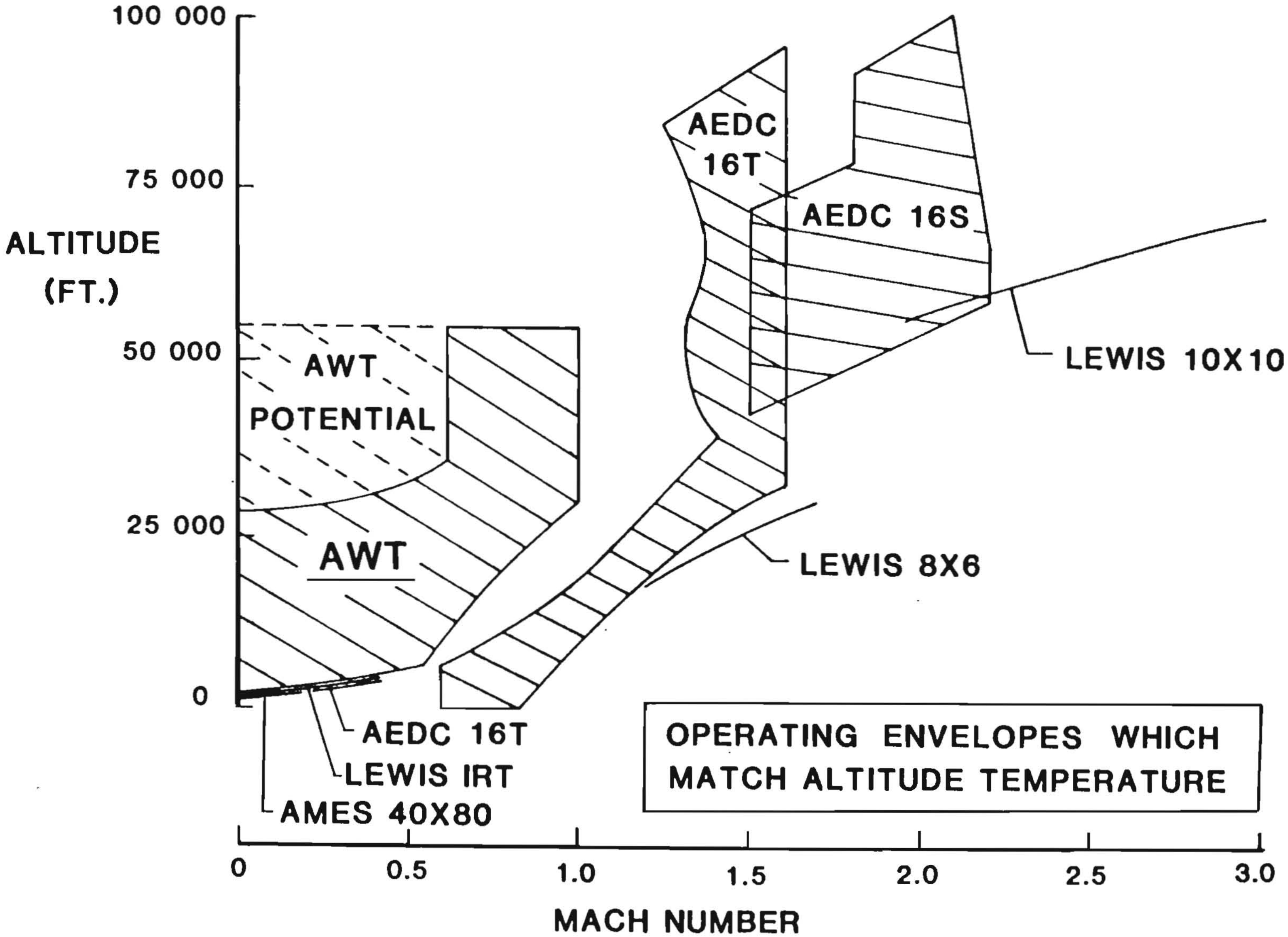
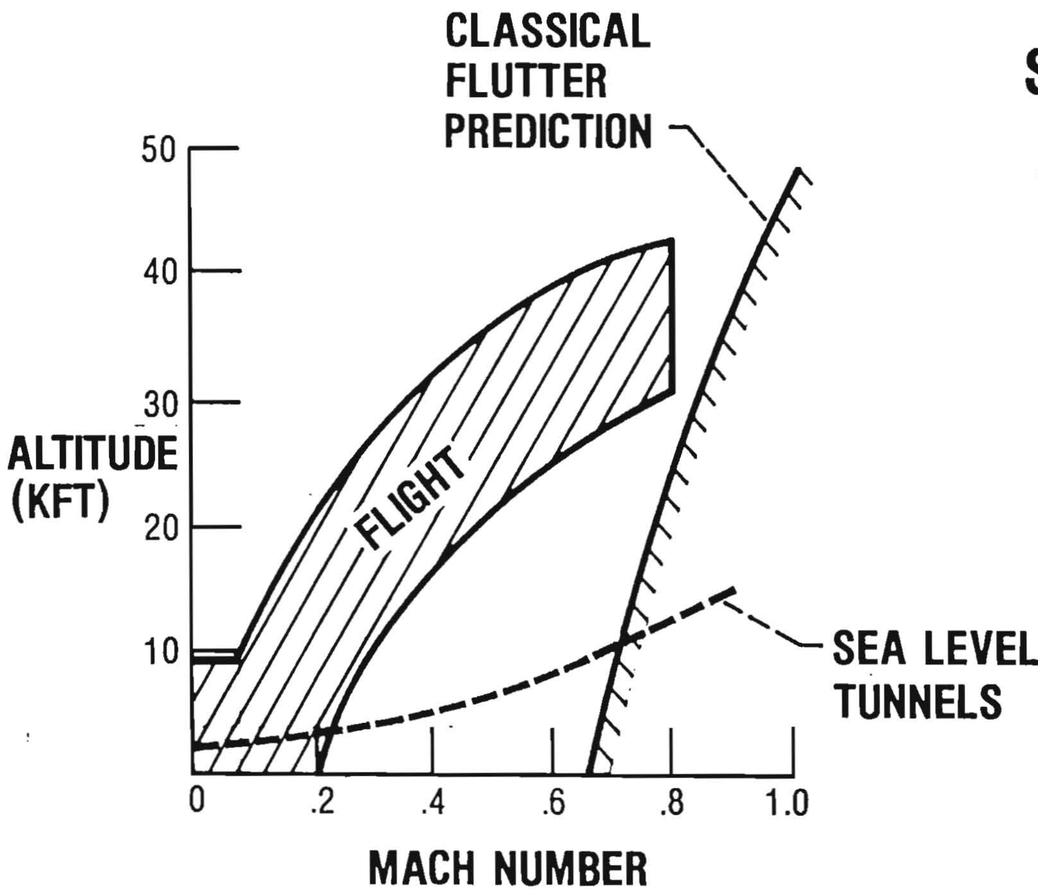


FIGURE 7

NASA

AWT ALTITUDE WIND TUNNEL

TURBOPROP TEST REQUIREMENT



SEA LEVEL TUNNELS

- 3 TIMES FLIGHT DENSITY
  - EXCESSIVE BLADE AIR LOADS
  - 3 TIMES POWER (GEARBOX LIMIT EXCEEDED)
- REDUCED FLUTTER SPEED

CORRECT AMBIENT PRESSURE

CD-84-14373

FIGURE 8

ALTITUDE WIND TUNNEL

NASA
Lewis Research Center

AWT MODELING PROGRAM AND INTERFACES

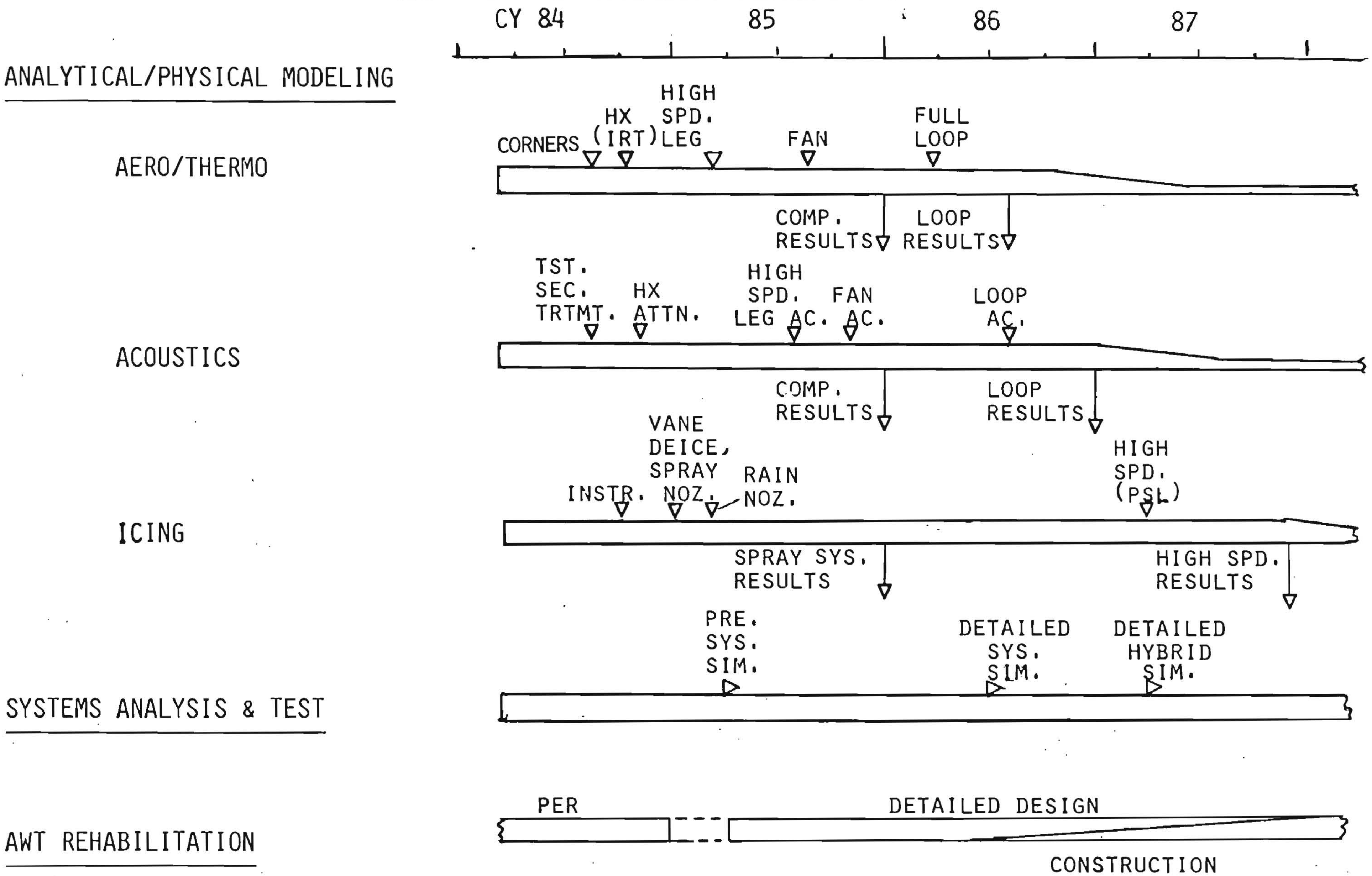


FIGURE 9

KEY: ▽ INITIATE TESTING, ▷ OPERATIONAL