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Task Group on Aeronautical Research and Development Facilities Report

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Table of Contents

TERMS, ABBREVIATIONS, AND ACRONYMS

AEDC	Arnold Engineering Development Center
A310-300	Airbus Transport Airplane
AMES 12 Ft.	Subsonic Pressure Wind Tunnel at NASA Ames
APTU	Aerodynamic and Propulsion Test Unit
ASTF	Aero-Propulsion Systems Test Facility
Atm.	atmosphere
B.L.	flow boundary layer
C_{Lmax}	maximum lift coefficient
DoD	Department of Defense
DRA	Defense Research Agency, England
ETW	European Transonic Wind Tunnel
GE	General Electric Company
GE 90	General Electric Transport Aircraft Engine
LSWT	proposed new Low Speed Wind Tunnel
$M(L/D)_{max}$	aircraft range efficiency parameter, Mach number times maximum lift to drag ratio
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
NAWC	Naval Air Warfare Center
NSWC	Naval Surface Warfare Center
NTF	National Transonic Facility
ONERA F-1	Subsonic Pressure Wind Tunnel in France
P&W	Pratt & Whitney
PW 4000 ADP	Pratt and Whitney Transport Aircraft Engine
PW 4084	Pratt and Whitney Transport Aircraft Engine
R&D	Research and Development
RN	Reynolds number
S/TSTO	single/two stage to orbit
T&E	Test and Evaluation
TBD	to be determined
TSWT	proposed new Transonic Wind Tunnel
UWAL	University of Washington Aeronautical Laboratory
U.K.	United Kingdom
V_{min}	minimum flight velocity
X/C_{trans}	chordwise location of boundary layer transition line, measured from leading edge in percent of local chord

I. EXECUTIVE SUMMARY

The Task Group on Aeronautics R&D Facilities examined the status and requirements for aeronautics facilities against the competitive need. Emphasis was placed on ground-based facilities for subsonic, supersonic and hypersonic aerodynamics, and propulsion. Subsonic and transonic wind tunnels were judged to be most critical and of highest priority. Results of the study are briefly summarized as follows:

No existing U.S. government or commercial development facilities have the combination of capability, productivity, and cost metrics to provide the American aircraft industry with the technology that will permit U.S. firms to compete effectively. In fact, the U.S. aircraft industry is currently using facilities in Europe in order to compete.

It is the consensus of U.S. industry and government that substantial gains in capability, productivity, and operating cost metrics are needed to provide the U.S. with world-class facilities and competitive advantage for both commercial and military aircraft development.

In order to alter the course of the competitive position of the U.S. aircraft industry, it was a consensus of industry and government that improvements to existing national facilities will not meet the requirements. The need exists for new wind tunnels with substantial increases in capability at subsonic and transonic speeds.

The industry estimates that technically a 10-15 percent improvement in transport aircraft cruise and takeoff/landing performance is available and could be achieved with new subsonic and transonic/high productivity wind tunnels. They also estimate that a 10 percent improvement in performance could result in a $5.0-$10 billion increase in sales each year starting 3 years after tunnel completion along with a reductions in operator costs of $10 million per year per new aircraft.

Facility concepts to meet the need have been defined. The cost of a new subsonic and a new transonic wind tunnel was estimated to be $3.2 billion when constructed with a schedule of ten years using normal government procurement practices. If nonstandard (i.e. commercial like) acquisition and concurrent design and construction were feasible the schedule could be reduced to 8 years and the cost reduced to $2.55 billion. Further reductions may be achievable; however, it will require the timely investment of FY 1994 new facility funds in the NASA budget.

The proposed new wind tunnels represent a balanced tradeoff in capability, productivity and cost to achieve the most effective design while maintaining the capability to improve their operating envelopes in the future.

A new supersonic wind tunnel is unnecessary at this time; however, an investment to bring existing facilities up to the productivity and flow quality standards needed for commercial and military product development is recommended, and research and development should be funded for 'quiet' flow supersonic wind tunnels to enable dramatically improved future aircraft.

For propulsion facilities, the overall assessment was that with a few exceptions, the U.S. industry and government laboratories have the largest and most capable propulsion facilities in the free world. A study is recommended to define mass flow requirements for engines beyond the current generation (PW4000/GE90) which could lead to a mass flow upgrade in the Aeropropulsion Systems Test Facility at the Air Force Arnold Engineering Development Center.

For hypersonic facilities,a two-phased plan has been developed that addresses the shortfalls considering the array of potential flight systems which are under study or development. Phase I consists of a focused program of facility research and three important and needed facilities which can be built relatively soon with low risk and a modest investment. Phase II facility construction would be undertaken later to provide enhanced hypersonic flow simulation capability along with systems certification facilities once the enabling facility technologies are in hand. The focused program of facility research is clearly the most urgent need in hypersonics.

A review of facility closures indicated that six major facilities are scheduled for closure between FY 1993 and 1995. Consolidation of testing between the Langley 8 Foot High Temperature Structures Tunnel and the AEDC Aeropropulsion Test Unit (APTU) is being worked. When new highly-productive subsonic and transonic wind tunnels are built: 1) the U.S. industry will stop testing in Europe ($12 million per year); 2) there will be a significant reduction in use of industry-owned tunnels with potential closing of some; i.e., Boeing Transonic Wind Tunnel (approx. $20 million per year), and 3) major government development oriented wind tunnels such as the Ames 12-Ft. and 11-Ft. Tunnels and the AEDC 16T will be phased down/out depending on workload (approximately $20 million per year). Only the very best facilities will be maintained long term.

Implementation of the recommended actions will result in the facilities required for the U.S. Aeronautics industry to compete effectively in the world market. The payoff will be in U.S. jobs and the U.S. economy; it will help to sustain or increase the U.S. share of an $815 billion market over the next 16 years. Although the cost of these facilities is significant, the investment will yield returns (such as economic growth, cost avoidance, and revenue generation) far in excess of the initial outlay.

II. INTRODUCTION

For many years, the United States has enjoyed significant economic benefit and military air superiority as a result of preeminence in aviation. In terms of economic impact, U.S. aviation industry sales exceeded $90 billion in 1991 and brought $28 billion to the U.S. in positive balance of trade, the largest of any industrial sector in the economy. Over one-million, high-quality jobs resulted. The economic significance of aeronautics has not been lost on others however, and in the past 20 years several countries have taken a very aggressive approach to establishing themselves as important economic competitors. Their successes are mirrored by the decline in the U.S. share of the global market. Since 1969, the U S share of the jet transport market has dropped by 30 percent and is predicted to continue to drop as shown in Figure 1. An enormous sales potential is expected in the future, $815 billion by 2010 with 65 percent of the sales being for foreign airlines, as shown in Figure 2. With this market potential, and with the technological advances that have and will continue to occur in aircraft, it is vital that the U.S. maintain the broad technological infrastructure necessary to allow the aeronautics industry to maintain or improve its position among the suppliers of aircraft and engines.

New aircraft required over the next 20 years, to fill this expanding market are not defined at this time as indicated by Figure 3. However, it is clear that several new families of airplanes will be required and the relative market shares of these airplanes will be significantly influenced by performance capabilities. The industry projects that a 10-15 percent improvement in cruise and takeoff/landing performance can be obtained through improved aerodynamic designs. For example, the high-lift performance (maximum lift coefficient) for current aircraft and the projection for the future is shown in Figure 4. ***At least an additional 10 percent is believed achievable if systems can be developed in higher-capability facilities.*** As shown in Figure 4, the Airbus A310 already achieves higher CL_{max} than current U.S. aircraft. This is attributed to the use of the European facilities that have higher Reynolds number capability. The transonic cruise aerodynamic efficiency parameter (Mach number times maximum lift to drag ratio) is shown in Figure 5. Significant improvements are believed to be available through aerodynamic refinements obtained with higher-capability wind tunnels. The payoff for the designs that achieve these improvements will be significant. As an example, at current fuel prices, a ***1 percent improvement in performance for a medium size airplane results in a reduction in operating costs of $1 million per year per aircraft. The industry estimates that a 10 percent improvement in both airplane cruise and takeoff performance could result in a $5-10 billion increase in US. airplane sales each year starting 3 years after tunnel completion along with a reduction in operator cost of $10 million per year per aircraft.***

All aircraft development, exemplified in Figure 3, is vitally dependent on wind tunnels. Wind tunnel test hours required for the development of an aircraft have remained relatively constant over the last 20 years as indicated in Figure 6. A typical new aircraft, transport or fighter, requires 20,000 to 25,000 test hours; and a major derivative such as the McDonnell

Douglas MD-11 or Boeing 737-300 requires 5,000 to 14,000 test hours. Even as computational Fluid Dynamics (CFD) has matured, these experimental test requirements have remained constant and are expected to continue in the foreseeable future, since CFD and experimental facilities are used in complementary roles in the design development process. To meet the challenges associated with increasing international competition, the U.S. must have the use of both "world class" computational and experimental development facilities.

Despite the ongoing and projected critical requirements, the average age of wind tunnel facilities in the U.S. is approximately 40 years. The intervening time since these facilities were initiated have produced changes in the worldwide competitive environment and in technology advancement, both of which have resulted in different approaches to aircraft development testing. The NASA Wind Tunnel Revitalization Program, conducted from FY 1989 to FY 1994, was a major step in modernizing and restoring existing NASA facilities to their full capability. These facilities are totally able to perform their intended role, and many contain special or unique features which will be needed for many years to come. However, it is clear that these facilities, even when coupled with other major capabilities in the DoD and industry, cannot provide the combination of productivity and flow conditions that emerging aircraft and engine systems will require.The U.S. industry is currently utilizing the national test capability to the maximum extent, and the current generation of aircraft designed utilizing these facilities is just competitive with the newest European aircraft and for some cases are behind the competition (as in Figure 4).

The European facilities including subsonic wind tunnels in England, France, and the Netherlands and the new European Transonic Wind Tunnel (ETW) to come on line in 1994, are at least a generation newer than their U.S. counterparts and emphasize not only high-quality test conditions but also high productivity. These facilities provide the European aircraft manufacturers a competitive advantage.

The National Facility Study was initiated to address these and other facility issues. The objectives of the Study were to: 1) determine where U.S. facilities do not meet the national aerospace needs, 2) define new facilities required to make U.S. capabilities world class, 3) define where consolidation and phaseout of existing facilities is appropriate, and 4) develop a long-term national plan for world-class facility acquisition and shared usage. For this report , the first two objectives have been combined. The Task Group on Aeronautics R&D Facilities (Appendix 1) examined the status and requirements for the broad spectrum of aeronautics facilities against the competitive need. Aerodynamics, acoustics, propulsion, and simulation facilities were considered. Because of a recent integrated study of hypersonic facilities, hypersonics was considered as a separate category. It was determined that the aspect of the infrastructure of most urgent concern is the nation's major development wind tunnels and propulsion facilities. Therefore, the Task Group focused on ground based facilities for subsonic, transonic, supersonic, hypersonic aerodynamics, and propulsion. Working Groups (Appendix 1) were formed to develop national government/industry consensus on the four Study objectives.

Detailed reports of these Working Groups are in the Appendices. Key findings, conclusions and recommendations of the Task Group are summarized in the remainder of this report.

III. FACILITY SURVEY/COMPARISON AND REQUIREMENTS

Subsonic/Transonic

An extensive inventory of worldwide wind tunnel facilities and their pertinent attributes has been accomplished in the study (Appendix 2). Most of the facilities in the inventory set are used for research, and not for the direct development of civil or military aircraft. A more meaningful subset, considered by a consensus of government and industry experts to be the core facilities for US. aircraft development, is presented in Figure 7. These core facilities are owned by the U.S. government, U.S. industry, and foreign interests. Three primary considerations were used in selecting the core facilities: capability (characterized by the aerodynamic parameter Reynolds number), productivity, and operating cost. The comparison metrics, maximum Reynolds number of the facility, productivity in terms of polars per occupancy hour (a polar is defined here as 25 data points, each point being obtained at a single value of an independent variable), and test costs in terms of dollars per polar are included in the figure. The test costs are the costs charged users and are not necessarily based on the same algorithm for all facilities. In general, the data show that the higher the Reynolds number the lower the productivity and the higher the operating costs. The more modern European tunnels have achieved a better balance between capability, productivity, and cost, although the Ames 12-Foot Tunnel, which is being rebuilt and will be reactivated in 1995, will have comparable metrics to the European subsonic tunnels. All of the world's subsonic tunnels, however, have serious limitations for the development of the complex high-lift systems to be implemented on future aircraft. ***It is the consensus of U.S. industry and government that substantial gains in Reynolds number, productivity, and cost metrics are needed to provide the U.S. with world-class capability and competitive advantage.***

Wind Tunnel Requirements.

The Task Group, through a process of interaction with the national aeronautical experts and_analysis of available data, arrived at a set of target requirements in terms of Reynolds number, productivity, and operating costs for both low speed and transonic wind tunnels. They were supported in this activity by the Aerodynamics and Acoustics Working Group (Appendix 3).

Low Speed Tunnels.- The primary Reynolds number sensitivity at low speed is associated with the high lift configurations at landing, Mach number = 0.20 and second segment climb conditions, Mach number = 0.30. The industry practice is to design high lift systems and obtain data over the limited Reynolds number range provided by existing wind tunnels and extrapolate these results to full scale conditions. There is limited data available on the maximum

Reynolds number required in order to be able to make this extrapolation with high confidence. However, the data of Figures 8 (a) and 8 (b) show examples of the problems encountered when testing in existing wind tunnels. The data in Figure 8 (a) show the effect of Reynolds number on the maximum lift (C_{Lmax}) for a configuration optimized at a Reynolds number of 9 million. A loss in lift occurs as the Reynolds number is increased to 16 million. These data suggest that in order to achieve maximum lift from a high lift system the design should be optimized at the flight Reynolds number. The data in the example of Figure 8 (b) also show that the variation of maximum lift is non linear with Reynolds number and the last wind tunnel data point is headed in a negative direction providing no clear indication of how to extrapolate to the flight Reynolds number. There is mounting evidence to suggest that the Reynolds number effects on high lift are correlated with flow transition and the boundary layer characteristics. Typical effect of the transition on the variation of maximum lift with Reynolds number is illustrated in Figure 9. Differences in lift as high as 15 percent have been obtained as a result of transition effects. The Reynolds number at which transition occurs is dependent on geometric characteristics (wing sweep and radius of curvature at the attachment line) and roughness or boundary layer contamination characteristics and can vary significantly for various configurations. For many airplane designs, the existing wind tunnels can provide data only below the transition Reynolds number which will result in trends like the ones shown in Figure 8. It is desirable to conduct all wind tunnel tests on high lift systems at Reynolds numbers beyond the transitional range or at full scale.

In arriving at a Reynolds number goal for testing, the objective was to achieve the highest Reynolds number practical (exceeding the transition Reynolds number for some airplanes) while achieving low operating costs and high productivity. Taking into consideration some cost optimization studies (to be discussed later), the government/industry consensus was that the ***low-speed tunnel goal should be the ability to test at full-scale Reynolds number (approximately 30 million) for some existing airplanes , productivity of 2 to 2 1/2 times existing wind tunnels which would yield 5 polars per occupancy hour, and operating costs equal to or less than current wind tunnels or approximately $1000 per polar.*** These goals should be accompanied by excellent flow quality, accessibility, and acoustic capability. The acoustic capability would be provided by an open jet test section surrounded by an anechoic chamber.

Transonic Tunnels.- At transonic speeds the National Transonic Facility (NTF) at NASA Langley provides full scale Reynolds number capability for validation and research, but at low productivity and very high operating costs which makes it unsuitable for development testing. Therefore, the objective in selecting the Reynolds number goal for the high volume transonic development testing was to obtain values high enough that Reynolds number effects will be generally predictable. To meet this criteria a Reynolds number of 30 million was selected. This corresponds to the condition where the boundary layer transition point is at the leading edge of the wing and the boundary layer flow is fully turbulent for a typical transport wing as shown in Figure 10. Therefore, the ***transonic goals were determined to be a Reynolds number of 30 million, productivity of 8 polars per occupancy hour, operating cost of $2000 per polar, with***

good flow quality and accessibility. Comparing these low speed and transonic goals with the capability of the "core" development facilities in Figure 7 leads to the conclusion that no U.S. facilities have the combination of capability, productivity, and cost metrics to provide the American aircraft industry with an effective competitive position.

Option to Meet Facility Requirements.

Both upgrades of existing facilities and new facilities were considered as ways to provide the desired capability.

Upgrades to Existing Wind Tunnels - Four of the core facilities were reviewed for upgrade; the 12-Ft. and 11-Ft. Tunnels at Ames, the National Transonic Facility (NTF) at Langley, and the 16-Ft. Transonic Tunnel (16T) at Arnold Engineering Development Center (AEDC). At the newly rebuilt 12-Ft. Tunnel, a factor of 2 increase in productivity is possible with aggressive pursuit of model handling, data acquisition, and control system modifications. It is also possible to increase the Reynolds number by a factor of 2 through the use of heavy gas as a test medium. However, there are fundamental technical questions concerning the applicability of test results obtained in heavy gas, and this approach cannot be relied upon for achievement of desired capability without a significant amount of research. Important modifications to the 11-Ft. Tunnel are included in the FY 1994 NASA budget and will provide for increased reliability and new fan blades. Other improvements, such as increased pressure capability and productivity were studied. At the NTF, the issue is low productivity, caused substantially by cryogenic temperatures, but further limited by drive system controls, limits in liquid nitrogen storage and production, and model handling techniques. The most urgent of these (nitrogen storage and controls) are covered in the FY 1994 NASA budget, but further gains in productivity are possible. Reliability is the primary concern at the AEDC 16T; the drive system and controls are quite old, motors need rewinding, and other productivity and reliability improvements are possible. Figures 11(a) and 11(b) show the potential impact of making the above modifications to the wind tunnel metrics relative to the goals for the low-speed and transonic tunnels.

Although these modifications can provide a significant productivity improvement, they will not meet or even approach the requirements for Reynolds number. The 12-Ft. Tunnel only achieves about 35 percent of the required Reynolds number (without using heavy gas) and the 11-Ft. Tunnel only about 50 percent of the required Reynolds number after modifications. In addition, none of the acoustic needs which are a significant part of the low-speed tunnel requirements would be addressed.

In order to alter the course of the competitive position of the U.S. aircraft industry, it is a consensus of industry and government that improvements to existing national facilities will not meet the requirements. The need exists for new wind tunnels with substantial increases in Reynolds number at subsonic and transonic speeds.

__New Wind Tunnels__ - The process of finalizing the requirements for the wind tunnels and developing a conceptual facility configuration involved analyzing the impact of various key parameters on the design and associated costs. The Task Group was assisted in this process through a Facility Study Office (FSO) jointly staffed by NASA and DoD personnel. The results of these analyses are reported in Volume II-A. A prior study, supported by the Boeing Company, had developed a preliminary design concept including cost and schedule estimates for a two wind tunnel complex with a low speed wind tunnel and a transonic wind tunnel (Figure 12). Although this complex (designated Concept A) did not satisfy the requirements for Reynolds number, productivity and operating cost, it provided a useful point of departure and was used as a costing baseline. Detailed analysis of specific concepts to meet the metric goals was done under the study by the FSO. Concept A provided a "close" solution transonically since the Reynolds number was so near the goal of 30 million. Achieving the desired metrics subsonically proved to be a challenge. Indeed, capitalization costs for options considered varied by a factor of almost 2.5 with the most costly variant being Reynolds number for the low-speed tunnel.

The options available for increasing Reynolds number in a wind tunnel are increases in pressure and size, reducing temperature and using a heavy test gas. The effect of these parameters on capitalization cost for a low-speed tunnel is illustrated in Figure 13 for an operating pressure of 5 atmospheres (considered to be the maximum usable for high-lift testing). The accompanying effect on productivity is illustrated in Figure 14. The curves in Figures 13 and 14 are not based on detailed engineering analysis but rather "first order" engineering approximations to illustrate the trends for the options available. Capitalization cost increases rapidly with increasing size; model costs and handling difficulties also increase. Based on these trends, and detailed analysis at specific points on the curves (Volume II-A), a 20 by 24 foot test section was considered to be the largest practical size for a subsonic development wind tunnel. This provides a Reynolds number of 20 million. Reducing the temperature to -20 degrees will increase the Reynolds number to 28 million for about a 20 percent increase in cost. Further temperature reductions require significant structural and systems changes resulting in much larger cost increases and productivity decrements. The use of a heavy test gas would be the most cost effective way of achieving high Reynolds number, but the fundamental technical concerns about aerodynamic testing in heavy gas make it too high a risk for application at this time.

Additional trade/optimization studies should be performed prior to final design of new wind tunnels. However, based on substantial analysis of capitalization costs and benefits, the preferred approach is the 20 x 24 foot tunnel with design provision for future improved capability through cooling and heavy gas. The Low Speed Wind Tunnel (LSWT), provides for efficient high Reynolds Number testing (20 million, on full span models, at a Mach number of 0.3). The goal in Reynolds number of 30 million is achieved through the use of semi-span (large, half-vehicle) models. It fully meets the productivity and cost metrics as shown in Figure 15. The effectiveness of the proposed LSWT tunnel in coverage for the projected airplane fleet over

the next 20 years is shown in Figure 16 for the second segment climb condition at a Mach number of 0.3. This figure shows the critical low speed Reynolds number requirements for various size aircraft, and their percentage of the total transport market. Also shown on the figure are the maximum Reynolds numbers for the existing and proposed wind tunnels at a Mach number of 0.3. The solid lines represent the maximum Reynolds number coverage with full models and the dashed line represents the coverage with semi-span models which can be used to provide data on key performance parameters and reduce the engineering risk. The existing wind tunnels do not provide full scale Reynolds number for any airplanes in the fleet, although they were used in the development of the current designs. ***The proposed wind tunnels however, provide full scale Reynolds number for the airplanes in the 101 to 150 seat range using a full model, and through an intermediate size (approximately 180-210 seat capacity) using semi-span models.*** For this part of the fleet, the U.S. will be in a position to develop configurations where aerodynamic characteristics may be strongly influenced by leading edge transition, relaminarization, etc. with minimum risk for performance estimates. For the larger size airplanes extrapolation will still be required; the transition effects discussed earlier, and illustrated at the bottom of figure 16, will still be a concern.

The curves on the lower part of figure 16 represent the range of transition effects on maximum lift ($C_{L_{max}}$) as a function of Reynolds number for the existing aircraft designs. The Reynolds number at which transition occurs is more a function of wing geometry and local flow environment than aircraft size. ***For large aircraft with leading edge geometric characteristics such that transition has occurred by approximately 35 million Reynolds number (LSWT semi-span limit at a Mach number of 0.3), extrapolation to full scale should have minimum risk.*** However ***for future large aircraft where transition may not have occurred by 35 million, some uncertainty in extrapolation to full scale will still exist.***

While the proposed LSWT will not provide full scale Reynolds number capability for all potentially large commercial aircraft, it will provide major increase in development wind tunnel testing capability over foreign competitors (existing conventional wind tunnels) and reduce risk in performance estimations and guarantees for U.S. aircraft. The facility will be at the practical limit of low speed, continuous flow wind tunnel testing capability without cooling. Clearly it would be desirable to provide sufficient capability to cover all conditions for future aircraft. However, this would require a Reynolds number capability double that of the proposed tunnel and it is the view of the Task Group that such a facility is well beyond reach for a high productivity development wind tunnel, both technically and economically. If required in the future this capability could be obtained by "mild" cooling or possibly the development of techniques for a "heavy gas".

The proposed Transonic Wind Tunnel (TSWT) has a test section of 11 by 15.5 Ft. and achieves the goal of 30 million Reynolds number at a Mach number of 1 with full span models. It also meets the productivity and cost metrics as shown in Figure 17. The effectiveness of the

proposed transonic wind tunnel in coverage for the projected airplane fleet over the next 20 years is shown in Figure 18 in the same format as used for the low-speed tunnel. The Mach number is 0.8. It provides full scale Reynolds number (using semi-span models) for all but the largest size airplane. This Reynolds number coverage, used with the NTF for validation of the large airplanes, will provide the industry capability to develop airplanes with minimum risk for cruise performance.

A conceptual sketch of a new wind tunnel complex is shown in Figure 19 and described in detail in Volume II-A. It shows both the low-speed and transonic wind tunnels. They have separate drive systems housed in a common building; each has three removable test sections and a removable plenum section to meet the productivity requirements. The low speed tunnel has acoustic testing capability at 1 atmosphere in an open jet test configuration with a large anechoic room built into the outer plenum shroud. A removable plenum section is used to facilitate the interchange of test sections and models. Engineering cost estimates for this complex were developed based on a work breakdown structure that defined the major elements of the project at the 5th tier level. Risk, escalation, contingency, and inspection services were also added to arrive at the total construction budget. Cost for planning and design, including the preliminary engineering report, government project management, special studies, and final design were added to develop a ***total project budget estimate of $3.2 billion and a schedule of ten years using normal government procurement practices. A joint industry-government team looked at applying acquisition and design build practices used by industry to the cost and schedule. The team concluded that if using nonstandard (i.e. commercial like) acquisition and concurrent design and construction approaches were feasible, the schedule could be reduced to 8 years and the cost reduced to $2.55 billion. The Aeronautics Task Group believes further reductions may be achievable; however, it will require the timely investment of FY 1994 new facility funds in the NASA budget to accomplish the preliminary engineering design and to conduct a number of technical efforts aimed at risk reduction.***

It is important to note that these wind tunnels are not the most capable that could be produced. Indeed, reasonably detailed study of more than ten options was accomplished with costs ranging from approximately $2 billion to almost $5 billion. Significant cost/benefit analysis was done; this analysis process contributed significantly to the final definition of the metric requirements. The proposed new wind tunnels represent a balanced tradeoff in capability, productivity and cost to achieve the most effective design.

<u>Funding and Operations</u>. - Three options for capitalization of the new wind tunnels were considered in the study: industry only, a government/industry consortia, and government only. These options are described in detail in Appendix 4. Based on extensive discussion with the U.S. industry, it was the conclusion that funding by industry alone is not a viable source for capitalization of the tunnels at this time. The possibility of a government/industry consortia could not be ruled out, and further work is needed to explore mechanisms to allow such an

option. However, in the current very difficult aerospace industry climate, preliminary indications were that broad-based industry funding may not be available for capitalization although industry is prepared to strongly support the design and construction process with substantial commitments of people for staffing support of the project office. Therefore, the Task Group recommendation at this time is for the government to provide the essential source of funding for capitalization. Further studies should be conducted to look at innovative funding approaches and government/ industry consortia arrangements.

Three options for operations funding of development testing were also considered. All options involved user fees ranging from (1) full cost (including direct, indirect and capitalization), (2) cost for direct and indirect charges only (no capitalization), and (3) direct cost covered by user fees with indirect costs covered by the government. The conclusion of the Study to date is that the most effective utilization of the new wind tunnels would be obtained through a fee policy that recovered direct and indirect costs (but not capitalization) for development tests with one shift of operation funded by the government to support DoD and government/industry cooperative programs. International customers should be charged for the full cost of operations, including direct and indirect costs and capitalization costs.

Management and Scheduling. - It is envisioned that the facilities will be constructed primarily with government funding. They could be managed by the government (either by NASA or jointly between NASA and DoD) or by an industry/government consortium. In any case, they would be operated by contractors. Management would be advised by an Advisory Board comprised of NASA, DoD and industry representatives due to the particular nature of the testing envisioned in the facilities.

Development testing would receive priority, and scheduling would be on a first-scheduled, first-served basis except in times of national emergency. The Advisory Board would periodically review the scheduling priorities to insure that national interest were being served.

Site Selection. The process for arriving at the best site for construction of new facilities should be based in technical and cost considerations. An approach to site selection was developed by the FSO and is included in Volume II-A. Examples of criteria are as follows: Primary considerations - life cycle cost, technical capability (engineering and support), existing site support facilities, assured utilities availability (high demand period limitations), site conditions, environmental acceptability. Secondary considerations - transportation infrastructure, work force stability (down period work), common support services, adequate community infrastructure, local scientific/academic conditions available or surplus government real estate/facilities.

The Aeronautics Task Group recommends that site selection be made as soon as practicable based on appropriate cost and technical criteria.

Supersonic Wind Tunnels

The capability of the major supersonic wind tunnels in the world is summarized in Figure 20 in terms of Reynolds number and size. The Mach numbers range from 2 to 5. The major supersonic tunnels in the United States were built under the Unitary Plan Wind Tunnel Act and provide better capability than the European tunnels. The primary demand for supersonic facilities has been from the Department of Defense and from its military aircraft manufacturers. Based on the input of those customers, ***today's facilities generally satisfy the requirements for fighter aircraft and missile product development but some upgrading is required.*** Currently, NASA and the civil aircraft industry are developing technology for environmentally acceptable, economically viable, High-Speed Civil Transport (HSCT) which would cruise at Mach 2.0 to 2.4. It was also concluded that the ***requirements for a first generation HSCT could be met with the supersonic facilities of today,*** supplemented by flight testing. For the near term, the most important requirement is for relatively straightforward reliability and productivity upgrade at the 16S Tunnel at AEDC.

Laminar flow technology for supersonic aircraft has been identified as a high-leverage technology for future generations of the HSCT. The ability to develop this technology from the "laboratory" to operational status was seen as critical to maintaining U.S. technological leadership. However, existing supersonic wind tunnels have levels of flow turbulence greater than are acceptable for development of laminar flow technology, and modifications to these facilities will not provide the necessary low levels of tunnel turbulence ("quiet flow"). Indeed advances in the state-of-the-art of supersonic tunnel nozzle design and fabrication are required. Therefore, the Task Group ***strongly recommends that research and development be funded which could lead to the construction of a new enabling "quiet" supersonic wind tunnel in the future.*** Such a facility does not exist anywhere in the world and would be indispensable to assure that the U.S. has the capability to develop supersonic laminar flow control technology for future aircraft.

Propulsion Facilities

The Nation's propulsion facility infrastructure has been a major factor in U.S. competitiveness in the area of commercial aircraft engines. Continued advances in propulsion technology are critical to improving cruise economy and minimizing environmental impact in terms of noise and emissions, and in general, reducing aircraft acquisition and operating costs. In assessing future propulsion facility requirements covered in detail in Appendix 5, the focus was primarily on development facilities for future subsonic and supersonic commercial transports. The facilities covered in the assessment are shown in Figure 21. ***The overall assessment was that with a few exceptions, the U.S. industry and government facilities have size and capability, that is clearly world-class.*** However, additional facilities may be required to ensure effective development of future propulsion systems in the areas of high mass flow for subsonic

transports, inclement weather simulation, and full-scale engine tests for the High Speed Civil Transport. In addition to the impact on turbomachinery design and performance, it should be noted that high mass flow propulsion systems for subsonic transports also has a requirement for testing at high Reynolds numbers in both low speed and transonic wind tunnels. This is the same requirement that was discussed previously in the sections covering new wind tunnels and will not be mentioned further in this section.

The mass flow capability of the Aeropropulsion System Test Facility (ASTF) at AEDC compared to existing engine requirements is shown in Figure 22. The only engine falling outside of the operating envelope is the growth version of the Pratt and Whitney 4000 (4000 ADP) at takeoff and climbout conditions. Projections by the airframe industry however, indicate a wide range of potential engine/ requirements mass flow over the next 20 to 30 years which would significantly exceed the capability of the ASTF. The magnitude of the additional requirement is very important; preliminary estimates of costs to increase mass flow by up to 50 percent range from \$250M to \$750M. Therefore, ***a study is recommended to define mass flow requirements for engines beyond the current generation (PW 4000/GE90) before an upgrade is undertaken.***

Other, relatively much smaller propulsion facility upgrades were identified as important for future systems. These include modifications for free jet/engine icing testing and engine nozzle capability testing at ASTF, and an increase in capability of the Icing Research Tunnel at Lewis. These upgrades are estimated to cost on the order of \$20M each.

Hypersonic Facilities

The situation for hypersonics (speeds greater than Mach 5) is quite different than that at lower speeds. Existing systems are essentially all space related, as opposed to aeronautics, and have been developed with ground-test facilities that were built largely in the 1960's to support a new and emerging space program. Today a number of hypersonic systems are under study or development (Figure 23). These categorically include orbital launch vehicles, air-breathing cruisers, interceptors (both ABM and theater air defense missiles), offensive missiles (cruise, maneuvering re-entry, and boost-glide), munitions, and space vehicles (rescue and planetary probes) Out of this array, ***several aircraft and aerospace vehicle systems are likely to be selected for full scale development within the next decade, to be followed by various derivatives.*** Ground test facilities which provide hypersonic flight conditions are absolutely necessary for understanding the fluid flow physics, the thermal environment, structural and material requirements, and the subsequent development of efficient as well as effective flight systems, just as they were for subsonic flight (1910-) and supersonic flight (1950-). ***Current facilities are inadequate, especially for air-breathing propulsion, aerothermal, and real-gas aerodynamic testing.*** Air-breathing propulsion testing presents the most challenging case. Although enabling facility technologies are available for facilities up to Mach 8, and some limited facility capability presently exists, there is no propulsion or real-gas development test capability above Mach 8 and

only limited, inadequate aerothermal test capability exists. For propulsion, there is even a high degree of uncertainty about how to provide the necessary capability since extremely high temperatures (greater than 10,000°F) and pressures (10,000 atmospheres) are required for direct simulation. Figure 24 illustrates the relative confidence level today in developing systems for flight as a result of these facility shortfalls. The confidence level prior to flight tests is high at the lower Mach numbers since the tools for ground testing and computations are reasonably well developed. This confidence is reduced dramatically at the higher hypersonic Mach numbers. Confidence level can be interpreted as inversely proportional to systems development risk; i.e. the higher the confidence, the lower the development risk. therefore, the development risk of hypersonic flight systems is very high with today's ground test capabilities.

A two phased plan has been developed that addresses the hypersonic facility shortfalls considering the array of potential flight systems which are under study or development. Phase 1 consists of a focused program of facility research and three important and needed facilities which can be built relatively soon with low risk and a modest investment. Phase II would be undertaken later to provide the needed systems certification facilities once the enabling facility technologies are in hand. ***The focused program of research is clearly the most urgent need in hypersonics;*** it is required to select, develop, and demonstrate the most promising concepts. A research plan has been jointly developed by NASA, DoD, and industry, and when executed, will provide the enabling technologies for the needed test facilities. Funding for this research program is required at a level of $15 to $20 million/year up to ten years. The bases for the facilities recommended in the plan are summarized in Figure 25. Five system classes and their key technical requirements are identified. The Phase I program proposes the three facilities which can be acquired within current technology. The Phase II program follows once sufficient facility technology has been developed. This chart shows the application of the four recommended Phase I facilities to the respective systems and their key technical requirements. The proposed Phase I facilities construction is shown in Figure 26 along with potential operational dates. This is a time-phased program driven in part by decision points based on technical information coming out of the research program. Clearly, the action milestones can be shifted in time depending on mission urgency. A more detailed report on hypersonic facilities is presented in Appendix 6.

IV. CONSOLIDATION AND CLOSURE

The Task Group recognized the importance of addressing U.S. aeronautical facility redundancy and overcapacity, particularly in the context of recommending substantial new national capabilities. In considering facility consolidation and closure, the Task Group also recognized that substantial efforts are ongoing in all agencies, as well as the private sector to reduce infrastructure as a major cost reduction measure. As an example, recent actions with the DoD Test and Evaluation (T&E) organizations have focused on reducing unnecessary duplication

and improving efficiency of military infrastructure by consolidation. A portion of this activity has been undertaken under the topic of "Test and Evaluation Project Reliance." Under Reliance, studies of selected testing categories examined facilities that perform similar functions, with the objectives of identifying those facilities that are unnecessary and those facilities that should be the site of any future T&E facility investments. Project Reliance will result in the Military Services increasingly relying on each other for various types of support. Other downsizing actions within the DoD have been the result of the Military Services' actions to become more efficient and to eliminate facilities that are no longer required or that cannot be supported in this period of declining budgets.

As a result of a Reliance study, large aircraft engine testing was consolidated at Arnold Engineering Development Center (AEDC), Tullahoma, Tennessee. After further study of this subject within the Navy, the decision was made to consolidate all aircraft engine testing (large, medium, and small). As a result, all aircraft engine testing will be moved from the facility at Trenton to AEDC. This Navy decision led to a base closure action that will result in the closing of the Trenton facility. In addition, the Army is planning to close the High Energy Laser Systems Test Facility in New Mexico that includes a large vacuum chamber. At the Navy's David Taylor Research Center (DTRC), the transonic tunnel was damaged and would have required significant funding to repair. The DoD decision was to shift the work to Air Force facilities rather than make additional investment to repair the older Navy facility.

At AEDC, the DoD does not finance the operation of all of the facilities all of the time. At any one time, several facilities will be in a "non-available" status where the facilities are not being maintained in an operational status. For example, as of December 1993, Major Propulsion Test Units J-2A, T-7, and T-6, and Flight Dynamic Test Units 1T, IVA, DET, Tunnel D, ART, and Tunnel F were not being maintained in an "available for use" status. In 1993, Range K was transferred to the University of Texas, and it was dismantled and moved in November 1993. There are regular reviews at AEDC to determine which facilities are to be maintained as available for use within the expected funding levels.

Other consolidation and downsizing actions in the DoD have included the following. The Air Force Large Trestle electromagnetic pulse test facility in New Mexico will close. The Air Force aircraft test fleet is being reduced by twelve aircraft and the Air Force aircraft test support fleet is being reduced by twenty-one aircraft. As part of these reductions of aircraft involved in T&E, the Air Force's 4950th Test Wing that was stationed at Wright-Patterson AFB, Ohio, has been moved to the Air Force Flight Test Center (AFFTC), Edwards AFB, California, and consolidated with the aircraft at that location. The Utah Test and Training Range has also been consolidated into the AFFTC.

The NASA aeronautics infrastructure is quite small relative to DoD, but similar actions are in progress at all of the NASA aeronautical centers. Recognizing the existence of these

activities the Task Group took an independent and aggressive look at potential facility closures in the categories considered in the National Facility Study. A total of 44 major government owned wind tunnels and propulsion facilities were considered. The facilities were grouped into four major categories: 1) Those considered to be unique national assets were not considered further for closure because of their uniqueness and unquestioned need, 2) those being worked as part of NASA infrastructure reduction , 3) those to be worked for consolidation between agencies, and 4) those impacted when the proposed new wind tunnels are available. The listing of facilities by category is shown in Figure 27.

In Category 2, ***five major facilities are scheduled for closure between FY 93 and 95. In Category 3, the Ames/Army 7 x 10 #2 is scheduled to close in FY 94. Consolidation of testing between the Langley 8 Ft. High Temperature Structures Tunnel and the AEDC Aeropropulsion Test Unit (APTU) is being worked.. The recent DoD facilities consolidation study has identified unique, non-overlapping roles for the USAF AEDC and NASA Ames arc jet facilities.*** For Category 4 , it is difficult to predict the total impact of the proposed new wind tunnels on the utilization of existing wind tunnels 10 years in the future due to the broad range of wind tunnels currently utilized in aircraft development programs. However, there is consensus on several points: ***1) The U.S. industry will stop testing in Europe ($12 million per year); 2) there will be a significant reduction in use (and likely closing) of industry-owned tunnels with potential closing of some, i.e. Boeing Transonic Wind Tunnel (approx. $20 million per year) , and 3) major government development oriented wind tunnels such as the Ames 12-Ft. and 11-Ft. Tunnels and the AEDC 16T will be phased down/out depending on workload (approximately 20 million per year).*** The status of facility consolidation is summarized in Figure 28.

IV. NATIONAL FACILITY PLAN

The Aeronautics portion of the National Facility Study has conducted an extensive review of requirements for development facilities to meet the competitive needs of the U.S aircraft industry. Options and approaches to achieving the requirements were also studied. The recommended facility actions are summarized in Figure 29.

The largest and most critical need is for new high Reynolds number, high productivity subsonic and transonic wind tunnels. As stated earlier, both the cost estimate and schedule (approximately $2.55 billion and 8 years) are believed to be conservative, and significant effort should be devoted immediately to innovative technical and contractual approaches to reduce the cost and schedule. The preliminary engineering design and technical efforts aimed at risk reduction should be undertaken now. For supersonics, upgrades to the AEDC 16-S for productivity, flow quality and reliability are required. There is also a strong recommendation that research and development be funded for "quiet" flow supersonic wind tunnels. For propulsion facilities there is a potential requirement for an upgrade in mass flow capability at the

AEDC ASTF. However, it is recommended that a study be conducted to define the actual mass flow requirements. Other upgrades include small modifications to ASTF for supersonic free jet engine icing capability and engine nozzle testing and the Lewis Icing Research Tunnel. In hypersonics, the emphasis is on facility research and development required to provide the enabling technologies for system certification facilities and the Phase I research facilities which can be built now with low risk and cost. The implementation of this plan in a timely manner requires budget decisions as indicated in Figure 30.

The Aeronautics Task Group strongly believes that the implementation of this plan will result in the facilities required for the U.S. Aeronautics industry to compete effectively in the world market for many years to come. It is recognized, however, that the cost of this plan will be a significant challenge in today's tight budgetary environment. Under these conditions various combinations of options are obviously available for implementing parts of the plan. For example, if only one new wind tunnel can be built due to funding constraints, it is the view of the Task Group that the transonic tunnel is of higher priority. The impact of this option will be to lose the high productivity, high Reynolds number test capability for high lift development and acoustic testing. These deficiencies could be partially alleviated through improvements to existing wind tunnels. Other options and the phasing of their initiation will clearly depend on national urgency and availability of funding.

An expedient release of the FY 94 new facility funds is required to prepare for a FY 96 budget start on the new wind tunnels. Facility R&D funds to initiate the facility R&D programs on supersonic and hypersonic facilities and mass flow requirements for the ASTF propulsion facility should be included in both NASA and DoD budgets.

Figures

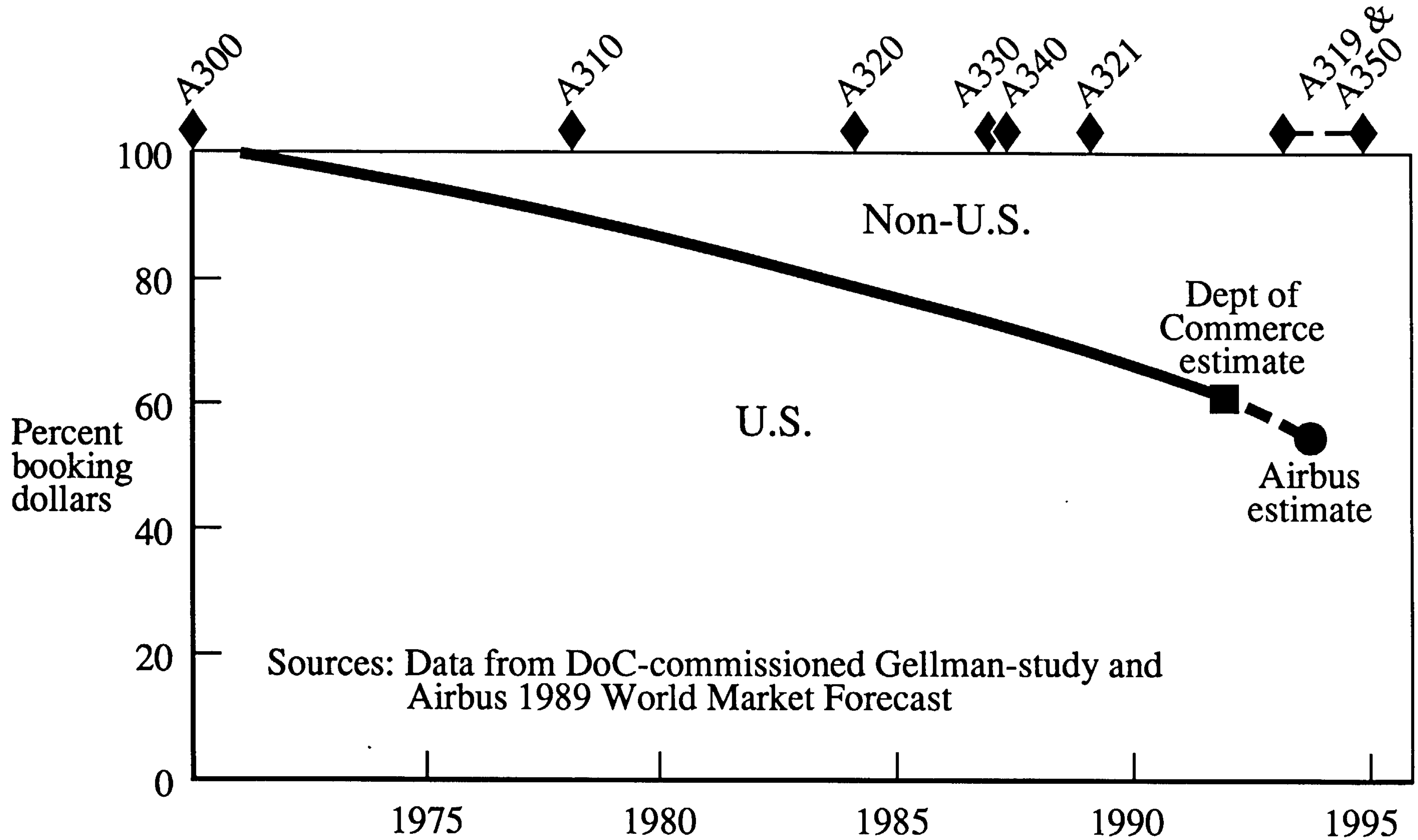


Fig. 1.- Trends in commercial aircraft market share for U.S. and foreign companies.

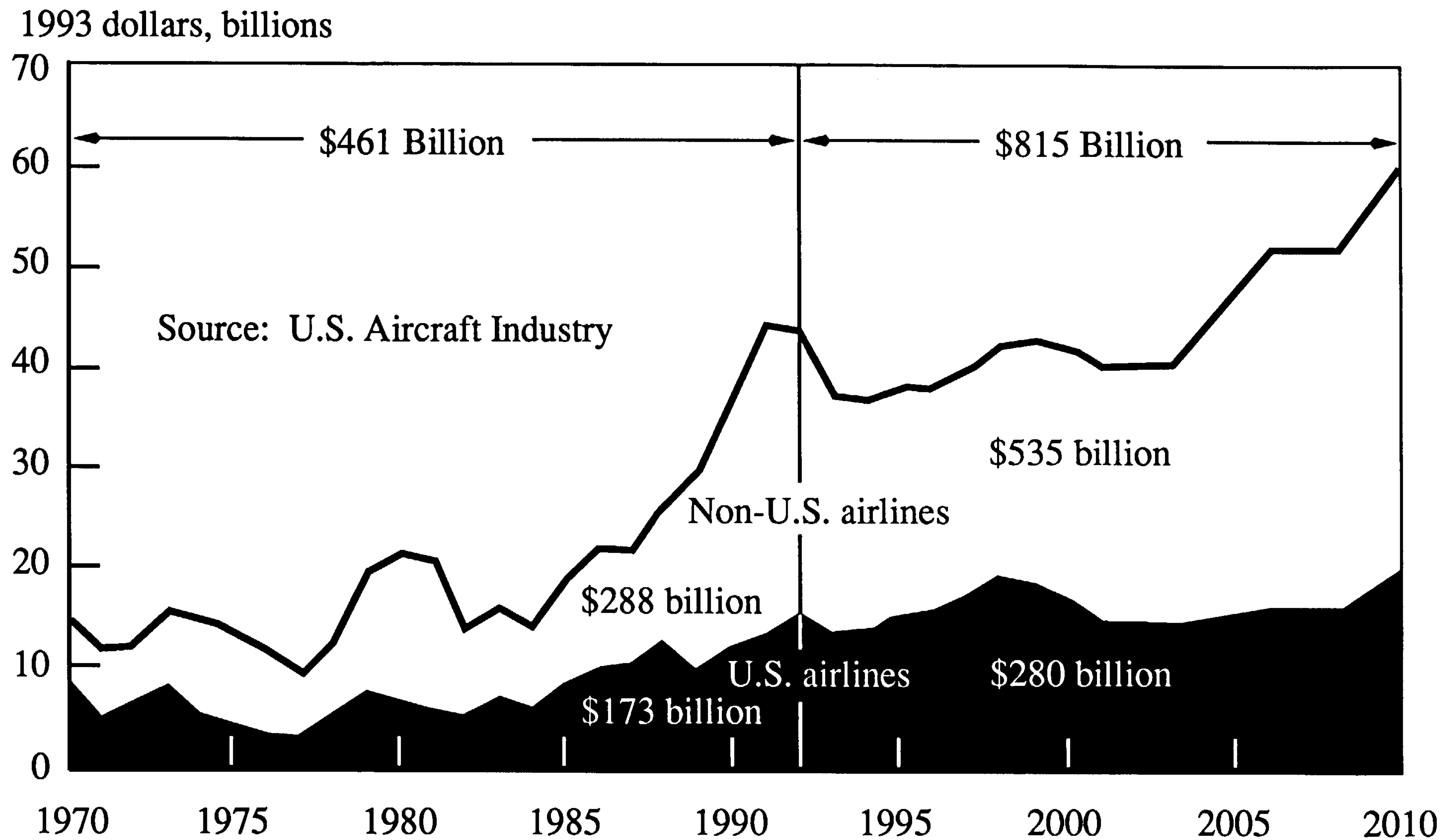


Fig. 2.- Market growth trends for new aircraft.

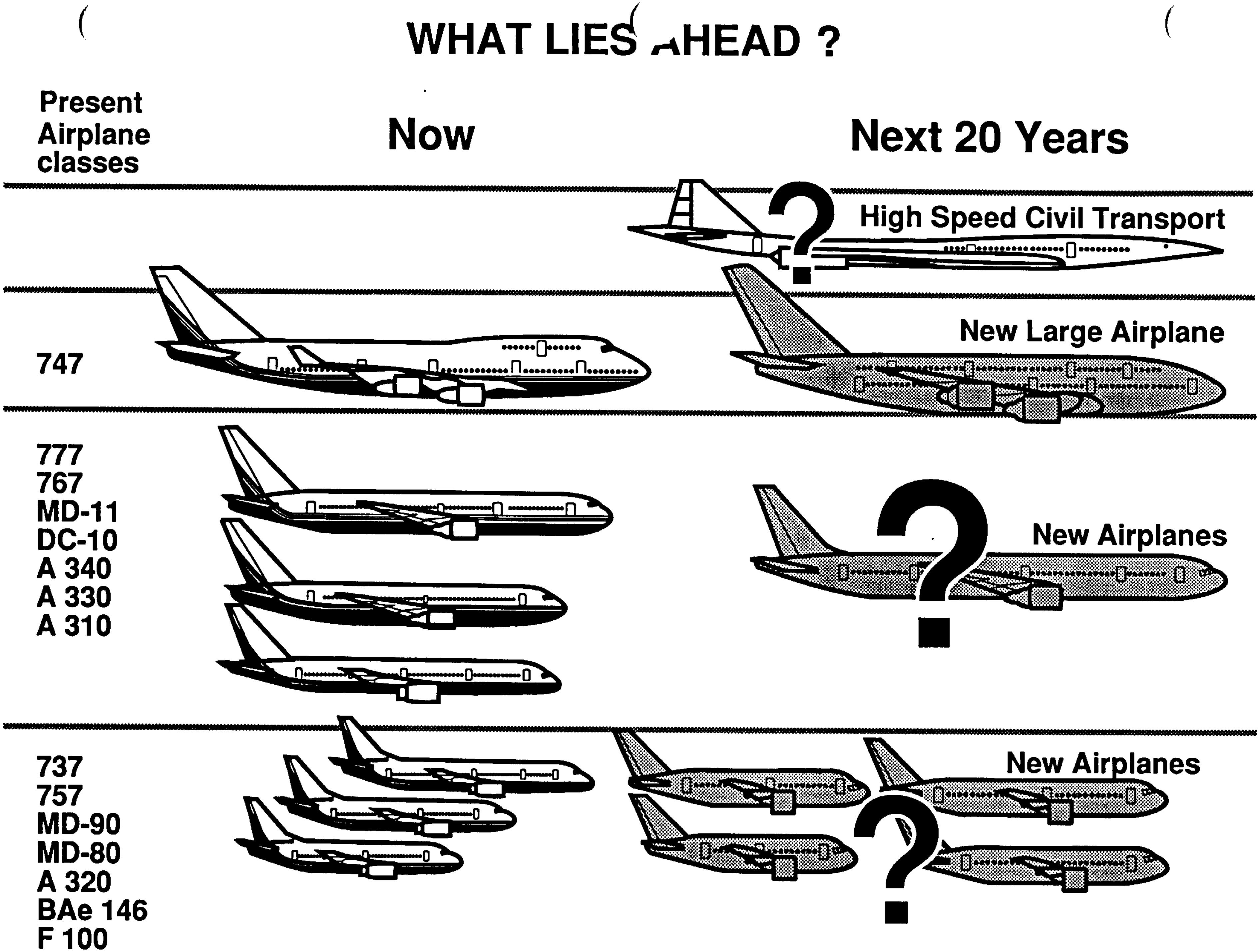


Fig. 3.- Aircraft projections for the future.

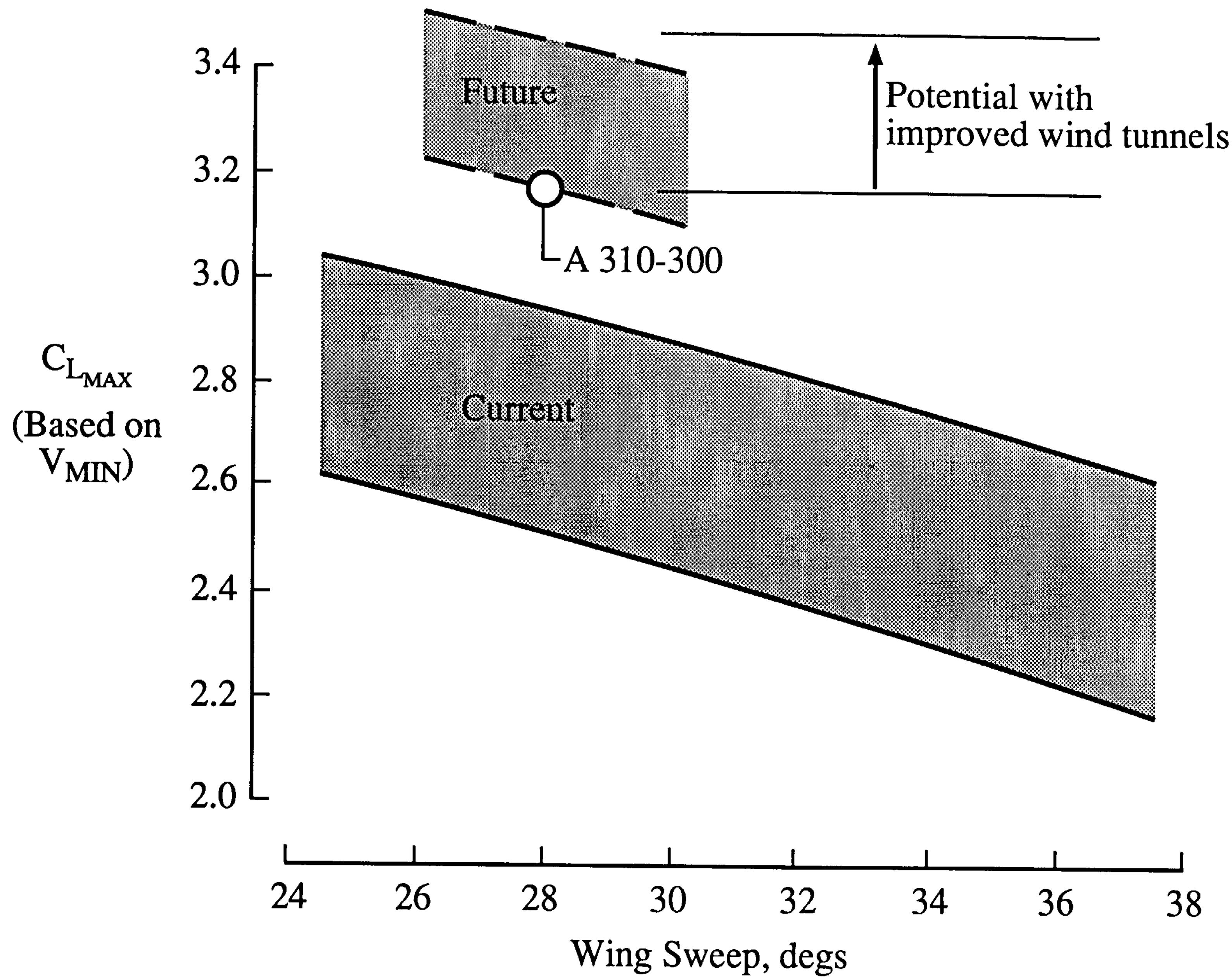


Fig. 4. - Potential improvements in high lift performance.

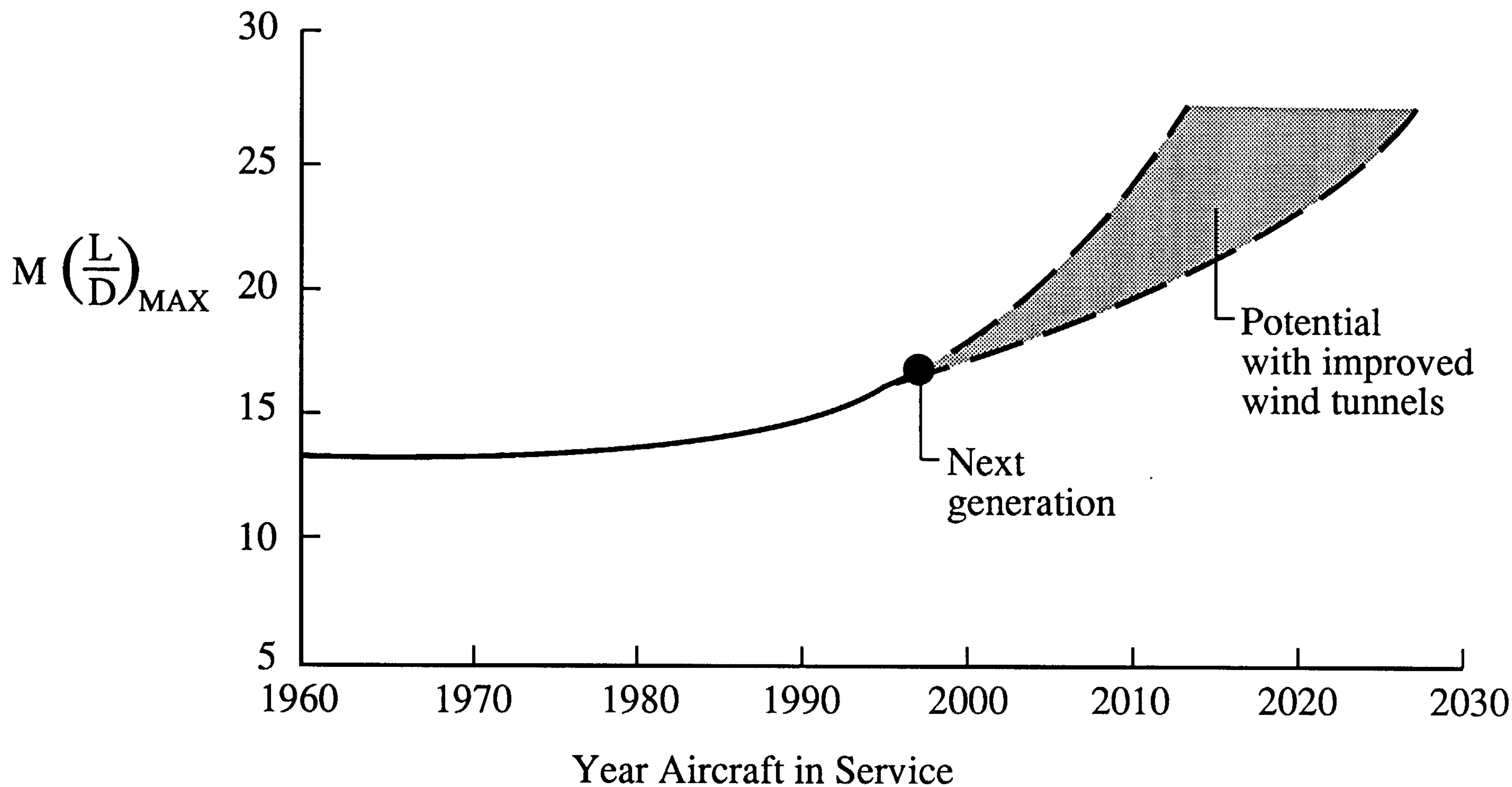


Fig. 5. - Potential improvements in aerodynamic cruise efficiency parameter for long range transport aircraft.

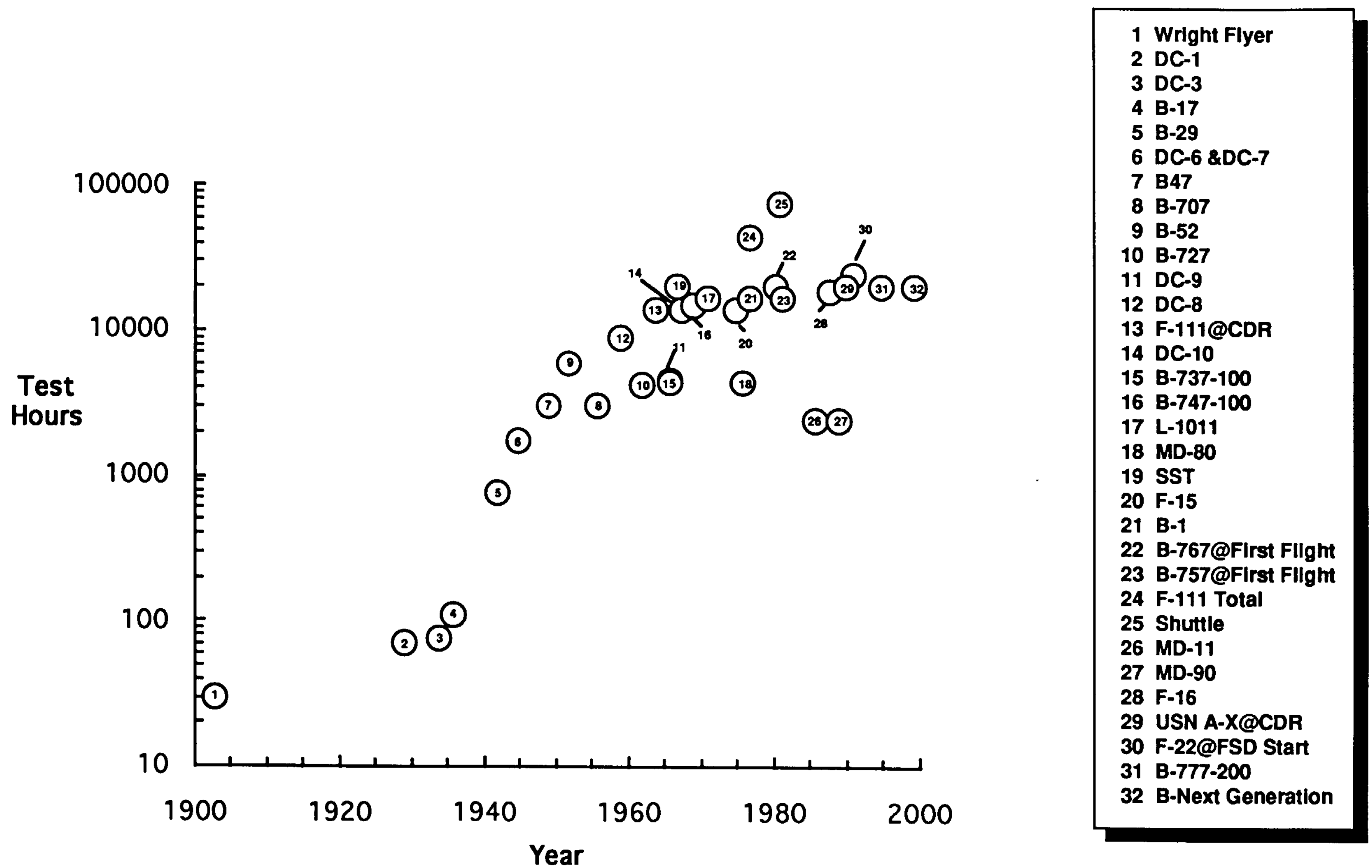


Fig. 6. - Wind tunnel testing hours as a function of aircraft type and year.

FACILITY	Reynolds No., Millions	Polars Per Hr.	$ Per Polar
Subsonic			
ARC 40x80	16. 6	0.34	596
ARC 80x120	10.8	0.34	5865
ARC 12-Ft. PWT	7.6	2.3	1300
LaRC 14x22-Ft.	3.2	0.6	1050
Lockheed 16x23-Ft.	3.9	3.5	225
Lockheed 8x12-Ft.	2.5	4.0	250
NAD 7x10 Ft.	2.0	2.5	200
DRA 5-Meter (Britain)	7.7	1.5	3000
ONERA F-1 (France)	7.5	1.7	3000
DNW (Netherlands)	3.6	4.0	1000
Transonic			
11-Ft.	10.3	2.15	2000
LaRC TDT	16.0	0.2	5000
LaRC NTF, Nitrogen	119.0	0.36	14300
LaRC NTF, Air	6.0	2.0	1537
AEDC 16T	9.6	4.5	1170
Boeing TWT	3.9	4.5	725
Calspan 8-Ft.	10.0	4.0	825
Rockwell 7-Ft.	7.0	2.0	1500
ETW (Europe)	50.0	1.5	5600

Fig. 7. Summary of Reynolds number, productivity, nad operating cost for the core development wind tunnels.

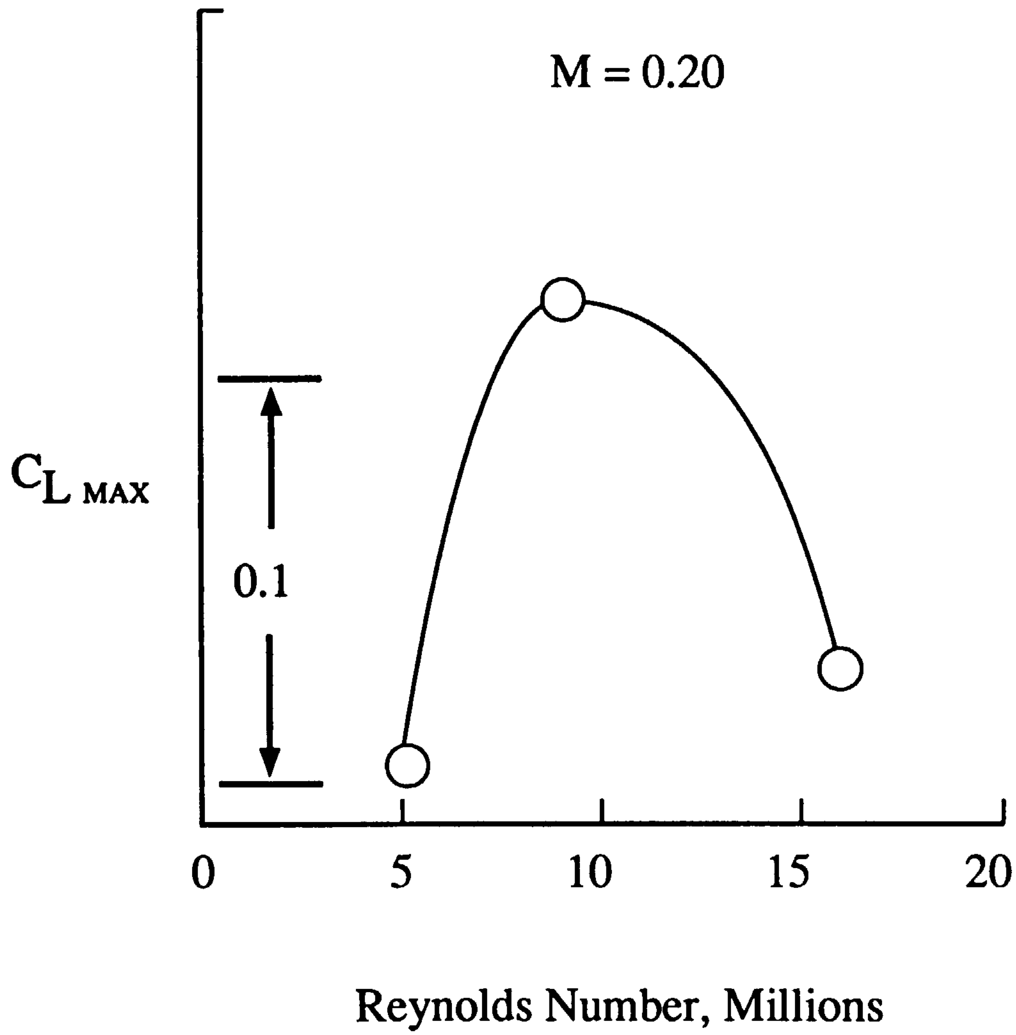


Fig. 8(a).- Reynolds number effects on a configuration optimized at a Reynolds number of 9 million.

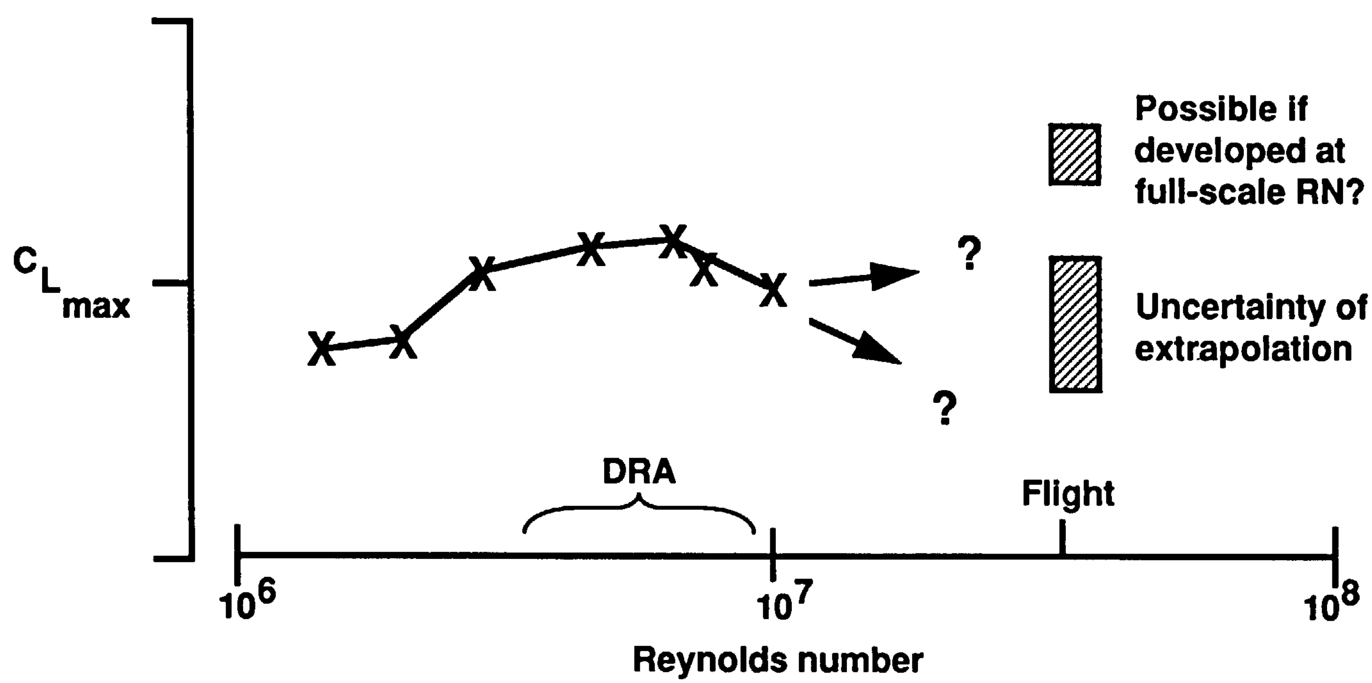


Fig. 8 (b) Example of wind tunnel scaling uncertainty.

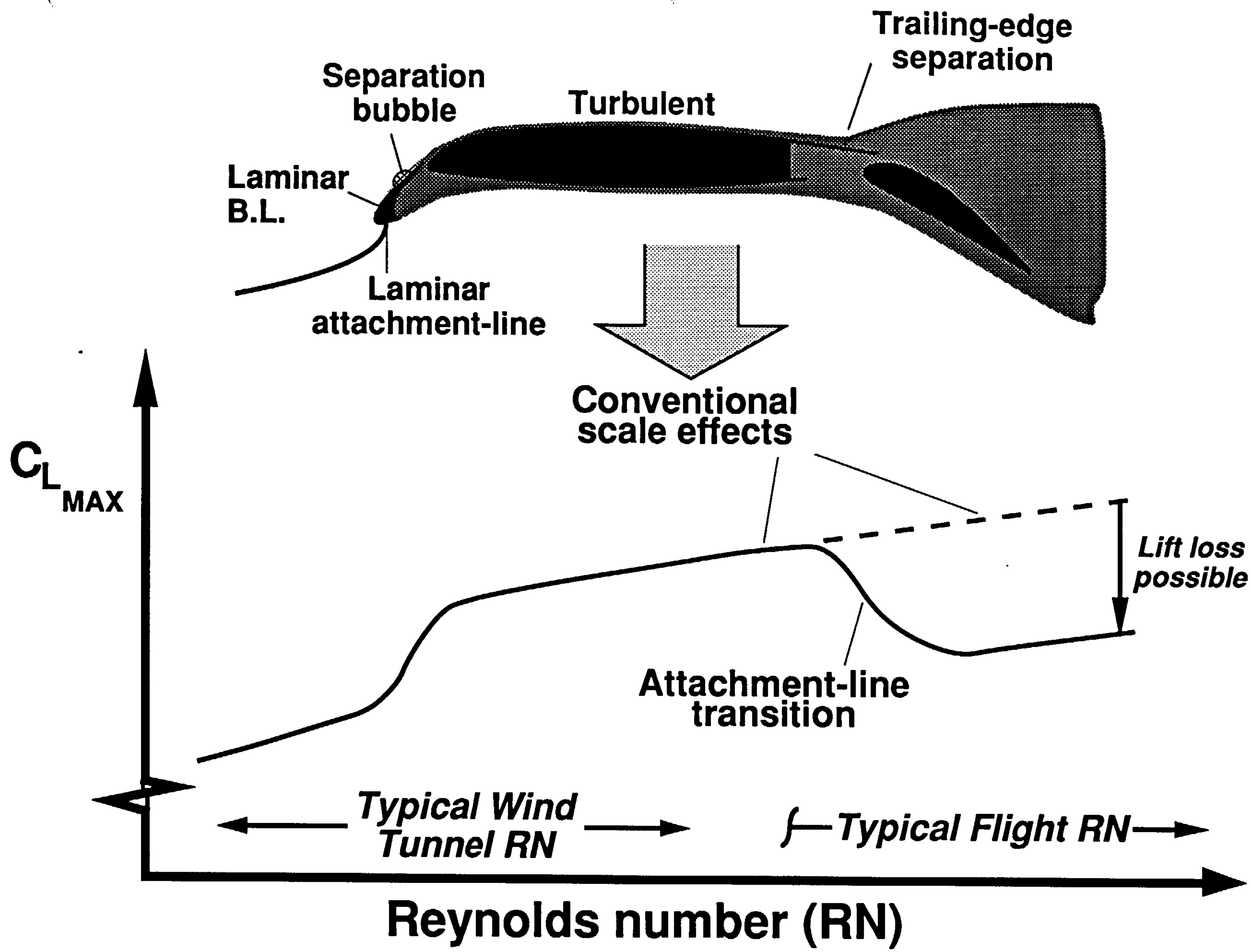


Fig. 9. - Typical Effect of Reynolds number, productivity, and operating cost for the core development wind tunnels.

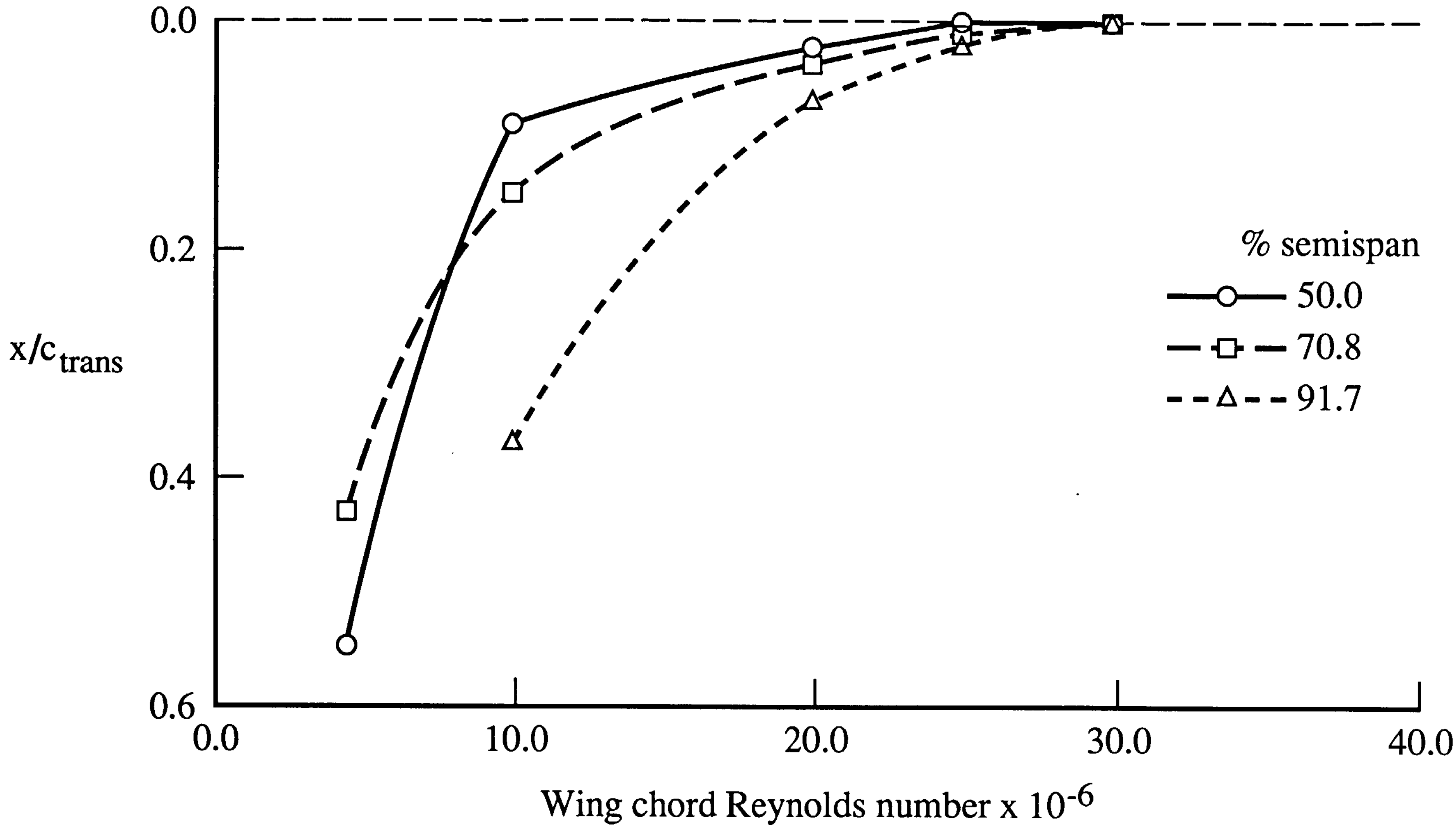


Fig. 10. - Predicted Reynolds number effect on upper surface transition location. Mach no. = 0.8.

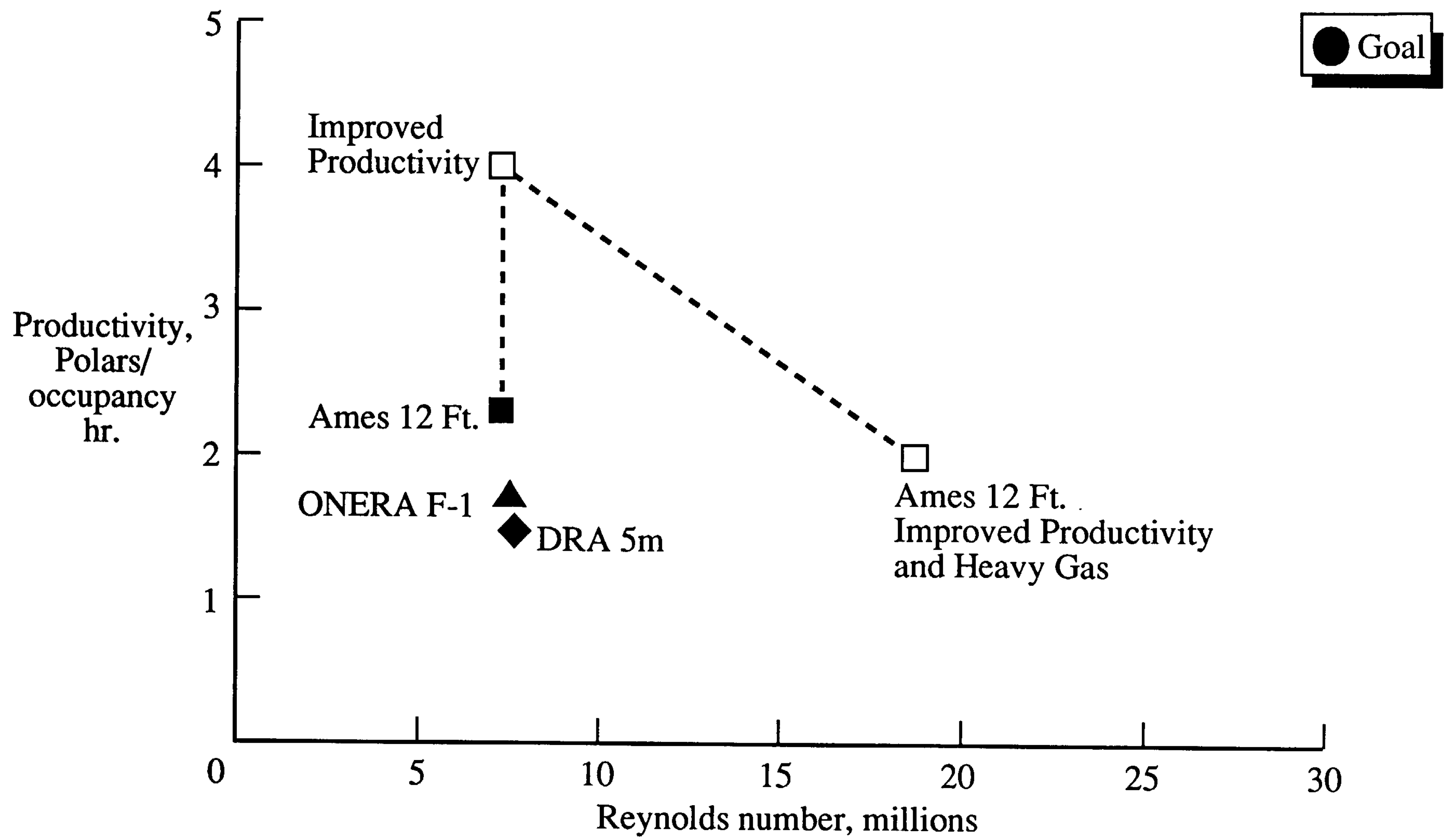


Fig. 11(a). - Comparison of productivity parameter for major low speed wind tunnels with the goal.

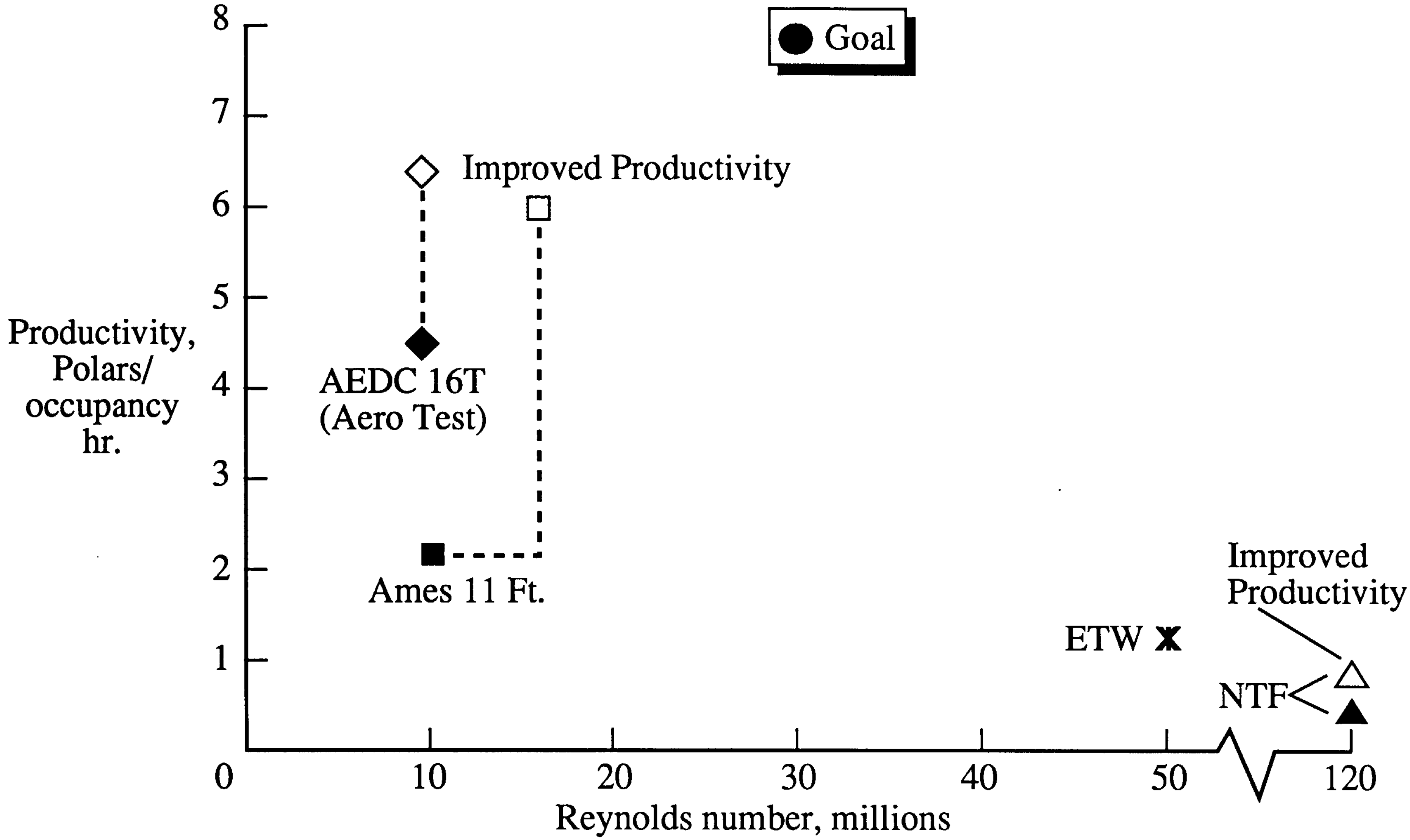


Fig. 11(b). - Comparison of productivity parameter for major transonic wind tunnels with the goal.

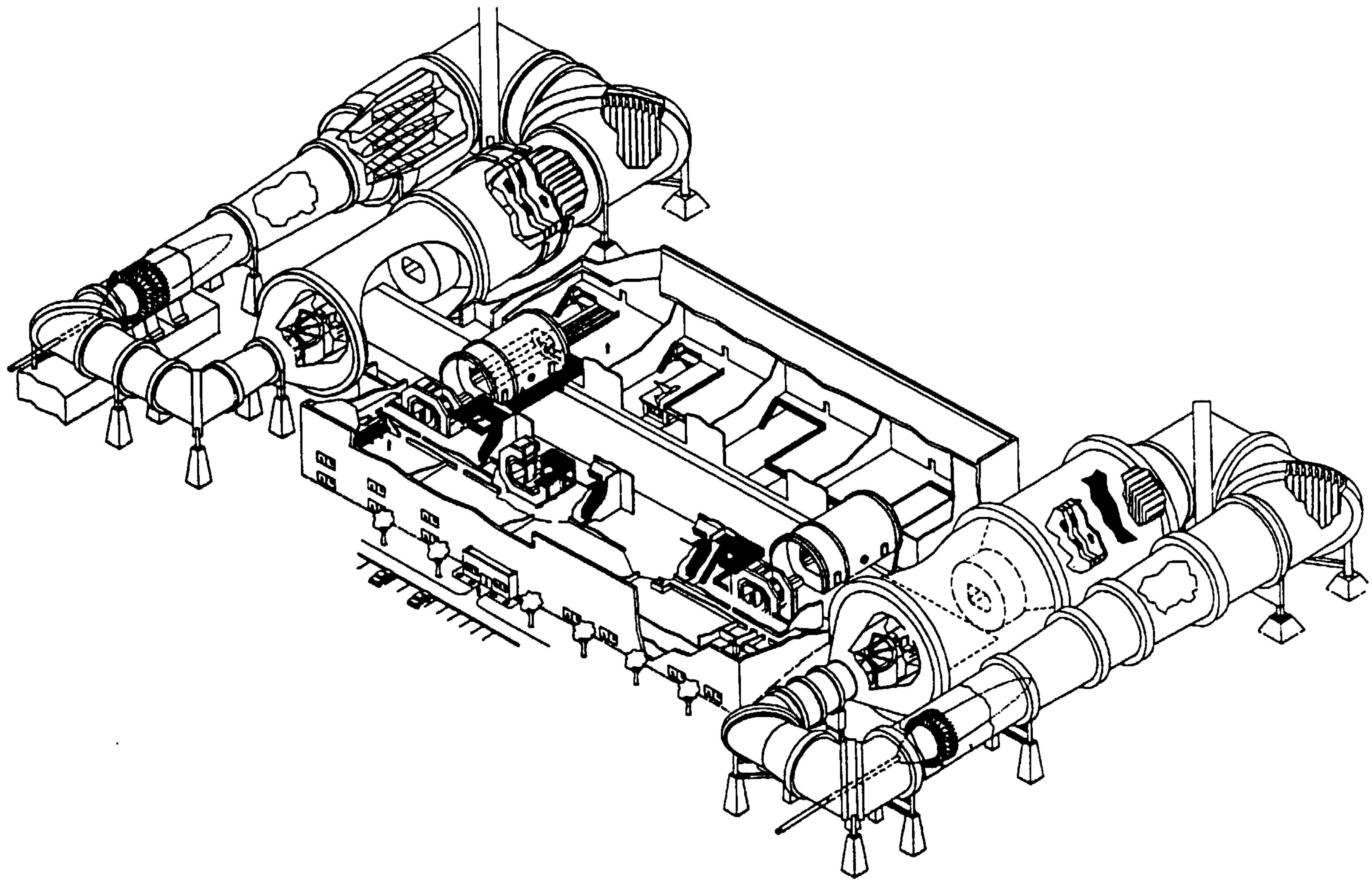


Fig. 12. - Artist's rendering of Concept A used as a costing baseline.

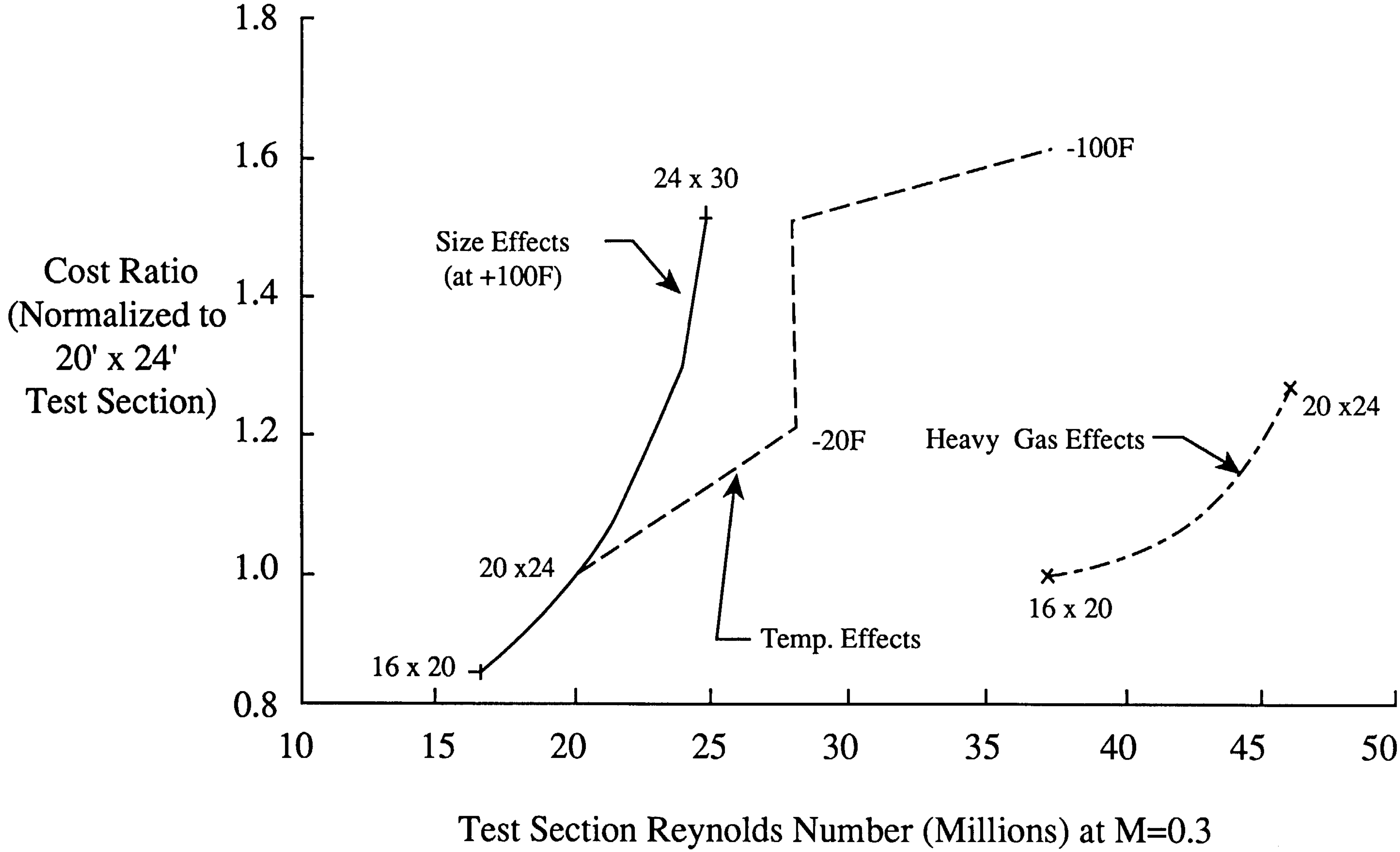


Fig. 13. - Effect of design parameters on cost for a low-speed wind tunnel.

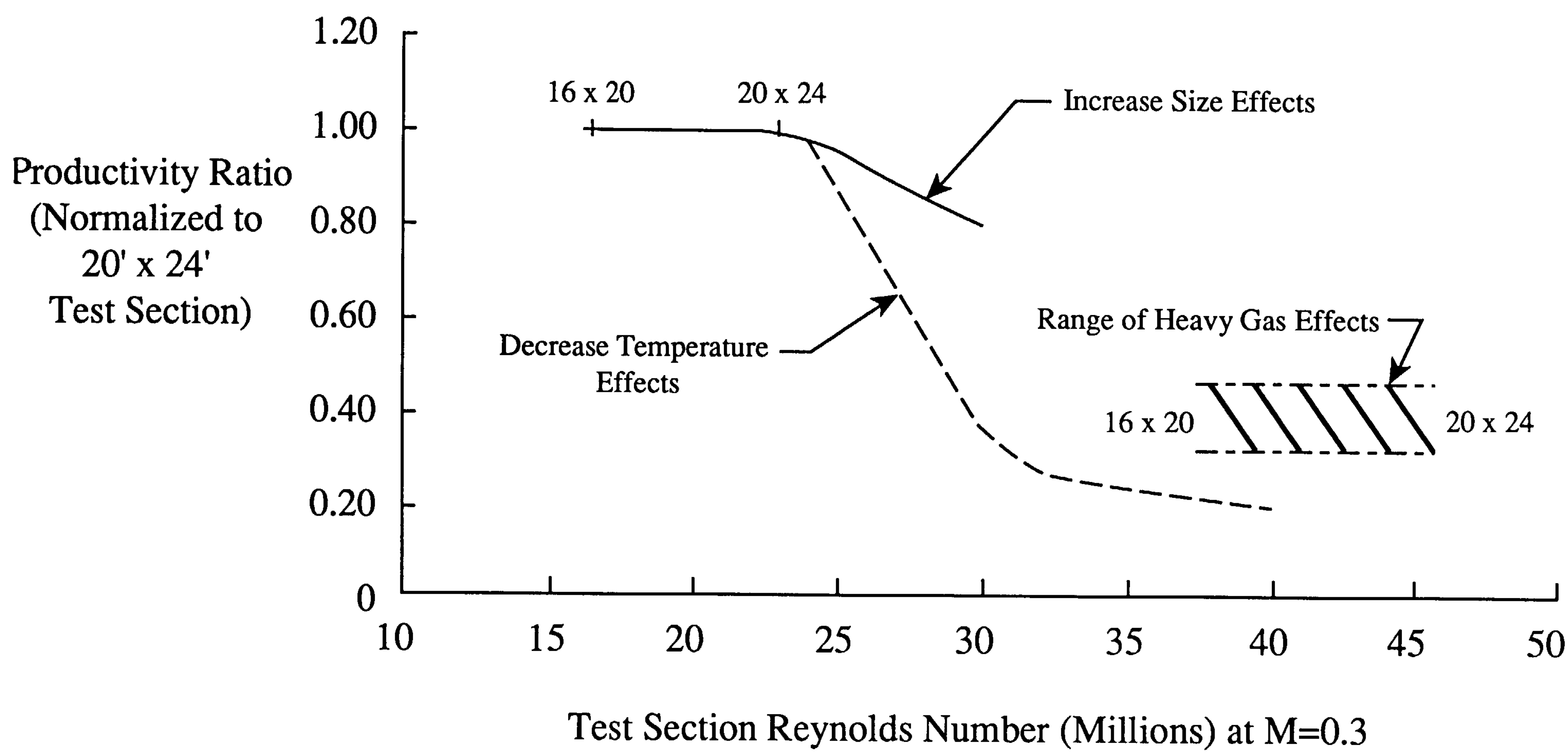


Fig. 14. - Effect of design paramerters on productivity for a low-speed wind tunnel.

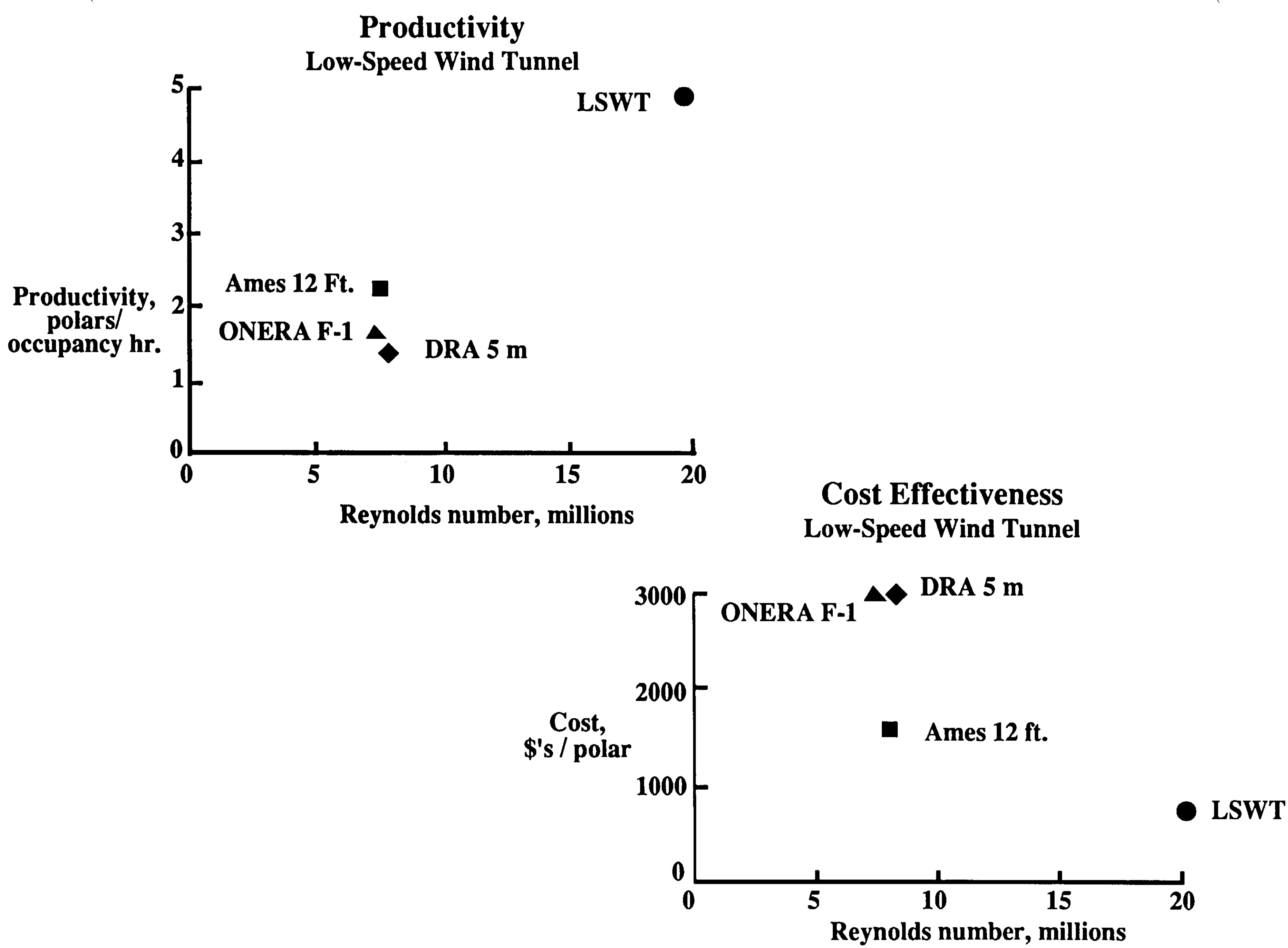


Fig. 15. Comparison of productivity and cost metrics for proposed new low-speed wind tunnel with existing major tunnels.

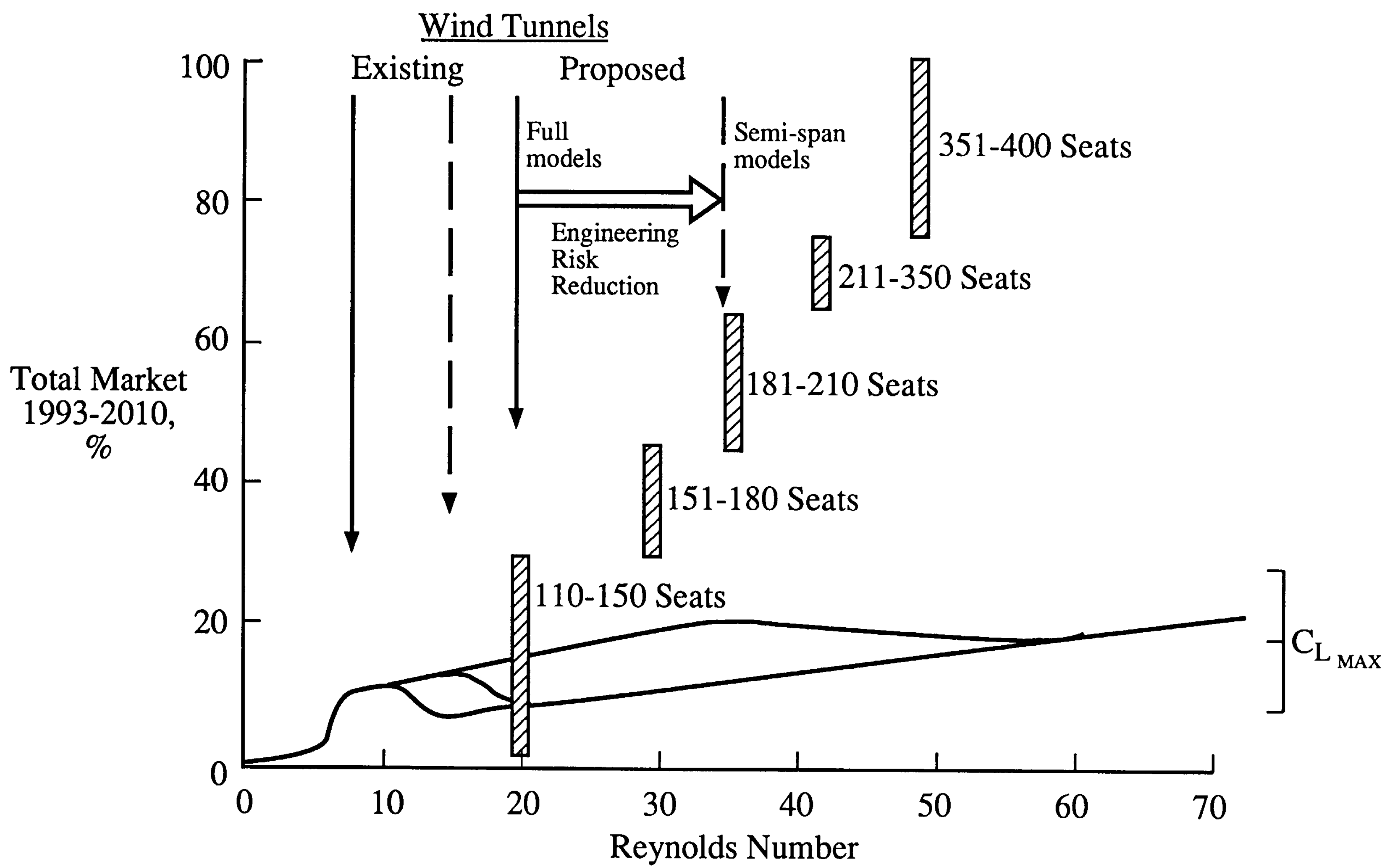


Fig. 16. - Airplane market coverage of proposed low-speed wind tunnel. Mach no. = 0.3.

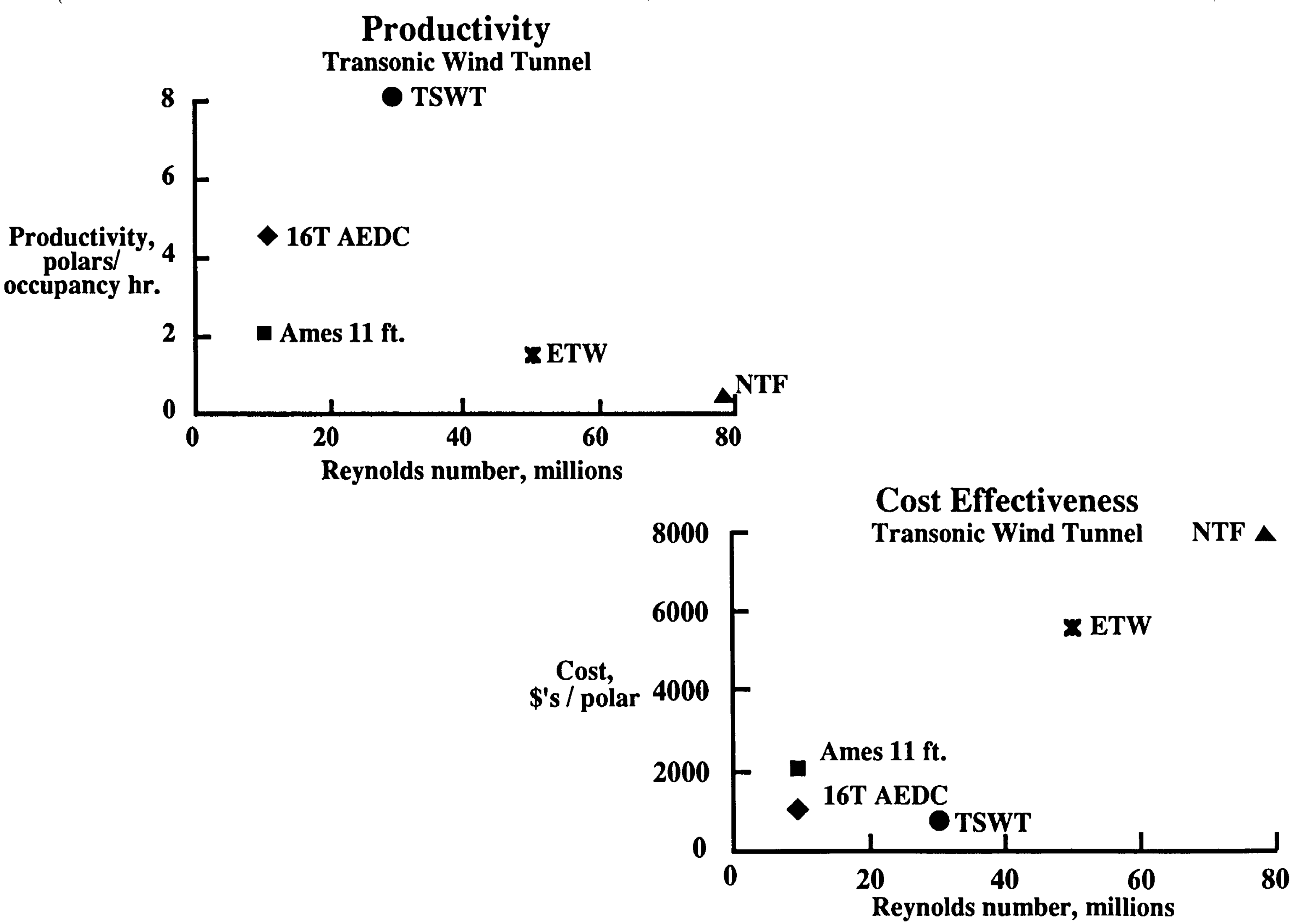


Figure 17. - Comparison of productivity and cost metrics for proposed new transonic wind tunnel with existing major tunnels.

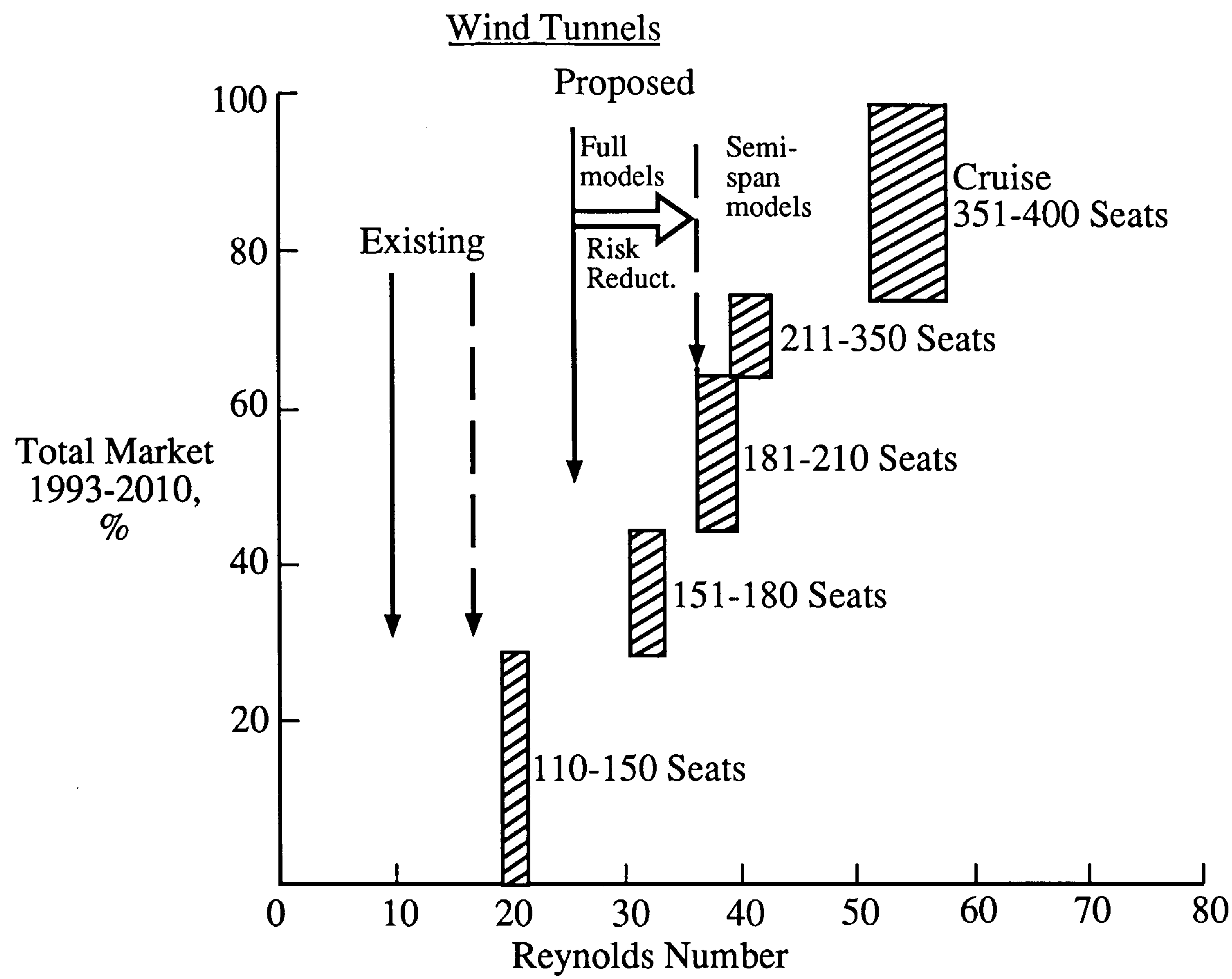


Fig. 18. - Airplane market coverage of proposed transonic wind tunnel. Mach no. = 0.8.

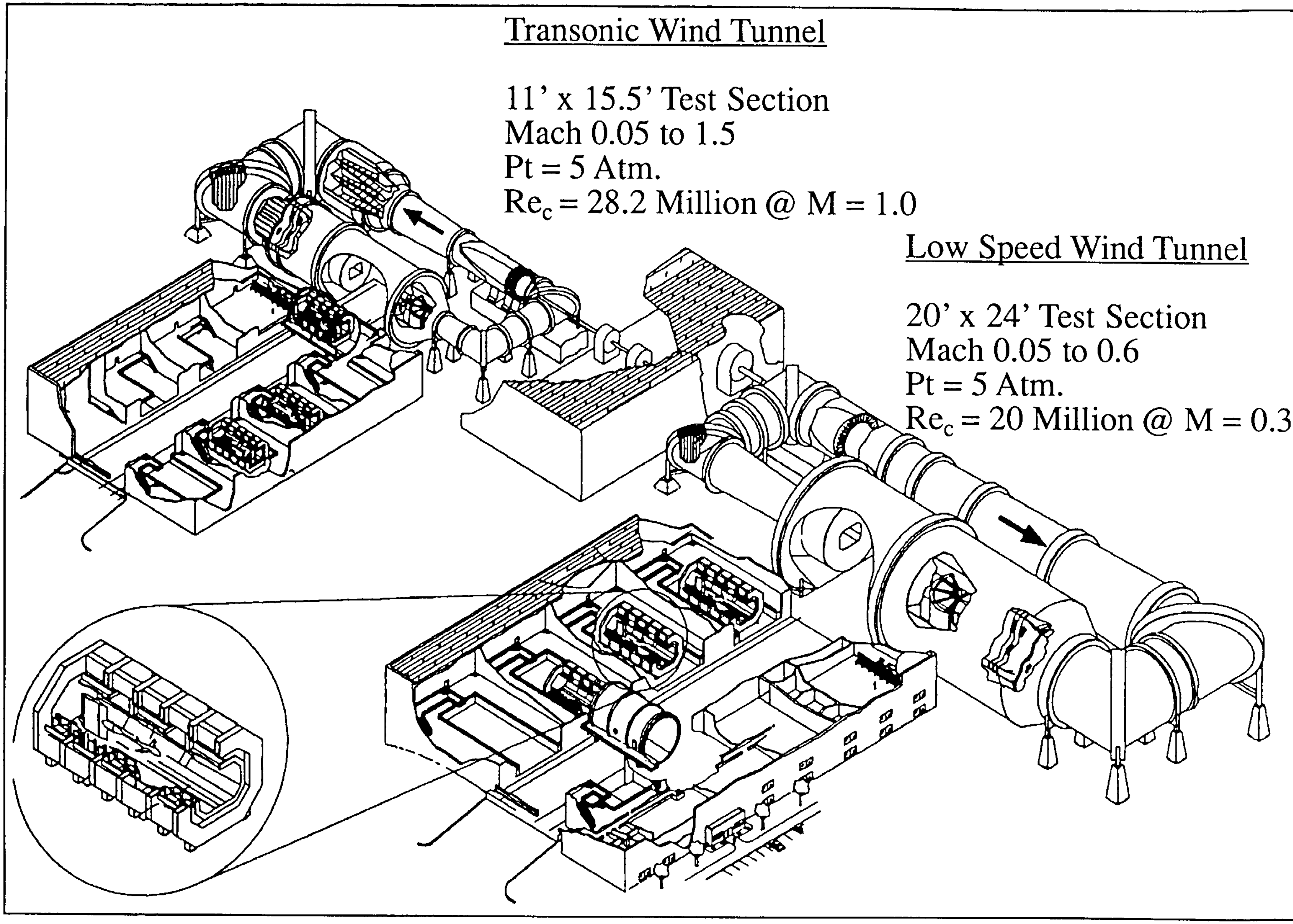


Fig. 19. Proposed National Wind Tunnel Complex

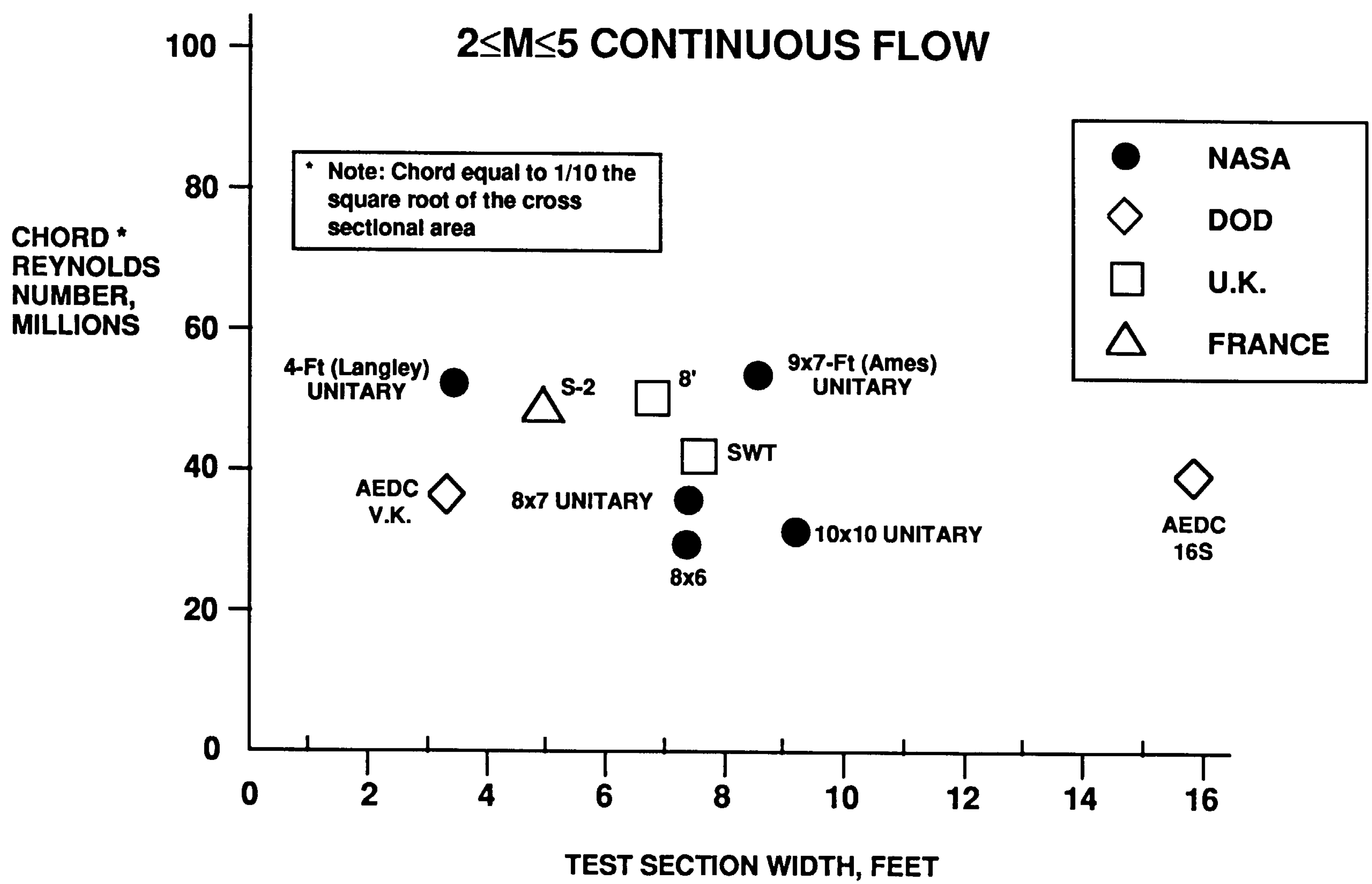


Figure 20. - Major supersonic wind tunnels.

Wind Tunnels

Lewis
- 10x10 SWT
- 8x6/9x15 WT
- Icing Research Tunnel (IRT)

Ames
- 80x120 WT
- 40x80 WT

AEDC
- 16T
- 16S

Industry
- Boeing

Component Facilities

Lewis
- Engine Research Building (ERB) Complex

Wright Labs.
- Compressor and Combustor Component Facilities

U.S. Industry
- Allied Signal/Garrett
  Turbine, Compressor and Combustor Facilities
- General Electric
  Turbine, Compressor and Combustor Facilities
- Pratt & Whitney
  Turbine, Compressor and Combustor Facilities
- Teledyne CAE
  Turbine, Compressor and Combustor Facilities

Altitude Engine Test Facilities

Lewis
- PSL 3 & 4

AEDC
- T-1 through T-6
- J-1 and J-2
- ASTF C1 and C2

NAWC
- Trenton (closing)
- 7 Test Cells

U.S. Industry
- Allison
  #871, 872, 873, 881, 885
- General Electric
  TC-43 and TC-44
  TC-A1
- Pratt & Whitney
  X-207, X-208 and X-209
  X-217 and X-218

Figure 21. - Primary U.S. Propulsion facilities review by the Propulsion Facilities Working Group.

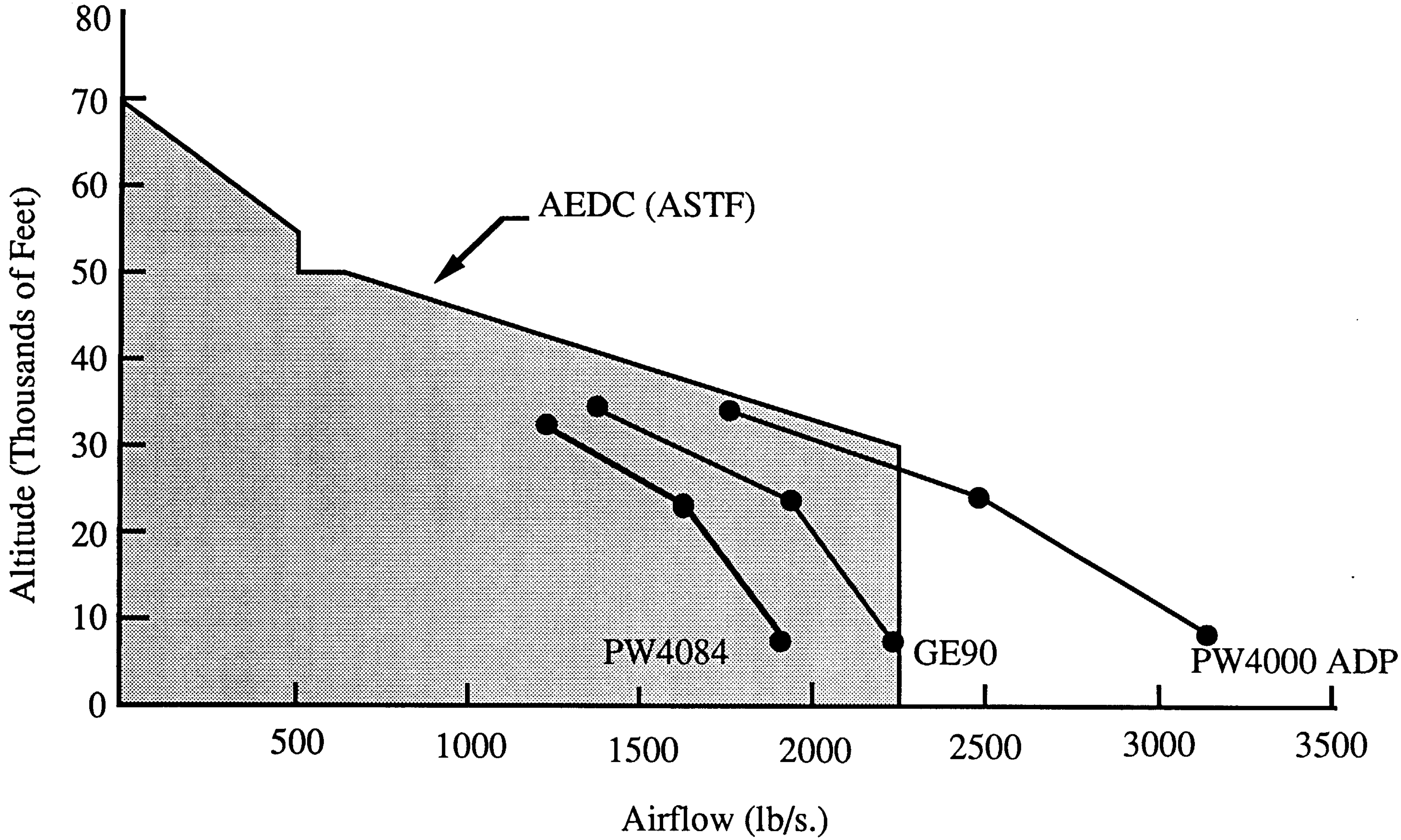


Fig. 22. - Engine mass flow test capability.

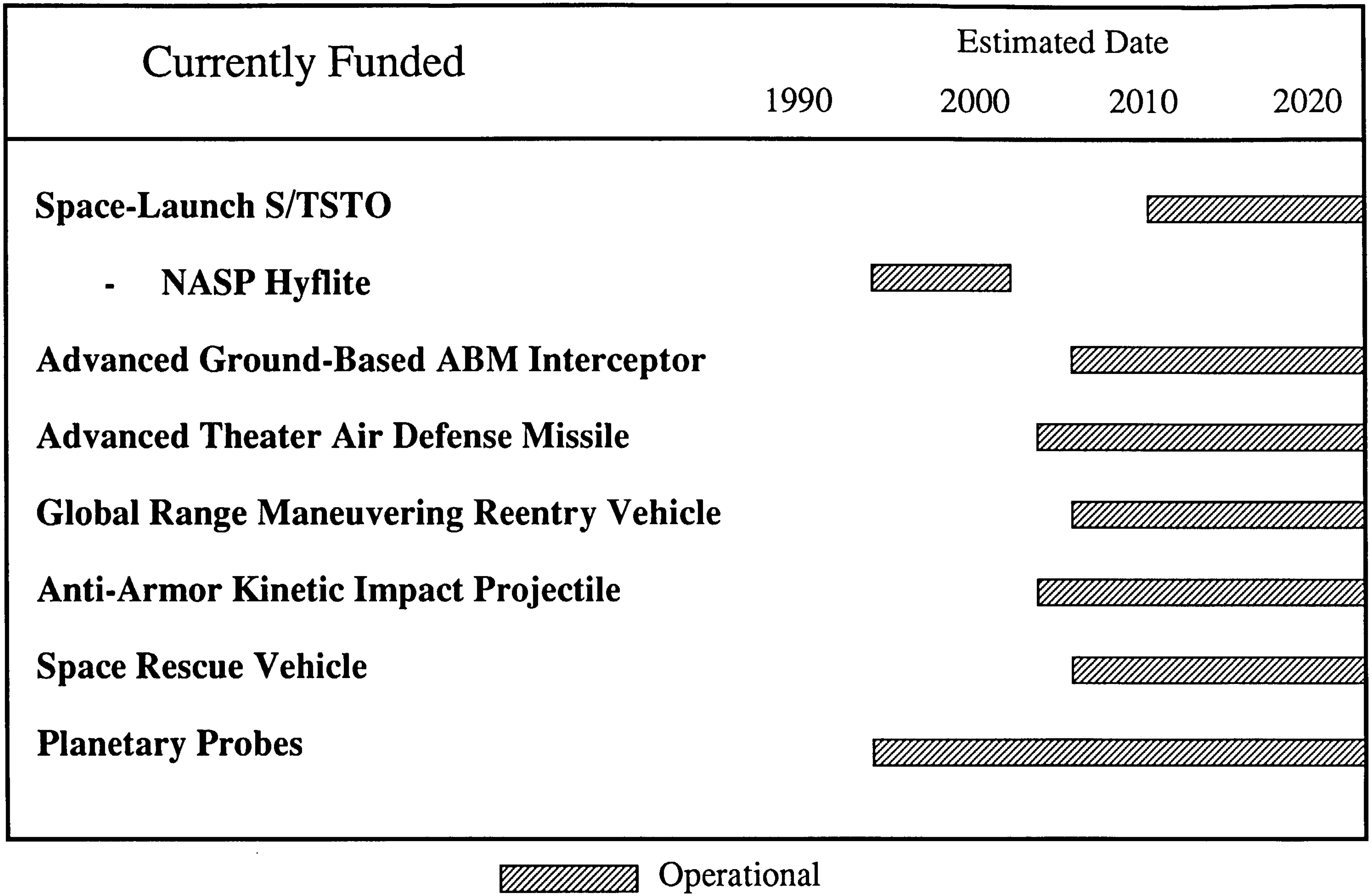


Fig. 23. - Some candidate hypersonic systems and potential operational dates.

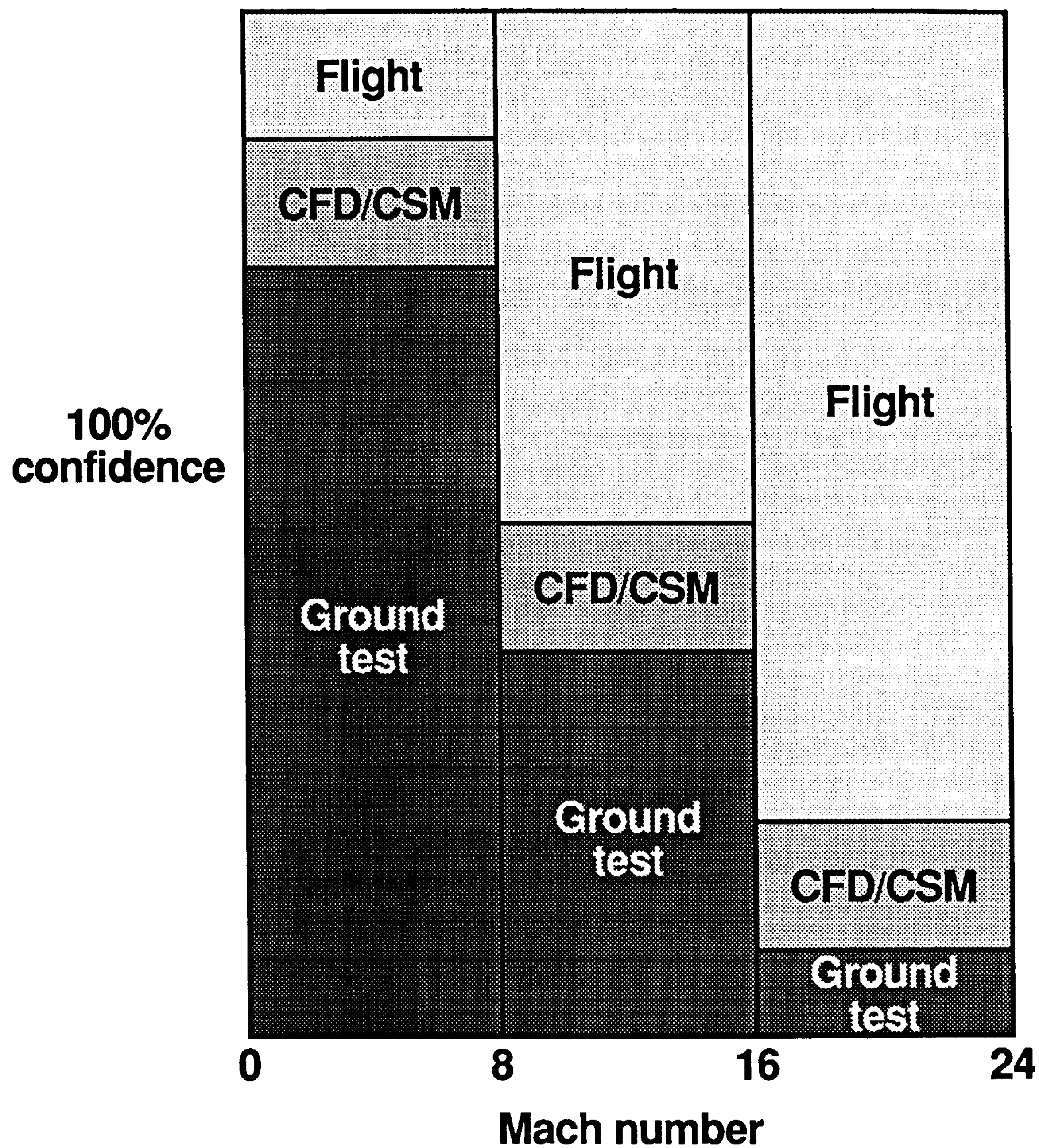


Fig. 24 - Confidence in hypersonic systems development using existing ground test facilities.

SYSTEM	MAX. MACH NO.	KEY TECHNICAL REQUIREMENTS	PHASE I TEST FACILITY	PHASE II TEST FACILITY
Space Launch and Rescue	25-30	Mach 12-24 airbreathing propulsion Real gas aerodynamics Hot primary structure	High-energy expansion tube/tunnel, M = 14-35 Liquid H_2 structures test facility	Liquid air arc/direct energy addition PGU multi-shock Large structures/airframe test facility
Cruise Aircraft	8-10	Mach 4-10 airbreathing propulsion Durable airframe/propulsion system	Mach 3-8 clean air T&E facility Liquid H_2 structures test facility	Mach 3-8 certification facility Large structures/airframe test facility
Interceptors	15-30	Real gas aero/control Thermal protection Sensor performance/life	High-energy expansion tube/tunnel, M = 14-35	PGU multi-shock Advanced Arc heater Large ballistic range Liquid air arc/direct energy
Missiles	10-50	Sensor performance/life Thermal protection Real gas aero/control	High-energy expansion tube/tunnel, M = 14-35	Large ballistic range Liquid air arc/direct energy Advanced arc heater PGU multi-shock
Planetary Entry Probe	30-50	Thermal protection Planetary gases Sensor performance/life	High-energy expansion tube/tunnel M = 14-35	Large ballistic range Liquid air arc/direct energy Advanced arc heater

Fig. 25. - Summary of hypersonic system and facility requirements.

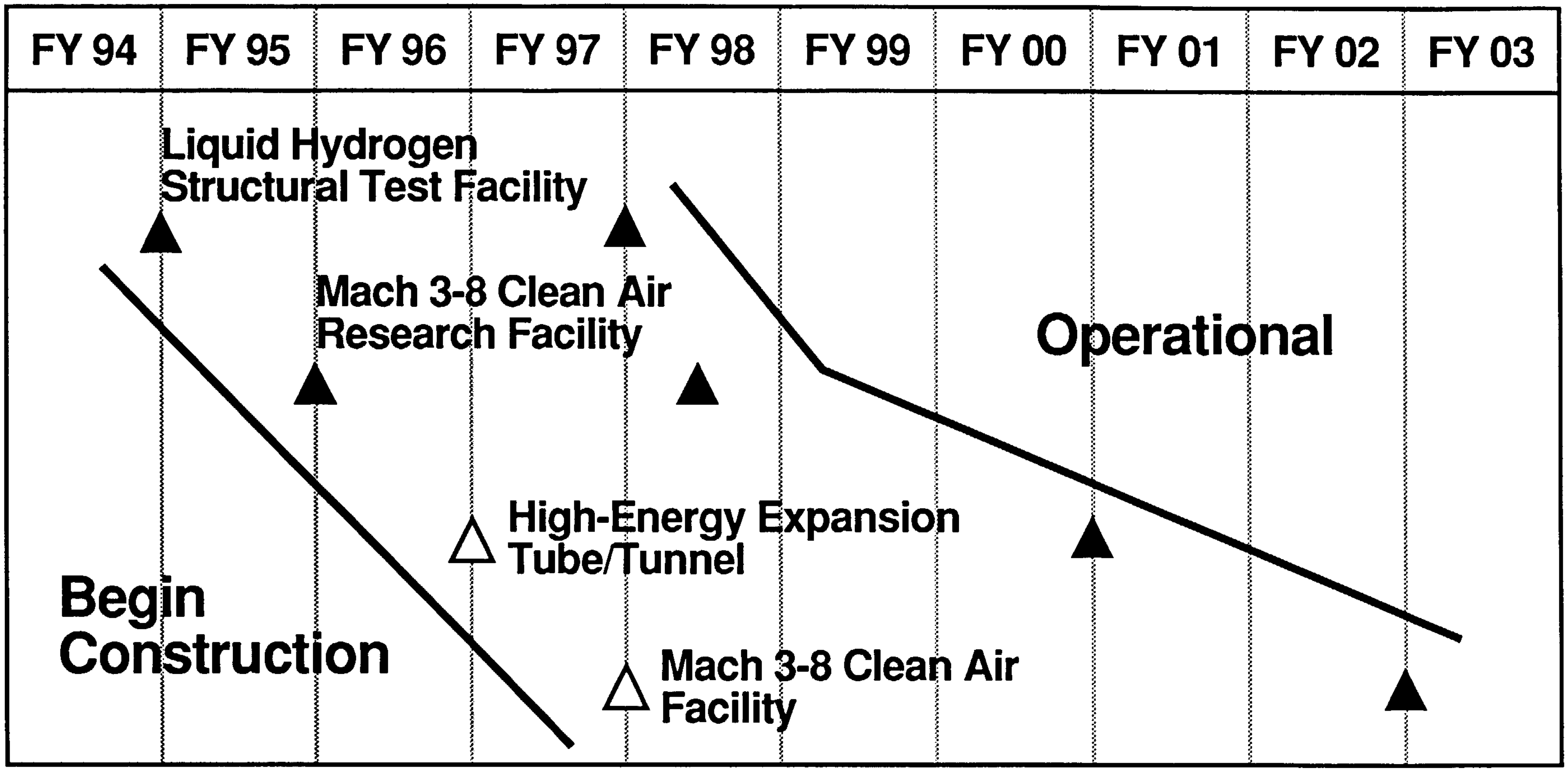


Fig. 26. - Proposed Phase I hypersonic facility construction schedule.

1 - Vital National Assets

- Ames 40x80x120
- Langley Spin Tunnel
- Lewis IRT
- Langley NTF
- Langley TDT
- Langley LTPT
- Ames 9x7 (Unitary)
- Ames 8x7 (Unitary)
- AEDC 16S
- AEDC 16T (Propulsion & Munitions)
- AEDC ASTF

2 - Being Worked as Part of NASA Infrastructure Reductions

- Langley 30x60
- Langley 7x10
- Lewis 9x15
- Langley 8 Ft. TPT
- Lewis 8x6
- Langley 4x4 (Unitary)
- Lewis 10x10 (Unitary)
- Ames 3.5 Ft.
- Langley 60 in. Helium Tunnel
- Langley M = 18 Nitrogen Tunnel
- Lewis PSL

3 - Consolidation Between Agencies

- Ames 7x10 (#1)
- Ames/Army 7x10 (#2)
- AEDC 4T
- Navy 7x10
- AEDC Tunnel A
- ARC 100 MW ARC
- Langley 8 Ft. HTT
- Lewis HTF
- AEDC APTU
- AEDC H1 ARC
- AEDC Tunnels B&C
- NSWC Tunnel 8 & 8A
- Sandia Hypersonic Wind Tunnel
- AEDC T-1, T-2, T-4, T-6
- AEDC J-1, J-2

4 - Impact of New Tunnels

- Ames 12 Ft. PWT
- Langley 14x22
- Ames 11 Ft. (Unitary)
- Langley 16 Ft. TT
- AEDC 16T (Aerodynamics)
- U.S. Corporate
  - Boeing TWT
  - Others TBD
- Use of Foreign Wind Tunnels

Fig. 27. - Listing of facilities considered in consolidation/closure study by category.

- **NASA Infrastructure Reduction**
  - Langley 7x10 — Closed — FY 93
  - Ames 3.5 Ft. — Close — FY 94
  - Langley 8 Ft. TPT — Close — FY 95
  - Langley 30x60 — Close — FY 95
  - Lewis HTF — Close — FY 95
- **Consolidation Between Agencies**
  - Navy 7x10 — Close — FY 93
  - Ames/Army 7x10 No. 2 — Close — FY 94
  - Langley 8 Ft. HTT/AEDC APTU (being worked)
  - Ames 100 mw arc/AEDC H1 arc (being worked)
- **Impact of New Tunnels - 2 Step Process**
  - Ames 12 Ft. PWT
  - Ames 11 Ft.

    } Reduce to one shift at activation of new wind tunnels. Place on operational standby (dependent on workload) when new wind tunnels achieve full operational status.
  - Langley 14x22
  - Langley 16 Ft. TT

    } Review at activation - action dependent on ability of new wind tunnels to accommodate functions.
  - AEDC 16T } Reduce to propulsion and munitions testing only.

Fig. 28. - Status of facility consolidation actions.

Subsonic/Transonic

- Construct 20x24 Ft. High Rn Low-Speed Wind Tunnel .... ~ $1500M
- Construct new 11.5x15 Ft. High Rn Transonic Wind Tunnel .... ~ $1500M

Supersonic

- Upgrade productivity/flow quality, reliability of AEDC 16S 42M
- Conduct R&D for M = 2.0 to 2.4 Quiet Tunnel - 4 M/Yr. for 3 Yrs. 12M
- Construct Quiet Supersonic Tunnel .... TBD

Propulsion

- Conduct study to determine mass flow requirements for next generation engines. . 1M
- ASTF upgrade
  - Potential upgrade to ASTF mass flow capability (based on study) .... TBD
  - Supersonic freejet/engine icing capability in ASTF 20M
  - Mods for engine/nozzle tests (ASTF) 15M
- Upgrade Lewis Icing Research Tunnel 20M

Hypersonics

- Conduct R&D on facility concepts for T&E - 20 M/Yr. for 10 Yrs. 200M
- Construct Phase I Aerothermodynamic Facilities 220M
- Construct Phase II T&E Facilities (based on R&D program) .... TBD

Fig. 29. - Recommended facility actions

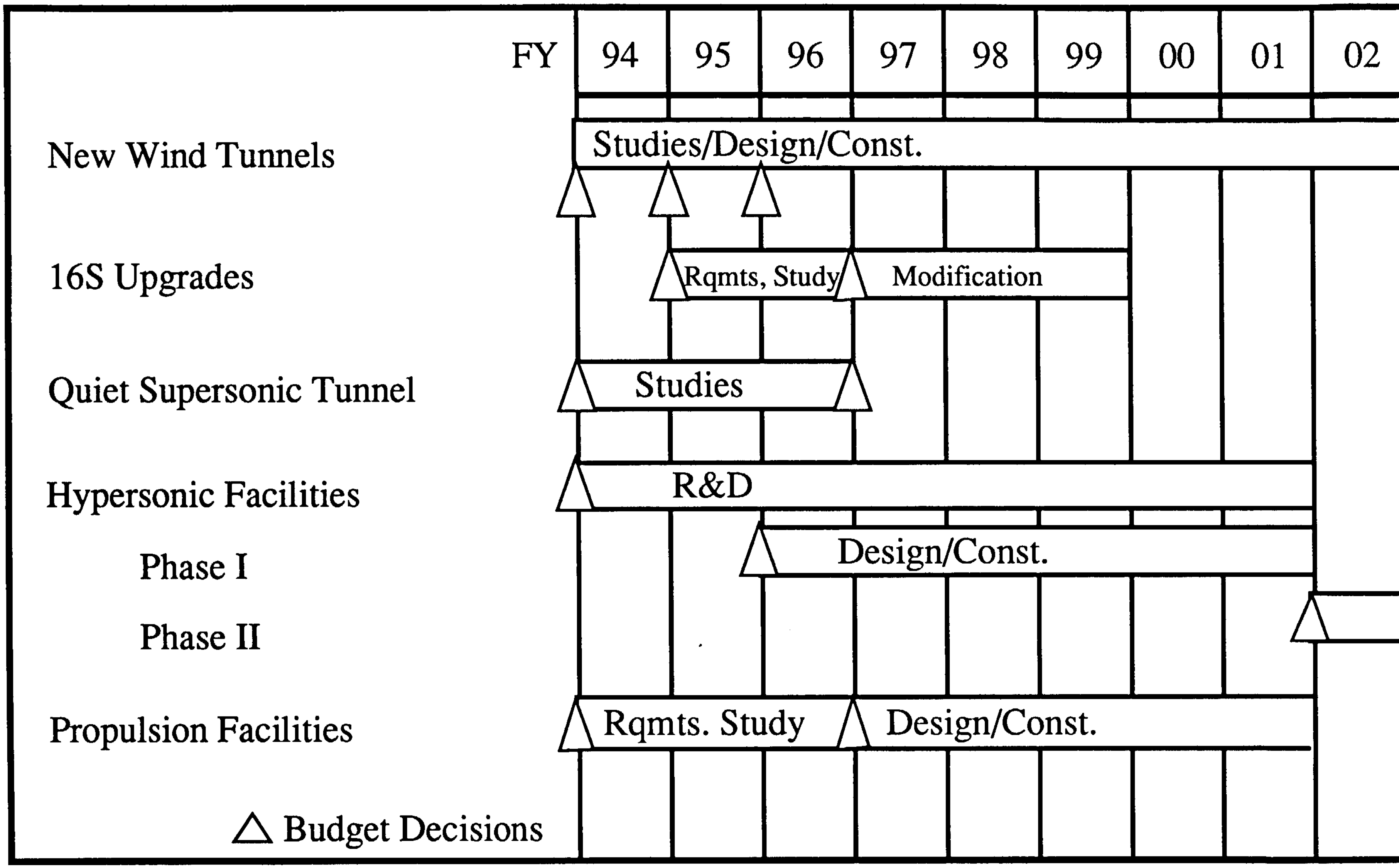


Fig. 30. Proposed budget implementation plan.

Appendix 1

Task Group and Working Group Members

APPENDIX 1

Task Group and Working Group Members

A. Aeronautics R&D Facilities Task Group

Dr. H. Lee Beach, Jr., Co-Chairman - NASA Langley Research Center
Mr. John V. Bolino, Co-Chairman - Office of Under Secretary of Defense (ACQ)
Mr. L. Wayne McKinney, Exec. Sec. - NASA Headquarters
Mr. William S. Clapper - General Electric Aircraft Engines
Mr. Richard A. Day - Boeing Commercial Airplane Group
Mr. John R. King - McDonnell Douglas Aerospace - Transport Aircraft Unit
Dr. David J. Poferl - NASA Lewis Research Center
Mr. John M. Rampy - U.S. Air Force, Arnold Engineering Development Center
Dr. Robert Rosen - NASA Ames Research Center
Mr. William L.Webb - United Technologies, Pratt & Whitney
Mr. Louis J. Williams - NASA Headquarters

B. Aerodynamics/Aeroacoustics Working Group

Mr. Louis J. Williams, Co-Chairman - NASA Headquarters
Dr. Marion L. Laster, Co-Chairman - U. S. Air Force, Arnold Engineering Development Center
Mr. Suey T. Yee, Co-Exec. Sec. - NASA Headquarters
Mr. William T. Eckert, Co-Exec. Sec. - NASA Headquarters
Mr. Zachary T. Applin - NASA Langley Research Center
Ms. Nancy F. Bingham - NASA Ames Research Center
Cmdr. Joseph S. Chlebanowski - Naval Surface Warfare Center
Dr. John W. Davis - Calspan Corporation, Arnold Engineering and Development Center
Mr. Richard A. Day - Boeing Commercial Airplane Group
Mr. Bobby R. Delaney - General Electric Aircraft Engines
Mr. Donald J. Dusa - General Electric Aircraft Engines
Mr. Arthur E. Fanning - Boeing Commercial Airplane Group
Mr. Heinz A. A. Gerhardt - Northrop
Mr. Edsel R. Glasgow - Lockheed
Mr. Blair B. Gloss - NASA Langley Research Center
Mr. E. Dabney Howe - Northrop
Mr. Frank T. Lynch - McDonnell Douglas Aerospace - Transport Aircraft Unit
Mr. Donald P. McErlean, Naval Air Warfare Center
Mr. Luis R. Miranda - Lockheed
Mr. Leroy L. Presley - NASAAmes Research Center

Mr. William C. Stamper - NASA Headquarters
Mr. Lewis E. Surber - Wright Laboratory
Dr. James C. Y. Yu - NASA Langley Research Center

C. Strategy Working Group

Dr. Robert Rosen, Co-Chairman - NASA Ames Research Center
Mr. Parker C. Horner, Co-Chairman - United States Air Force
Dr. Thomas A. Edwards, Exec. Sec. - NASA Lewis Research Center
Ms. Sally H. Bath - Department of Commerce
Mr. John V. Bolino - Office of the Under Secretary of Defense (ACQ)
Mr. Mark D. Brenner - Department of Commerce
Mr. H. Douglas Nation - Office of the Under Secretary of Defense
Mr. Marion L. Laster - Arnold Engineering Development Center
Mr. Arvid G. Larson - Walcoff & Associates

D. Propulsion Working Group

Dr. David J. Poferl, Co-Chairman - NASA Lewis Research Center
Mr. David Duesterhaus, Co-Chairman - Arnold Engineering Development Center
Mr. John R. Bennett - General Electric Aircraft Engines
Mr. H. Bruce Block - NASA Lewis Research Center
Mr. Stan Blyskal - Naval Air Warfare Center
Mr. Leland L. Coons - United Technologies, Pratt & Whitney
Mr. Bobby R. Delaney - General Electric Aircraft Engines
Mr. John R. Facey - NASA Headquarters
Mr. Richard J. Hill - Wright Laboratory
Mr. Glen R. Lazalier - Sverdrup Technologies, Arnold Engineering Development Center

E. Hypersonic Working Group

Dr. G. Keith Richey, Chairman - Wright Laboratory
Mr. Carlos Tirres, Exec. Sec. - U.S. Air Force, Arnold Engineering Development Center
Dr. James O. Arnold - NASA Ames Research Center
Mr. Dennis M. Bushnell - NASA Langley Research Center
Mr. Robert L. P. Voisinet - Naval Surface Warfare Center
Mr. Michael V. DeAngelis - Dryden Flight Resarch Facility
Dr. Gerald A. Roffe - General Applied Science Laboratories
Dr. Marion L. Laster - U.S. Air Force, Arnold Engineering Development Center
Mr. Robert L. P. Voisinet - Naval Surface Warfare Center
Dr. Paul J. Waltrup - The Johns Hopkins University, Applied Physics Laboratory
Mr. James L. Mark - McDonnell Douglas Aerospace, East

Appendix 2

Report of the Facility Benchmarking Working Group

NATIONAL FACILITIES TASK GROUP

WIND TUNNEL BENCHMARKING

WORKING GROUP REPORT

DECEMBER, 1993

NATIONAL FACILITIES TASK GROUP

WIND TUNNEL BENCHMARKING WORKING GROUP

REPORT

REPORT OUTLINE

A. INTRODUCTION

The Wind Tunnel Benchmarking Working Group took on the task to document the capabilities of operational wind tunnels available for product development. This benchmarking effort was a part of a larger effort to quantify the need for and generate the specifications for subsonic and transonic wind tunnels required to support United States Aeronautical competitiveness into the twenty first century. Emphasis is on product development of commercial transport aircraft with research needs assuming to be satisfied by current or in process wind tunnels. The process used to acquire and quantify the capability of current facilities was that of direct solicitation. Initial sorting of active wind tunnels was significantly assisted by the cataloging effort conducted by Arnold Engineering and Development Center under the guidance of Dr. Don Daniel. This was supplemented by the TEA Database maintained by the Miter Corporation for the U.S. DoD.

Background:

Advances in science and engineering of aeronautical products has closely paralleled the capability of the wind tunnels to support development of products encompassing the theoretical characteristics developed in the minds of our leading academicians and industrial theoreticians and confirmed in research wind tunnels. This was noted in the British Journal of Aeronautical Engineering where it commented "they (NACA) were the first to establish, and indeed to visualize, a variable-density (wind) tunnel; and (with) a full-scale tunnel in which complete aeroplanes up to 35-foot span can be tested. The present day American position in all branches of aeronautical knowledge can, without a doubt, be attributed mainly to this far-seeing policy and expenditure on up-to-date laboratory equipment." Major advances have been made in the efficiency with which commercial airline industry transports people and cargo throughout the world. One illustration of this is the growth in passenger seat miles just during the jet age of commercial aircraft. Starting with the Comet of the mid 1950's with 20 seat miles per gallon of fuel burned, we have progressed to today where several active aircraft yield 85 seat miles per gallon. The capability and availability of modern wind tunnels to support development of technology and application of technology to products has been largely responsible for these advances.

B. WIND TUNNEL BENCHMARKING

The process of benchmarking starts with a challenge to select the appropriate parameters for comparison and then collect all the data in the quantifying units that will support benchmarking. The parameters selected on which to conduct wind tunnel benchmarking are related to the test Reynolds numbers that can be established and the productivity generated in support of product testing.

This rather simplistic approach was the result of many hours of listening to a number of very capable people discuss wind tunnel characteristics needed to support aerodynamic tests of aircraft ranging in size from single engine fighters up through transports having greater than one million pounds takeoff gross weight. Although there are many wind tunnel operating characteristics that are important to a successful test, it was concluded that the tried and proven parameters relating to basic aerodynamic design and cost of testing were the ones most meaningful.

When this task was initiated, it was anticipated that benchmarking would include many other operating parameters relating to wind tunnel quietness and the ability to set a test point precisely. However, as the above described discussions were taking place it became apparent that the basis for a more wide ranging comparison was not available or pertinent. Therefore, the wind tunnel benchmarking presented here for the three categories of wind tunnels in question are limited to measures of Reynolds number and productivity. The entire scope of data collected in this survey is included in the report for those that will find it useful as a reference in the future.

The summary tables for subsonic, transonic and supersonic wind tunnels are presented here in two categories. The first is a description of the mechanical features and the second is a description of the productivity features. Included here is the results of all wind tunnels surveyed. Therefore, responses for those currently inactive are also noted. Throughout the data, the notation N/A indicates that no response was received for that wind tunnel in that operating characteristic.

BENCHMARKING:

Subsonic Wind Tunnels - The ONERA F1 wind tunnel located in France is currently the benchmark for development wind tunnels having the capability to provide a test Reynolds number of 10M/ft. and a data generation rate of 6 polars/hr. Grumman's 7x10 ft. tunnel is another capable stand for the productivity with a data rate of 10 polars/hr.

Transonic Wind Tunnels - The situation is much less clear in selecting the transonic wind tunnel benchmark than it is in subsonic wind tunnels. The NASA-Langley NTF with a Reynolds number of 150M/ft. is by far the best. However, with a productivity level of 500 polars/year, it cannot provide test data at a rate necessary to support a product development program.

Next in order is the European Transonic Wind Tunnel GmbH, located in Germany, having the capability to provide a test Reynolds number of 70M/ft. and generate test data at a rate of 5000 polars/year (when operating at 3 runs/shift). This tunnel is just now coming on line and, therefore, some unforeseen disruption may, in fact, have the tunnel yield lower values. Regardless of these unknowns, this tunnel is considered the Transonic Wind Tunnel Benchmark. However, if testing at higher data rates is more important than the higher Reynolds number, the AEDC 16x16 or 4x4 with 15 polars/Air-on-HR and 25 polars/Air-on-HR could be more satisfactory.

Supersonic Wind Tunnel - The number of variables to be considered in benchmarking supersonic wind tunnels is different and less straightforward than the subsonic or transonic. Some of the tunnels included in this survey probably more properly belong in a collection of Hypersonic (Mn > 4) tunnels. They have been retained in the data collection but are not considered in benchmarking process. We have included in the supersonic wind tunnel listing all those facilities that exceed Mn = 1. However, we have not included those with Mn < 2 for benchmarking process. When considering the applicability of supersonic wind tunnels, the physical size of the test model is an important factor along with Reynolds number in simulating the aircraft operating conditions.

Wind Tunnel 16S at AEDC with its 16x16 ft. test selection is by far the largest test section available. However, it can only provide Reynolds number of 2.3M/ft.

The two supersonic wind tunnels which are the benchmark for Reynolds number are NLR 1.2M x 1.2M, located in the Netherlands, and Vought 4x4 ft. at 37M/ft. and 34M/ft. respectively. In terms of productivity, Onera S2MA located in France with 6 polars/occupancy hour and Vought 4x4 ft. at 8 polars/occupancy hour are the benchmarks.

C. WIND TUNNEL SURVEY RESULTS

The known wind tunnels located outside the former Soviet Union, meeting a minimum size criteria, were included in the survey. The wind tunnel benchmark solicitation is included as Appendix 1 and the name address list of those surveyed is included as Appendix 2.

In conducting the survey, attempts were made to have all data consistent. However, in a survey of this nature it is inevitable that some data will not be available in the units requested. This was especially true in the case of wind tunnel operating cost and acoustic characteristics. The data is presented as submitted. When it was not possible to normalize to a standard base, entries of N/A indicate that no data were submitted for that operating characteristic.

These data have also been provided to the Miter Corporation where the U.S. DoD maintains the TEA Database for facilities of interest.

SUBSONIC WIND TUNNEL MECHANICAL BENCHMARK

COUNTRY	FACILITY	STATUS	TEST SECTION, ft.	TEST SECTION WALLS	MACH NUMBER	REYNOLDS No.
Belgium	VKI L-1A	Active	9.8	N/A	0.005 to 0.17	1.2M/ft
France	Onera F1	Active	14.8x11.5	Solid	0 to 0.36	10M/ft
France	Onera S1MA	Active	26.2	Solid or slotted	0 to 1	4M/ft
Germany	DLR 2.4x2.4 m Kryo-Kanal	Active	7.9x7.9	Solid	0 to 0.38	N/A
Germany	DLR 3m x 3 m Gottingen	Decommissioned				N/A
Japan	NAL 6.5x5.5 m	Active	21.3x18.0	Solid	0 to 0.18	1.2M/ft
Netherlands	DNW 9.5x9.5 m	Active	31x31	Solid, slotted(8x8&6)	0 to 0.40	1.5M/ft
Netherlands	NLR 3.0x2.25 m	Active	9.84x7.38	Solid	0 to 0.23	1.8M/ft
UK	BAe 12x10 ft Filton	Active	12x10	N/A	0 to 0.25	1.8M/ft
UK	BAe 15 Ft Hatfield	Decommissioned				N/A
UK	BAe 2.7x2.1 m Warton	Active	8.9x6.9	Solid	0 to 0.2	1.5M/ft
UK	BAe 4.0x2.7 m Warton	Active	13.1x8.9	N/A	0.01 to 0.31	2M
UK	BAe 5.5x5.0 m Warton	Active	18.0x16.4	Solid	0.035 to 0.065	0.5M/ft
UK	BAe 9x7 Ft Hatfield	Deactivated				N/A
UK	DRA 13 x 9 ft Bedford	Active	13x9	Solid	0.04 to 0.27	1.5M/ft
UK	DRA 5 m Farnborough	Active	16.4x13.8	N/A	0 to 0.35	3M/ft
USA	AMES 12 ft N-206	Active	12	Solid	0 to 0.6	12M/ft
USA	AMES 40x80 ft N-221	Active	40x80	N/A	0 to 0.45	3M/ft
USA	AMES 7x10 ft N-215	Active	7x10	N/A	N/A	2.5M/ft
USA	AMES 7x10 ft N-216	Active	7x10	N/A	0 to 0.3	2.5M/ft
USA	AMES 80x120 ft N-221B	Active	80x120	N/A	0 to 0.15	1M/ft
USA	BOEING 9x9 ft	Active	9x9	Solid	0 to 0.3	N/A
USA	BOEING AERO/ICING	Active	4x6	Solid	0 to 0.38	N/A
USA	Grumman 7x10 ft	Active	7x10	Solid	0 to 0.3	1.5M/ft
USA	LANGELY 14x22 ft	Active	14.5x21.8	N/A	0 to 0.28	2.1M/ft
USA	Lockheed 8x12 ft.	Active	8x12	N/A	0.04 to 0.37	2.5M/ft
USA	MDA-E 8.5x12 ft	Active	8.5x12.0	Solid	0 to 0.26	2M
USA	MIT 7.5x10 ft ELLIPSE	Active	7.5x10	Solid	0 to 0.37	N/A
USA	Northrop 7x10 ft.	Active	7x10	Solid	0 to 0.37	2M/ft
USA	UTRC 18 ft OCT	Active	18	Solid	0 to 0.9	6M/ft
USA	Vought 7x10 ft	Active	7x10	Solid	0.035 to 0.29	2M/ft

-BEST IN CLASS

SUBSONIC WIND TUNNEL PRODUCTIVITY BENCHMARK

COUNTRY	FACILITY	TEST SECTION, ft	OPERATING TEMP, F	PLENUM CARTS	TEST GAS	PRODUCTIVITY
Belgium	VKI L-1A	9.8	Ambient	N/A	Air	N/A
France	Onera F1	14.8x11.5	86 to 104	N/A	Air	6 polar/occ hour
France	Onera S1MA	26.2	5 to 140	N/A	Air	6 polar/occ hours
Germany	DLR 2.4x2.4 m Kryo-Kanal	7.9x7.9	-279 to 80	N/A	Nitrogen	40 polars/day
Germany	DLR 3m x 3 m Gottingen					
Japan	NAL 6.5x5.5 m	21.3x18.0	41 to 104	One	Air	3 polars/occ hour
Netherlands	DNW 9.5x9.5 m	31x31	Ambient to 104	Three	Air	4 to 12 polars/hour
Netherlands	NLR 3.0x2.25 m	9.84x7.38	Ambient	None	Air	4 polar/occ hour
UK	BAe 12x10 ft Filton	12x10	Ambient	N/A	Air	2 polar/hour
UK	BAe 15 Ft Hatfield					
UK	BAe 2.7x2.1 m Warton	8.9x6.9	Ambient	N/A	Air	N/A
UK	BAe 4.0x2.7 m Warton	13.1x8.9	Ambient	N/A	Air	N/A
UK	BAe 5.5x5.0 m Warton	18.0x16.4	Ambient	N/A	Air	N/A
UK	BAe 9x7 Ft Hatfield					
UK	DRA 13 x 9 ft Bedford	13x9	Ambient	N/A	Air	2 polar/hour
UK	DRA 5 m Farnborough	16.4x13.8	32 to 104	N/A	Air	12 polar/day, 3200polar/yr
USA	AMES 12 ft N-206	12	70 to 140	N/A	Air, provision	2polar/occ hr
USA	AMES 40x80 ft N-221	40x80	Ambient to 120	None	Air	N/A
USA	AMES 7x10 ft N-215	7x10	N/A	N/A	Air	N/A
USA	AMES 7x10 ft N-216	7x10	90	N/A	Air	N/A
USA	AMES 80x120 ft N-221B	80x120	Ambient to 125	None	Air	N/A
USA	BOEING 9x9 ft	9x9	Ambient	N/A	Air	4polar/hr
USA	BOEING AERO/ICING	4x6	-40 to 110	N/A	Air	1polar/occ hr
USA	Grumman 7x10 ft	7x10	0 to 120	None	Air	10 polars/occ hour
USA	LANGELY 14x22 ft	14.5x21.8	30 to 160	N/A	Air	N/A
USA	Lockheed 8x12 ft.	8x12	Ambient	N/A	Air	5 polar/hour
USA	MDA-E 8.5x12 ft	8.5x12.0	Ambient	None	N/A	5 Polar/occ hour
USA	MIT 7.5x10 ft ELLIPSE	7.5x10	0 to 120	None	Air	4polar/hr
USA	Northrop 7x10 ft.	7x10	60 to 100	N/A	Air	4 polar/occ hour
USA	UTRC 18 ft OCT	18	Ambient to 120	N/A	Air	N/A
USA	Vought 7x10 ft	7x10	40 to 150	N/A	Air	3 polar/occ hour

- BEST IN CLASS

TRANSONIC WIND TUNNEL MECHANICAL BENCHMARK

COUNTRY	FACILITY	TEST SECTION, ft	TEST SECTION WALLS	MACH NUMBER	REYNOLDS No.
France	Onera S2MA	5.8x5.7	Solid or perforated	0.15 to 1.3	9M/ft
Germany,	European Transonic Windtunnel GmbH	6.6x7.9	Slotted	0.15 to 1.3	70M/ft
Japan	NAL 2x2m Transonic	6.6x6.6	Slotted, perforated	0.1 to 1.4	5M/ft
Netherlands	NLR 2.0x1.8 m	6.56x5.9	Slotted	0 to 1.25	8M/ft
USA	AEDC 16x16 ft	16x16	Perforated, inclined(6% poros)	0.06 to 1.6	5.5M/ft
USA	AEDC 4x4 ft	4x4	Perforated, inclined(0-10% poros)	0.1 to 2.0	7M/ft
USA	AMES 11x11 ft N-227A	11x11	Solid or Slotted	0.3 to 1.5	9.4M/ft
USA	AMES 14x14 ft N-218	14x14	Slotted	0.6 to 0.98	4.2M/ft
USA	Fluidyne 5.5x5.5 ft.	5.5x5.5	Slotted	0 to 1.15	4.2M
USA	LANGELY 8 ft	7.1x7.1	N/A	0.2 to 1.4	4.1M/ft
USA	LANGELY NTF	8.2x8.2	N/A	0.2 to 1.2	150M/ft
USA	MDA-E 4x4 ft	4x4	Porous	0.3 to 1.80	19M/ft
USA	Rockwell 7x7 Ft.	7x7	Solid	1.4 to 3.5	9M/ft
USA	Vought 4x4 ft Intermittent Blowdown	4x4	90 deg holes (22.5% poros)	0.4 to 1.8	15M/ft

-BEST IN CLASS

TRANSONIC WIND TUNNEL PRODUCTIVITY BENCHMARK

COUNTRY	FACILITY	TEST SECTION , ft	OPERATING TEMP, F	PLENUM CARTS	TEST GAS	PRODUCTIVITY
France	Onera S2MA	5.8x5.7	86 to 104	N/A	Air	6 to 14 polar/occ hour
Germany	European Transonic Windtunnel GmbH	6.6x7.9	-297 to 104	N/A	Nitrogen	5000 polar/year, 2 runs/shift
Japan	NAL 2x2m Transonic	6.6x6.6	104 to 140	One	Air	16 polars/day
Netherlands	NLR 2.0x1.8 m	6.56x5.9	86 to 104	None	Air	5 polar/occ hour
USA	AEDC 16x16 ft	16x16	80 to 160	N/A	Air	15 polars/air-on- hr
USA	AEDC 4x4 ft	4x4	90 to 135	N/A	Air	25 polars/air-on-hr
USA	AMES 11x11 ft N-227A	11x11	70 to 125	N/A	Air	4 polar/hr
USA	AMES 14x14 ft N-218	14x14	Ambient to 150	None	Air	N/A
USA	Fluidyne 5.5x5.5 ft.	5.5x5.5	100	N/A	Air	1 polar/ occ hour
USA	LANGELY 8 ft	7.1x7.1	100 to 120	N/A	Air	N/A
USA	LANGELY NTF	8.2x8.2	-320 to 150	N/A	Air and nitrogen	500 polars/yr
USA	MDA-E 4x4 ft	4x4	100	One	Air	5 polar/occ hour
USA	Rockwell 7x7 Ft.	7x7	70	One	Air	2 polars/occ hour, 2400 polars/year
USA	Vought 4x4 ft Intermittent Blowdown	4x4	100	One	Air	8 polars/occ hour

-BEST IN CLASS

SUPERSONIC WIND TUNNEL MECHANICAL BENCHMARK

COUNTRY	FACILITY	TEST SECTION , ft	TEST SECTION WALLS	MACH NUMBER	REYNOLDS No.
France	Onera S2MA	6.3x5.7	Solid or perforated	1.5 to 3.1	3.8M l=.1(sq rt S)
France	Onera S3MA	2.5x2.6	Solid	3.4 to 5.5	5 M l=.1(sq rt S)
Germany	DLR 0.5 m DIA Gottingen	1.6	N/A	5 to 6.9	15M/ft
Germany	DLR 0.5x0.5 m Gottingen	1.6x1.6	N/A	2.8 to 4.5	23M/ft
Germany	DLR 0.6 m DIA H2K	2.0	Free jet	5.3 to 11.2	6M/ft
Germany	DLR 0.6x0.6 m TMK	2.0x2.0	Perforated, 6% open area ratio, 30o inclined holes	0.5 to 4.5	24M/ft
Germany	DLR 1.2 m (HEG) Gottingen	3.9	Solid	7 to 10	N/A
Germany	DLR 1m x 1m Transonic Gottingen	3.3x3.3	Flexible laval nozzle	1.33 to 2.21	1.8M l=.1(sq rt S)
Germany	European Transonic Windtunnel GmbH	6.6x7.9	Slotted	0.15 to 1.3	61M/ft
Japan	NAL 2 m	6.6x6.6	Slotted, perforated	0.1 to 1.4	6M/ft
Netherlands	NLR 1.2x1.2	3.94x3.94	Solid	1.3 to 4	37M/ft
UK	BAe 1.22x1.22 m Blowdown, Warton	4x4	Solid	1.4 to 4.0	22M/ft
UK	DRA 3x4 ft Bedford High Supersonic	3x4	Solid, variable geometry throat	2.5 to 5.0	13M/ft
UK	DRA 8x8 ft Bedford	8x8	Solid	1.3 to 2.6	6M/ft
USA	AEDC 16S	16x16	Solid	1.6 to 4.75	2.3M/ft
USA	AEDC Tunnel A	3.3x3.3	Solid	1.5 to 5.5	8.5M/ft
USA	AEDC Tunnel B	4.2	Solid	6 and 8	4.7M/ft
USA	AEDC Tunnel C	4.2	Solid	4,8, and 10	7.8M/ft
USA	AMES 8x7 ft N-227C	8x7	Solid	2.5 to 3.5	5.2M/ft
USA	AMES 9x7 ft N-227B	9x7	Solid	1.55 to 2.5	6.5M/ft
USA	Fluidyne 5.5x5.5 ft.	5.5x5.5	Slotted	0 to 1.15	8M/ft
USA	MDA-E 4x4 ft	4x4	Porous	0.3 to 5.5	48M
USA	Rockwell 7x7 ft.	7x 7	Solid	1.4 to 3.5	19M/ft
USA	Vought 4x4 ft	4x4	Solid	1.6 to 4.8	34M/ft

-BEST IN CLASS

SUPERSONIC WIND TUNNEL PRODUCTIVITY BENCHMARK

COUNTRY	FACILITY	TEST SECTION , ft	OPERATING TEMP, F	PLENUM CARTS	TEST GAS	PRODUCTIVITY
France	Onera S2MA	6.3x5.7	86 to 104	N/A	Air	1500 hrs/yr, 6 polar/occ hour
France	Onera S3MA	2.5x2.6	59 to 662	N/A	Air	4 polar/occ hour
Germany	DLR 0.5 m DIA Gottingen	1.6	800	N/A	Air	20 polar/day
Germany	DLR 0.5x0.5 m Gottingen	1.6x1.6	260	N/A	Air	20 polar/day
Germany	DLR 0.6 m DIA H2K	2.0	2057	N/A	Air	12 runs/day
Germany	DLR 0.6x0.6 m TMK	2.0x2.0	Ambient to 464	One	Air	10 polars/day
Germany	DLR 1.2 m (HEG) Gottingen	3.9	1325 to 3125	None	Air, nitrogen, argon	1 polar/day
Germany	DLR 1m x 1m Transonic Gottingen	3.3x3.3	68 to 107	Three	Air	Polar/2 min
Germany	European Transonic Windtunnel GmbH	6.6x7.9	-297 to 104	N/A	Nitrogen	5000/year, 3 runs/shift
Japan	NAL 2 m	6.6x6.6	104 to 140	One	Air	16 polars/day
Netherlands	NLR 1.2x1.2	3.94x3.94	Ambient	None	Air	2 polar/hr
UK	BAe 1.22x1.22 m Blowdown, Warton	4x4	Ambient	N/A	Air	N/A
UK	DRA 3x4 ft Bedford High Supersonic	3x4	Ambient to 302	N/A	Air	12 min for 16 point polar
UK	DRA 8x8 ft Bedford	8x8	50 to 104	N/A	Air	>24 polars/day assume
USA	AEDC 16S	16x16	100 to 650 possible	N/A	Air	6 polar/air-on-hr
USA	AEDC Tunnel A	3.3x3.3	100 to 360	N/A	Air	20 polar/air-on-hr
USA	AEDC Tunnel B	4.2	390 to 890	N/A	Air	20 polar/air-on-hr
USA	AEDC Tunnel C	4.2	1440	N/A	Air	10 polar/air-on-hr
USA	AMES 8x7 ft N-227C	8x7	70 to 140	None	Air	1 polar/30 min
USA	AMES 9x7 ft N-227B	9x7	N/A	None	Air	1 polar/30 min
USA	Fluidyne 5.5x5.5 ft.	5.5x5.5	100	N/A	Air	1 polar/occ hour
USA	MDA-E 4x4 ft	4x4	100	One	Air	2 min for polar (30deg)
USA	Rockwell 7x7 ft.	7x 7	70	One	Air	2 polars/occ hr, 2400 polars/year
USA	Vought 4x4 ft	4x4	100	N/A	Air	8 polars/occ hour

-BEST IN CLASS

SUBSONIC WIND TUNNELS

FACILITY : **VKI L-1A**

OPERATIONAL : **Active**

COUNTRY : **Belgium**

ADDRESS : **Chaussee De Waterloo, 72**

CITY : **B-1640 Rhode Saint GENASA**

STATE/PROVINCE :

ZIP/POSTAL CODE :

CONTACT : **Prof. Mario Carbonaro**

PHONE : **32-2-358-1901**

TITLE : **N/A**

FAX : **02-358-2885**

TEST SEC. DIMENSIONS, m : **3.0** feet : **9.8**

TEST SEC. GEOMETRY : **N/A**

MACH NUMBER RANGE : **0.005 to 0.17**

REYNOLDS NUMBER : **1.2M/ft**

OPERATING TEMPERATURE, C : **Ambient**

F : **Ambient**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL :

SHELL OPERATING PRESSURE, atm : **N/A**

COOLING SYSTEM : **N/A**

THERMAL INSULATION, C : **N/A**

F : **N/A**

DRIVE POWER : **580 kW**

PLENUM CARTS : **N/A**

PRESSURIZATION RATE : **N/A**

TEST GAS : **Air**

PRODUCTIVITY : **N/A**

OPERATING COST : **N/A**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **N/A**

CUSTOMERS, Military : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **VKI L-1A** CONT'D

HIGH PRESS. AIR FOR PROP. : N/A

SUPPLY RATE : N/A

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : N/A F : N/A

PUMP RATE : N/A

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : N/A

MAX STORAGE PRESS., Pa : N/A PSIA : N/A

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : N/A

FLOW ANG, CLS'D TS DEG : N/A

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : N/A

TURB INTENSITY, CLS'D TS% : 0.3%

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :N/A

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **Onera F1**

OPERATIONAL : **Active**

COUNTRY : France

ADDRESS : F1 Onera Centre du Fauga-Mauzac

CITY :

STATE/PROVINCE :

ZIP/POSTAL CODE :

CONTACT : M. Bazin

PHONE : (1)46-73-40-40

TITLE : Deputy Director, Large Testing Dept

FAX : (1)46-73-41-44

TEST SEC. DIMENSIONS, m : **4.5x3.5** feet : **14.8x11.5**

TEST SEC. GEOMETRY : **Solid**

MACH NUMBER RANGE : **0 to 0.36**

REYNOLDS NUMBER : **10M/ft**

OPERATING TEMPERATURE, C : **30 to 40**

F : **86 to 104**

OPERATING PRESSURE, atm : **3.8 atm**

SHELL MATERIAL : **Concrete**

SHELL OPERATING PRESSURE, atm : **4 atm**

COOLING SYSTEM : **Water**

THERMAL INSULATION, C : **None**

F : **None**

DRIVE POWER : **9.5 MW**

PLENUM CARTS : N/A

PRESSURIZATION RATE : **0.05 atm/min**

TEST GAS : **Air**

PRODUCTIVITY : **6 polar/occ hour**

OPERATING COST : **N/A**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **90**

CUSTOMERS, Military : **10**

FACILITY : **Onera F1** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **3 Kg/s**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **20 to 80** F : **68 to 176**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **1400**

MAX STORAGE PRESS., Pa : **27M** PSIA : **3909**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.002 q**

FLOW ANG, CLS'D TS DEG : **.08**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **.0015%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :Yes

LAMINAR TESTING : **Yes**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

DRIVE FAN PROVISIONS : **Variable pitch, constant speed**

SUBSONIC WIND TUNNELS

FACILITY : **Onera S1MA**

OPERATIONAL : Active

COUNTRY : France

ADDRESS : Onera Centre de Modane-Avrieux-BP25

CITY : 73500 Modane

STATE/PROVINCE : France

ZIP/POSTAL CODE :

CONTACT : M. Bazin

PHONE : (1)46-73-40-40

TITLE : Deputy Director, Large Testing Dept

FAX : (1)46-73-41-44

TEST SEC. DIMENSIONS, m : 8.0   feet : 26.2

TEST SEC. GEOMETRY : Solid or slotted

MACH NUMBER RANGE : 0 to 1

REYNOLDS NUMBER : 4M/ft

OPERATING TEMPERATURE, C : -15 to 60

F : 5 to 140

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Steel

SHELL OPERATING PRESSURE, atm : 1 atm

COOLING SYSTEM : Air

THERMAL INSULATION, C : None

F : None

DRIVE POWER : 88 MW

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 6 polar/occ hour

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **Onera S1MA** CONT'D

HIGH PRESS. AIR FOR PROP. : N/A

SUPPLY RATE : N/A

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : N/A F : N/A

PUMP RATE : N/A

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : N/A

MAX STORAGE PRESS., Pa : N/A PSIA : N/A

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : N/A

FLOW ANG, CLS'D TS DEG : 0

FLOW ANG DIST, CLOSED TS : 0.05/m

TOTAL TEMP DIST,CLS'D DEG : N/A

TURB INTENSITY, CLS'D TS% : .001%

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :Yes

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **DLR 2.4x2.4 m Kryo-Kanal**

OPERATIONAL : Active

COUNTRY : Germany

ADDRESS : Hauptabteilung Windkanal-Abteilung Gottingen

CITY : Bunsenstrabe 10

STATE/PROVINCE : Gottingen

ZIP/POSTAL CODE : D-37073

CONTACT : Dr. Fritz Lethaus

PHONE : (49) 551-709-2148

TITLE : N/A

FAX : (49) 551-709-2179

TEST SEC. DIMENSIONS, m : 2.4x2.4

feet : 7.9x7.9

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.38

REYNOLDS NUMBER : N/A

OPERATING TEMPERATURE, C : -173 to 27

F : -279 to 80

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Concrete

SHELL OPERATING PRESSURE, atm : 1.1 atm

COOLING SYSTEM : Liquid nitrogen

THERMAL INSULATION, C : -173

F : -243

DRIVE POWER : 1 MW

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Nitrogen

PRODUCTIVITY : 40 polars/day

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **DLR 2.4x2.4 m Kryo-Kanal** CONT'D

HIGH PRESS. AIR FOR PROP. : N/A

SUPPLY RATE : N/A

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : N/A F : N/A

PUMP RATE : N/A

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : N/A

MAX STORAGE PRESS., Pa : N/A PSIA :

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : 0.1

FLOW ANG, CLS'D TS DEG : 0.08

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : 0.5 C

TURB INTENSITY, CLS'D TS% : 0.15%

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :NO

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **DLR 3m x 3 m Gottingen**

OPERATIONAL : Decommissioned 1994

COUNTRY : Germany

ADDRESS : Hauptabteilung Windkanal-Abteilung Gottingen

CITY : Bunsenstrabe 10

STATE/PROVINCE : Gottingen

ZIP/POSTAL CODE : D-37073

CONTACT : Dr. F. Lethaus

PHONE : (49) 551-709-1

TITLE : N/A

FAX : (49) 551-2179

TEST SEC. DIMENSIONS, m :

feet :

TEST SEC. GEOMETRY :

MACH NUMBER RANGE :

REYNOLDS NUMBER : N/A

OPERATING TEMPERATURE, C :

F :

OPERATING PRESSURE, atm :

SHELL MATERIAL :

SHELL OPERATING PRESSURE, atm :

COOLING SYSTEM :

THERMAL INSULATION, C :

F :

DRIVE POWER :

PLENUM CARTS :

PRESSURIZATION RATE :

TEST GAS :

PRODUCTIVITY :

OPERATING COST :

COSTS; REPLACEMENT :

CUSTOMERS, Civilian :

CUSTOMERS, Military :

SUBSONIC WIND TUNNELS

FACILITY : **DLR 3m x 3 m Gottingen** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE :

SUPPLY TIME :

SUPPLY TEMPERATURE, C : F :

PUMP RATE :

MINIMUM PRESSURE, Pa : PSIA :

SFC STORAGE :

MAX STORAGE PRESS., Pa : PSIA :

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS :

FLOW ANG, CLS'D TS DEG :

FLOW ANG DIST, CLOSED TS :

TOTAL TEMP DIST,CLS'D DEG :

TURB INTENSITY, CLS'D TS% :

DYN PRESS DIST, OPEN JET :

FLOW ANGULAR, OPEN JET :

FLOW ANG DIST, OPEN JET :

TOTAL TEMP DIST, OPEN JET :

TURB INTENSITY, OPEN JET :

ACOUSTIC NOISE :

LAMINAR TESTING :

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) :

40.0KHz:PSD (1/3 OCT SPL) :

OUT-of-FLOW NOISE LVL, 35 ft :

1.25KHz:PSD(1/3 OCT. SPL) :

40.0KHz:PSD(1/3 OCT. SPL) :

DRIVE FAN PROVISIONS :

OPEN JET TEST SECTION :

ANECHOIC CHAMBER :

MAX TEST PRESSURE, atm:

OPEN JET, TEST GAS :

JET LENGTH, m : feet :

MAX MEAS RADIUS, m : feet :

DIRECTIVITY ANGLES :

CIRCUIT ACOUSTIC TREAT. :

SUBSONIC WIND TUNNELS

FACILITY : NAL 6.5x5.5 m

OPERATIONAL : Active

COUNTRY : Japan

ADDRESS : Aircraft Aerodynamics Division, National Aerospace Laboratory

CITY : 7-44-1 Jindaijihigashi-Machi Chofu-shi

ZIP/POSTAL CODE :

STATE/PROVINCE : Tokyo

PHONE : N/A

CONTACT : Y. Hayashi

TITLE : N/A

FAX : N/A

TEST SEC. DIMENSIONS, m : 6.5x5.5 feet : 21.3x18.0

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.18

REYNOLDS NUMBER : 1.2M/ft

OPERATING TEMPERATURE, C : 5 to 40

F : 41 to 104

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Concrete and steel

SHELL OPERATING PRESSURE, atm : 1 atm

COOLING SYSTEM : None

THERMAL INSULATION, C : None

F : None

DRIVE POWER : 1.6 MW

PLENUM CARTS : One

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 3 polars/occ hour

OPERATING COST : 350,000 Yen/occ hour, 130,000 Yen/polar

COSTS; REPLACEMENT : 7 billion Yen

CUSTOMERS, Civilian : 85

CUSTOMERS, Military : 15

SUBSONIC WIND TUNNELS

FACILITY : **NAL 6.5x5.5 m** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **80 Kg/s**

SUPPLY TIME : **30 min**

SUPPLY TEMPERATURE, C : **5 to 40** F : **41 to 104**

PUMP RATE : **8.3 Kg/s**

MINIMUM PRESSURE, Pa : **1 M** PSIA : **146**

SFC STORAGE : **72000**

MAX STORAGE PRESS., Pa : **2 M** PSIA : **284**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.5%**

FLOW ANG, CLS'D TS DEG : **0.3**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **0.19%**

DYN PRESS DIST, OPEN JET : **0.5%**

FLOW ANGULAR, OPEN JET : **0.3**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **0.17**

ACOUSTIC NOISE :No

LAMINAR TESTING : **72 dB at 15 KHz**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **NO**

MAX TEST PRESSURE, atm: **Atmospheric**

OPEN JET, TEST GAS : **Air**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **None**

DRIVE FAN PROVISIONS : **Not designed for low noise**

SUBSONIC WIND TUNNELS

FACILITY : **DNW 9.5x9.5 m**

OPERATIONAL :**Active**

COUNTRY : Netherlands

ADDRESS : Deutsch-Nederlandischer Windkanal

CITY : Postbus 175

STATE/PROVINCE : Emmeloord

ZIP/POSTAL CODE : 8300 AD

CONTACT :Prof. H. U. Meier

PHONE : 31-0-5274-8556

TITLE : N/A

FAX : 31-0-5274-8582

TEST SEC. DIMENSIONS, m : **9.5x9.5** feet : **31x31**

TEST SEC. GEOMETRY : **Solid, slotted(8x8&6)**

MACH NUMBER RANGE : **0 to 0.40**

REYNOLDS NUMBER : **1.5M/ft**

OPERATING TEMPERATURE, C : **Ambient to 40**

F : **Ambient to 104**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **Steel**

SHELL OPERATING PRESSURE, atm : **N/A**

COOLING SYSTEM : **Water**

THERMAL INSULATION, C :**N/A**

F : **N/A**

DRIVE POWER : **12.5 MW**

PLENUM CARTS : **Three**

PRESSURIZATION RATE :**N/A**

TEST GAS :**Air**

PRODUCTIVITY :**4 to 12 polars/hour**

OPERATING COST :**$3350 to $5140/hr. (1993 tarrif)**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **90%**

CUSTOMERS, Military : **10%**

SUBSONIC WIND TUNNELS

FACILITY : **DNW 9.5x9.5 m** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **6 Kg/s cont, 30 Kg/s max**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **N/A** PSIA : **N/A**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.1%**

FLOW ANG, CLS'D TS DEG : **0.1**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **1 C**

TURB INTENSITY, CLS'D TS% : **0.12%**

DYN PRESS DIST, OPEN JET : **0.1%**

FLOW ANGULAR, OPEN JET : **0.1**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **1C**

TURB INTENSITY, OPEN JET : **0.25%**

ACOUSTIC NOISE :YES

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : YES

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **Atmospheric**

OPEN JET, TEST GAS : **Air**

JET LENGTH, m : **10** feet : **32.8**

MAX MEAS RADIUS, m : **10** feet : **32.8**

DIRECTIVITY ANGLES : **45 to 155**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **NLR 3.0x2.25 m**

OPERATIONAL : **Active**

COUNTRY : **Netherlands**

ADDRESS :

CITY : **Emmeloord**

STATE/PROVINCE :

ZIP/POSTAL CODE :

CONTACT : **Henk A. Dambrink**

PHONE : **31-0-20-511-3399**

TITLE : **N/A**

FAX : **31-0-20-511-3210**

TEST SEC. DIMENSIONS, m : **3.0 x 2.25** feet : **9.84x7.38**

TEST SEC. GEOMETRY : **Solid**

MACH NUMBER RANGE : **0 to 0.23**

REYNOLDS NUMBER : **1.8M/ft**

OPERATING TEMPERATURE, C : **Ambient**

F : **Ambient**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **Steel**

SHELL OPERATING PRESSURE, atm : **1 atm**

COOLING SYSTEM : **None**

THERMAL INSULATION, C : **None**

F : **None**

DRIVE POWER : **700 kW**

PLENUM CARTS : **None**

PRESSURIZATION RATE : **N/A**

TEST GAS : **Air**

PRODUCTIVITY : **4 polar/occ hour**

OPERATING COST : **N/A**

COSTS; REPLACEMENT : **$10 M**

CUSTOMERS, Civilian : **90%**

CUSTOMERS, Military : **10%**

FACILITY : **NLR 3.0x2.25 m** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **6 kg/sec**

SUPPLY TIME : **Continuous**

SUPPLY TEMPERATURE, C : **70** F : **158**

PUMP RATE : **6 kg/sec**

MINIMUM PRESSURE, Pa : **1 M** PSIA : **147**

SFC STORAGE : **443000**

MAX STORAGE PRESS., Pa : **N/A** PSIA : **N/A**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.1%**

FLOW ANG, CLS'D TS DEG : **0.1**

FLOW ANG DIST, CLOSED TS : **0.05/m**

TOTAL TEMP DIST,CLS'D DEG : **2 C**

TURB INTENSITY, CLS'D TS% : **0.08%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE : N/A

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **BAe 12x10 ft Filton**

OPERATIONAL : Active

COUNTRY : UK

ADDRESS : BAE, PO Box 77

CITY : Bristol

STATE/PROVINCE : England

ZIP/POSTAL CODE : BS99 7AR

CONTACT : M. H. Marsden

PHONE : (0272)36-2809

TITLE : Manager - Aero Labs

FAX : (0272)36-4535

TEST SEC. DIMENSIONS, m : 3.7 x 3.0

feet : 12x10

TEST SEC. GEOMETRY : N/A

MACH NUMBER RANGE : 0 to 0.25

REYNOLDS NUMBER : 1.8M/ft

OPERATING TEMPERATURE, C : Ambient

F : Ambient

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : N/A

SHELL OPERATING PRESSURE, atm : N/A

COOLING SYSTEM : N/A

THERMAL INSULATION, C : N/A

F : N/A

DRIVE POWER : N/A

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 2 polar/hour

OPERATING COST : $5,000/day

COSTS; REPLACEMENT : $12 M

CUSTOMERS, Civilian : 100%

CUSTOMERS, Military : 0

SUBSONIC WIND TUNNELS

FACILITY : **BAe 12x10 ft Filton** CONT'D

HIGH PRESS. AIR FOR PROP. : N/A

SUPPLY RATE : N/A

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : N/A F : N/A

PUMP RATE : N/A

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : N/A

MAX STORAGE PRESS., Pa : N/A PSIA : N/A

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : N/A

FLOW ANG, CLS'D TS DEG : N/A

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : N/A

TURB INTENSITY, CLS'D TS% : N/A

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :No

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : BAe 15 Ft Hatfield

OPERATIONAL : Decommissioned

COUNTRY : UK

ADDRESS :

CITY : Glasgow

STATE/PROVINCE :

ZIP/POSTAL CODE :

CONTACT : University Glasgow

PHONE :

TITLE :

FAX :

TEST SEC. DIMENSIONS, m :

feet :

TEST SEC. GEOMETRY :

MACH NUMBER RANGE :

REYNOLDS NUMBER : N/A

OPERATING TEMPERATURE, C :

F :

OPERATING PRESSURE, atm :

SHELL MATERIAL :

SHELL OPERATING PRESSURE, atm :

COOLING SYSTEM :

THERMAL INSULATION, C :

F :

DRIVE POWER :

PLENUM CARTS :

PRESSURIZATION RATE :

TEST GAS :

PRODUCTIVITY :

OPERATING COST :

COSTS; REPLACEMENT :

CUSTOMERS, Civilian :

CUSTOMERS, Military :

SUBSONIC WIND TUNNELS

FACILITY : **BAe 15 Ft Hatfield** CONT'D

HIGH PRESS. AIR FOR PROP. :

SUPPLY RATE :

SUPPLY TIME :

SUPPLY TEMPERATURE, C : F :

PUMP RATE :

MINIMUM PRESSURE, Pa : PSIA :

SFC STORAGE :

MAX STORAGE PRESS., Pa : PSIA :

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS :

FLOW ANG, CLS'D TS DEG :

FLOW ANG DIST, CLOSED TS :

TOTAL TEMP DIST,CLS'D DEG :

TURB INTENSITY, CLS'D TS% :

DYN PRESS DIST, OPEN JET :

FLOW ANGULAR, OPEN JET :

FLOW ANG DIST, OPEN JET :

TOTAL TEMP DIST, OPEN JET :

TURB INTENSITY, OPEN JET :

ACOUSTIC NOISE :

LAMINAR TESTING :

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) :

40.0KHz:PSD (1/3 OCT SPL) :

OUT-of-FLOW NOISE LVL, 35 ft :

1.25KHz:PSD(1/3 OCT. SPL) :

40.0KHz:PSD(1/3 OCT. SPL) :

DRIVE FAN PROVISIONS :

OPEN JET TEST SECTION :

ANECHOIC CHAMBER :

MAX TEST PRESSURE, atm:

OPEN JET, TEST GAS :

JET LENGTH, m : feet :

MAX MEAS RADIUS, m : feet :

DIRECTIVITY ANGLES :

CIRCUIT ACOUSTIC TREAT. :

SUBSONIC WIND TUNNELS

FACILITY : **BAe 2.7x2.1 m Warton**

OPERATIONAL : Active

COUNTRY : UK

ADDRESS : Warton Aerodrome

CITY : Warton Preston

STATE/PROVINCE : Lancashire

ZIP/POSTAL CODE : PR4 1AX

CONTACT : N. D. Davey

PHONE : (0772) 633333

TITLE : Chief Wind Tunnel Engineer

FAX : (0772) 855501

TEST SEC. DIMENSIONS, m : 2.7x2.1 feet : 8.9x6.9

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.2

REYNOLDS NUMBER : 1.5M/ft

OPERATING TEMPERATURE, C : Ambient

F : Ambient

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Timber and steel

SHELL OPERATING PRESSURE, atm : N/A

COOLING SYSTEM : N/A

THERMAL INSULATION, C : N/A

F : N/A

DRIVE POWER : 380 kW DC Motor

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : N/A

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **BAe 2.7x2.1 m Warton** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **1 Kg/s**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **1200 CFM**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **2.1M** PSIA : **300**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **N/A**

FLOW ANG, CLS'D TS DEG : **0.43**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **0.25%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE : No

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

DRIVE FAN PROVISIONS : **Five bladed**

SUBSONIC WIND TUNNELS

FACILITY : **BAe 4.0x2.7 m Warton**

OPERATIONAL : Active

COUNTRY : UK

ADDRESS : Warton Aerodrome

CITY : Warton Preston

STATE/PROVINCE : Lancashire

ZIP/POSTAL CODE : PR4 1AX

CONTACT : N. D. Davey

PHONE : (0772) 633333

TITLE : Chief Wind Tunnel Engineer

FAX : (0772) 855501

TEST SEC. DIMENSIONS, m : 4.0x2.7 feet : 13.1x8.9

TEST SEC. GEOMETRY : N/A

MACH NUMBER RANGE : 0.01 to 0.31

REYNOLDS NUMBER : 2M

OPERATING TEMPERATURE, C : Ambient

F : Ambient

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Steel

SHELL OPERATING PRESSURE, atm : N/A

COOLING SYSTEM : N/A

THERMAL INSULATION, C : N/A

F : N/A

DRIVE POWER : 1.3 MW AC Motor

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : N/A

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **BAe 4.0x2.7 m Warton** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **12 Kg/s**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **4.2M** PSIA : **609**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **N/A**

FLOW ANG, CLS'D TS DEG : **N/A**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **N/A**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :No

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **BAe 5.5x5.0 m Warton**

OPERATIONAL : **Active**

COUNTRY : UK

ADDRESS : Warton Aerodrome

CITY : Warton Preston

STATE/PROVINCE : Lancashire

ZIP/POSTAL CODE : PR4 1AX

CONTACT : N. D. Davey

PHONE : (0772) 633333

TITLE : Chief Wind Tunnel Engineer

FAX : (0772) 855501

TEST SEC. DIMENSIONS, m : **5.5x5.0** feet : **18.0x16.4**

TEST SEC. GEOMETRY : **Solid**

MACH NUMBER RANGE : **0.035 to 0.065**

REYNOLDS NUMBER : **0.5M/ft**

OPERATING TEMPERATURE, C : **Ambient**

F : **Ambient**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **N/A**

SHELL OPERATING PRESSURE, atm : **N/A**

COOLING SYSTEM : **None**

THERMAL INSULATION, C : **N/A**

F : **N/A**

DRIVE POWER : **220 kW**

PLENUM CARTS : **N/A**

PRESSURIZATION RATE : **N/A**

TEST GAS : **Air**

PRODUCTIVITY : **N/A**

OPERATING COST : **N/A**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **N/A**

CUSTOMERS, Military : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **BAe 5.5x5.0 m Warton** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **8 Kg/s**

SUPPLY TIME : **Continuous**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **4M** PSIA : **580**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **N/A**

FLOW ANG, CLS'D TS DEG : **N/A**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **N/A**

DYN PRESS DIST, OPEN JET : **0.5%**

FLOW ANGULAR, OPEN JET : **0.3**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :No

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **BAe 9x7 Ft Hatfield**

OPERATIONAL : **Deactivated**

COUNTRY : UK

ADDRESS :

CITY :

STATE/PROVINCE :

ZIP/POSTAL CODE :

CONTACT :

PHONE :

TITLE :

FAX :

TEST SEC. DIMENSIONS, m :

feet :

TEST SEC. GEOMETRY :

MACH NUMBER RANGE :

REYNOLDS NUMBER : N/A

OPERATING TEMPERATURE, C :

F :

OPERATING PRESSURE, atm :

SHELL MATERIAL :

SHELL OPERATING PRESSURE, atm :

COOLING SYSTEM :

THERMAL INSULATION, C :

F :

DRIVE POWER :

PLENUM CARTS :

PRESSURIZATION RATE :

TEST GAS :

PRODUCTIVITY :

OPERATING COST :

COSTS; REPLACEMENT :

CUSTOMERS, Civilian :

CUSTOMERS, Military :

SUBSONIC WIND TUNNELS

FACILITY : **BAe 9x7 Ft Hatfield** CONT'D

HIGH PRESS. AIR FOR PROP. :

SUPPLY RATE :

SUPPLY TIME :

SUPPLY TEMPERATURE, C : F :

PUMP RATE :

MINIMUM PRESSURE, Pa : PSIA :

SFC STORAGE :

MAX STORAGE PRESS., Pa : PSIA :

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS :

FLOW ANG, CLS'D TS DEG :

FLOW ANG DIST, CLOSED TS :

TOTAL TEMP DIST,CLS'D DEG :

TURB INTENSITY, CLS'D TS% :

DYN PRESS DIST, OPEN JET :

FLOW ANGULAR, OPEN JET :

FLOW ANG DIST, OPEN JET :

TOTAL TEMP DIST, OPEN JET :

TURB INTENSITY, OPEN JET :

ACOUSTIC NOISE :

LAMINAR TESTING :

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) :

40.0KHz:PSD (1/3 OCT SPL) :

OUT-of-FLOW NOISE LVL, 35 ft :

1.25KHz:PSD(1/3 OCT. SPL) :

40.0KHz:PSD(1/3 OCT. SPL) :

DRIVE FAN PROVISIONS :

OPEN JET TEST SECTION :

ANECHOIC CHAMBER :

MAX TEST PRESSURE, atm:

OPEN JET, TEST GAS :

JET LENGTH, m : feet :

MAX MEAS RADIUS, m : feet :

DIRECTIVITY ANGLES :

CIRCUIT ACOUSTIC TREAT. :

SUBSONIC WIND TUNNELS

FACILITY : **DRA 13 x 9 ft Bedford**

OPERATIONAL : Active

COUNTRY : UK

ADDRESS : Defense Research Agency

CITY : Bedford

STATE/PROVINCE :

ZIP/POSTAL CODE : MK41 6AE

CONTACT : 13 x 9 ft Tunnel Manager

PHONE : (0234)225990

TITLE : N/A

FAX : (0234)225848

TEST SEC. DIMENSIONS, m : 4x2.7 feet : 13x9

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0.04 to 0.27

REYNOLDS NUMBER : 1.5M/ft

OPERATING TEMPERATURE, C : Ambient

F : Ambient

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Timber and steel

SHELL OPERATING PRESSURE, atm : N/A

COOLING SYSTEM : None

THERMAL INSULATION, C : None

F : None

DRIVE POWER : 1.1 MW

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 2 polar/hour

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

FACILITY : **DRA 13 x 9 ft Bedford** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : 4.5 Kg/s

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : N/A F : N/A

PUMP RATE : 4.5 Kg/s

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : 3200

MAX STORAGE PRESS., Pa : 4.5M PSIA : 132

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : 0.1%

FLOW ANG, CLS'D TS DEG : N/A

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : N/A

TURB INTENSITY, CLS'D TS% : 0.025%

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE : N/A

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **DRA 5 m Farnborough**

OPERATIONAL : Active

COUNTRY : UK

ADDRESS : Aerodynamics & Propulsion Dept.

CITY : DRA Farnborough

STATE/PROVINCE : Hants

ZIP/POSTAL CODE : GU14 6TD

CONTACT : Dr. David Woodward

PHONE : 44-252-395377

TITLE : Head of Low Speed Aero Division

FAX : 44-252-377783

TEST SEC. DIMENSIONS, m : 5.0 x 4.2

feet : 16.4x13.8

TEST SEC. GEOMETRY : N/A

MACH NUMBER RANGE : 0 to 0.35

REYNOLDS NUMBER : 3M/ft

OPERATING TEMPERATURE, C : 0 to 40

F : 32 to 104

OPERATING PRESSURE, atm : 3 atm

SHELL MATERIAL : N/A

SHELL OPERATING PRESSURE, atm : N/A

COOLING SYSTEM : N/A

THERMAL INSULATION, C : N/A

F : N/A

DRIVE POWER : 12 MW

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 12 polar/day, 3200polar/yr

OPERATING COST : $980k/month, $3k/polar

COSTS; REPLACEMENT : $90 M

CUSTOMERS, Civilian : 60%

CUSTOMERS, Military : 40%

SUBSONIC WIND TUNNELS

FACILITY : **DRA 5 m Farnborough** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **32 Kg/s**

SUPPLY TIME : **30 minutes**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **1 atm/15 min**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **10M** PSIA : **1450**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **N/A**

FLOW ANG, CLS'D TS DEG : **N/A**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **0.08%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :132 dB @ M=0.3

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **AMES 12 ft N-206**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROVINCE : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT : Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Deve

FAX : N/A

TEST SEC. DIMENSIONS, m : 3.7

feet : 12

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.6

REYNOLDS NUMBER : 12M/ft

OPERATING TEMPERATURE, C : 21 to 60

F : 70 to 140

OPERATING PRESSURE, atm : 6 atm

SHELL MATERIAL : Steel

SHELL OPERATING PRESSURE, atm : N/A

COOLING SYSTEM : Interval water HEX

THERMAL INSULATION, C : None

F : None

DRIVE POWER : 15K Hp

PLENUM CARTS : N/A

PRESSURIZATION RATE :6 atm/hr

TEST GAS : Air, provisions for heavy

PRODUCTIVITY : 2polar/occ hr

OPERATING COST : $2600/hr

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

FACILITY : **AMES 12 ft N-206** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : 160lb/sec

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : N/A F : N/A

PUMP RATE : 22lb/sec

MINIMUM PRESSURE, Pa : 20M PSIA : 315

SFC STORAGE : 6M at 3000psi

MAX STORAGE PRESS., Pa : 20.5M PSIA : 3000

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : N/A

FLOW ANG, CLS'D TS DEG : 0.02

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : 4 F

TURB INTENSITY, CLS'D TS% : 0.05%

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :N/A

LAMINAR TESTING : 0.15% cprms

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : Independent RPV/IGV

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : None

SUBSONIC WIND TUNNELS

FACILITY : **AMES 40x80 ft N-221**

OPERATIONAL : **Active**

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROVINCE : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT : Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Deve

FAX : N/A

TEST SEC. DIMENSIONS, m : **12.2x24.4** feet : **40x80**

TEST SEC. GEOMETRY : **N/A**

MACH NUMBER RANGE : **0 to 0.45**

REYNOLDS NUMBER : **3M/ft**

OPERATING TEMPERATURE, C : **Ambient to 49**

F : **Ambient to 120**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **Steel, acoustic liner**

SHELL OPERATING PRESSURE, atm : **1.1 atm**

COOLING SYSTEM : **10% air exchange**

THERMAL INSULATION, C : **None**

F : **None**

DRIVE POWER : **110MW**

PLENUM CARTS : **None**

PRESSURIZATION RATE : **N/A**

TEST GAS : **Air**

PRODUCTIVITY : **N/A**

OPERATING COST : **$6100/hr**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **N/A**

CUSTOMERS, Military : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **AMES 40x80 ft N-221** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **40lb/sec**

SUPPLY TIME : **not limiting**

SUPPLY TEMPERATURE, C : **204** F : **400**

PUMP RATE : **28lb/sec**

MINIMUM PRESSURE, Pa : **690K** PSIA : **100**

SFC STORAGE : **7M at 3000psi**

MAX STORAGE PRESS., Pa : **22.8M** PSIA : **3300**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.5%**

FLOW ANG, CLS'D TS DEG : **0.5**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **1 F**

TURB INTENSITY, CLS'D TS% : **0.5%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :Yes

LAMINAR TESTING : **0.5% flow turbulence**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **69dB**

40.0KHz:PSD (1/3 OCT SPL) : **30dB**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **Quiet low fan tip speed**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **Yes-to 100hz**

MAX TEST PRESSURE, atm: **Atmospheric**

OPEN JET, TEST GAS : **Air**

JET LENGTH, m : **22.8** feet : **75**

MAX MEAS RADIUS, m : **15.2** feet : **50**

DIRECTIVITY ANGLES : **ALL**

CIRCUIT ACOUSTIC TREAT. : **Some**

SUBSONIC WIND TUNNELS

FACILITY : **AMES 7x10 ft N-215**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROVINCE : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT : Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Deve

FAX : N/A

TEST SEC. DIMENSIONS, m : 2.1x3.0

feet : 7x10

TEST SEC. GEOMETRY : N/A

MACH NUMBER RANGE : N/A

REYNOLDS NUMBER : 2.5M/ft

OPERATING TEMPERATURE, C : N/A

F : N/A

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : N/A

SHELL OPERATING PRESSURE, atm : 1 atm

COOLING SYSTEM : N/A

THERMAL INSULATION, C : None

F : None

DRIVE POWER :

PLENUM CARTS : N/A

PRESSURIZATION RATE :N/A

TEST GAS : Air

PRODUCTIVITY : N/A

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **AMES 7x10 ft N-215** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : 20 lb/sec

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : 204 F : 400

PUMP RATE : N/A

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : N/A

MAX STORAGE PRESS., Pa : 20.5M PSIA : 3000

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : N/A

FLOW ANG, CLS'D TS DEG : N/A

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : N/A

TURB INTENSITY, CLS'D TS% : N/A

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE : N/A

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **AMES 7x10 ft N-216**

OPERATIONAL :Active

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROVINCE : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT :Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Deve

FAX : N/A

TEST SEC. DIMENSIONS, m : 2.1x3.0

feet : 7x10

TEST SEC. GEOMETRY : N/A

MACH NUMBER RANGE : 0 to 0.3

REYNOLDS NUMBER : 2.5M/ft

OPERATING TEMPERATURE, C : 32

F : 90

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Steel, Transite

SHELL OPERATING PRESSURE, atm : 0.9 atm

COOLING SYSTEM : Air exch tower ambient

THERMAL INSULATION, C :None

F : None

DRIVE POWER : 1600Hp

PLENUM CARTS : N/A

PRESSURIZATION RATE :N/A

TEST GAS :Air

PRODUCTIVITY : N/A

OPERATING COST :$200K/yr

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

FACILITY : **AMES 7x10 ft N-216** CONT'D

HIGH PRESS. AIR FOR PROP. : N/A

SUPPLY RATE : **N/A**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **N/A** PSIA : **N/A**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.1%**

FLOW ANG, CLS'D TS DEG : **0.2**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **0.01%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :N/A

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **8 blade, 30' dia**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **None**

SUBSONIC WIND TUNNELS

FACILITY : **AMES 80x120 ft N-221B**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROVINCE : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT : Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Deve

FAX : N/A

TEST SEC. DIMENSIONS, m : 24.4x36.6

feet : 80x120

TEST SEC. GEOMETRY : N/A

MACH NUMBER RANGE : 0 to 0.15

REYNOLDS NUMBER : 1M/ft

OPERATING TEMPERATURE, C : Ambient to 52

F : Ambient to 125

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Steel, acoustic liner

SHELL OPERATING PRESSURE, atm : 1 atm

COOLING SYSTEM : None

THERMAL INSULATION, C : None

F : None

DRIVE POWER : 110MW

PLENUM CARTS : None

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : N/A

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **AMES 80x120 ft N-221B** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **40lb/sec**

SUPPLY TIME : **not limiting**

SUPPLY TEMPERATURE, C : **204** F : **400**

PUMP RATE : **28lb/sec**

MINIMUM PRESSURE, Pa : **690K** PSIA : **100**

SFC STORAGE : **7M at 3000psi**

MAX STORAGE PRESS., Pa : **22.8** PSIA : **3300**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.5%**

FLOW ANG, CLS'D TS DEG : **0.5**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **1 F**

TURB INTENSITY, CLS'D TS% : **0.5%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :Yes

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **93dB**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **Quiet low fan tip speed**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **Yes-to 400hz**

MAX TEST PRESSURE, atm: **Atmospheric**

OPEN JET, TEST GAS : **Air**

JET LENGTH, m :**45.7** feet : **150**

MAX MEAS RADIUS, m : **30.5** feet : **100**

DIRECTIVITY ANGLES : **ALL**

CIRCUIT ACOUSTIC TREAT. : **None**

SUBSONIC WIND TUNNELS

FACILITY : **BOEING 9x9 ft**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : P.O. Box 3707, MS 6R-MT

CITY : Seattle

STATE/PROVINCE : WA

ZIP/POSTAL CODE : 98124-2207

CONTACT : Richard A. Day

PHONE : N/A

TITLE : Director Engineering Laboratories

FAX : N/A

TEST SEC. DIMENSIONS, m : 2.7x2.7 feet : 9x9

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.3

REYNOLDS NUMBER : N/A

OPERATING TEMPERATURE, C : Ambient

F : Ambient

OPERATING PRESSURE, atm : 1 atm

SHELL MATERIAL : Wood/steel

SHELL OPERATING PRESSURE, atm : N/A

COOLING SYSTEM : N/A

THERMAL INSULATION, C : N/A

F : N/A

DRIVE POWER : N/A

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 4polar/hr

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **BOEING 9x9 ft** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : 35/lb sec

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : 316 F : 600

PUMP RATE : 28lb/sec

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : 1M

MAX STORAGE PRESS., Pa : 7M PSIA : 1000

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : N/A

FLOW ANG, CLS'D TS DEG : N/A

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : N/A

TURB INTENSITY, CLS'D TS% : N/A

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :N/A

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **BOEING AERO/ICING**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : P.O. Box 3707,MS 6R-MT

CITY : Seattle

STATE/PROVINCE : WA

ZIP/POSTAL CODE : 98124-2207

CONTACT : Richard A. Day

PHONE : N/A

TITLE : Director Engineering Laboratories

FAX : N/A

TEST SEC. DIMENSIONS, m : 1.2x1.8 feet : 4x6

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.38

REYNOLDS NUMBER : N/A

OPERATING TEMPERATURE, C : -40 to 43

F : -40 to 110

OPERATING PRESSURE, atm : 1 atm

SHELL MATERIAL : Steel

SHELL OPERATING PRESSURE, atm : 1.2 atm

COOLING SYSTEM : Refrigerant F22

THERMAL INSULATION, C : R32

F : R32

DRIVE POWER : 2000 Hp

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 1polar/occ hr

OPERATING COST : N/A

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

FACILITY : **BOEING AERO/ICING** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **10lb/sec**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **649** F : **1200**

PUMP RATE : **23lb/sec**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **7M** PSIA : **1000**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **1%**

FLOW ANG, CLS'D TS DEG : **<0.2**

FLOW ANG DIST, CLOSED TS : **0.5**

TOTAL TEMP DIST,CLS'D DEG : **1 F**

TURB INTENSITY, CLS'D TS% : **0.5%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE : N/A

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **Entire tunnel**

DRIVE FAN PROVISIONS : **Low noise fan, variable incidence**

SUBSONIC WIND TUNNELS

FACILITY : **Grumman 7x10 ft**

OPERATIONAL : **Active**

COUNTRY : USA

ADDRESS : N/A

CITY : N/A

STATE/PROVINCE : N/A

ZIP/POSTAL CODE :

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SEC. DIMENSIONS, m : **2.1x3** feet : **7x10**

TEST SEC. GEOMETRY : **Solid**

MACH NUMBER RANGE : **0 to 0.3**

REYNOLDS NUMBER : **1.5M/ft**

OPERATING TEMPERATURE, C : **-18 to 49**

F : **0 to 120**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **Steel**

SHELL OPERATING PRESSURE, atm : **1 atm**

COOLING SYSTEM : **Water**

THERMAL INSULATION, C : **None**

F : **None**

DRIVE POWER : **1750 Hp**

PLENUM CARTS : **None**

PRESSURIZATION RATE : **N/A**

TEST GAS : **Air**

PRODUCTIVITY : **10 polars/occ hour**

OPERATING COST : **35/polar**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **N/A**

CUSTOMERS, Military : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **Grumman 7x10 ft** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **10 lb/sec**

SUPPLY TIME : **20 min**

SUPPLY TEMPERATURE, C : **21 to 371** F : **70 to 700**

PUMP RATE : **0.75 lb/sec**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **1800**

MAX STORAGE PRESS., Pa : **3.4M** PSIA : **500**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.5%**

FLOW ANG, CLS'D TS DEG : **0**

FLOW ANG DIST, CLOSED TS : **0.1**

TOTAL TEMP DIST,CLS'D DEG : **1.0 F**

TURB INTENSITY, CLS'D TS% : **1.15**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :No

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **LANGELY 14x22 ft**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : Langley Research Center Applied Aero Division

CITY : Hampton

STATE/PROVINCE : VA

ZIP/POSTAL CODE : 23665-5225

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SEC. DIMENSIONS, m : **4.4x6.6** feet : **14.5x21.8**

TEST SEC. GEOMETRY : **N/A**

MACH NUMBER RANGE : **0 to 0.28**

REYNOLDS NUMBER : **2.1M/ft**

OPERATING TEMPERATURE, C : **-1 to 71**

F : **30 to 160**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **Carbon steel**

SHELL OPERATING PRESSURE, atm : **1 atm**

COOLING SYSTEM : **Air exchange**

THERMAL INSULATION, C : **None**

F : **None**

DRIVE POWER : **8000 Hp**

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : **Air**

PRODUCTIVITY : N/A

OPERATING COST : **$2.4M/yr**

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

SUBSONIC WIND TUNNELS

FACILITY : **LANGELY 14x22 ft** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **30lb/sec**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **4 to 93** F : **40 to 200**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **N/A** PSIA : **N/A**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **N/A**

FLOW ANG, CLS'D TS DEG : **0.15**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **0.15%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE : N/A

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **Lockheed 8x12 ft.**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : Low Speed Wind Tower, 3050 Pacific Hwy

CITY : San Diego

STATE/PROVINCE : CA

ZIP/POSTAL CODE : 92101

CONTACT : R. S. Crooks

PHONE : (619)542-8158

TITLE : Chief, Low Speed Wind Tunnel

FAX : (619)542-7237

TEST SEC. DIMENSIONS, m : 2.4 x 3.7 feet : 8x12

TEST SEC. GEOMETRY : N/A

MACH NUMBER RANGE : 0.04 to 0.37

REYNOLDS NUMBER : 2.5M/ft

OPERATING TEMPERATURE, C : Ambient

F : Ambient

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Reinforced Concrete

SHELL OPERATING PRESSURE, atm : 1.1 atm

COOLING SYSTEM : None

THERMAL INSULATION, C : None

F : None

DRIVE POWER : 2250 Hp Sync Motor

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : 5 polar/hour

OPERATING COST : $200/polar, $1200/occ hour

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : 20%

CUSTOMERS, Military : 80%

FACILITY : **Lockheed 8x12 ft.** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : 12 lb/sec

SUPPLY TIME : N/A

SUPPLY TEMPERATURE, C : Ambient F : Ambient

PUMP RATE : 3 lb/sec

MINIMUM PRESSURE, Pa : 690K PSIA : 100

SFC STORAGE : 3500

MAX STORAGE PRESS., Pa : 4.1M PSIA : 600

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : N/A

FLOW ANG, CLS'D TS DEG : 0.2

FLOW ANG DIST, CLOSED TS : N/A

TOTAL TEMP DIST,CLS'D DEG : N/A

TURB INTENSITY, CLS'D TS% : 0.08%

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :No

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : N/A

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **MDA-E 8.5x12 ft**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : N/A

CITY : St. Louis

STATE/PROVINCE : MO

ZIP/POSTAL CODE : N/A

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SEC. DIMENSIONS, m : 2.6x3.7

feet : 8.5x12.0

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.26

REYNOLDS NUMBER : 2M

OPERATING TEMPERATURE, C : Ambient

F : Ambient

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Steel

SHELL OPERATING PRESSURE, atm : 1 atm

COOLING SYSTEM : Water

THERMAL INSULATION, C : None

F : None

DRIVE POWER : N/A

PLENUM CARTS : None

PRESSURIZATION RATE : N/A

TEST GAS : N/A

PRODUCTIVITY : 5 Polar/occ hour

OPERATING COST : $118/polar

COSTS; REPLACEMENT : $25 M

CUSTOMERS, Civilian : 12

CUSTOMERS, Military : 88

FACILITY : **MDA-E 8.5x12 ft** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **20 lb/sec**

SUPPLY TIME : **Continuous**

SUPPLY TEMPERATURE, C : **-18 to 454** F : **0 to 850**

PUMP RATE : **20 lb/sec**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **4.3M** PSIA : **629**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.25%**

FLOW ANG, CLS'D TS DEG : **0.05**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **1.13**

DYN PRESS DIST, OPEN JET : **1.1%**

FLOW ANGULAR, OPEN JET : **0.05**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **1.13**

ACOUSTIC NOISE :Yes

LAMINAR TESTING : **100 dB at 675 Hz**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **89 dB**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **AVA**

1.25KHz:PSD(1/3 OCT. SPL) : **63.2 dB**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **None**

OPEN JET TEST SECTION : Yes

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **Atmospheric**

OPEN JET, TEST GAS : **Air**

JET LENGTH, m : **6.1** feet : **20**

MAX MEAS RADIUS, m : **6.1** feet : **20**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **None**

SUBSONIC WIND TUNNELS

FACILITY : **MIT 7.5x10 ft ELLIPSE**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS : Room 33-215

CITY : Cambridge

STATE/PROVINCE : MA

ZIP/POSTAL CODE : 02135

CONTACT : Eugene E. Covert

PHONE : (617)253-2604

TITLE : T. Wilson Professor of Aeronautics

FAX : (617)253-0051

TEST SEC. DIMENSIONS, m : 2.3x3

feet : 7.5x10

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.37

REYNOLDS NUMBER : N/A

OPERATING TEMPERATURE, C : -18 to 49

F : 0 to 120

OPERATING PRESSURE, atm : 2 atm

SHELL MATERIAL : Steel

SHELL OPERATING PRESSURE, atm : 4 atm

COOLING SYSTEM : N/A

THERMAL INSULATION, C : None

F : None

DRIVE POWER : 1000 Hp

PLENUM CARTS : None

PRESSURIZATION RATE :2atm/40 min

TEST GAS :Air

PRODUCTIVITY : 4polar/hr

OPERATING COST :$375/hr direct cost

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

FACILITY : **MIT 7.5x10 ft ELLIPSE** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **4.8lb/sec**

SUPPLY TIME : **Continuous**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **N/A** PSIA : **N/A**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **N/A** PSIA : **N/A**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.75%**

FLOW ANG, CLS'D TS DEG : **~1**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **1 F**

TURB INTENSITY, CLS'D TS% : **0.75%**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :N\A

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **Northrop 7x10 ft.**

OPERATIONAL : **Active**

COUNTRY : USA

ADDRESS : N/A

CITY : Hawthorne

STATE/PROVINCE : CA

ZIP/POSTAL CODE : 90250-3277

CONTACT : B. M. WALKER

PHONE : 310-332-3929

TITLE : N/A

FAX : N/A

TEST SEC. DIMENSIONS, m : **2.1 x 3.0** feet : **7x10**

TEST SEC. GEOMETRY : **Solid**

MACH NUMBER RANGE : **0 to 0.37**

REYNOLDS NUMBER : **2M/ft**

OPERATING TEMPERATURE, C : **16 to 38**

F : **60 to 100**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **Steel**

SHELL OPERATING PRESSURE, atm : **1 atm**

COOLING SYSTEM : **Water**

THERMAL INSULATION, C : **None**

F : **None**

DRIVE POWER : **4000 Hp electric**

PLENUM CARTS : **N/A**

PRESSURIZATION RATE : **N/A**

TEST GAS : **Air**

PRODUCTIVITY : **4 polar/occ hour**

OPERATING COST : **N/A**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **N/A**

CUSTOMERS, Military : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **Northrop 7x10 ft.** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **10 lb/sec**

SUPPLY TIME : **20 min**

SUPPLY TEMPERATURE, C : **-18 to 38** F : **0 to 100**

PUMP RATE : **2 lb/sec**

MINIMUM PRESSURE, Pa : **6.9 M** PSIA : **1000**

SFC STORAGE : **2000**

MAX STORAGE PRESS., Pa : **22M** PSIA : **3200**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.5**

FLOW ANG, CLS'D TS DEG : **0.1**

FLOW ANG DIST, CLOSED TS : **0.01**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **N/A**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :No

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

DRIVE FAN PROVISIONS : **N/A**

SUBSONIC WIND TUNNELS

FACILITY : **UTRC 18 ft OCT**

OPERATIONAL : Active

COUNTRY : USA

ADDRESS :

CITY : E. Hartford

STATE/PROVINCE : CT

ZIP/POSTAL CODE : 06108

CONTACT : Anthony Fasano

PHONE : 203-727-7275

TITLE : Manager, Test Facilities

FAX : N/A

TEST SEC. DIMENSIONS, m : 5.5 feet : 18

TEST SEC. GEOMETRY : Solid

MACH NUMBER RANGE : 0 to 0.9

REYNOLDS NUMBER : 6M/ft

OPERATING TEMPERATURE, C : Ambient to 49

F : Ambient to 120

OPERATING PRESSURE, atm : Atmospheric

SHELL MATERIAL : Concrete

SHELL OPERATING PRESSURE, atm : 1 atm

COOLING SYSTEM : Air exchange

THERMAL INSULATION, C : N/A

F : N/A

DRIVE POWER : 9000 Hp

PLENUM CARTS : N/A

PRESSURIZATION RATE : N/A

TEST GAS : Air

PRODUCTIVITY : N/A

OPERATING COST : $1500/occ hr

COSTS; REPLACEMENT : N/A

CUSTOMERS, Civilian : N/A

CUSTOMERS, Military : N/A

FACILITY : **UTRC 18 ft OCT** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : 20lb/sec

SUPPLY TIME : Continuous

SUPPLY TEMPERATURE, C : 203 F : 400

PUMP RATE : 20/lb sec

MINIMUM PRESSURE, Pa : N/A PSIA : N/A

SFC STORAGE : 15000

MAX STORAGE PRESS., Pa : 2.8M PSIA : 400

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : <1%

FLOW ANG, CLS'D TS DEG : <1

FLOW ANG DIST, CLOSED TS : <1%

TOTAL TEMP DIST,CLS'D DEG : <1 F

TURB INTENSITY, CLS'D TS% : <1%

DYN PRESS DIST, OPEN JET : N/A

FLOW ANGULAR, OPEN JET : N/A

FLOW ANG DIST, OPEN JET : N/A

TOTAL TEMP DIST, OPEN JET : N/A

TURB INTENSITY, OPEN JET : N/A

ACOUSTIC NOISE :N/A

LAMINAR TESTING : N/A

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : 138 dB

40.0KHz:PSD (1/3 OCT SPL) : N/A

OUT-of-FLOW NOISE LVL, 35 ft : N/A

1.25KHz:PSD(1/3 OCT. SPL) : N/A

40.0KHz:PSD(1/3 OCT. SPL) : N/A

DRIVE FAN PROVISIONS : N/A

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : N/A

MAX TEST PRESSURE, atm: N/A

OPEN JET, TEST GAS : N/A

JET LENGTH, m : N/A feet : N/A

MAX MEAS RADIUS, m : N/A feet : N/A

DIRECTIVITY ANGLES : N/A

CIRCUIT ACOUSTIC TREAT. : N/A

SUBSONIC WIND TUNNELS

FACILITY : **Vought 7x10 ft**

OPERATIONAL : **Active**

COUNTRY : USA

ADDRESS : N/A

CITY : Dallas

STATE/PROVINCE : TX

ZIP/POSTAL CODE : N/A

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SEC. DIMENSIONS, m : **2.1x3.0** feet : **7x10**

TEST SEC. GEOMETRY : **Solid**

MACH NUMBER RANGE : **0.035 to 0.29**

REYNOLDS NUMBER : **2M/ft**

OPERATING TEMPERATURE, C : **4 to 66**

F : **40 to 150**

OPERATING PRESSURE, atm : **Atmospheric**

SHELL MATERIAL : **Steel**

SHELL OPERATING PRESSURE, atm : **N/A**

COOLING SYSTEM : **None**

THERMAL INSULATION, C : **N/A**

F : **N/A**

DRIVE POWER : **1500 Hp electric motor**

PLENUM CARTS : **N/A**

PRESSURIZATION RATE : **N/A**

TEST GAS : **Air**

PRODUCTIVITY : **3 polar/occ hour**

OPERATING COST : **$200/polar**

COSTS; REPLACEMENT : **N/A**

CUSTOMERS, Civilian : **20**

CUSTOMERS, Military : **80**

SUBSONIC WIND TUNNELS

FACILITY : **Vought 7x10 ft** CONT'D

HIGH PRESS. AIR FOR PROP. : Yes

SUPPLY RATE : **18 lb/sec**

SUPPLY TIME : **N/A**

SUPPLY TEMPERATURE, C : **N/A** F : **N/A**

PUMP RATE : **N/A**

MINIMUM PRESSURE, Pa : **3.4 M** PSIA : **500**

SFC STORAGE : **N/A**

MAX STORAGE PRESS., Pa : **N/A** PSIA : **N/A**

FLOW QUALITY :

DYN PRESS DIST, CLOSED TS : **0.75%**

FLOW ANG, CLS'D TS DEG : **0.25**

FLOW ANG DIST, CLOSED TS : **N/A**

TOTAL TEMP DIST,CLS'D DEG : **N/A**

TURB INTENSITY, CLS'D TS% : **1.02**

DYN PRESS DIST, OPEN JET : **N/A**

FLOW ANGULAR, OPEN JET : **N/A**

FLOW ANG DIST, OPEN JET : **N/A**

TOTAL TEMP DIST, OPEN JET : **N/A**

TURB INTENSITY, OPEN JET : **N/A**

ACOUSTIC NOISE :N/A

LAMINAR TESTING : **N/A**

IN-FLOW NOISE LEVEL :

1.25KHz:PSD(1/3 OCT SPL) : **N/A**

40.0KHz:PSD (1/3 OCT SPL) : **N/A**

OUT-of-FLOW NOISE LVL, 35 ft : **N/A**

1.25KHz:PSD(1/3 OCT. SPL) : **N/A**

40.0KHz:PSD(1/3 OCT. SPL) : **N/A**

DRIVE FAN PROVISIONS : **N/A**

OPEN JET TEST SECTION : N/A

ANECHOIC CHAMBER : **N/A**

MAX TEST PRESSURE, atm: **N/A**

OPEN JET, TEST GAS : **N/A**

JET LENGTH, m : **N/A** feet : **N/A**

MAX MEAS RADIUS, m : **N/A** feet : **N/A**

DIRECTIVITY ANGLES : **N/A**

CIRCUIT ACOUSTIC TREAT. : **N/A**

TRANSONIC WIND TUNNELS

FACILITY : **Onera S2MA**

COUNTRY : **France**

ADDRESS : **Onera Centre de Modane-Aurieux-BP25**

CITY : **73500 Modane**

STATE/PROV. : **France**

ZIP/POSTAL CODE :

CONTACT : **M. Bazin**

PHONE : **(1)46-73-40-40**

TITLE : **Deputy Director, Large Testing Department**

FAX : **(1)46-73-41-44**

TEST SECTION SIZE, m : **1.77x1.75** feet: **5.8x5.7**

TEST SECTION GEOMETRY : **Rectangular**

TEST SECTION WALLS : **Solid or perforated**

MACH NUMBER RANGE : **0.15 to 1.3**

REYNOLDS No. (FULL SPAN) : **9M/ft**

(SEMI SPAN) : **12M**

OPERATING TEMP, C : **30 to 40**

F : **86 to 104**

MODEL SPAN/TUNNEL WIDTH : **0.7**

OPERATING PRESSURE, atm : **0.2 to 2.5**

SHELL MATERIAL : **Steel**

SHELL DESIGN PRESS, atm : **2.5**

INTERNALS MATERIAL : **Al and steel**

COOLING SYSTEM : **Water**

THERMAL INSULATION : **N/A**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **N/A**

TEST GAS : **Air**

DRIVE POWER : **55 MW**

PRESSURIZATION RATE : **0.2 atm/min**

FLOW QUALITY-TURBULENCE : **0.1%**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-ANGLE, deg : **N/A**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.001**

PRODUCTIVITY : **6 to 14 polar/occ hour**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **10%**

CUSTOMERS: MILITARY : **90%**

TRANSONIC WIND TUNNELS

FACILITY : **European Transonic Windtunnel GmbH**

COUNTRY : **Germany**

ADDRESS : **Post box 906116**

CITY : **D-51127 Koln**

STATE/PROV. : **Germany**

ZIP/POSTAL CODE :

CONTACT : **T. B. Saunders**

PHONE : **02203-60901**

TITLE : **Managing Director**

FAX : **02203-609124**

TEST SECTION SIZE, m : **2.0x2.4** feet: **6.6x7.9**

TEST SECTION GEOMETRY : **Rectangular**

TEST SECTION WALLS : **Slotted**

MACH NUMBER RANGE : **0.15 to 1.3**

REYNOLDS No. (FULL SPAN) : **70M/ft**

(SEMI SPAN) : **83M**

OPERATING TEMP, C : **-183 to 40**

F : **-297 to 104**

MODEL SPAN/TUNNEL WIDTH : **0.65**

OPERATING PRESSURE, atm : **1.23 to 4.4**

SHELL MATERIAL : **Stainless steel**

SHELL DESIGN PRESS, atm : **5.1**

INTERNALS MATERIAL : **Stainless Steel**

COOLING SYSTEM : **Liquid nitrogen**

THERMAL INSULATION : **Internal**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **Three**

TEST GAS : **Nitrogen**

DRIVE POWER : **50 MW**

PRESSURIZATION RATE : **1 atm/min**

FLOW QUALITY-TURBULENCE : **0.05%**

FLOW QUALITY-NOISE @ M=.8 : **0.004 Cp**

FLOW QLTY-ANGLE, deg : **0.1**

FLOW QUALITY-S.A.GRADIENT : **0.02 degree/meter**

FLOW QUALITY-MACH DISTRIB : **0.001**

PRODUCTIVITY : **5000 polar/year, 3 runs/shift**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **100%**

CUSTOMERS: MILITARY : **0%**

TRANSONIC WIND TUNNELS

FACILITY : **NAL 2x2m Transonic**

COUNTRY : Japan

ADDRESS : National Aerospace Laboratory

STATE/PROV. : Tokyo 182

CONTACT : I. Kawamoto

TITLE : Head, Transonic Wind Tunnel

CITY : 7-44-1 Jindaijihigashi-Machi Chofu-shi

ZIP/POSTAL CODE :

PHONE : N/A

FAX : 81-422-49-0793

TEST SECTION SIZE, m : 2x2 feet: 6.6x6.6

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Slotted, perforated

MACH NUMBER RANGE : 0.1 to 1.4

REYNOLDS No. (FULL SPAN) : 5M/ft

(SEMI SPAN) : 22M

OPERATING TEMP, C : 40 to 60

F : 104 to 140

MODEL SPAN/TUNNEL WIDTH : 0.6

OPERATING PRESSURE, atm : 0.39 to 1.48

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : 2.4

INTERNALS MATERIAL : N/A

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : One

TEST SECTION CARTS : Three

TEST GAS : Air

DRIVE POWER : 22.5 MW main blower and 8 MW auxiliary

PRESSURIZATION RATE : 5 kPa/min

FLOW QUALITY-TURBULENCE : 0.2%

FLOW QUALITY-NOISE @ M=.8 : 1% cprms

FLOW QLTY-ANGLE, deg : 0.09

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.003

PRODUCTIVITY : 16 polars/day

COST/POLAR: $3000

O&M COST: $11 M

REPLACEMENT VALUE: $300 M (1993)

CUSTOMERS: CIVILIAN : 92%

CUSTOMERS: MILITARY : 8%

TRANSONIC WIND TUNNELS

FACILITY : **NLR 2.0x1.8 m**

COUNTRY : **Netherlands**

ADDRESS : **P.O. Box 90502**

CITY : **1006 BM Amsterdam**

STATE/PROV. : **Netherlands**

ZIP/POSTAL CODE :

CONTACT : **Henk A. Dambrink**

PHONE : **31-0-20-5113399**

TITLE : **N/A**

FAX : **31-0-20-5113210**

TEST SECTION SIZE, m : **2.0x1.8** feet: **6.56x5.9**

TEST SECTION GEOMETRY : **Rectangular**

TEST SECTION WALLS : **Slotted**

MACH NUMBER RANGE : **0 to 1.25**

REYNOLDS No. (FULL SPAN) : **8M/ft**

(SEMI SPAN) : **12M**

OPERATING TEMP, C : **30 to 40**

F : **86 to 104**

MODEL SPAN/TUNNEL WIDTH : **0.7**

OPERATING PRESSURE, atm : **4**

SHELL MATERIAL : **Steel**

SHELL DESIGN PRESS, atm :

INTERNALS MATERIAL : **Steel**

COOLING SYSTEM : **Water**

THERMAL INSULATION : **None**

PLENUM CARTS : **None**

TEST SECTION CARTS : **None**

TEST GAS : **Air**

DRIVE POWER : **14.7 MW**

PRESSURIZATION RATE : **0.4 atm/min**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **0.9% cprms**

FLOW QLTY-ANGLE, deg : **0.2**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.01**

PRODUCTIVITY : **5 polar/occ hour**

COST/POLAR: **$500/polar**

O&M COST: **$6 M/year**

REPLACEMENT VALUE: **$50 M**

CUSTOMERS: CIVILIAN : **90%**

CUSTOMERS: MILITARY : **10%**

TRANSONIC WIND TUNNELS

FACILITY : **AEDC 16x16 ft**

COUNTRY : **USA**

ADDRESS : **100 Kindel Drive, Suite A237**

CITY : **Arnold AFB**

STATE/PROV. : **TN**

ZIP/POSTAL CODE : **37389-1327**

CONTACT : **Donald C. Daniel, PhD**

PHONE : **(615)454-7721**

TITLE : **Chief Scientist**

FAX : **N/A**

TEST SECTION SIZE, m : **4.9x4.9** feet: **16x16**

TEST SECTION GEOMETRY : **Square**

TEST SECTION WALLS : **Perforated, inclined(6% poros)**

MACH NUMBER RANGE : **0.06 to 1.6**

REYNOLDS No. (FULL SPAN) : **5.5M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **27 to 71**

F : **80 to 160**

MODEL SPAN/TUNNEL WIDTH : **0.75**

OPERATING PRESSURE, atm : **0.06 to 1.8**

SHELL MATERIAL : **Steel**

SHELL DESIGN PRESS, atm : **1.9**

INTERNALS MATERIAL : **Steel**

COOLING SYSTEM : **Water(Cryo deactivated)**

THERMAL INSULATION : **None**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **Two**

TEST GAS : **Air**

DRIVE POWER : **2-35K Hp, 2-83K Hp electric motors**

PRESSURIZATION RATE : **60 psi/hr**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **135-150 dB**

FLOW QLTY-ANGLE, deg : **<0.05**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.0004**

PRODUCTIVITY : **15 polars/air-on- hr**

COST/POLAR: **N/A**

O&M COST: **$5K/occ hr**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

TRANSONIC WIND TUNNELS

FACILITY : **AEDC 4x4 ft**

COUNTRY : USA

ADDRESS : 100 Kindel Drive, Suite A237

CITY : Arnold AFB

STATE/PROV. : TN

ZIP/POSTAL CODE : 37389-1327

CONTACT : Donald C. Daniel, PhD

PHONE : (615)454-7721

TITLE : Chief Scientist

FAX : N/A

TEST SECTION SIZE, m : 1.2x1.2 feet: 4x4

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Perforated, inclined(0-10% poros)

MACH NUMBER RANGE : 0.1 to 2.0

REYNOLDS No. (FULL SPAN) : 7M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 32 to 57

F : 90 to 135

MODEL SPAN/TUNNEL WIDTH : 0.75

OPERATING PRESSURE, atm : 0.06 to 1.6

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : Steel

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : N/A

TEST SECTION CARTS : None

TEST GAS : Air

DRIVE POWER : 2-89K Hp compressors

PRESSURIZATION RATE : 5 min

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : 145-153 dB

FLOW QLTY-ANGLE, deg : <0.1

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.003

PRODUCTIVITY : 25 polars/air-on-hr

COST/POLAR: N/A

O&M COST: $4K/ occ hr

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

TRANSONIC WIND TUNNELS

FACILITY : **AMES 11x11 ft N-227A**

COUNTRY : **USA**

ADDRESS : **Ames Research Center**

CITY : **Moffett Field**

STATE/PROV. : **CA**

ZIP/POSTAL CODE : **94035-1000**

CONTACT : **Dr. Robert Rosen**

PHONE : **(415)604-5333**

TITLE : **Assistant Director for Program Development**

FAX : **N/A**

TEST SECTION SIZE, m : **3.4x3.4** feet: **11x11**

TEST SECTION GEOMETRY : **Square**

TEST SECTION WALLS : **Solid or Slotted**

MACH NUMBER RANGE : **0.3 to 1.5**

REYNOLDS No. (FULL SPAN) : **9.4M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **21to 52**

F : **70 to 125**

MODEL SPAN/TUNNEL WIDTH : **N/A**

OPERATING PRESSURE, atm : **N/A**

SHELL MATERIAL : **Steel**

SHELL DESIGN PRESS, atm : **2.5**

INTERNALS MATERIAL : **N/A**

COOLING SYSTEM : **Water**

THERMAL INSULATION : **None**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **None**

TEST GAS : **Air**

DRIVE POWER : **180000 Hp**

PRESSURIZATION RATE : **50000 SCFM**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-ANGLE, deg : **N/A**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **N/A**

PRODUCTIVITY : **4 polar/hr**

COST/POLAR: **N/A**

O&M COST: **$6k/occ hr**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

TRANSONIC WIND TUNNELS

FACILITY : **AMES 14x14 ft N-218**

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROV. : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT : Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Development

FAX : N/A

TEST SECTION SIZE, m : 4.3x4.3 feet: 14x14

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Slotted

MACH NUMBER RANGE : 0.6 to 0.98

REYNOLDS No. (FULL SPAN) : 4.2M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : Ambient to 66

F : Ambient to 150

MODEL SPAN/TUNNEL WIDTH : N/A

OPERATING PRESSURE, atm : 1

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm :

INTERNALS MATERIAL : Steel

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : None

TEST SECTION CARTS : None

TEST GAS : Air

DRIVE POWER : 110000 Hp

PRESSURIZATION RATE : N/A

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-ANGLE, deg : N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : N/A

COST/POLAR: N/A

O&M COST: $3.5k/occ hr

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

TRANSONIC WIND TUNNELS

FACILITY : **Fluidyne 5.5x5.5 ft.**

COUNTRY : USA

ADDRESS : 5900 Olson Memorial Highway

CITY : Minneapolis

STATE/PROV. : MN

ZIP/POSTAL CODE : 55422

CONTACT : Richard Brasket

PHONE : 612-544-2721

TITLE : Vice President

FAX : 612-546-5617

TEST SECTION SIZE, m : 1.7x1.7 feet: 5.5x5.5

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Slotted

MACH NUMBER RANGE : 0 to 1.15

REYNOLDS No. (FULL SPAN) : 4.2M

(SEMI SPAN) : N/A

OPERATING TEMP, C : 38

F : 100

MODEL SPAN/TUNNEL WIDTH : N/A

OPERATING PRESSURE, atm : 1

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm :

INTERNALS MATERIAL : Al or steel

COOLING SYSTEM : None

THERMAL INSULATION : None

PLENUM CARTS : N/A

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : Air ejectors

PRESSURIZATION RATE : N/A

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-ANGLE, deg : N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : 1 polar/ occ hour

COST/POLAR: 1500

O&M COST: $1500/test

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : 80%

CUSTOMERS: MILITARY : 20%

TRANSONIC WIND TUNNELS

FACILITY : **LANGELY 8 ft**

COUNTRY : **USA**

ADDRESS : **Langley Research Center, Applied Aero Div.**

CITY : **Hampton**

STATE/PROV. : **VA**

ZIP/POSTAL CODE : **23665-5225**

CONTACT : **Blair Gloss**

PHONE : **(804)864-5113**

TITLE : **N/A**

FAX : **(804)864-5023**

TEST SECTION SIZE, m : **2.2x2.2** feet: **7.1x7.1**

TEST SECTION GEOMETRY : **Square**

TEST SECTION WALLS : **N/A**

MACH NUMBER RANGE : **0.2 to 1.4**

REYNOLDS No. (FULL SPAN) : **4.1M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **38 to 49**

F : **100 to 120**

MODEL SPAN/TUNNEL WIDTH : **N/A**

OPERATING PRESSURE, atm : **1.1 to 2**

SHELL MATERIAL : **Carbon steel**

SHELL DESIGN PRESS, atm :

INTERNALS MATERIAL : **Carbon & Stainless steel**

COOLING SYSTEM : **Water**

THERMAL INSULATION : **None**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **N/A**

TEST GAS : **Air**

DRIVE POWER : **25000 Hp**

PRESSURIZATION RATE : **30 psi/hr**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-ANGLE, deg : **0.01**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **N/A**

PRODUCTIVITY : **N/A**

COST/POLAR: **N/A**

O&M COST: **$62K/wk**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

TRANSONIC WIND TUNNELS

FACILITY : **LANGELY NTF**

COUNTRY : **USA**

ADDRESS : **Langley Research Center, Applied Aero Div.**

CITY : **Hampton**

STATE/PROV. : **VA**

ZIP/POSTAL CODE : **23665-5225**

CONTACT : **Blair Gloss**

PHONE : **(804)864-5113**

TITLE : **N/A**

FAX : **(804)864-5023**

TEST SECTION SIZE, m : **2.5x2.5** feet: **8.2x8.2**

TEST SECTION GEOMETRY : **Square**

TEST SECTION WALLS : **N/A**

MACH NUMBER RANGE : **0.2 to 1.2**

REYNOLDS No. (FULL SPAN) : **150M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **-580 to 66**

F : **-320 to 150**

MODEL SPAN/TUNNEL WIDTH : **N/A**

OPERATING PRESSURE, atm : **1 to 8.8**

SHELL MATERIAL : **Stainless steel**

SHELL DESIGN PRESS, atm : **8.8**

INTERNALS MATERIAL : **Al, Ni steel, composite**

COOLING SYSTEM : **Water & liquid nitrogen**

THERMAL INSULATION : **Yes**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **None**

TEST GAS : **Air and nitrogen**

DRIVE POWER : **120000 Hp**

PRESSURIZATION RATE : **1 psi/min**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-ANGLE, deg : **0.15**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.002**

PRODUCTIVITY : **500 polars/yr**

COST/POLAR: **N/A**

O&M COST: **$550K/yr**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

TRANSONIC WIND TUNNELS

FACILITY : **MDA-E 4x4 ft**

COUNTRY : USA

ADDRESS : N/A

CITY : St. Louis

STATE/PROV. : MO

ZIP/POSTAL CODE :

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SECTION SIZE, m : 1.2x1.2 feet: 4x4

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Porous

MACH NUMBER RANGE : 0.3 to 1.80

REYNOLDS No. (FULL SPAN) : 19M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 37.8

F : 100

MODEL SPAN/TUNNEL WIDTH : 0.5

OPERATING PRESSURE, atm : 0.6 to 6

SHELL MATERIAL : Carbon steel

SHELL DESIGN PRESS, atm :

INTERNALS MATERIAL : Al or stainless

COOLING SYSTEM : N/A

THERMAL INSULATION : None

PLENUM CARTS : One

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : N/A

PRESSURIZATION RATE : On set point in 3-5 sec.

FLOW QUALITY-TURBULENCE : 1.15%

FLOW QUALITY-NOISE @ M=.8 : 143 dB

FLOW QLTY-ANGLE, deg : 0.1

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.0015

PRODUCTIVITY : 5 polar/occ hour

COST/POLAR: 118

O&M COST: N/A

REPLACEMENT VALUE: $10 M

CUSTOMERS: CIVILIAN : 10%

CUSTOMERS: MILITARY : 90%

TRANSONIC WIND TUNNELS

FACILITY : **Rockwell 7x7 Ft.**

COUNTRY : USA

ADDRESS : N/A

CITY : N/A

STATE/PROV. : N/A

ZIP/POSTAL CODE :

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SECTION SIZE, m : 2.1x2.1 feet: 7x7

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.4 to 3.5

REYNOLDS No. (FULL SPAN) : 9M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 21

F : 70

MODEL SPAN/TUNNEL WIDTH : 0.75

OPERATING PRESSURE, atm : 2 to 7

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : Steel

COOLING SYSTEM : None

THERMAL INSULATION : None

PLENUM CARTS : One

TEST SECTION CARTS : One

TEST GAS : Air

DRIVE POWER : Blowdown (10,000 Hp Compressors)

PRESSURIZATION RATE : 25 min

FLOW QUALITY-TURBULENCE : 1.1

FLOW QUALITY-NOISE @ M=.8 : 150 dB

FLOW QLTY-ANGLE, deg : 0.18

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.003

PRODUCTIVITY : 2 polars/occ hour, 2400 polars/year

COST/POLAR: $1500/polar

O&M COST: N/A

REPLACEMENT VALUE: $70 M

CUSTOMERS: CIVILIAN : 45%

CUSTOMERS: MILITARY : 55%

TRANSONIC WIND TUNNELS

FACILITY : **Vought 4x4 ft Intermittent Blowdown**

COUNTRY : USA

ADDRESS : N/A

CITY : Dallas

STATE/PROV. : TX

ZIP/POSTAL CODE :

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SECTION SIZE, m : 1.2x1.2 feet: 4x4

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : 90 deg holes (22.5% poros)

MACH NUMBER RANGE : 0.4 to 1.8

REYNOLDS No. (FULL SPAN) : 15M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 38

F : 100

MODEL SPAN/TUNNEL WIDTH : 0.7

OPERATING PRESSURE, atm : 1.35 to 2.75

SHELL MATERIAL : Stainless steel

SHELL DESIGN PRESS, atm :

INTERNALS MATERIAL : Al or stainless

COOLING SYSTEM : None

THERMAL INSULATION : None

PLENUM CARTS : One

TEST SECTION CARTS : One

TEST GAS : Air

DRIVE POWER : 8000 Hp compressor

PRESSURIZATION RATE : 5 psi/min

FLOW QUALITY-TURBULENCE : 0.05%

FLOW QUALITY-NOISE @ M=.8 : 140 dB

FLOW QLTY-ANGLE, deg : 0.05

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.003

PRODUCTIVITY : 8 polars/occ hour

COST/POLAR: $200/polar

O&M COST: N/A

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : 10%

CUSTOMERS: MILITARY : 90%

SUPERSONIC WIND TUNNELS

FACILITY : **Onera S2MA**

COUNTRY : France

ADDRESS : Onera Centre de Modane-Avrieux-BP25

CITY : 73500 Modane

STATE/PROV. : France

ZIP/POSTAL CODE :

CONTACT : M. Bazin

PHONE : (1)46-73-40-40

TITLE : Deputy Director, Large Testing Department

FAX : (1)46-73-41-44

TEST SECTION SIZE, m : 1.93x1.75 feet: 6.3x5.7

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Solid or perforated

MACH NUMBER RANGE : 1.5 to 3.1

REYNOLDS No. (FULL SPAN) : 3.8M l=.1(sq rt S)

(SEMI SPAN) : 8.0

OPERATING TEMP, C : 30 to 40

F : 86 to 104

MODEL SPAN/TUNNEL WIDTH : 0.7

OPERATING PRESSURE, atm : 1.8

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : 2.5 atm

INTERNALS MATERIAL : Steel

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : N/A

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : 55 MW

PRESSURIZATION RATE : 0.2 atm/min

FLOW QUALITY-TURBULENCE : 0.01%

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE 0.2

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.01

PRODUCTIVITY : 1500 hrs/yr, 6 polar/occ hour

COST/POLAR: N/A

O&M COST: N/A

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : 10

CUSTOMERS: MILITARY : 90

SUPERSONIC WIND TUNNELS

FACILITY : **Onera S3MA**

COUNTRY : **France**

ADDRESS : **Onera Centre de Modane-Auleux-BP25**

CITY : **73500 Modane**

STATE/PROV. : **France**

ZIP/POSTAL CODE :

CONTACT : **M. Bazin**

PHONE : **(1)46-73-40-40**

TITLE : **Deputy Director, Large Testing Department**

FAX : **(1)46-73-41-44**

TEST SECTION SIZE, m : **0.76x0.80** feet: **2.5x2.6**

TEST SECTION GEOMETRY : **Rectangular**

TEST SECTION WALLS : **Solid**

MACH NUMBER RANGE : **3.4 to 5.5**

REYNOLDS No. (FULL SPAN) : **5 M l=.1(sq rt S)**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **15 to 350**

F : **59 to 662**

MODEL SPAN/TUNNEL WIDTH : **0.7**

OPERATING PRESSURE, atm : **7**

SHELL MATERIAL : **Steel**

SHELL DESIGN PRESS, atm : **9 atm**

INTERNALS MATERIAL : **N/A**

COOLING SYSTEM : **N/A**

THERMAL INSULATION : **N/A**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **N/A**

TEST GAS : **Air**

DRIVE POWER : **Blowdown**

PRESSURIZATION RATE : **N/A**

FLOW QUALITY-TURBULENCE : **0.25%**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-STRM ANGLE DE **0.2**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.01**

PRODUCTIVITY : **4 polar/occ hour**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **10**

CUSTOMERS: MILITARY : **90**

SUPERSONIC WIND TUNNELS

FACILITY : **DLR 0.5 m DIA Gottingen**

COUNTRY : **Germany**

ADDRESS : **Institute of Experimental Fluid Mechanics**

CITY : **Bunsenstr.10**

STATE/PROV. : **D-37073 Gottingen**

ZIP/POSTAL CODE :

CONTACT : **Dr. Paul Krogmann**

PHONE : **49(551)709-2268**

TITLE : **N/A**

FAX : **49(551)709-2889**

TEST SECTION SIZE, m : **0.5** feet: **1.6**

TEST SECTION GEOMETRY : **Circular**

TEST SECTION WALLS : **N/A**

MACH NUMBER RANGE : **5 to 6.9**

REYNOLDS No. (FULL SPAN) : **15M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **427**

F : **800**

MODEL SPAN/TUNNEL WIDTH : **N/A**

OPERATING PRESSURE, atm : **39**

SHELL MATERIAL : **N/A**

SHELL DESIGN PRESS, atm : **N/A**

INTERNALS MATERIAL : **N/A**

COOLING SYSTEM : **N/A**

THERMAL INSULATION : **N/A**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **N/A**

TEST GAS : **Air**

DRIVE POWER : **N/A**

PRESSURIZATION RATE : **N/A**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-STRM ANGLE DE **0.1**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.5**

PRODUCTIVITY : **20 polar/day**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

SUPERSONIC WIND TUNNELS

FACILITY : **DLR 0.5x0.5 m Gottingen**

COUNTRY : **Germany**

ADDRESS : **Institute of Experimental Fluid Mechanics**

CITY : **Bunsenstr.10**

STATE/PROV. : **D-37073 Gottingen**

ZIP/POSTAL CODE :

CONTACT : **Dr. Paul Krogmann**

PHONE : **49(551)709-2268**

TITLE : **N/A**

FAX : **49(551)709-2889**

TEST SECTION SIZE, m : **0.5x0.5** feet: **1.6x1.6**

TEST SECTION GEOMETRY : **Square**

TEST SECTION WALLS : **N/A**

MACH NUMBER RANGE : **2.8 to 4.5**

REYNOLDS No. (FULL SPAN) : **23M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **127**

F : **260**

MODEL SPAN/TUNNEL WIDTH : **N/A**

OPERATING PRESSURE, atm : **10**

SHELL MATERIAL : **N/A**

SHELL DESIGN PRESS, atm : **N/A**

INTERNALS MATERIAL : **N/A**

COOLING SYSTEM : **N/A**

THERMAL INSULATION : **N/A**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **Rear sting**

TEST GAS : **Air**

DRIVE POWER : **N/A**

PRESSURIZATION RATE : **N/A**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-STRM ANGLE DE **0.1**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.5**

PRODUCTIVITY : **20 polar/day**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

SUPERSONIC WIND TUNNELS

FACILITY : **DLR 0.6 m DIA H2K**

COUNTRY : Germany

ADDRESS : DLR Wind Tunnel Division

CITY : Linder Hohe

STATE/PROV. : Koln

ZIP/POSTAL CODE : D-51147

CONTACT : Helmut Esch

PHONE : (49)22036012345

TITLE : N/A

FAX : (49)22036012085

TEST SECTION SIZE, m : 0.6 feet: 2.0

TEST SECTION GEOMETRY : Circular

TEST SECTION WALLS : Free jet

MACH NUMBER RANGE : 5.3 to 11.2

REYNOLDS No. (FULL SPAN) : 6M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 1125

F : 2057

MODEL SPAN/TUNNEL WIDTH : 0.5

OPERATING PRESSURE, atm : 39

SHELL MATERIAL : Stainless steel

SHELL DESIGN PRESS, atm : 1 atm

INTERNALS MATERIAL : Mixed normal, stainless steel

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : N/A

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : Blow down, (5.0 MW heating)

PRESSURIZATION RATE : N/A

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : 12 runs/day

COST/POLAR: N/A

O&M COST: $100,000 for typical 100 run programs

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **DLR 0.6x0.6 m TMK**

COUNTRY : Germany

ADDRESS : DLR Wind Tunnel Division

CITY : Linder Hohe

STATE/PROV. : Koln

ZIP/POSTAL CODE : D-51147

CONTACT : Helmut Esch

PHONE : (49) 22036012345

TITLE : N/A

FAX : (49)22036012085

TEST SECTION SIZE, m : 0.6x0.6 feet: 2.0x2.0

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Perforated, 6% open area ratio, 30o inclined holes

MACH NUMBER RANGE : 0.5 to 4.5

REYNOLDS No. (FULL SPAN) : 24M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : Ambient to 277

F : Ambient to 464

MODEL SPAN/TUNNEL WIDTH : 0.3

OPERATING PRESSURE, atm : N/A

SHELL MATERIAL : N/A

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : N/A

COOLING SYSTEM : N/A

THERMAL INSULATION : None

PLENUM CARTS : One

TEST SECTION CARTS : Three

TEST GAS : Air

DRIVE POWER : Blow down, 1000 cubic meter at 59 atm

PRESSURIZATION RATE : N/A

FLOW QUALITY-TURBULENCE : 0.5%

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE 0.3

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.5

PRODUCTIVITY : 10 polars/day

COST/POLAR: N/A

O&M COST: $144,000 for 100 runs

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **DLR 1.2 m (HEG) Gottingen**

COUNTRY : **Germany**

ADDRESS : **Institute of Experimental Fluid Mechanics**

CITY : **Bunsenstr.10**

STATE/PROV. : **D-37073 Gottingen**

ZIP/POSTAL CODE :

CONTACT : **Dr. G. Eitelberg**

PHONE : **49(551)709-2268**

TITLE : **N/A**

FAX : **49(551)709-2889**

TEST SECTION SIZE, m : **1.2** feet: **3.9**

TEST SECTION GEOMETRY : **Circular**

TEST SECTION WALLS : **Solid**

MACH NUMBER RANGE : **7 to 10**

REYNOLDS No. (FULL SPAN) : **N/A**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **727 to 1727**

F : **1325 to 3125**

MODEL SPAN/TUNNEL WIDTH : **N/A**

OPERATING PRESSURE, atm : **2**

SHELL MATERIAL : **Stainless steel**

SHELL DESIGN PRESS, atm : **10 atm**

INTERNALS MATERIAL : **Stainless steel**

COOLING SYSTEM : **None**

THERMAL INSULATION : **None**

PLENUM CARTS : **None**

TEST SECTION CARTS : **Two**

TEST GAS : **Air, nitrogen, argon**

DRIVE POWER : **Free piston**

PRESSURIZATION RATE : **N/A**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-STRM ANGLE DE **N/A**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **N/A**

PRODUCTIVITY : **1 polar/day**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

SUPERSONIC WIND TUNNELS

FACILITY : **DLR 1m x 1m Transonic Gottingen**

COUNTRY : Germany

ADDRESS : Hauptabteilung Windkanal-Abteilung Gottingen

CITY : Bunsenstrabe 10

STATE/PROV. : Gottingen

ZIP/POSTAL CODE : D-37073

CONTACT : Dr. Fritz Lethaus

PHONE : (49) 551-709-1

TITLE : N/A

FAX : (49) 551-709-2179

TEST SECTION SIZE, m : 1x1 feet: 3.3x3.3

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Flexible laval nozzle

MACH NUMBER RANGE : 1.33 to 2.21

REYNOLDS No. (FULL SPAN) : 1.8M l=.1(sq rt S)

(SEMI SPAN) : N/A

OPERATING TEMP, C : 20 to 42

F : 68 to 107

MODEL SPAN/TUNNEL WIDTH : 0.85

OPERATING PRESSURE, atm : 0.3 to 1.48

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : N/A

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : Three

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : 12 MW

PRESSURIZATION RATE : 0.1 atm/min

FLOW QUALITY-TURBULENCE : 0.05%

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE 0.05

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.001

PRODUCTIVITY : Polar/2 min

COST/POLAR: N/A

O&M COST: $20,000/day

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **European Transonic Windtunnel GmbH**

COUNTRY : **Germany**

ADDRESS : **906116 D-51127**

CITY : **Koln**

STATE/PROV. :

ZIP/POSTAL CODE :

CONTACT : **T. B. Saunders**

PHONE : **02203-60901**

TITLE : **Managing Director**

FAX : **02203-609124**

TEST SECTION SIZE, m : **2.0x2.4** feet: **6.6x7.9**

TEST SECTION GEOMETRY : **Rectangular**

TEST SECTION WALLS : **Slotted**

MACH NUMBER RANGE : **0.15 to 1.3**

REYNOLDS No. (FULL SPAN) : **61M/ft**

(SEMI SPAN) : **83M at M=0.9**

OPERATING TEMP, C : **-183 to 40**

F : **-297 to 104**

MODEL SPAN/TUNNEL WIDTH : **0.65**

OPERATING PRESSURE, atm : **1.23 to 4.4**

SHELL MATERIAL : **Stainless steel**

SHELL DESIGN PRESS, atm : **5.1 atm**

INTERNALS MATERIAL : **Stainless Steel**

COOLING SYSTEM : **Liquid nitrogen**

THERMAL INSULATION : **Internal**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **Three**

TEST GAS : **Nitrogen**

DRIVE POWER : **50 MW**

PRESSURIZATION RATE : **1 atm/min**

FLOW QUALITY-TURBULENCE : **0.05%**

FLOW QUALITY-NOISE @ M=.8 : **0.004 Cp**

FLOW QLTY-STRM ANGLE DE **0.1**

FLOW QUALITY-S.A.GRADIENT : **0.02 degree/meter**

FLOW QUALITY-MACH DISTRIB : **0.001**

PRODUCTIVITY : **5000/year, 3 runs/shift**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **100**

CUSTOMERS: MILITARY : **0**

SUPERSONIC WIND TUNNELS

FACILITY : **NAL 2 m**

COUNTRY : Japan

ADDRESS : National Aerospace Laboratory

CITY : 7-44-1 Jindaijihigashi-Machi Chofu-shi

STATE/PROV. : Tokyo

ZIP/POSTAL CODE :

CONTACT : I. Kawamoto

PHONE : N/A

TITLE : Head, Transonic Wind Tunnel

FAX : 81-422-49-0793

TEST SECTION SIZE, m : 2x2 feet: 6.6x6.6

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Slotted, perforated

MACH NUMBER RANGE : 0.1 to 1.4

FLOW QUALITY-TURBULENCE : 1.0

REYNOLDS No. (FULL SPAN) : 6M/ft

FLOW QUALITY-NOISE @ M=.8 : N/A

(SEMI SPAN) : 22M at M=0.8

FLOW QLTY-STRM ANGLE DE 0.09

FLOW QUALITY-S.A.GRADIENT : N/A

OPERATING TEMP, C : 40 to 60

FLOW QUALITY-MACH DISTRIB : 0.003

F : 104 to 140

MODEL SPAN/TUNNEL WIDTH : 0.6

OPERATING PRESSURE, atm : 0.39 to 1.48

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : 0.1 to 2.4 atm

PRODUCTIVITY : 16 polars/day

INTERNALS MATERIAL : N/A

COST/POLAR: 3000

COOLING SYSTEM : Water

O&M COST: $11 M

THERMAL INSULATION : None

REPLACEMENT VALUE: $300 M (1993)

PLENUM CARTS : One

TEST SECTION CARTS : Three

TEST GAS : Air

DRIVE POWER : 22.5 MW main blower and 8 MW auxiliary

CUSTOMERS: CIVILIAN : 92

PRESSURIZATION RATE : 5 kPa/min for Pressurization and -2.5 kPa/min Vacuum

CUSTOMERS: MILITARY : 8

SUPERSONIC WIND TUNNELS

FACILITY : **NLR 1.2x1.2**

COUNTRY : **Netherlands**

ADDRESS :

CITY : **Amsterdam**

STATE/PROV. :

ZIP/POSTAL CODE :

CONTACT : **Henk A. Dambrink**

PHONE : **31-0-20-5113399**

TITLE : **N/A**

FAX : **31-0-20-5113210**

TEST SECTION SIZE, m : **1.2x1.2** feet: **3.94x3.94**

TEST SECTION GEOMETRY : **Rectangular**

TEST SECTION WALLS : **Solid**

MACH NUMBER RANGE : **1.3 to 4**

REYNOLDS No. (FULL SPAN) : **37M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **Ambient**

F : **Ambient**

MODEL SPAN/TUNNEL WIDTH : **0.7**

OPERATING PRESSURE, atm : **15**

SHELL MATERIAL : **Steel**

SHELL DESIGN PRESS, atm : **19 atm**

INTERNALS MATERIAL : **Steel**

COOLING SYSTEM : **None**

THERMAL INSULATION : **None**

PLENUM CARTS : **None**

TEST SECTION CARTS : **None**

TEST GAS : **Air**

DRIVE POWER : **2 x 4.5 MW Compressor, Blowdown**

PRESSURIZATION RATE : **30 min**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-STRM ANGLE DE **0.3**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.01**

PRODUCTIVITY : **2 polar/hr**

COST/POLAR: **2000**

O&M COST: **$2 M/year**

REPLACEMENT VALUE: **$25 M**

CUSTOMERS: CIVILIAN : **50**

CUSTOMERS: MILITARY : **50**

SUPERSONIC WIND TUNNELS

FACILITY : **BAe 1.22x1.22 m Blowdown, Warton**

COUNTRY : UK

ADDRESS : Warton Aerodrome

CITY : Warton Preston

STATE/PROV. : Lancashire

ZIP/POSTAL CODE : PR4 1AX

CONTACT : N. D. Davey

PHONE : (0772) 633333

TITLE : Chief Wind Tunnel Engineer

FAX : (0772) 855501

TEST SECTION SIZE, m : 1.22x1.22 feet: 4x4

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.4 to 4.0

REYNOLDS No. (FULL SPAN) : 22M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : Ambient

F : Ambient

MODEL SPAN/TUNNEL WIDTH : N/A

OPERATING PRESSURE, atm : 10

SHELL MATERIAL : N/A

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : N/A

COOLING SYSTEM : N/A

THERMAL INSULATION : N/A

PLENUM CARTS : N/A

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : Blowdown 4000 KPa (600 psi)

PRESSURIZATION RATE : N/A

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : N/A

COST/POLAR: N/A

O&M COST: N/A

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **DRA 3x4 ft Bedford High Supersonic**

COUNTRY : **UK**

ADDRESS : **DRA Bedford**

CITY : **Bedfordshire**

STATE/PROV. :

ZIP/POSTAL CODE : **MK41 6AE**

CONTACT : **John Warren**

PHONE : **(0234)225973**

TITLE : **3x4 ft Tunnel Manager**

FAX : **(0234)225848**

TEST SECTION SIZE, m : **0.9x1.2** feet: **3x4**

TEST SECTION GEOMETRY : **Rectangular**

TEST SECTION WALLS : **Solid, variable geometry throat**

MACH NUMBER RANGE : **2.5 to 5.0**

REYNOLDS No. (FULL SPAN) : **13M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **Ambient to 150**

F : **Ambient to 302**

MODEL SPAN/TUNNEL WIDTH : **N/A**

OPERATING PRESSURE, atm : **0.1 to 12**

SHELL MATERIAL : **N/A**

SHELL DESIGN PRESS, atm : **N/A**

INTERNALS MATERIAL : **N/A**

COOLING SYSTEM : **N/A**

THERMAL INSULATION : **N/A**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **Two**

TEST GAS : **Air**

DRIVE POWER : **66 MW**

PRESSURIZATION RATE : **N/A**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-STRM ANGLE DE **N/A**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **N/A**

PRODUCTIVITY : **12 min for 16 point polar**

COST/POLAR: **N/A**

O&M COST: **N/A**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

SUPERSONIC WIND TUNNELS

FACILITY : **DRA 8x8 ft Bedford**

COUNTRY : UK

ADDRESS : DRA Bedford

CITY : Bedfordshire

STATE/PROV. :

ZIP/POSTAL CODE : MK41 6AE

CONTACT : Barry Welsh

PHONE : (0234)225008

TITLE : 8x8 ft Tunnel Manager

FAX : (0234)225848

TEST SECTION SIZE, m : 2.4x2.4 feet: 8x8

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.3 to 2.5

REYNOLDS No. (FULL SPAN) : 6M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 10 to 40

F : 50 to 104

MODEL SPAN/TUNNEL WIDTH : N/A

OPERATING PRESSURE, atm : 0.1 to 3.9

SHELL MATERIAL : N/A

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : N/A

COOLING SYSTEM : YES

THERMAL INSULATION : N/A

PLENUM CARTS : N/A

TEST SECTION CARTS : Two

TEST GAS : Air

DRIVE POWER : 69 MW

PRESSURIZATION RATE : N/A

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : >24 polars/day assume

COST/POLAR: N/A

O&M COST: N/A

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **AEDC 16S**

COUNTRY : USA

ADDRESS : 100 Kindel Drive, Suite A327

CITY : Arnold AFB

STATE/PROV. : TN

ZIP/POSTAL CODE : 37389-1327

CONTACT : Donald C. Daniel, PhD

PHONE : (615)454-7721

TITLE : Chief Scientist

FAX : N/A

TEST SECTION SIZE, m : 4.9x4.9 feet: 16x16

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.6 to 4.75

REYNOLDS No. (FULL SPAN) : 2.3M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 38 to 343 possible

F : 100 to 650 possible

MODEL SPAN/TUNNEL WIDTH : 0.6

OPERATING PRESSURE, atm : 0.1 to 0.8

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : Steel

COOLING SYSTEM : Water

THERMAL INSULATION : Fiberglass pads internal

PLENUM CARTS : N/A

TEST SECTION CARTS : Three half carts

TEST GAS : Air

DRIVE POWER : 2-35K Hp, 2-83K Hp electric motors

PRESSURIZATION RATE : 0.5 psi/min

FLOW QUALITY-TURBULENCE : 0.3%

FLOW QUALITY-NOISE @ M=.8 : <131 dB

FLOW QLTY-STRM ANGLE DE 0.3

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : 6 polar/air-on-hr

COST/POLAR: N/A

O&M COST: $8000/occ hr

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **AEDC Tunnel A**

COUNTRY : USA

ADDRESS : 100 Kindel Drive, Suite A237

CITY : Arnold AFB

STATE/PROV. : TN

ZIP/POSTAL CODE : 37389-1327

CONTACT : Donald C. Daniel, PhD

PHONE : (615)454-7721

TITLE : Chief Scientist

FAX : N/A

TEST SECTION SIZE, m : 1.0x1.0 feet: 3.3x3.3

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.5 to 5.5

REYNOLDS No. (FULL SPAN) : 8.5M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 38 to 182

F : 100 to 360

MODEL SPAN/TUNNEL WIDTH : 0.65

OPERATING PRESSURE, atm : 0.4 to 10

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : Steel

COOLING SYSTEM : Water

THERMAL INSULATION : N/A

PLENUM CARTS : N/A

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : 92.5 K Hp

PRESSURIZATION RATE : 40 min

FLOW QUALITY-TURBULENCE : 0.07%

FLOW QUALITY-NOISE @ M=.8 : 101.9 dB

FLOW QLTY-STRM ANGLE DE 0.2

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.018

PRODUCTIVITY : 20 polar/air-on-hr

COST/POLAR: N/A

O&M COST: $6000/occ hr

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **AEDC Tunnel B**

COUNTRY : USA

ADDRESS : 100 Kindel Drive, Suite A237

CITY : Arnold AFB

STATE/PROV. : TN

ZIP/POSTAL CODE : 37389-1327

CONTACT : Donald C. Daniel, PhD

PHONE : (615)454-7721

TITLE : Chief Scientist

FAX : N/A

TEST SECTION SIZE, m : 1.3 feet: 4.2

TEST SECTION GEOMETRY : Circular

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 6 and 8

REYNOLDS No. (FULL SPAN) : 4.7M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 199 to 475

F : 390 to 890

MODEL SPAN/TUNNEL WIDTH : 0.55

OPERATING PRESSURE, atm : 2.7 to 58

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : Steel

COOLING SYSTEM : Water

THERMAL INSULATION : Stilling chamber

PLENUM CARTS : N/A

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : 92.5 K Hp

PRESSURIZATION RATE : 60 min

FLOW QUALITY-TURBULENCE : 0.45%

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE 0.1

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.03

PRODUCTIVITY : 20 polar/air-on-hr

COST/POLAR: N/A

O&M COST: $6000/occ hr

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **AEDC Tunnel C**

COUNTRY : **USA**

ADDRESS : **100 Kindel Drive, Suite A237**

CITY : **Arnold AFB**

STATE/PROV. : **TN**

ZIP/POSTAL CODE : **37389-1327**

CONTACT : **Donald C. Daniel, PhD**

PHONE : **(615)454-7721**

TITLE : **Chief Scientist**

FAX : **N/A**

TEST SECTION SIZE, m : **1.3** feet: **4.2**

TEST SECTION GEOMETRY : **Circular**

TEST SECTION WALLS : **Solid**

MACH NUMBER RANGE : **4,8, and 10**

REYNOLDS No. (FULL SPAN) : **7.8M/ft**

(SEMI SPAN) : **N/A**

OPERATING TEMP, C : **1060**

F : **1440**

MODEL SPAN/TUNNEL WIDTH : **0.55**

OPERATING PRESSURE, atm : **13.6 to 129**

SHELL MATERIAL : **Steel**

SHELL DESIGN PRESS, atm : **N/A**

INTERNALS MATERIAL : **Steel**

COOLING SYSTEM : **Water**

THERMAL INSULATION : **Stilling chamber**

PLENUM CARTS : **N/A**

TEST SECTION CARTS : **N/A**

TEST GAS : **Air**

DRIVE POWER : **92.5 K Hp**

PRESSURIZATION RATE : **80 min**

FLOW QUALITY-TURBULENCE : **N/A**

FLOW QUALITY-NOISE @ M=.8 : **N/A**

FLOW QLTY-STRM ANGLE DE **0.12**

FLOW QUALITY-S.A.GRADIENT : **N/A**

FLOW QUALITY-MACH DISTRIB : **0.07**

PRODUCTIVITY : **10 polar/air-on-hr**

COST/POLAR: **N/A**

O&M COST: **$6000/occ hr**

REPLACEMENT VALUE: **N/A**

CUSTOMERS: CIVILIAN : **N/A**

CUSTOMERS: MILITARY : **N/A**

SUPERSONIC WIND TUNNELS

FACILITY : **AMES 8x7 ft N-227C**

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROV. : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT : Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Development

FAX : N/A

TEST SECTION SIZE, m : 2.4x2.1 feet: 8x7

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 2.5 to 3.5

REYNOLDS No. (FULL SPAN) : 5.2M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 21 to 60

F : 70 to 140

MODEL SPAN/TUNNEL WIDTH : N/A

OPERATING PRESSURE, atm : N/A

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : 2.5

INTERNALS MATERIAL : Steel

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : None

TEST SECTION CARTS : None

TEST GAS : Air

DRIVE POWER : 180000 Hp

PRESSURIZATION RATE : 50000 SCFM

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : 1 polar/30 min

COST/POLAR: N/A

O&M COST: $7000/occ hr

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **AMES 9x7 ft N-227B**

COUNTRY : USA

ADDRESS : Ames Research Center

CITY : Moffett Field

STATE/PROV. : CA

ZIP/POSTAL CODE : 94035-1000

CONTACT : Dr. Robert Rosen

PHONE : (415)604-5333

TITLE : Assistant Director for Program Development

FAX : N/A

TEST SECTION SIZE, m : 2.7x2.1 feet: 9x7

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.55 to 2.5

REYNOLDS No. (FULL SPAN) : 6.5M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : N/A

F : N/A

MODEL SPAN/TUNNEL WIDTH : N/A

OPERATING PRESSURE, atm : N/A

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : 2.5

INTERNALS MATERIAL : N/A

COOLING SYSTEM : Water

THERMAL INSULATION : None

PLENUM CARTS : None

TEST SECTION CARTS : None

TEST GAS : Air

DRIVE POWER : 180000 Hp

PRESSURIZATION RATE : 50000 SCFM

FLOW QUALITY-TURBULENCE :

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : 1 polar/30 min

COST/POLAR: N/A

O&M COST: $7000/occ hr

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **Fluidyne 5.5x5.5 ft.**

COUNTRY : USA

ADDRESS : 5900 Olson Memorial Highway

CITY : Minneapolis

STATE/PROV. : MN

ZIP/POSTAL CODE : 55422

CONTACT : Richard Brasket

PHONE : 612-544-2721

TITLE : Vice President

FAX : 612-546-5617

TEST SECTION SIZE, m : 1.7x1.7 feet: 5.5x5.5

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Slotted

MACH NUMBER RANGE : 0 to 1.15

REYNOLDS No. (FULL SPAN) : 8M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 38

F : 100

MODEL SPAN/TUNNEL WIDTH : N/A

OPERATING PRESSURE, atm : 1

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : 1 atm

INTERNALS MATERIAL : Al on steel

COOLING SYSTEM : None

THERMAL INSULATION : None

PLENUM CARTS : N/A

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : Air ejectors

PRESSURIZATION RATE : N/A

FLOW QUALITY-TURBULENCE : N/A

FLOW QUALITY-NOISE @ M=.8 : N/A

FLOW QLTY-STRM ANGLE DE N/A

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : N/A

PRODUCTIVITY : 1 polar/occ hour

COST/POLAR: N/A

O&M COST: $1500/test

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : N/A

CUSTOMERS: MILITARY : N/A

SUPERSONIC WIND TUNNELS

FACILITY : **MDA-E 4x4 ft**

COUNTRY : USA

ADDRESS : N/A

CITY : N/A

STATE/PROV. : N/A

ZIP/POSTAL CODE : N/A

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SECTION SIZE, m : 1.2x1.2 feet: 4x4

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Porous

MACH NUMBER RANGE : 0.3 to 5.5

REYNOLDS No. (FULL SPAN) : 48M

(SEMI SPAN) : N/A

OPERATING TEMP, C : 38

F : 100

MODEL SPAN/TUNNEL WIDTH : 0.5

OPERATING PRESSURE, atm : 0.6 to 27

SHELL MATERIAL : Carbon steel

SHELL DESIGN PRESS, atm : 2 atm

INTERNALS MATERIAL : Al or stainless

COOLING SYSTEM : N/A

THERMAL INSULATION : None

PLENUM CARTS : One

TEST SECTION CARTS : N/A

TEST GAS : Air

DRIVE POWER : N/A

PRESSURIZATION RATE : On set point in 3-5 sec.

FLOW QUALITY-TURBULENCE : 1.15

FLOW QUALITY-NOISE @ M=.8 : 143 dB

FLOW QLTY-STRM ANGLE DE 0.1

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.0015

PRODUCTIVITY : 2 min for polar (30deg)

COST/POLAR: 677

O&M COST: N/A

REPLACEMENT VALUE: $35 M

CUSTOMERS: CIVILIAN : 10

CUSTOMERS: MILITARY : 90

SUPERSONIC WIND TUNNELS

FACILITY : Rockwell 7x7 ft.

COUNTRY : USA

ADDRESS : N/A

CITY : N/A

STATE/PROV. : N/A

ZIP/POSTAL CODE :

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SECTION SIZE, m : 2.1x 2.1 feet: 7x 7

TEST SECTION GEOMETRY : Square

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.4 to 3.5

REYNOLDS No. (FULL SPAN) : 19M/ft

(SEMI SPAN) : 19M/ft

OPERATING TEMP, C : 21

F : 70

MODEL SPAN/TUNNEL WIDTH : 0.75

OPERATING PRESSURE, atm : 2 to 7

SHELL MATERIAL : Steel

SHELL DESIGN PRESS, atm : N/A

INTERNALS MATERIAL : Steel

COOLING SYSTEM : None

THERMAL INSULATION : None

PLENUM CARTS : One

TEST SECTION CARTS : One

TEST GAS : Air

DRIVE POWER : Blowdown (10,000 HP Compressors)

PRESSURIZATION RATE : 25 min

FLOW QUALITY-TURBULENCE : 1.1

FLOW QUALITY-NOISE @ M=.8 : 150 dB

FLOW QLTY-STRM ANGLE DE 0.18

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.003

PRODUCTIVITY : 2 polars/occ hr, 2400 polars/year

COST/POLAR: 1500

O&M COST: N/A

REPLACEMENT VALUE: $70 M

CUSTOMERS: CIVILIAN : 45

CUSTOMERS: MILITARY : 55

SUPERSONIC WIND TUNNELS

FACILITY : **Vought 4x4 ft**

COUNTRY : USA

ADDRESS : N/A

CITY : Dallas

STATE/PROV. : TX

ZIP/POSTAL CODE : N/A

CONTACT : N/A

PHONE : N/A

TITLE : N/A

FAX : N/A

TEST SECTION SIZE, m : 1.2x1.2 feet: 4x4

TEST SECTION GEOMETRY : Rectangular

TEST SECTION WALLS : Solid

MACH NUMBER RANGE : 1.6 to 4.8

REYNOLDS No. (FULL SPAN) : 34M/ft

(SEMI SPAN) : N/A

OPERATING TEMP, C : 38

F : 100

MODEL SPAN/TUNNEL WIDTH : 0.7

OPERATING PRESSURE, atm : 1.7 to 23

SHELL MATERIAL : Stainless steel

SHELL DESIGN PRESS, atm : 30 atm

INTERNALS MATERIAL : Al & stainless

COOLING SYSTEM : None

THERMAL INSULATION : None

PLENUM CARTS : N/A

TEST SECTION CARTS : One

TEST GAS : Air

DRIVE POWER : 8000 Hp compressor

PRESSURIZATION RATE : 5 psi/min

FLOW QUALITY-TURBULENCE : 0.12%

FLOW QUALITY-NOISE @ M=.8 : 140 dB

FLOW QLTY-STRM ANGLE DE 0.05

FLOW QUALITY-S.A.GRADIENT : N/A

FLOW QUALITY-MACH DISTRIB : 0.003

PRODUCTIVITY : 8 polars/occ hour

COST/POLAR: 2000

O&M COST: N/A

REPLACEMENT VALUE: N/A

CUSTOMERS: CIVILIAN : 10

CUSTOMERS: MILITARY : 90

APPENDIX 1: CONDUCTING THE SURVEY

Aeronautical wind tunnels have been the subject of almost continuous attention by some study group, facilities upgrade analysis or the National Research Council for the last 10 years. When this benchmarking task was initiated, there was an assumption made that it could be acomplished by gathering up the reports from these efforts and conduct a benchmarking process. However, the task was much more involved because few of the past efforts focused on the comprehensive compilation of wind tunnel operating capability necessary to conduct a benchmark. Therefore, the completion of the assigned task required the process start at the beginning with gathering of the data.

The data request, included below in full, was prepared as a broad area survey covering subsonic, transonic and supersonic wind tunnels. It was mailed to the owners (or operators) of all known wind tunnels meeting the cutoff criteria in the western world.

The addressees are listed in Appendix 2.

Here is a sample of the request.

UNITED TECHNOLOGIES
PRATT&WHITNEY

400 Main Street,
East Hartford, Connecticut 06108

PH: (203) 565-1060
FAX: (203) 565-0168

Ref:WLW.93168

September 1, 1993

European Transonic Windtunnel
Postfach 90 61-16
D-51127 Koln
Germany

Attention: Mr. Joachim Krengel
Head of Transonic Windtunnel

Dear Mr. Krengel:

The National Aeronautics and Space Administration, in partnership with the Department of Defense, is conducting a study of Aeronautical Facilities.

One element of this study is an attempt to benchmark existing facilities to identify the capability of existing wind tunnels that could serve as a reference for future users and as a baseline for any future wind tunnels.

I have been selected to lead the benchmarking effort part of this task, and need your cooperation and assistance in completing this assignment. Because of the vast number of facilities that exist, we are limiting the first part of the effort to what may be described as large wind tunnels and propulsion test facilities. The parameters describing "large" are listed below in Table 1.

Table 1
Parameters defining "Large" Aeronautical Test Facilities

Speed Range		Minimum Test Section Size
Subsonic	(Mach less than 1)	6 feet
Transonic	(Mach range 0.1 to 1.5 approx.)	4 feet
Supersonic	(Mach 1.2 to 3.5)	2 feet
	(Mach 3.5 to 5.0)	1 foot

Your cooperation in making this wind tunnel benchmark as complete as possible will be appreciated.

When responding with the operating characteristics of your facilities, please provide those test conditions that can be achieved under normal operating conditions. This request is for data that you would expect to divulge to the public. It is not a request for **private** or **proprietary** information and it would be appreciated if none were submitted.

The parameters of interest are listed on Attachment 1 for Subsonic Tunnels and Attachment 2 for Transonic Tunnels. The values given under the baseline column are for illustrative purposes only to communicate the desired parametric response. I would appreciate similar responses for supersonic test facilities, also.

If you wish to express your facility capability in other parameters, please do so. There is no example shown for "user cost" because so many different basis's are used in charging users to conduct tests. Some more common are $/month, $/run hour, $/occupancy hour, etc. However, if possible, it would be appreciated if the collective response for a wind tunnel could result in cost/polar generated. It would also be helpful if these costs were expressed on the basis of what you would charge a foreign-based customer. Sometimes polars/hour is not an adequate measure of comparing one facility to another. If you would also estimate annual productivity (polars/year) for a variety of test types and assuming a fully utilized facility, it would be helpful.

Partial responses will be appreciated where complete responses are not possible or practical.

If you could provide the requested data by October 15, 1993, it would be appreciated.

Best Regards,

UNITED TECHNOLOGIES CORPORATION
Pratt & Whitney

William L. Webb, lct

William L. Webb
Vice President, Advanced Engine Programs

Attachments
/lct

REQUIREMENTS

LOW SPEED WIND TUNNEL

	Facility Baseline
Test section size	16 x 20 feet
Test section geometry	Solid wall
Mach Number range	0 – 0.60
Operating temperature	–100°F to 110°F
Operating pressure	.03 to 5 atm
Shell operating pressure	.03 to 5 atm
Shell material	Stainless steel
Internals material	Aluminum or stainless
Cooling system	Water cooled and refrigerant
Thermal insulation	–100°F temperature
Drive power	M=0.3; 5 atm
Plenum carts	One
Test section carts	1 Rear sting; 2 floor mounts; 1 ground belt/rear sting
Pressurization rate	5 atm in 25 minutes
Test gas	Provide heavy gas
Productivity	5 polars/occupancy hour
Operating cost	

Attachment 1

JP2568L,09/01/93

REQUIREMENTS

LOW SPEED WIND TUNNEL

	Facility Baseline	
High pressure air for propulsion		
Supply rate	150 lb/sec	
Supply time	1500 sec/40 min	
Supply temperature	700°F	
Pump rate	63 lb/sec	
Minimum pressure	3000 psia	
SCF storage	As required	
Maximum storage pressure	4500 psia	
Flow quality	Closed T.S.	Open jet
Dynamics pressure distribution	±0.1	±0.2
Flow angularity	<±0.10°	±0.1
Flow angularity distribution	±0.01°	
Total temperature distribution	±0.50°F	±0.50°F
Turbulence intensity, %	Longitudinal: 0.04	0.2
	Lateral: 0.08	0.12
	Vertical: 0.08	0.12
Acoustic noise		
Laminar testing (PSD, pressure distribution level)	86 dB @ 10 HZ 76 dB @ 1K HZ to 40K HZ	

Attachment 1
(Continued)

ACOUSTIC REQUIREMENTS

LOW SPEED WIND TUNNEL

	Facility Baseline
Background noise level, M = 0.30	
o In–flow noise level	
1.25K HZ: PSD (1/3 octave SPL)	59.4 dB (84.0 dB)
40.0K HZ: PSD (1/3 octave SPL)	27.4 dB (67.0 dB)
o Out–of–flow noise level, (35 feet)	
1.25K HZ: PSD (1/3 octave SPL)	47.9 dB (72.5 dB)
40.0K HZ: PSD (1/3 octave SPL)	10.4 dB (50.0 dB)
Open jet test section	Yes
Anechoic chamber	100 HZ cutoff frequency
Maximum test pressure	1 atm absolute
Test gas	Air only
Jet length	35 feet
Maximum measurement radius	35 feet
Directivity angles	60 degrees forward, 50 degrees aft 180 degrees radially
Circuit acoustic treatment	Fan nacelle First and fourth turning vane sets
Drive fan provisions	Low noise fan design (Low tip speed, Variable incidence blades, Proper IGV/rotor/stator spacing)

Attachment 1
(Continued)

BASELINE REQUIREMENTS

TRANSONIC WIND TUNNEL

	Baseline
Test section size	11 x 15.5 feet
Test section geometry	Rectangular
Test section walls	Slotted
Mach Number	0 to 1.6
Reynolds No. (full span)	50M @ M = 0.9
Reynolds No. (semi–span)	70M @ M = 0.9
Operating temperature	Nominal 100°F @ M = 1.0
Operating pressure	0.1 to 5 atm
Shell material	Stainless steel
Shell design pressure	8 atm
Internals material	Aluminum or stainless
Cooling system	Water
Thermal insulation	None (allowance in shell dimensions)
Drive power	Max Rn @ M = 1.0, 5 atm
Plenum carts	One
Test section carts	At least one
Pressurization rate	0.1 atm/min
Test gas	Air
Model span/tunnel width	0.85
Productivity	1.75 min for 25 point polar (30 degrees)

Attachment 2

BASELINE REQUIREMENTS
TRANSONIC WIND TUNNEL

	Baseline
Flow quality	
Turbulence	.12% rms
Noise @ M = 0.8	95 dB
Stream angle	.1 degree
Stream angle gradient	.01 degree/foot
Mach distribution	.001

Attachment 2

APPENDIX 2: WIND TUNNEL SURVEY LISTING

The survey was conducted in three parts. The first was a request to USG facilities of NASA and DoD. This was the first report as an attempt to "test" the approach and assure clarity in purpose when conducting the wider survey. Second, a short "form request" was made of operators of wind tunnels known to be used in support of commercial airplane development to support an interim report of the National Facilities Task group. Third, was the all encompassing survey to gather as much data as available in support of a worldwide wind tunnel benchmarking task.

Wind tunnels located in the former USSR were not included in this survey due to the inability of the benchmarking working group to acquire a high confidence address list for the operators. There are highly capable wind tunnels located there, some being used by western firms so it was not to imply lack of interest. When the survey returns were in, we found that some listed wind tunnels had been deactivated and there are probably others not included because of the lack of knowledge on the part of the working group.

The list of wind tunnels survey in any of the three above listed steps were:

National Aerospace Laboratory Center
21000 Brookpark Road, M/S 3-6
Cleveland, OH 44135

Attention: Dr. David J. Poferl
Director of Technical Services

Flight Performance Division
7-44-1, Jinaiji Higashi-machi
Chofu-shi, Tokyo 182

Attention: Mr. Iwao Kawamoto
Chief of Transonic Wind Tunnel Facility

National Aerospace Laboratory
Flight Performance Division
7-44-1, Jindaiji Higashi-machi
Chofu-shi, Tokyo 182

Attention: Mr. Yoshio Hayashi
Chief of Low Speed Wind Tunnel Facility

Deutschce Forschungsanstalt Fuer Luft
Bunsenstrasse 10
D-37073 Goettingen
Germany

Attention: Dr. Fritz Lehthaus
Head of NWG

Office National D'Etudes Et De Recherche
BP25
73500 Modane
France

Attention: Mr. Jean Laverre
Chief of Center

Defense Research Agency
Building 17
Clampham Bedford MK416AE
England

Attention: Mr. Stewart Buckingham
Head of High Speed Aero Division

Office National D'Etudes Et De Recherche
29, Avenue De La Division Leclerc
F-92322 Chatillon C
France

Attention: Mr. Jean-Marie Carrara
Chief of CFM

/WLW.93211

Von Karman Institute for Fluid Dynamics
Chaussee De Waterloo, 72
B-1640 Rhode Saint GENASA
Belgium

Attention: Professor Mario Carbonaro

Deutsche Forschoungsanstalt Fuer Luft
Flughafen
D-38110 Braunschweig
Germany

Attention: Dr. Gerhard Kausche
Head of Wind Tunnels, Braunschweig

National Lucht-en Ruimtevaartiaboratorium
Anthony Fokkerweg 2
1059 CM AMSTERDAM
Netherlands

Attention: Mr. F. Jaarsma
Chief, Aerodynamics Facilities - Low Speed

National Lucht-en Ruimtevaartlaboratorium
P.O. Box 175
8300 AD Emmeloord
Netherlands

Attention: Professor Dr. Ing. H.U. Meier
General Director - Low Speed Wind Tunnel

BAE Warton Aerodrome
Preston, Lancashire PR4 1AX
England

Attention: Mr. Nigel Davey
Chief Wind Tunnel Engineer

National Lucht-en Ruimtevarrtlaboratorium
Anthony Fokkerweg 2
1059 CM AMSTERDAM
Netherlands

Attention: Mr. H. A. Dambrink
Chief, Aerodynamics Facilities

RAE Farnborough
Royal Aerospace
Farnborough, Hampshire GU14 6TD
England

Attention: Dr. David Woodward
Head of L.S. Aero Division

/WLW.93211

British Aerospace
P.O. Box 77 Filton House
Filton, Bristol, Avon BS99
England

Attention: Mr. Mike Marsden
Manager, Aerodynamic Laboratories

Fluidyne Engineering Corp.
5900 Olson Memorial Highway
Minneapolis, MN 55422

Attention: Mr. Richard Brasket
Vice President - Aero Test

CALSPAN CORPORATION
P.O. Box 400
Buffalo, NY 14225

Attention: Mr. Michael DiDuro
Head of Transonic Wind Tunnel

Boeing Commercial Airplane Group
P.O. Box 3707, Mail Stop 6R-MT
Seattle, WA 98124

Attention: Mr. Richard A. Day
Director, Engineering Laboratory

NASA Ames Research Center
M/S 200-1A
Moffett Field, CA 94035

Attention: Dr. Robert Rosen
Assistant Director for Program Development

NASA Langley Research Center
M/S 285
Hampton, VA 23681-0001

Attention: Mr. Blair B. Gloss
Assistant Chief to the Applied Aerodynamics Division

Arnold Engineering Development Center
100 Kindel Drive, Suite A327
Code AEDC/CA
Arnold Air Force Base, TN 37389-1327

Attention: Dr. Donald C. Daniel
Chief Scientist

/WLW.93211

Massachusetts Institute of Technology
77 Massachusetts Avenue, Room 33-215
Cambridge, MA 02139

Attention: Dr. Eugene E. Covert
T. Wilson Professor of Aeronautics

United Technologies Research Center
Silver Lane, Mail Stop 129-4
East Hartford, CT 06108

Attention: Mr. John F. Cassidy, Jr.
Director, United Technologies Research Center

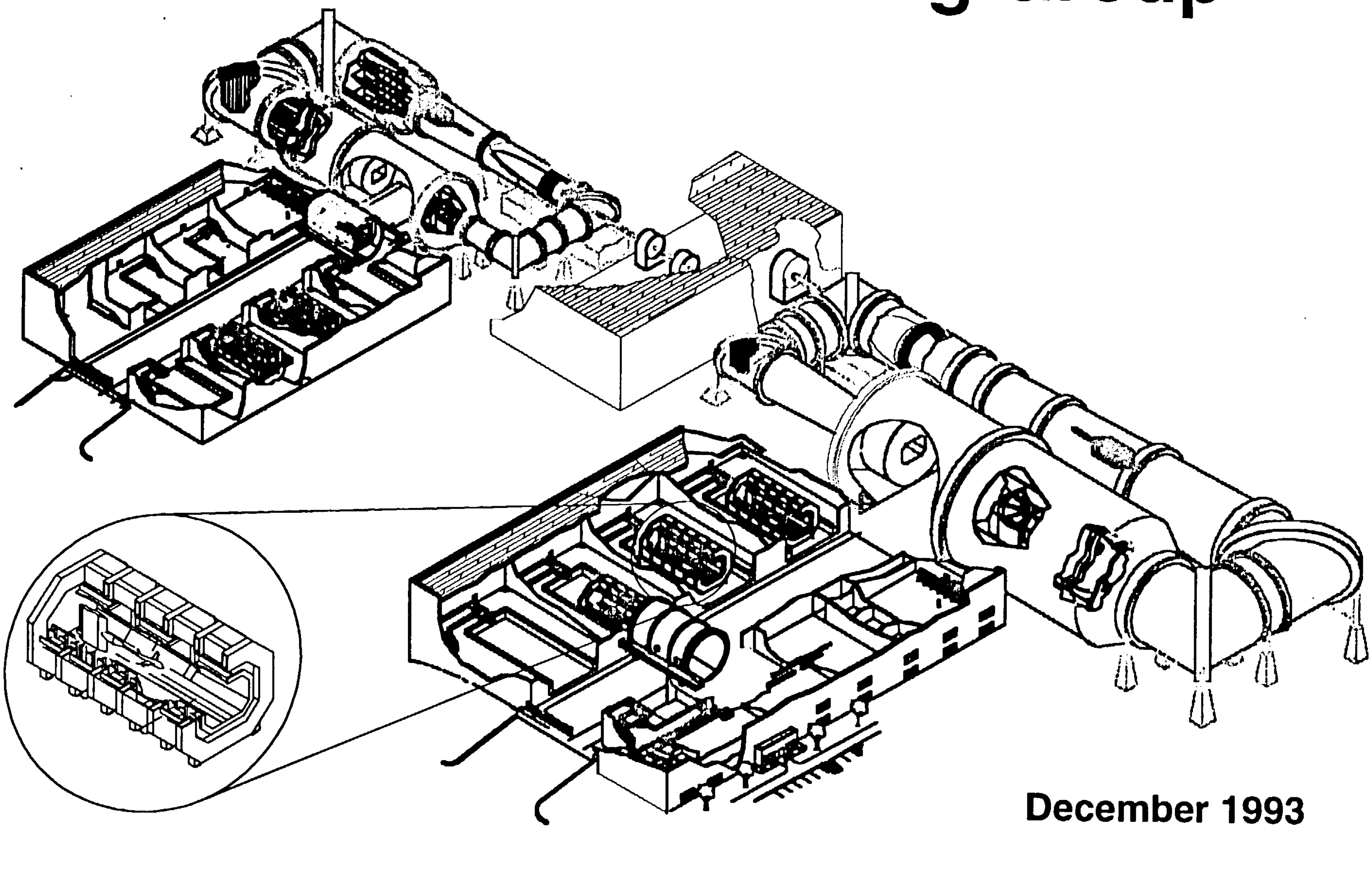
/WLW.93211

Appendix 3

Report of the Aerodynamics and Acoustics Working Group

Office of Aeronautics
National Aeronautics and Space Administration

Report of the Aerodynamics and Aeroacoustics Working Group



December 1993

Report of the Aerodynamics and Aeroacoustics Working Group

This report presents the accomplishments of the Aerodynamics and Aeroacoustics Working Group which, after reviewing the needs of U.S. aircraft manufacturers, and assessing the capabilities of other countries, determined the national requirements for wind tunnel testing. The conclusions and recommendations of the working group reflect the consensus of both government and industry officials and addresses the projected needs of both civil and military aviation for the next 30 years.

This working group furnished its findings and recommendations to the Aeronautics R&D Facilities Task Group and provided guidance in support of the cost estimating efforts. The Aeronautics and Aeroacoustic Working Group was chaired by Mr. Louis Williams, Director of the High-Speed Research Division, Office of Aeronautics, NASA Headquarters, and co-chaired by Dr. Lynn Laster, Arnold Engineering Development Center, United States Air Force.

Office of Aeronautics
National Aeronautics and Space Administration

Report of the Aerodynamics and Aeroacoustics Working Group

Louis Williams - Chairman
Lynn Laster - Deputy Chairman

Outline

This report reviews the information developed by the working group and contains an assessment of the current capabilities of available wind tunnel facilities and the needs of the U.S. aerospace industry. In order to meet those needs the working group assessed the potential for modifying existing wind tunnels and then identified those requirements which could only be met with the construction of new facilities.

Subsonic and transonic wind tunnels fulfill the majority of testing requirements, however, supersonic wind tunnel testing does have a critical role to fill. Facility development and test techniques for supersonic testing and evaluation were found to be insufficiently mature to warrant major facility development. The working group thus treated supersonic wind tunnel testing in a different manner identifying the associated research and development needs.

Outline

- Working group charter & membership
- Current subsonic & transonic capability
- National needs
- Potential for modifications
- New capabilities
- Supersonic wind tunnels
- Summary

Aerodynamics/Aeroacoustics Working Group

Charter

The charter under which the working group operated was to identify the national needs for wind tunnel testing for the next 30 years and to find the best means of meeting those needs. Specific areas for review were aerodynamic and aeroacoustic requirements. The working group was to address this issue from a national perspective including government and industry needs and with specific attention placed on the health of aircraft and engine manufacturers and their ability to enhance the quality their products.

The group was also requested to evaluate existing wind tunnel facilities to assess the potential of saving money by identifying facilities for closure particularly in light of the construction of new facilities. Closure in this context refers to a range of possible actions such as reduced number of operating hours (even to zero) or actually putting the facility in an extended standby mode ("mothballs"). The information gather by the working group was provided to the Aeronautics R&D Facilities Task Group report and is presented as part of their report.

With regard to the above, the group was asked to recommend a plan for implementation including specifics on technical approach, location of new facilities, schedule and cost estimates.

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Charter

- Address future aerodynamics and aeroacoustics national facility requirements
- Define national needs not being met
- Identify redundant / marginal capability
- Recommend a plan to address both of above
  - Technical approach
  - Location options
  - Timing
  - Cost

Aerodynamics/Aeroacoustics Working Group

Membership

In order to assure a quality assessment by the working group, the above membership roster was developed. The group included experts from government and industry. The government representatives were from the NASA and the Department of Defense (Air Force and Navy) installations where wind tunnel testing is conducted. The industry members included both civil and military aircraft manufacturers. Specifically included were: The Boeing Commercial Airplane Co., McDonnell Douglas Aerospace Transport Aircraft Unit, Northrop, Lockheed, and General Electric Aircraft Engine Co.

Aerodynamics/Aeroacoustics Working Group
Membership

Louis J. Williams, Chairman
Director, High Speed Research
NASA Headquarters

Dr. Lynn Laster, Deputy Chairman
Arnold Engineering Development Center

Suey T. Yee / Bill Eckert, Exec. Sec.
Program Manager
NASA Headquarters

Zachary T. Applin
Subsonic Aerodynamics Branch, AAD
NASA Langley Research Center

Ed Glasgow
Lockheed

Nancy Bingham
Manager 12 ft Wind Tunnel Project
Ames Research Center

Cmdr. Joe Chlebanowski
Commander
Naval Surface Warfare Center

Dr. John W. Davis
Vice Pres. & General Manager
CALSPAN Corp.
Arnold Engineering Development Center

Richard A. Day
Director, Engineering Labs.
Boeing Commercial Airplane Co.

Art Fanning
Boeing Commercial Airplane Co.

Heinz Gerhardt
Northrop

Blair B. Gloss
Assistant Chief, AAD
NASA Langley Research Center

E. Dabney Howe
Manager, LO & WT Models
Northrop

Frank T. Lynch
Manager, Flight Performance
McDonnell Douglas Aerospace-Transport Aircraft Unit

Donald P. McErlean
Head, Air Vehicle & Crew System Department .
Naval Air Warfare Center

Luis R. Miranda
Manager Flight Sciences Div.
Lockheed

L. Presley
Chief, Aerodynamics Div.
Ames Research Center

William C. Stamper
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NASA Headquarters

Lewis E. Surber
Technical Manager
Wright Laboratory

Dr. James C. Y. Yu
Assistant Chief, Acoustic Div.
NASA Langley Research Center

Bobby T. Delaney
GE Aircraft Engines

Current Capabilities

In this section major subsonic and transonic wind tunnels from around the world are compared for their capabilities, including how well they simulate flight conditions and their productivity for providing the required data. The age of NASA facilities and a listing of the premier European wind tunnels are also presented.

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Current Capabilities

Major Subsonic Tunnels

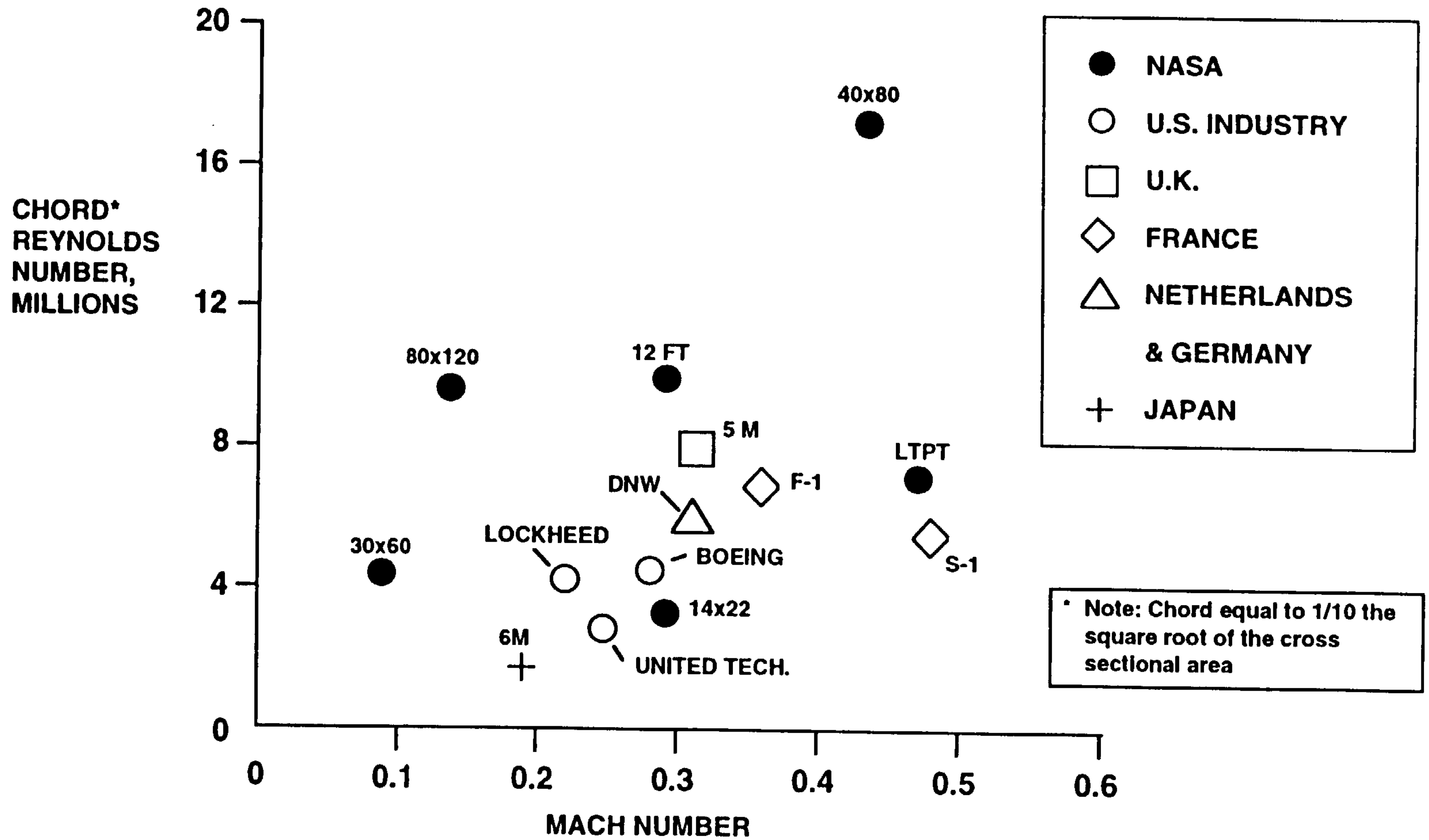
The “goodness” of a wind tunnel is measured in a number of ways. One measure is the ability to simulate the flight environment of an aircraft. This is measured by both a Mach number and a Reynolds number. The Mach no. is a parameter for scaling the velocity while the Reynolds no. indicates the scaling parameter required to simulate both the size and the speed of the final product.

In order to assure a valid comparison of the wind tunnel’s size, the chord of a notional aircraft model was set at one-tenth of the square root of the test section area when calculating the Reynolds number.

$$\text{Reynolds no.} = \frac{\text{Velocity} \bullet \text{Chord} \bullet \text{Density}}{\text{Viscosity}}$$

$$\text{Mach no.} = \frac{\text{Velocity}}{\text{Speed of Sound}}$$

Major Subsonic Tunnels



Productivity - Low Speed Wind Tunnel, LSWT

Another means of measuring the value of a wind tunnel facility is its productivity. In this case productivity is measured by polars* per occupancy hour. The greater the quantity of data that can be measured during the time that a model is installed and occupying the facility, the more cost effective the test will be to the customer.

This chart depicts the three highest rated tunnels (by industry) for high-Reynolds number low-speed testing. Over the past few years the Ames 12 ft. tunnel has been under reconstruction and the primary industry users have conducted their testing in the French, ONERA F-1 facility at Le Fauga and at the DRA 5 meter facility at Farnborough, United Kingdom.

* In normal 'production' wind tunnel testing, the data is collected over a range of attitudes of the airplane model (angle-of-attack). The lift and drag forces are measured over that range of angle-of-attack, typically 20 data points, and when plotted the resulting curve is referred to as the lift-drag polar.

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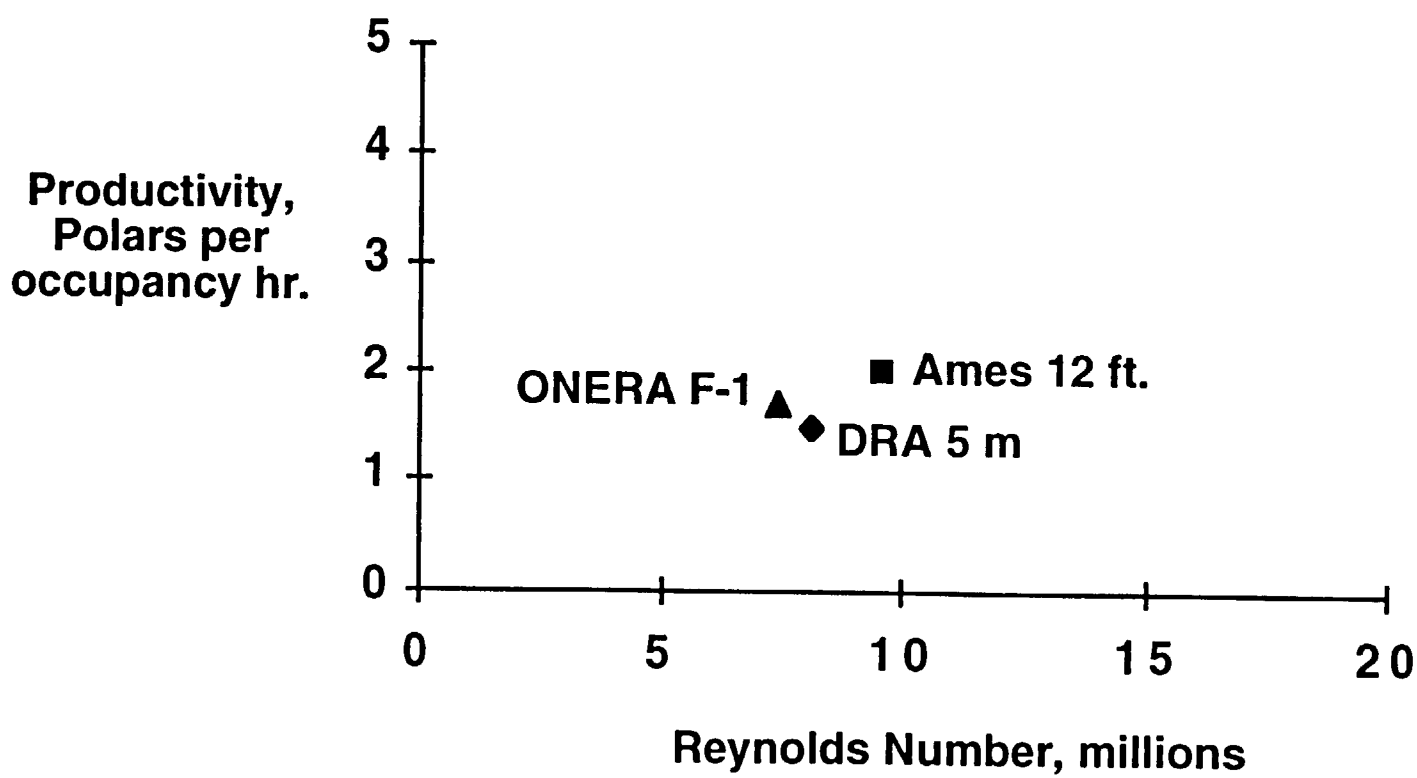
Productivity - Low Speed Wind Tunnel, LSWT



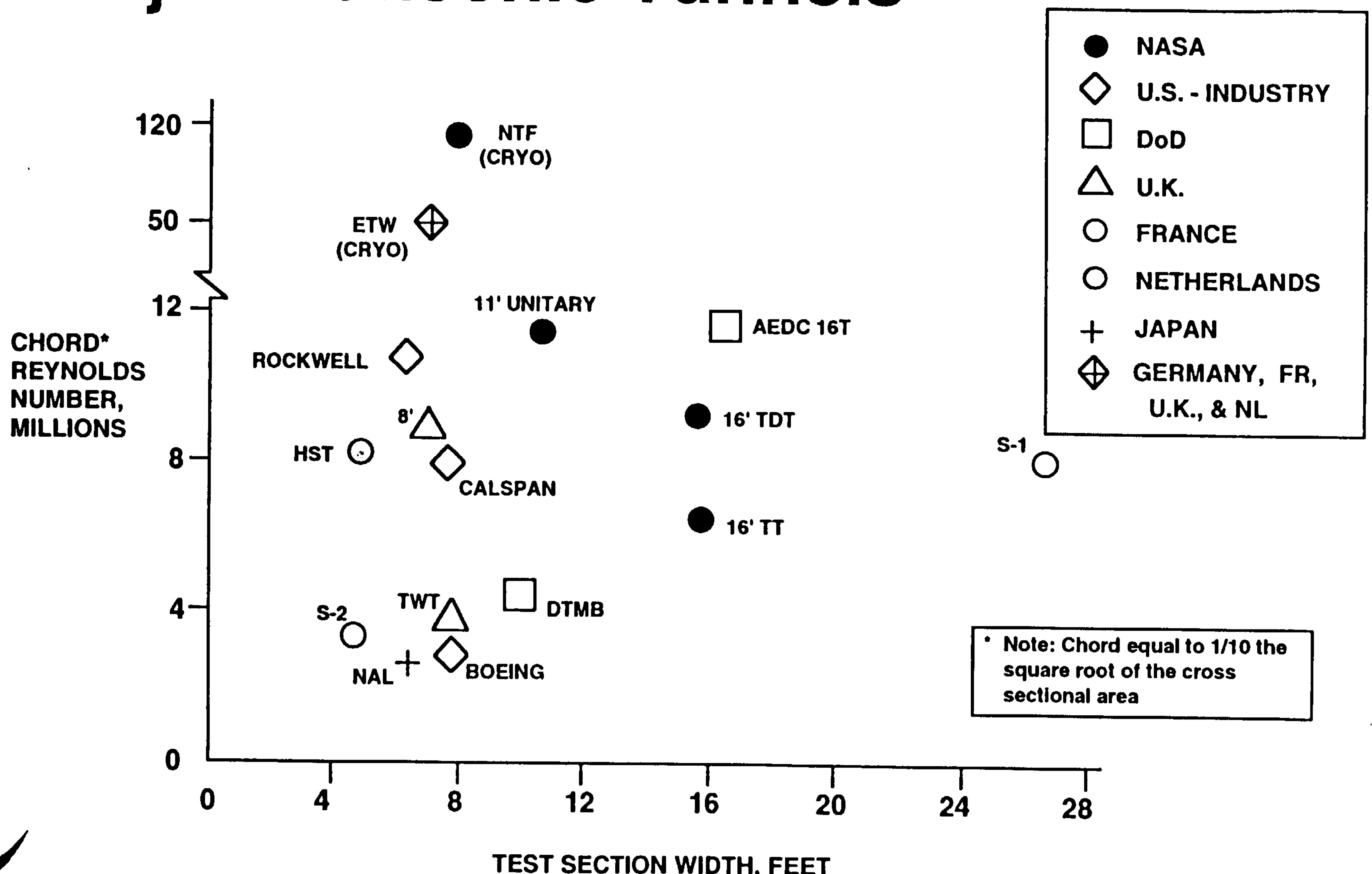
Major Transonic Tunnels

The major wind tunnel facilities with a transonic capability are presented in this chart. Since these tunnels all have essentially the same Mach no., the Reynolds no. is plotted versus the width of the test section. This form of presentation provides a sense for the size of model which can be tested.

The two tunnels most heavily used by U.S. industry are the NASA Ames 11 ft. Unitary and the USAF (Arnold Engineering Development Center) 16T. Although there has been no major foreign wind tunnel with competitive capabilities, the European Transonic Wind tunnel (ETW) beginning operations in 1994 will alter that situation.

Despite the fact that the National Transonic Facility (NTF), located at NASA-Langley, has the highest Reynolds no. capability of all the facilities on this chart, it does not fit in the category of a production facility . Specifically, the NTF utilizes the effects of reducing the temperature of air, i.e., the lower the temperature the lower its viscosity, thus greater Reynolds numbers. The down side of this approach is that testing at cryogenic temperatures (-300°F) results in poor productivity due to the limitations of the models and of people's ability to work with them. The relative productivity of the NTF and the other wind tunnels is depicted on the next chart.

Major Transonic Tunnels



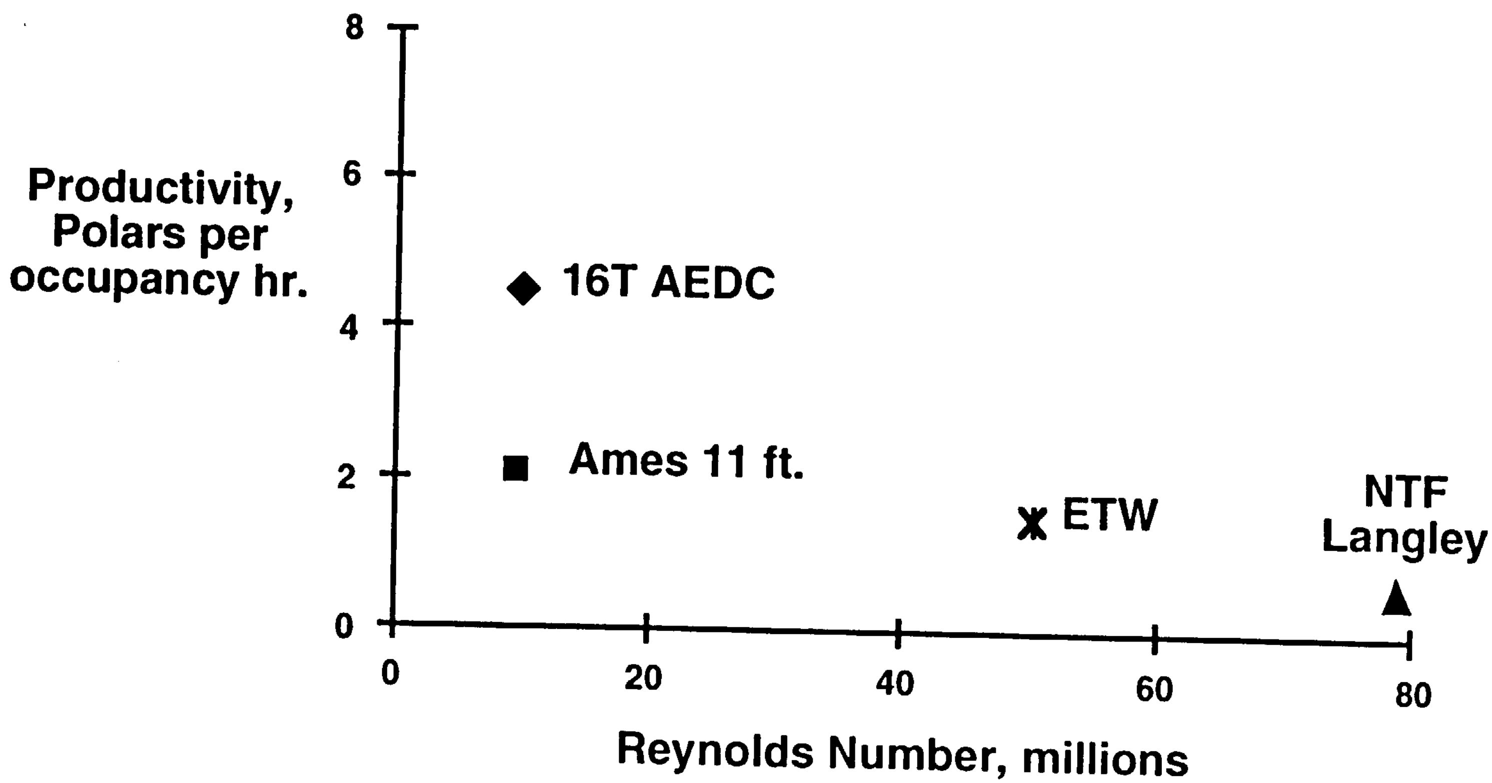
* Note: Chord equal to 1/10 the square root of the cross sectional area

Productivity - Transonic Wind Tunnel, TSWT

In addition to the capability of a wind tunnel to simulate flight conditions, the ability of that facility to produce data in a timely manner will dictate its utility to the aircraft manufacturers. Thus we see that NTF which had the greatest Reynolds number capability also has the lowest productivity of the major facilities. Consequently the NTF is not utilized by industry for product development testing.

The number of polars per occupancy hour for the European Transonic Wind Tunnel (ETW) is based on its advertised performance of 1.5 polars per hour. One of the main factors for achieving improvement in productivity, over the NTF, is the special attention paid to the design of the facility's model handling and preparation attributes. However, it is believed that because of the limitations on cold model handling, for configuration changes during actual tests, productivity will still be severely restricted. Never the less, this is an important lesson for designing a new wind tunnel where high productivity is a requirement.

Productivity - Transonic Wind Tunnel, TSWT



Age of Major NASA Wind Tunnels

It is not surprising that most of the U.S. wind tunnels do not provide the capabilities demanded in today's highly competitive international aviation market, particularly when considering their vintage. Many of the key wind tunnels, particularly within NASA, which support industry are quite old and were built with the requirements from 30 to 60 years ago. In the 1950's the demand for Reynolds no. necessary to develop the next generation large transport for the 21st century were never imagined. The commercial competition was also on a lower plateau and product development costs, which are affected by test productivity, was not a critical factor in wind tunnel designs.

Another significant issue is that because of their age, many of these facilities require more and more maintenance which would lead to an ever increasing burden on ownership while becoming less cost-effective for the industry to use.

The average age of the major NASA wind tunnels is 37 years.

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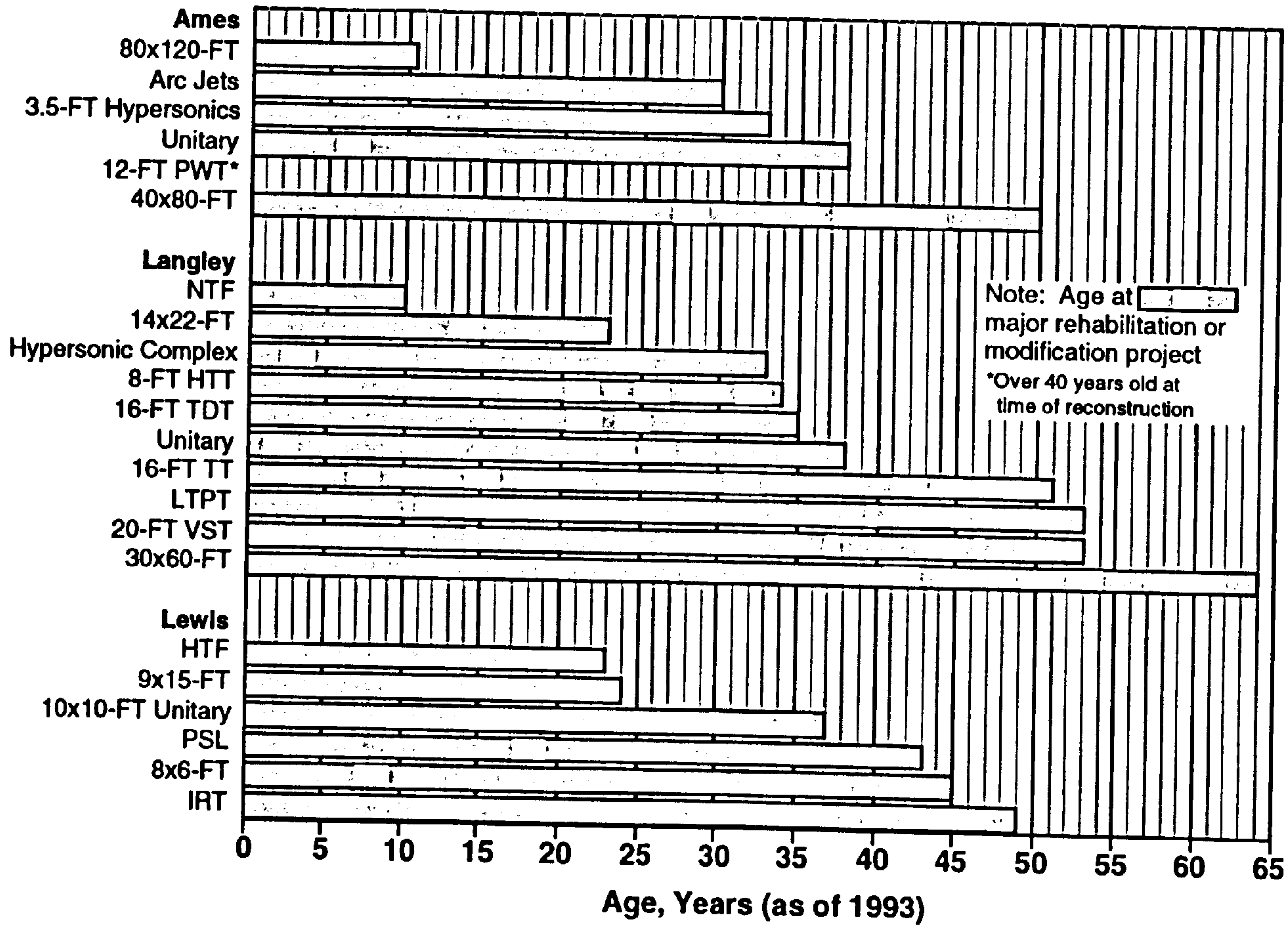
Age of Major NASA Wind Tunnels



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Premier European Wind Tunnels

While the majority of U.S. facilities have operated for over 35 years, the Europeans have invested in top-notch facilities of their own. Although U.S. industry has indicated that their preference would be to protect their designs and keep tighter control by testing exclusively in the United States, they have been driven to Europe to satisfy their test needs.

Industry (both airframe and engine manufacturers) reports that, along with the high-Reynolds no. capability of these foreign subsonic facilities, they are finding comparatively high productivity. For example, the ONERA F-1 testing is accomplished in approximately half of the time required in the NASA tunnels. Similar, the English DRA 5-meter provides good productivity as a result of its interchangeable cart system. That system allows all of the model preparation to occur external to the wind tunnel, saving many hours of occupancy (i.e., reducing cost).

With airport and community noise restrictions on the rise, aircraft and engine designs must be quieter and manufacturers must be able to assess that aspect of performance. The DNW facility in the Netherlands was designed with this issue in mind, and has excellent acoustic properties with its anechoic chamber and open test section.

Premier European Wind Tunnels

- ONERA F-1 (Le Fauga, France) - 1977
  - High Reynolds number subsonic
  - Pressurized with test section isolation
  - U.S. industry reports F-1 testing takes place in less than 1/2 the time compared with best NASA facilities
- DRA 5-meter (Farnborough, U.K.) - 1978
  - High Reynolds number subsonic
  - Pressurized
  - Interchangeable test "carts"
  - High test capability
- DNW (Northeastpolder, Netherlands) - 1976
  - Large, quiet subsonic tunnel
  - Open and closed sections
  - Largest anechoic chamber in the world
  - Interchangeable test sections

Premier European Wind Tunnels

Although there are many factors which have contributed to the increased market share of commercial transports by the Airbus Industrie, the competitive performance and reduced cost of developing its products are critical to their future success. To that end the governments of Britain, Germany, France, and the Netherlands have made a major investment in building the new European Transonic Wind Tunnel. This facility addresses the transonic portion of the aircraft's flight envelope (Mach 0.75 to 0.9) which is the cruise condition for a subsonic transport for about 90 percent of the flight time.

The ETW facility was designed to accurately simulate the flight conditions of large transport aircraft at high Reynolds number by vaporizing liquid nitrogen into the wind tunnel circuit in order to lower the temperature significantly, to values as low as -180°C. This facility was also designed to maximize productivity and has a modular overhead cart system with three model preparation rooms, each equipped with model handling equipment, sting-support systems, and data-acquisition systems.

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Premier European Wind Tunnels

- ETW (Cologne, Germany) - 1994
  - High Reynolds number transonic
  - Cryogenic & pressurized
  - High-productivity design
  - Over $400M European Investment

Competitive Pressure

The working group's assessment of the current capabilities of U.S. wind tunnel facilities is that they do not satisfy industry's requirements in terms of capability or productivity. Even with the completion of the NASA Ames 12 ft. subsonic facility, the U.S. capability will still only be comparable to that of the Europeans in the subsonic speed regime, and will still be lagging in the ability to accurately simulate the critical cruise conditions of current and future transports in a high productivity development facility.

The trend of increasing European market share in the aircraft manufacturing industry will probably continue, unless the United States takes action to help assure superior products through the availability of the best design tools.

Although questions will be raised about our ability to find the resources necessary to enhance our country's capability, the more prudent question is whether we can afford not to.

Competitive Pressure

What Ever Else the Competition Has Going for It, We Must Not Let Them Have a Lead in the Tools to Do the Job.

National Needs

Having summarized the state of current facilities in the U.S. and examined the premier facilities available to the competition, the working group focused on the national needs for wind tunnel testing. Specifically, what would be required to maintain and improve the health of the U.S. aviation industry. In defining these needs the group attempted to define the penalties of not being able to accurately simulate flight conditions and, conversely, the payoff for reducing the uncertainty of product performance.

National Needs

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National Testing Requirements

This chart summarizes the basic goals for the national aeronautics test facilities. The working group has assessed the needs of the military aircraft manufacturers as well as those of the commercial aircraft manufacturers. The conclusions are the same for both, that is: (1) High quality data which accurately simulates flight conditions; (2) Lowest possible costs for wind tunnel test program; and (3) Shorter product development cycle. To paraphrase these objectives: To beat the competition, manufacturers must provide the highest quality product for the lowest cost and have that product available for their customer first.

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National Testing Requirements

- Better Facilities than the Competition
  - Commercial aircraft
  - Military aircraft
- Better in Areas that Make a Difference
  - Technical data which provides accurate simulation of flight conditions
  - Lower test program cost
  - Shorter product development cycle

Wind Tunnel-to-Flight Scaling

The issue of not being able to accurately simulate the actual flight conditions in a wind tunnel facility is illustrated in this graph. The aerodynamic forces of lift and drag will vary as a function of scale size and speed. Therefore, there is an uncertainty about how the actual aircraft will perform once produced. The designer cannot gamble that the aircraft's performance will be better than expected and must design conservatively. The result is an increase in the aircraft's wing size to assure sufficient lift which translates into extra structural weight and consequently a heavier vehicle requiring more thrust, and consuming more fuel to offset the increase in drag.

Another example of the penalty associated with performance uncertainty is found in the design of engine inlets. Conservative designs result in larger and blunter inlets causing an increase in weight and drag. At cruise this could result in as much 0.5 percent increase in Specific Fuel Consumption which translates into 65,000 gallons per year per aircraft (B747-type).

Today this situation can be avoided only with actual flight data, requiring a prototype be fabricated, a very costly proposition.

<u>Note:</u>

UWAL is the University of Washington Aeronautical Laboratory (8 x 12 ft atmospheric wind tunnel)

DRA is the British Defense Research Agencie's 5 meter wind tunnel

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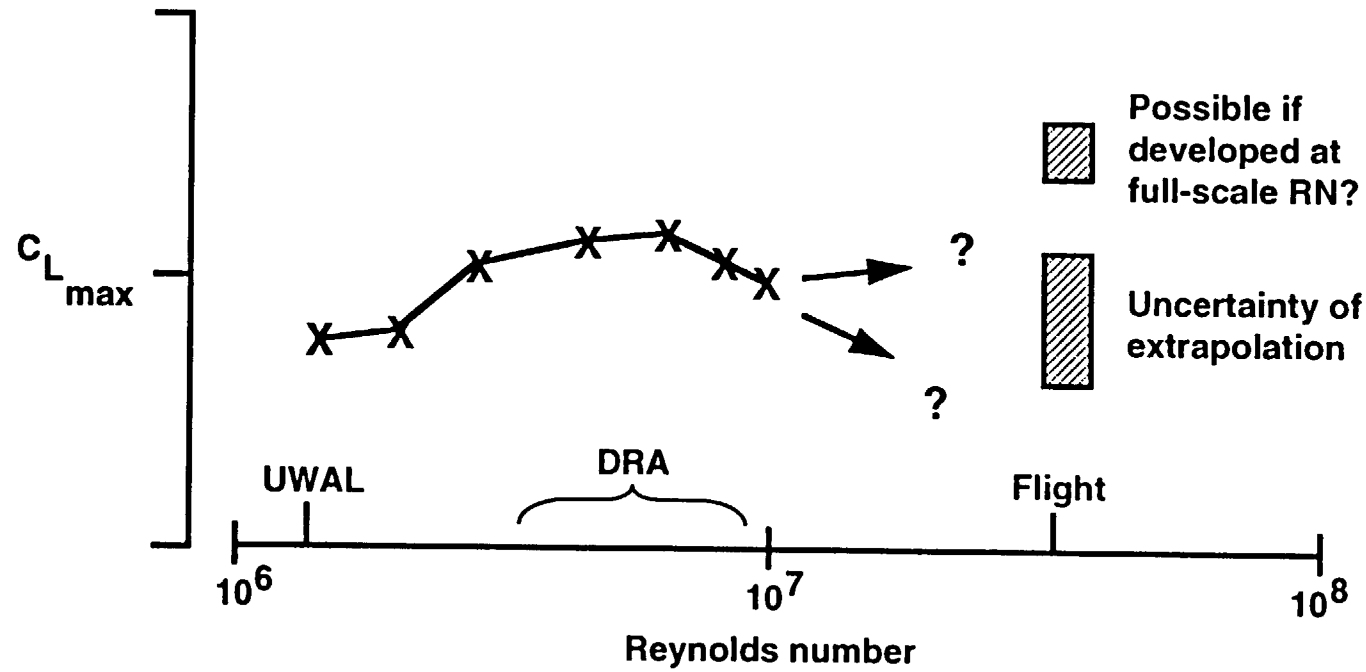
Wind Tunnel-to-Flight Scaling



- This uncertainty necessitates a conservative design

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Wind Tunnel-to-Flight Scaling

This figure depicts in some detail the aerodynamics that are associated with lower than flight Reynolds number data. Shown is the interaction of the shock wave on the upper surface of a wing of a subsonic transport during transonic cruise. Since the shock can cause separation of the air flow from the wing's upper surface, precise knowledge of the location of the shock is essential in calculating the aircraft's performance.

Transonic testing at a Reynolds number significantly below flight is very likely to provide the wrong design information.

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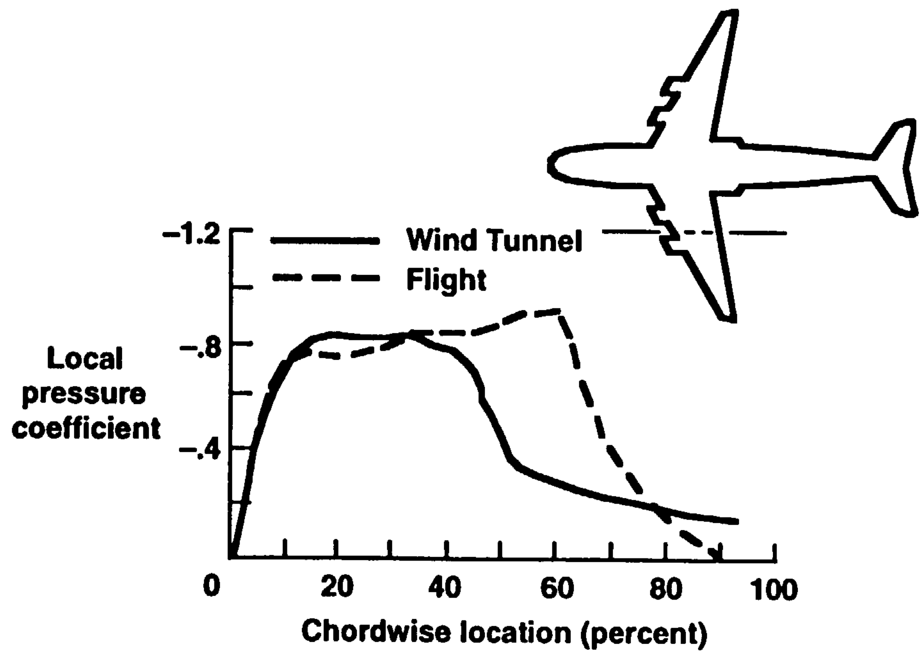
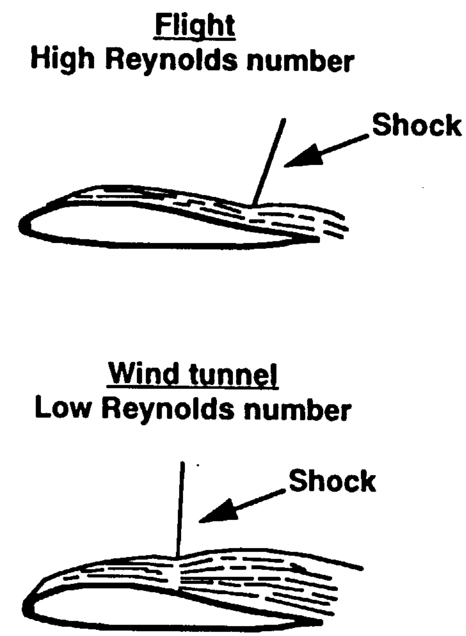
Wind Tunnel-to-Flight Scaling





- **Low Reynolds number wind tunnel testing can give misleading information, resulting in performance penalties.**

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Facility Objectives

The items listed were identified as possible approaches for achieving higher Reynolds number test capability and reducing design cycle time through increased productivity.

Since the Reynolds no. is a function of density, velocity, and model size (chord), increasing some combination of these parameters would be advantageous. The working group evaluated the benefits of all of the above and found that cooling the airstream had the greatest payoff. (It also turned out to have the greatest impact on cost.) Also, identified for consideration was the use of a heavy gas as a test medium in place of air. This approach would essentially double the Reynolds no., however, there are a number of uncertainties in this approach and the group recommended that research continue in this area to provide a possible option for future growth.

Flow quality was identified as a critical attribute for any facility under consideration, either not to be degraded as a result of upgrading existing facilities, or to be a specification for a new tunnel design.

The working group embraced the concept of an interchangeable cart system with multiple model preparation rooms. It is clear that productivity enhancement can be achieved in this manner and that facility upgrades should incorporate the latest in automated controls and data systems.

Facility Objectives

- Improve simulation of flight conditions
  - Reynolds number
    - Increased pressure
    - Increased model size
    - Reduced viscosity (cool airstream)
    - Increased density (heavy gas)
  - Flow quality
    - Reduced turbulence and nonuniformities
    - Reduced noise
- Reduce cycle time for testing by increasing productivity
  - Automated controls
  - Quick-change model systems
  - Simultaneous preparation of multiple models

Testing at Flight Conditions can have Big Payoffs

The working group has concluded that existing U.S. facilities do not have the capability to meet the challenge of our foreign competitors.

An assessment has been made of the value of improving aircraft performance. The analysis shows that a commercial transport with a 5 percent improvement in aerodynamic performance, for the low-speed takeoff conditions, could convert that enhancement directly into increased profitability of $3.5 million per year (per airplane). This is because increased efficiency in the lift-to-drag ratio allows the aircraft to be designed with a smaller wing thus lighter weight requiring smaller engines which are also lighter and require less fuel. For a given size aircraft, this improved performance allows for a greater payload and greater revenue per flight. It is felt that low-speed aerodynamic efficiency improvements on the order of 15 percent are possible.

Cruise performance improvement has an even greater leverage on the bottom line, where a 1 percent improvement converts into $1 million per year per airplane as a result of lower fuel consumption. It is felt that cruise aerodynamic efficiency improvements on the order of 10 percent are possible.

These are significant enticements for making the investment to upgrade the capabilities of the U.S. facilities. Our most serious competitor is the European Airbus Industrie, which has seen the payoffs of their investment in terms of their increasing share of the international market. With the opening of the ETW facility we are very concerned about the future.

Testing at Flight Conditions can have Big Payoffs

- International competition has raised the stakes in simulation capability
  - Existing U.S. test capability is no longer good enough
- Testing at flight conditions will reduce uncertainty and result in better designs
  - 5% improvement in efficiency at takeoff will result in additional $3.5M income per year per airplane
  - 1% improvement in efficiency at cruise will result in additional $1M income per year per airplane
  - 1% improvement in engine efficiency will save up to 130,000 gallons of fuel per year per airplane

Potential for Modifications to Existing Wind Tunnels

To achieve the objectives of enhancing the testing capabilities and productivity of the nation's wind tunnel facilities, the working group first sought opportunities for 'low' cost options. The group evaluated the potential for upgrading existing facilities as the first choice before considering the construction of new ones.

It became clear, early on, that only a few of the wind tunnels from the cadre of facilities nationwide, would lend themselves to cost-effective upgrading. Those tunnels include the National Transonic Facility, the NASA Ames 11-ft Unitary Plan Wind Tunnel, the 12-ft Pressure Wind Tunnel, and the AEDC 16T.

Potential for Modifications to Existing Wind Tunnels

Options Considered

The following list of options were considered by the working group and ranked in an order of being most beneficial.

The NTF can benefit the most from eliminating the impediments to, and reducing the cost of continuous access to an ample supply of liquid nitrogen.

The 11-Foot transonic portion of the Ames Unitary Wind Tunnel can provide an increased the Reynolds no. in the transonic speed regime by increasing the operating pressure. Raising the pressure from the current 2 atmospheres to 3 would provide nominally a 50 percent increase in Reynolds no.

The 12-Foot subsonic tunnel, currently under construction, was designed with an option for adding heavy gas testing in the future. The group supports a precursor heavy gas evaluation test to assess its potential. Analysis indicates that heavy gas will double the Reynolds number capability.

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Options Considered

(Dollar values are rough estimates used to facilitate discussions)

- **NTF Modifications**
  - a - LIQUID NITROGEN STORAGE CAPACITY / PRODUCTION CAPABILITY - $6M / $24M
  - b - DRIVE CONTROL SYSTEM SEPARATION FROM 16-FT TUNNEL - $12M
  - c - NEW BALANCE CALIBRATION MACHINE - $4M
  - d - BALANCE DEVELOPMENT - $1M
  - e - MODEL ATTITUDE MEASURING SYSTEM - $2M
  - f - PRESSURE MEASURING SYSTEM (E.G., PRESSURE SENSITIVE PAINT) - $1M
  - g - MODEL FILLER MATERIAL STUDY - $1M
  - h - VENT STACK HEATER SYSTEM - $1M
  - i - IMPROVED CONTROL SYSTEM-$1M (FOR PER)
  - j- MODEL ACCESS - $2.5M (FOR PER)
- **Ames Unitary Modifications**
  - a - INCREASE OPERATING PRESSURE - $10M
  - b - COMPOSITE BLADES - $7M
  - c - AUTOMATED ADAPTIVE WALLS - $4M
  - d - REWIND MOTORS - $7M
  - e - CHOKED SECOND THROAT IN DIFFUSER - $1M
  - f - PRODUCTIVITY IMPROVEMENTS - $2M
- **Ames 12 ft**
  - HEAVY GAS EXPERIMENT - $10M
  - TEST SECTION MODIFICATIONS TO INCREASE SIZE & PRODUCTIVITY - $45M

Major Subsonic Tunnels - with 12 FT Upgrade

This graph illustrates the potential increase in capability offered by using heavy gas as a test medium (more than doubling the Reynolds no.). Among the tunnels identified only the 12-Foot PWT was design and built with pressure seals and penetrations to accommodate the use of a heavy gas.

It should be noted, however, that small-scale research is underway to evaluate the viability of using heavy gas in place of air. Assessment of the interaction properties of heavy gas and the resultant compressibility and viscous effects must be understood before wind tunnel results would be meaningful.

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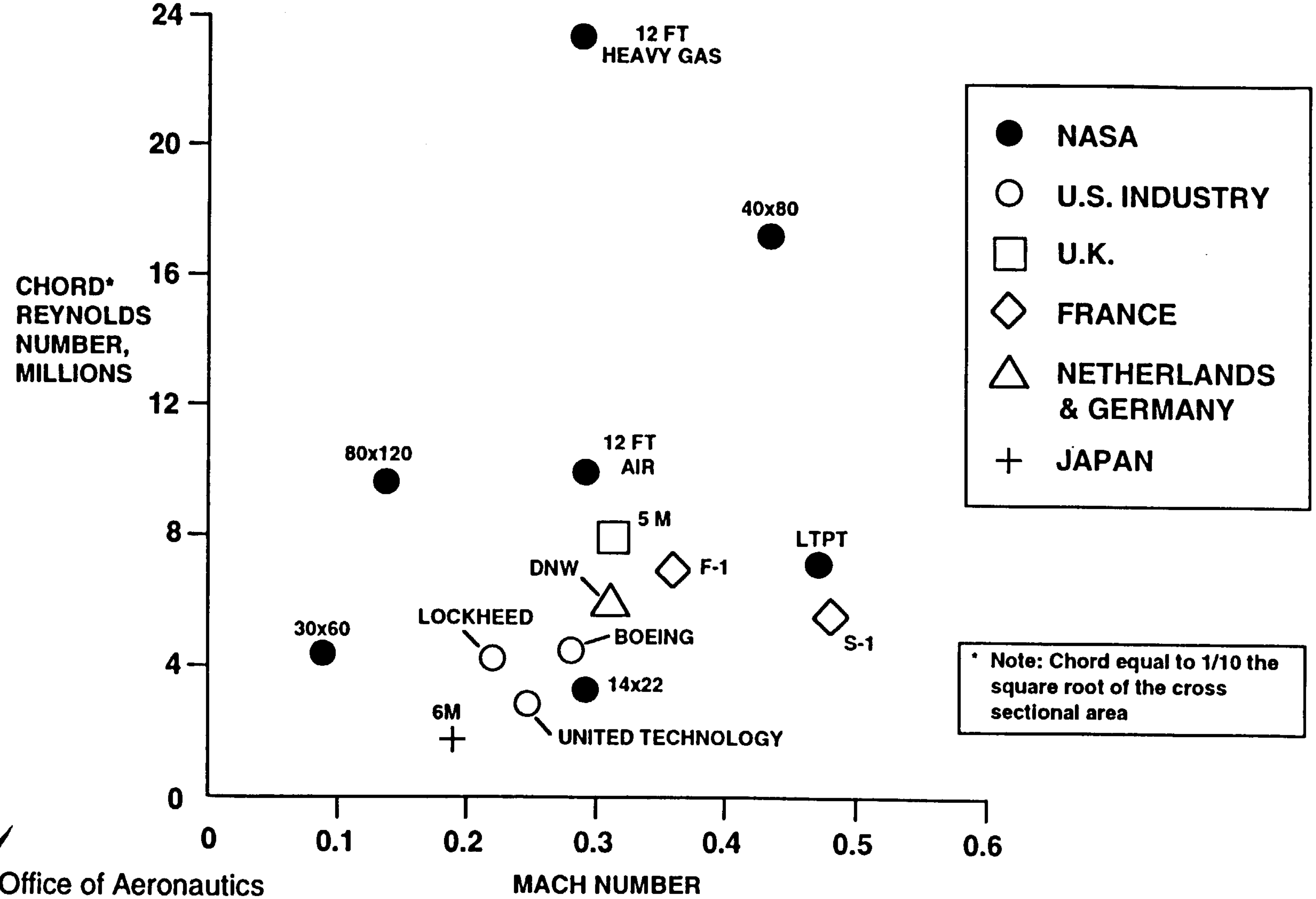
Major Subsonic Tunnels - with 12 FT Upgrade



* Note: Chord equal to 1/10 the square root of the cross sectional area

Summary of Potential for Modifying Existing Wind Tunnels

– The Ames 12-FT is the only facility that could approach industry needs. However, the potential modifications to increase the size of its test section or to cool the air could raise the Reynolds by only 25 percent, which would be significantly below the minimum acceptable level. The impact on flow quality of reductions in the contraction ratio in order to increase the test section size would also be unacceptable.

– As discussed earlier, conducting a heavy gas experiment is recommended.

– For the transonic facilities, raising the operating pressure in order to increase the Reynolds no. of the Unitary tunnel at Ames was considered. This is possible for the Unitary because the pressure shell of the tunnel is rated for 3 atm (although not certified). However, the new capability still falls short of the requirements for transonic testing (Re = 30 million for full span models at Mach 1).

– Specific recommendations for improving the productivity of the NTF have been endorsed by the working group. The nature of cryogenic testing, however, will not allow productivity to reach levels which can support product development. However, the modifications proposed will allow industry to simulate flight conditions for design verification tests.

Summary of Potential for Modifying Existing Wind Tunnels

<u>Subsonic</u>

- It is impractical / impossible to increase the size or to cool the existing Ames 12 ft tunnel to meet the threshold Reynolds number (a factor of 2).
- Heavy gas remains an option, but scaling capability is still questionable

<u>Transonic</u>

- It is impractical / impossible to increase the pressure of the Ames 11 ft or the AEDC 16T to the meet the Reynolds number requirement (a factor of 2.5).
- It is impractical / impossible to increase productivity and reduce operating costs of the NTF to the levels required for development testing

New Capabilities

In order to alter the course of the competitive position of the U.S. aircraft industry, small incremental fixes to our national facilities will not suffice. The need exists for substantial improvement in capabilities. The following section defines the minimum facility requirements and their relation to commercial products. The proposed facilities are described in terms of top-level specifications for the test section.

The details of actual size of the tunnel circuit, power requirements, etc., were defined by the Facility Study Office, which was also responsible for establishing an initial cost estimate. These refinements are not presented in this report.

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New Capabilities

Need For New Capability

A balance between full-scale simulation and highly productive facilities must be provided in order to meet industry's development requirements. This illustration depicts the current wind tunnels and the goal. For example, there are wind tunnels which have high-Reynolds no. capability, such as the NTF, but are not used for product development because of low productivity and high cost. The DRA 5 meter tunnel which is depicted here provides relatively good productivity but does not provide the needed capabilities in either simulation capability or productivity .

The desired developmental facilities which are indicated would provide adequate Reynolds number at very high productivity.

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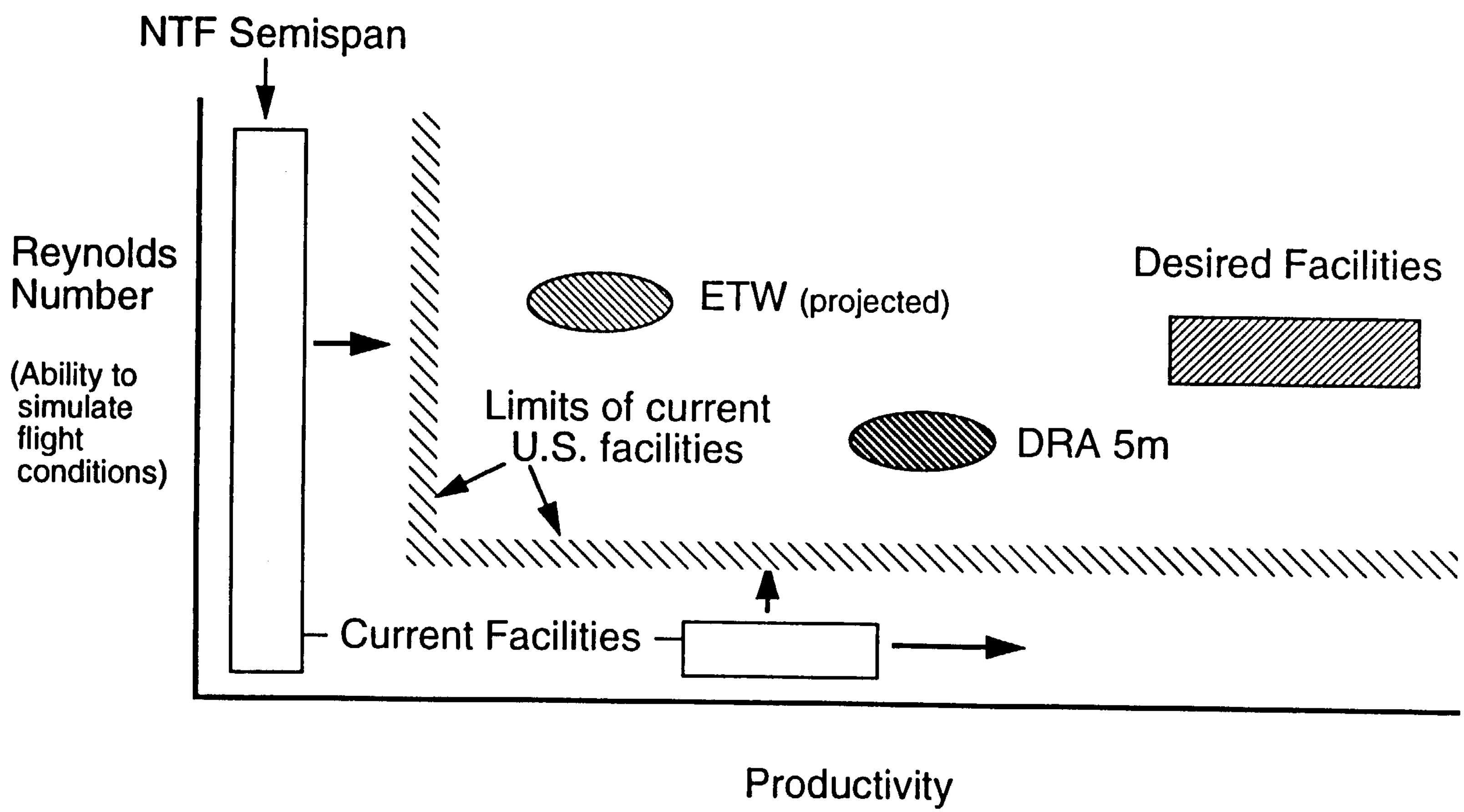
Need For New Capability



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Simulation Capability - Subsonic

This chart indicates the Reynolds numbers required to simulate flight conditions for specific commercial transports. The maximum capabilities of the DRA 5-meter and the Ames 12-Ft wind tunnels are also shown.

The curves on this chart, both the solid and the dashed lines, represent the capability for a new facility with a 16 by 20 Ft test section operating at 5 atmospheres. The curves also show the possibilities for testing half models, also known as semi-span models, which physically allows a larger model to be used and results in higher Reynolds number simulation.

Since the goal of the new facility recommended by the working group was to provide a Reynolds no. of 20 million at Mach 0.3 with a conventional full-span model, cooling of the air was assessed as a means of achieving that goal. The effect of cooling is depicted by the two higher curves at T = -100°F. It is assumed that the cooling would be achieved with a high-capacity refrigeration plant as opposed to liquid nitrogen normally used to reach cryogenic temperature testing.

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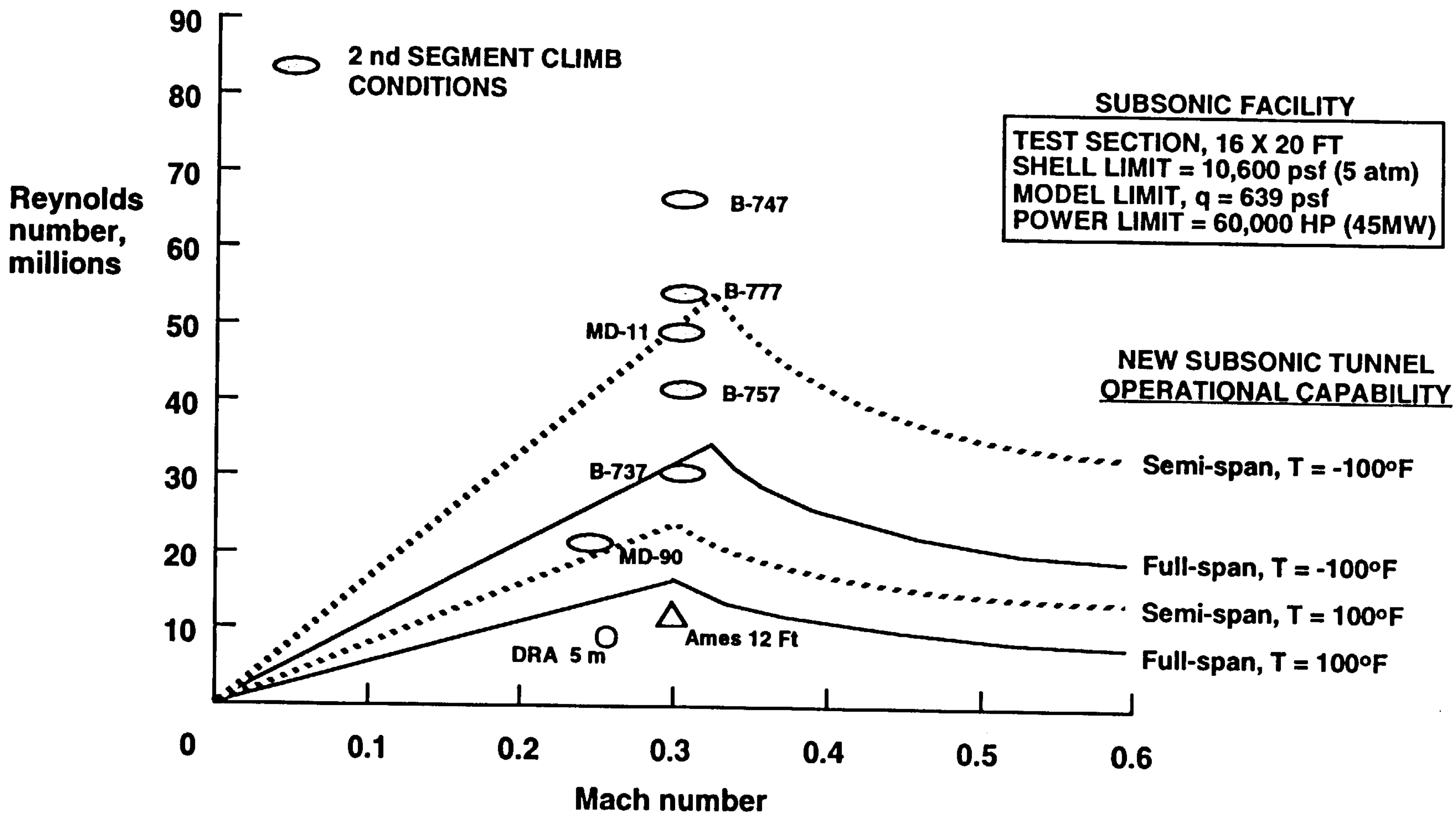
Simulation Capability - Subsonic



* Note: Chord equal to 1/10 the square root of the cross sectional area

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Simulation Capability - Recommended

After a cost estimate indicated that the cost of cooling the air flow, which requires a refrigeration system, insulation, and other special features, was prohibitive, the working group looked for another alternative. The evaluation concluded that a larger test section, of 20 by 24 ft would provide the needed capability at a substantially lower cost. This option allows semi-span testing that encompasses the flight conditions for a B-737 or MD-90 aircraft. This situation provides an opportunity for correlating wind tunnel measurements to actual flight data.

Although this facility does not provide the highest Reynolds number desired it does satisfy the minimum requirements and thus offers a cost effective solution.

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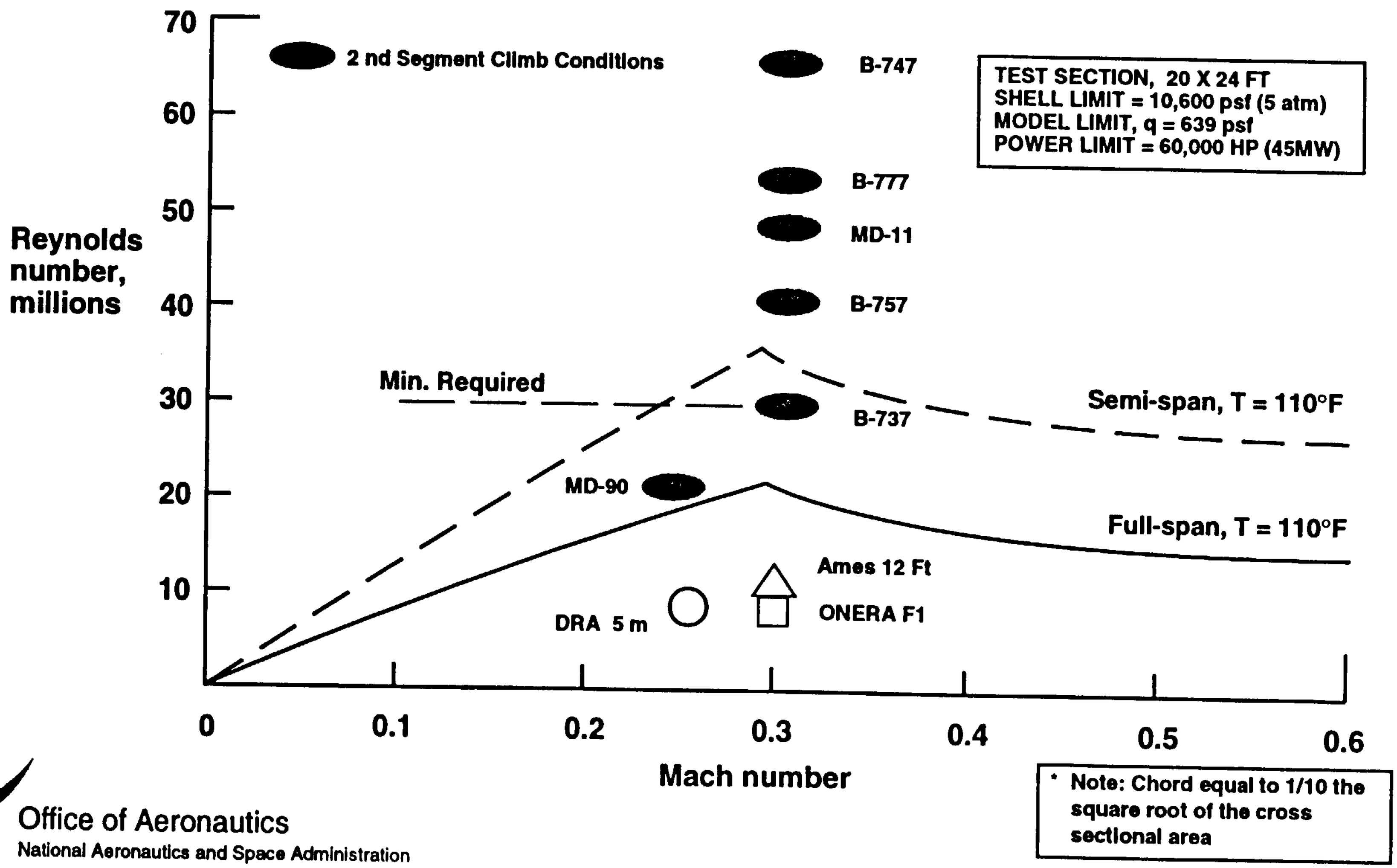
Simulation Capability - Recommended



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Productivity - Low Speed Wind Tunnel, LSWT

This chart was shown earlier to describe current capabilities. In this version the productivity goal for the new subsonic facility, the "Low Speed Wind Tunnel," is also presented.

It should be noted that the measurement of polars per occupancy hour is not based on the duration of a single polar, but rather it is based on an average taken over a complete transport aircraft test program.

Specific assumptions are listed and were applied to all the facilities shown:

1. High-Lift system development model, installed on bipod mount for pitch and pause test procedure.
2. 100 configurations tested
3. 5 polars per configuration at $M = 0.2$
4. 20 data points per polar
5. 10,000 total data points for the test

Although a productivity of 5 polars per occupancy hour is greater than today's development facilities, it was determined that the technologies necessary for this performance are readily available.

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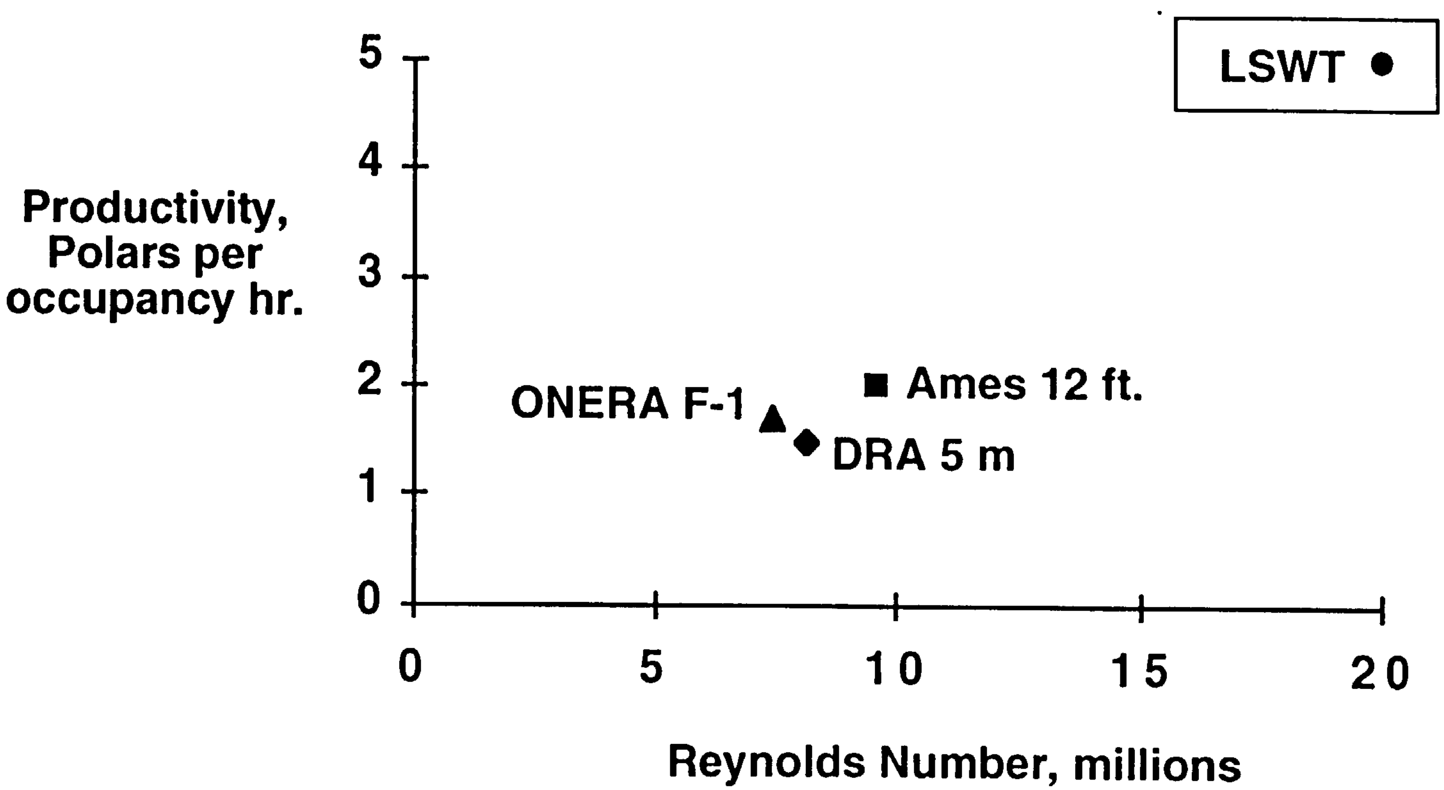
Productivity - Low Speed Wind Tunnel, LSWT



Cost Effectiveness

- Low Speed Wind Tunnel, LSWT

The bottom line to the facility users is the cost for producing a new aircraft. Those costs will be partially driven by the cost of obtaining the large quantity of data required. Therefore, this metric of cost per polar was found to be an appropriate figure-of-merit for existing facilities and for the proposed LSWT.

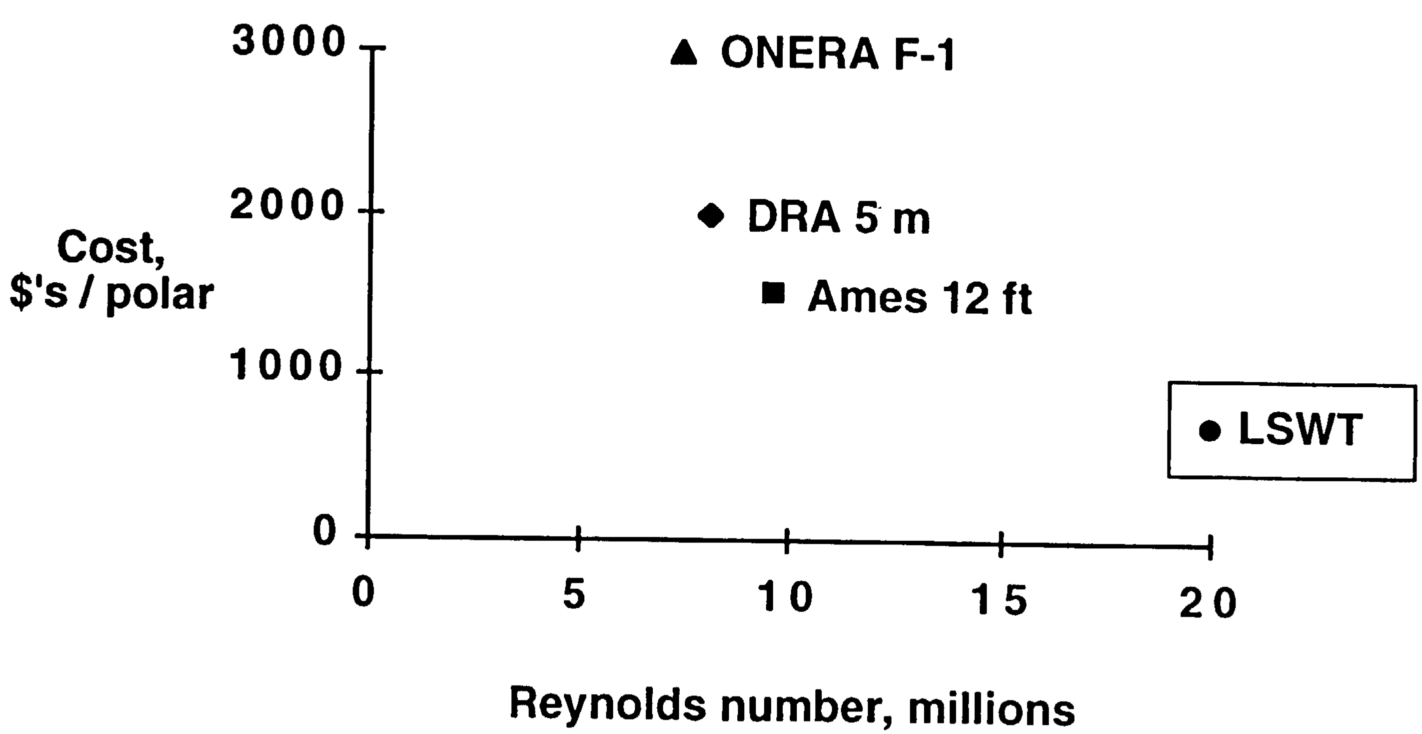
The cost per polar for the ONERA F-1 and the DRA 5 meter are based on actual charges to the aircraft companies for testing in those respective facilities. For the Ames 12-Ft, the costs are based on the current pricing policies used at Ames for the Unitary wind tunnel. The proposed LSWT uses the following additional assumptions to the previous chart for productivity:

1. Staff size of 100 required (for all aspects of the operations)
2. Power cost of $47 per Megawatt Hour
3. 3 shift operation
4. Maintenance costs are based on the 16T complex at AEDC

The working group concluded that a world-class facility to support industry must be as cost-effective as possible. The cost estimating activity of the Facility Study Office concluded that this goal was achievable for the recommended new LSWT.

Cost Effectiveness

- Low Speed Wind Tunnel, LSWT



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Simulation Capability - Transonic

This chart depicts the Reynolds numbers required to simulate the actual cruise flight conditions of specific commercial transport aircraft. It also illustrates the wide gap between the requirements and the currently available capability, represented by the Ames Unitary tunnel (11- ft).

The curves also show the potential operational envelope for a new transonic speed wind tunnel (TSWT) with a test section of 11 by 15.5 ft, operating at 5 atmospheres of pressure. Semi-span testing, an accepted test methodology, will almost double the facility's Reynolds number range allowing the accurate simulation of the actual flight conditions for a number of existing transport aircraft.

The TSWT would meet the working group's minimum requirement of a Reynolds number of 30 million for a full-span model at a Mach no. of 1.

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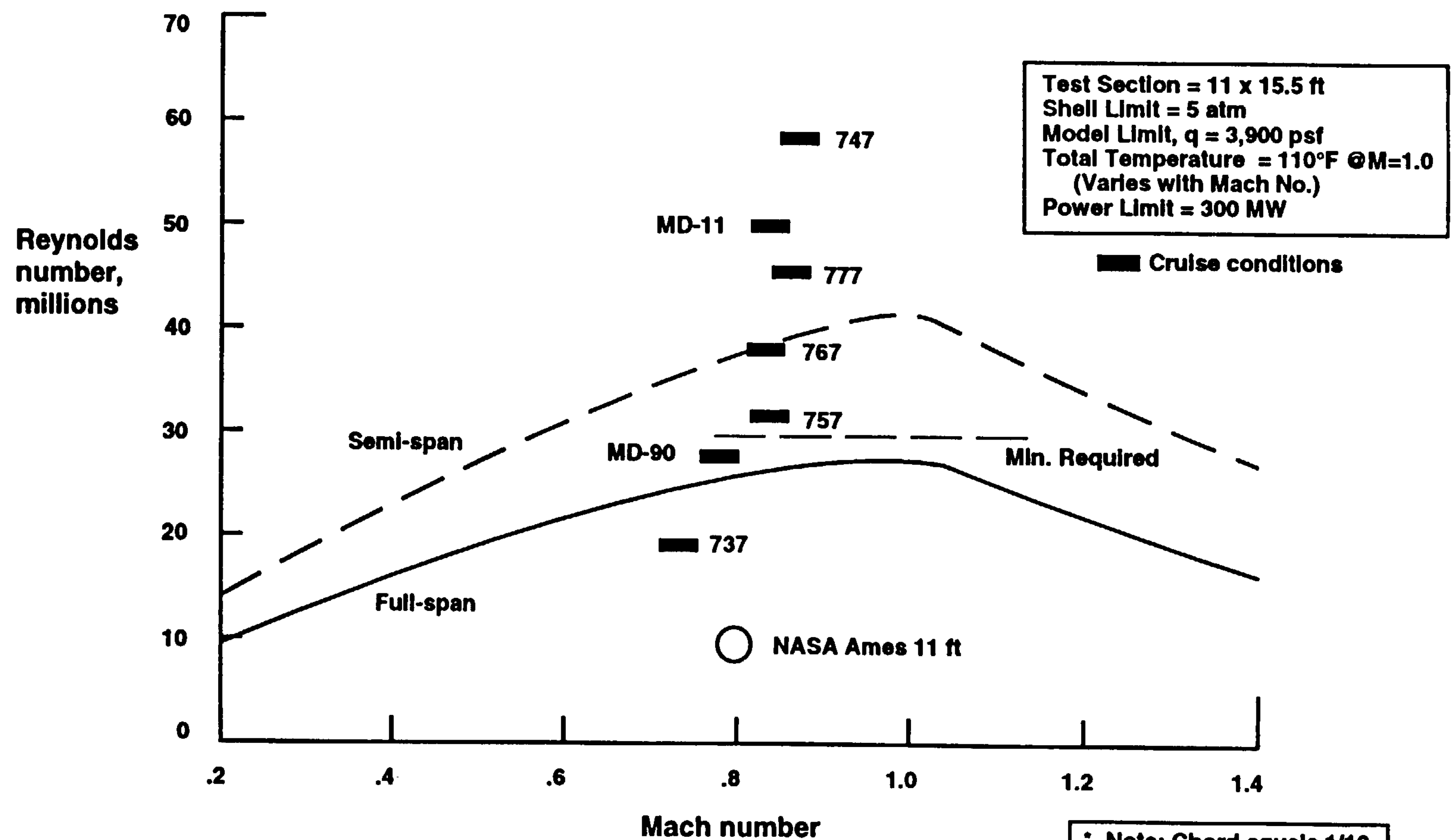
Simulation Capability - Transonic



* Note: Chord equals 1/10 the square root of the cross sectional area

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Productivity - Transonic Wind Tunnel, TSWT

This chart describes current productivity of transonic tunnels and the goal for the new facility. The productivity goal for the new transonic facility, the "Transonic Speed Wind Tunnel," is 8 polars per occupancy hour. This level of productivity is essential based on the strong influence of productivity on the cost of testing as shown on the next chart in terms of cost per polar.

The measurement of polars per occupancy hour is not based on the duration of a single polar, but rather on an average taken over a complete test program. The data for the 16T, the Ames 11- ft, and for the NTF are based on actual performance, while the value for the ETW (European Transonic Wind Tunnel) is an advertised number.

Specific assumptions are listed and were applied to all the facilities shown:

1. Stability, control, and performance on a rear sting mount with a pitch and pause test procedure
2. 80 configurations tested
3. 5 polars per configuration
4. 20 data points per polar
5. 11,200 total data points for the test

Although a productivity of 8 polars per occupancy hour is greater than today's facilities, in the working group's assessment the technologies are available to achieve this performance.

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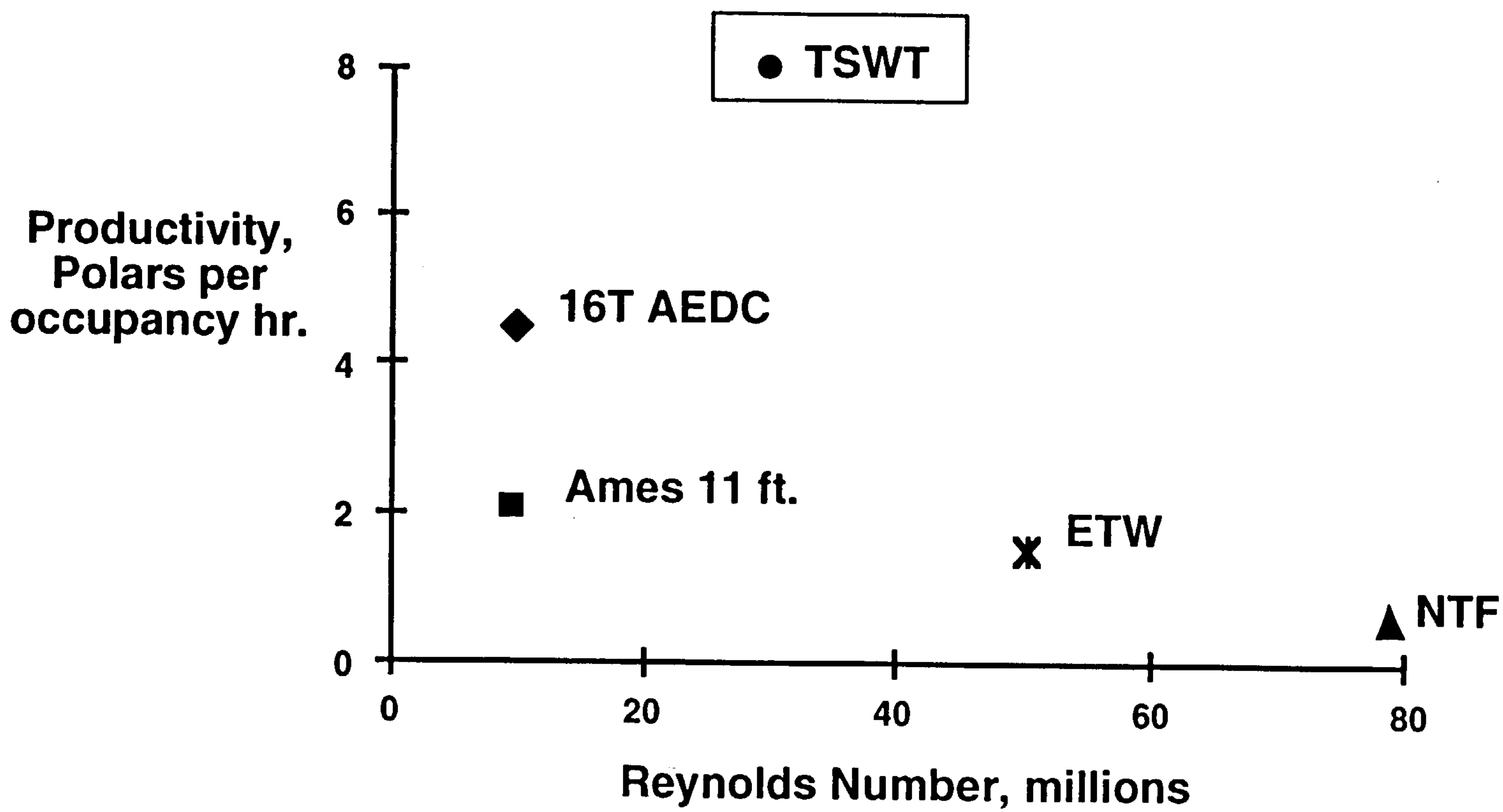
Productivity - Transonic Wind Tunnel, TSWT



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Cost Effectiveness

- Transonic Wind Tunnel, TSWT

Facility usage costs are important to industry when developing new aircraft. The metric of cost per polar is used as a figure-of-merit for existing facilities and for the proposed TSWT.

The cost per polar for the 16T, the Ames 11-Ft, and for the NTF are based on either actual costs or fees charged to the customers. The value for the proposed TSWT was calculated, and uses the following additional assumptions to the previous chart for productivity:

1. Staff size of 100 required (for all aspects of the operations)
2. Power cost of $47 per Megawatt Hour
3. 3 shift operation
4. Maintenance costs are based on the 16T complex at AEDC

The cost estimating activity of the Facility Study Office developed these estimates.

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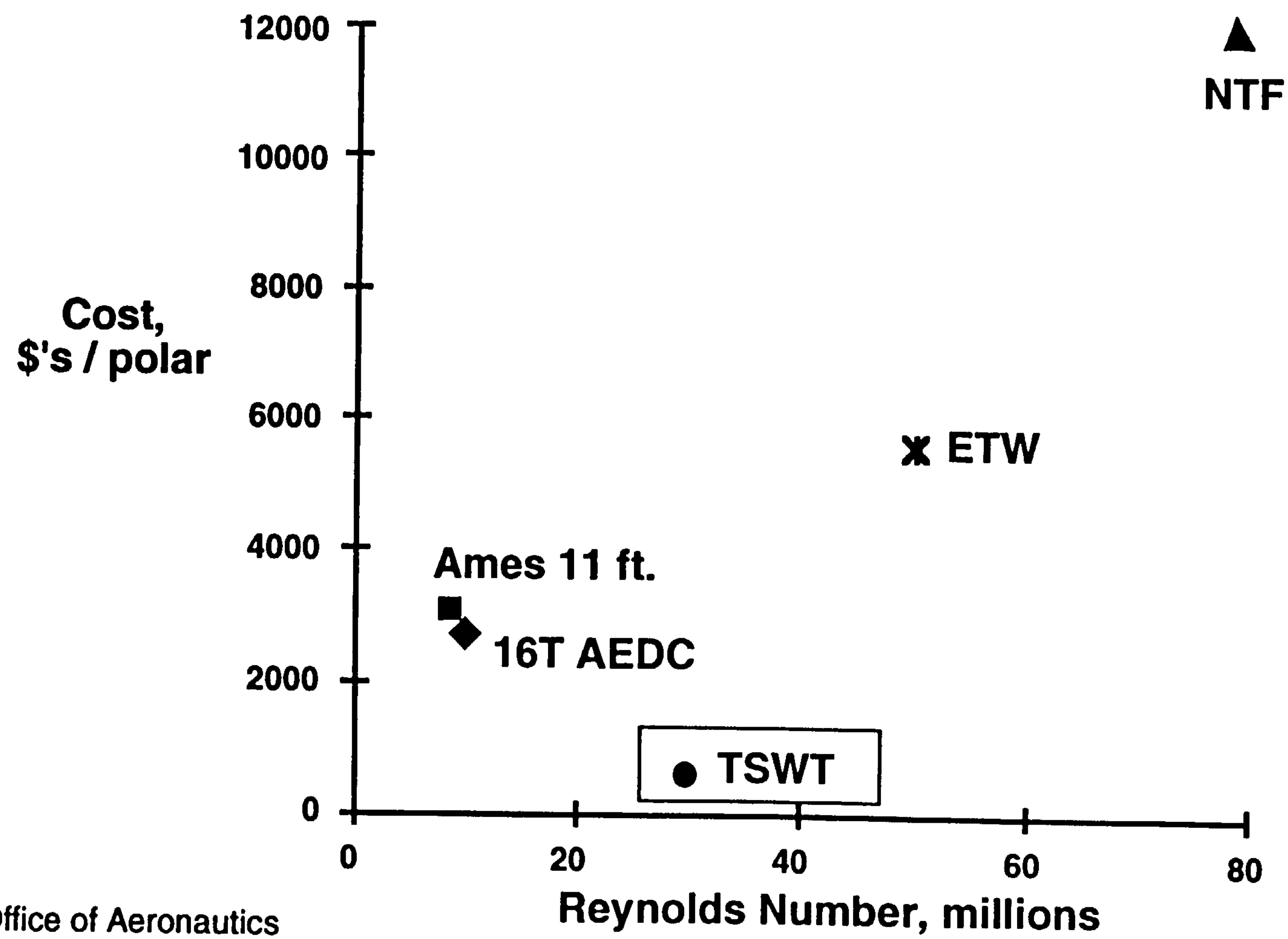
Cost Effectiveness

- Transonic Wind Tunnel, TSWT



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Required Capability

The following is a top-level summary of the recommended attributes for the new subsonic and transonic wind tunnels.

The competitiveness posture of U.S. aircraft manufacturers will be a function of facility performance and cost, which has driven the requirements of productivity, test section size/Reynolds number, and flow quality. In addition, the ability of new aircraft to meet governmental and local community noise limits will be crucial to the marketability of future aircraft. The issue of noise is primarily for takeoff, climb-to-cruise, and approach -- which are subsonic speed conditions. Therefore, the working group has endorsed the inclusion of an anechoic test chamber surrounding an open test section in the LSWT.

The test section itself would essentially be an interchangeable cart with the conventional closed test section. This capability would allow the evaluation of airframe- and engine-generated noise as well as noise suppression systems, in low background noise conditions.

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Required Capability

- Subsonic wind tunnel (Mach number 0 - 0.6)
  - Productivity
    - High data acquisition rates through automation
    - Self-contained, interchangeable cart-type test sections
  - Test section size: 20 ft by 24 ft
  - Reynolds number up to 100% of flight through size and pressure
  - Flow quality: low turbulence; test section and fan acoustic treatment
  - Acoustic testing capability: Open jet with acoustic test chamber
- Transonic wind tunnel (Mach number 0.1 - 1.6)
  - Productivity
    - High data acquisition rates through automation
    - Self-contained, interchangeable cart-type test sections
  - Test section size: 11 ft by 15.5 ft
  - Near flight Reynolds number through size and pressure
  - Flow quality: low turbulence; test section and fan acoustic treatment

Predicted Performance Envelopes

This summary of the capability of the two proposed new facilities clearly depicts the strengths of each one. The low speed tunnel will address the shortfall in our ability to develop the best high-lift systems and low-noise configurations, and the transonic tunnel will focus on developing the most efficient cruise designs.

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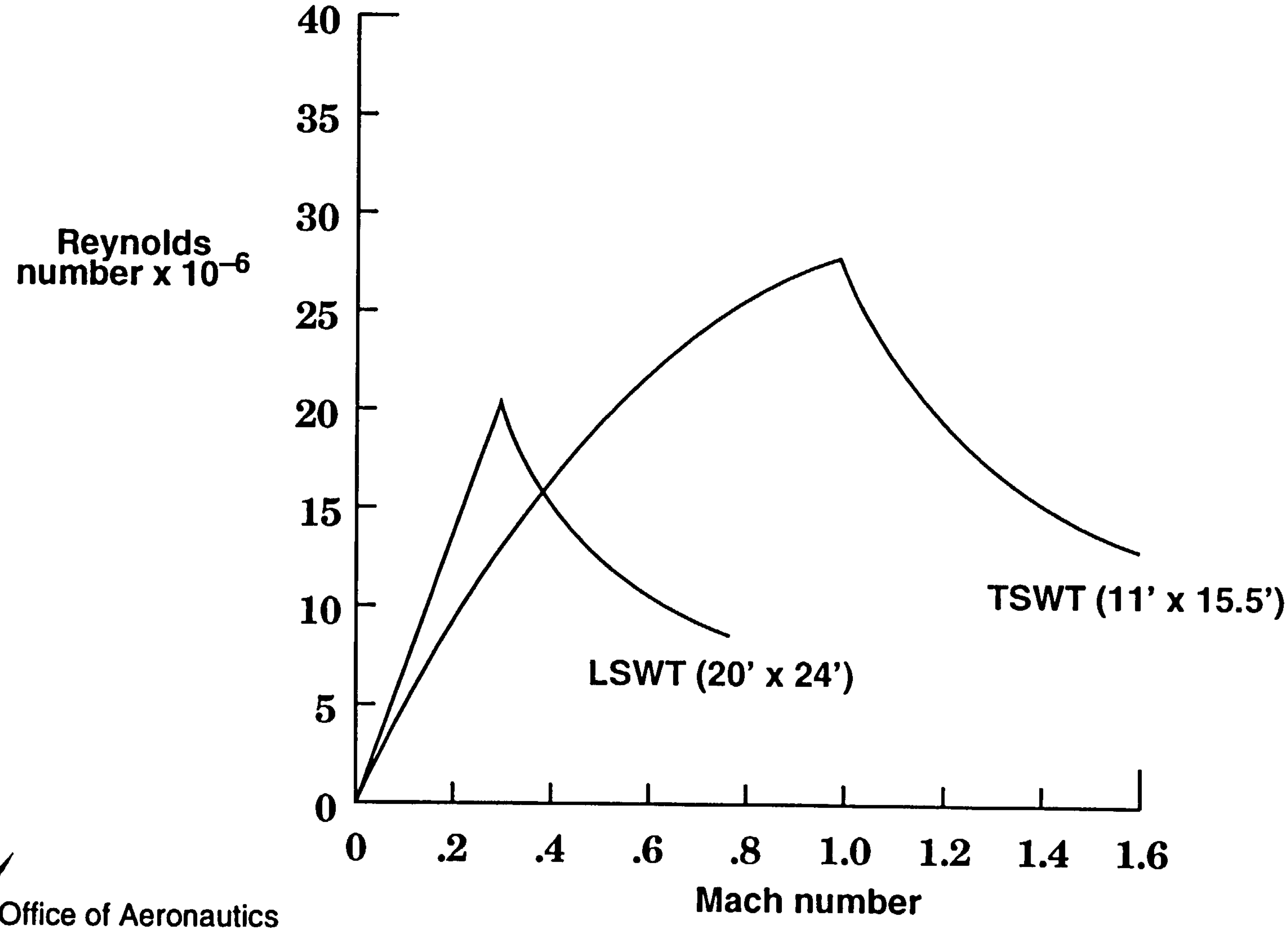
Predicted Performance Envelopes



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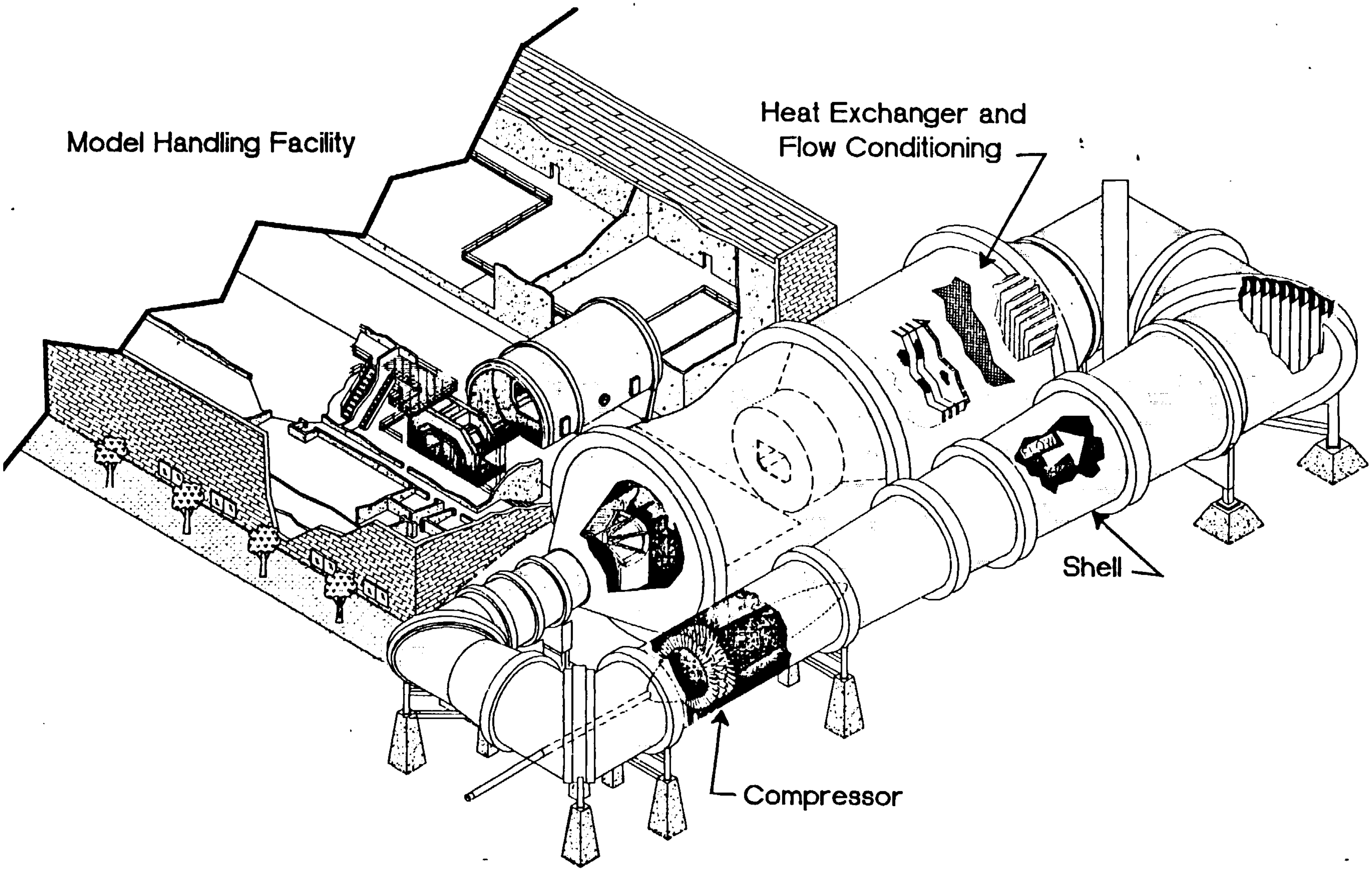
New Wind Tunnels - LSWT

The following two figures show a notional layout of the new wind tunnel complex, which includes both the Low Speed Wind Tunnel and the Transonic Wind Tunnel. A key feature of this complex is the common Model Handling Facility, located between and shared by the two wind tunnels. Also illustrated are the plenum carts which can be moved to the model handling facility to receive a new model for testing and then inserted back into the tunnel as an integral piece of the circuit.



Low Speed Wind Tunnel

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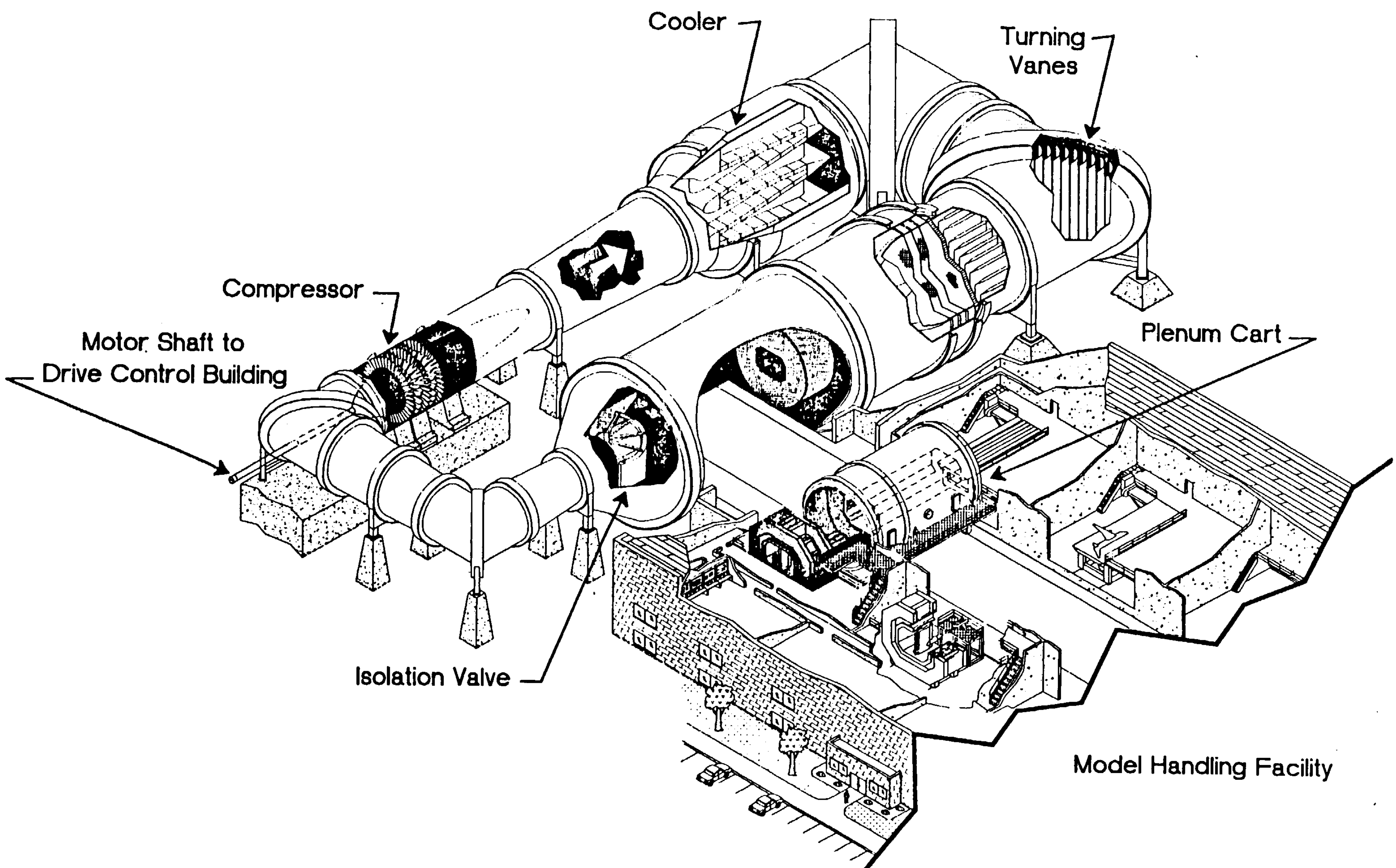
New Wind Tunnels - TSWT

The new transonic wind tunnel would also use a cart system similar to the subsonic wind tunnel and share a common model preparation area.



Transonic Wind Tunnel

Supersonic Wind Tunnels

This section describes the state of supersonic wind tunnels in terms of capabilities, shortfalls, and recommended investments to address future needs. The working group found that the capabilities of existing supersonic facilities fall short in terms of productivity and flow turbulence but that these issues must be addressed by research prior to initiating efforts to acquire a new supersonic wind tunnel.

Supersonic Wind Tunnels

Major Supersonic Wind Tunnels

This graph presents the capabilities of the major international supersonic facilities. Since the Mach numbers are in the range of 2.0 to 5.0, the Reynolds number is plotted versus tunnel size. This allows for comparison of simulation capability of the tunnels based on Reynolds number, while giving a sense of model size at the same time.

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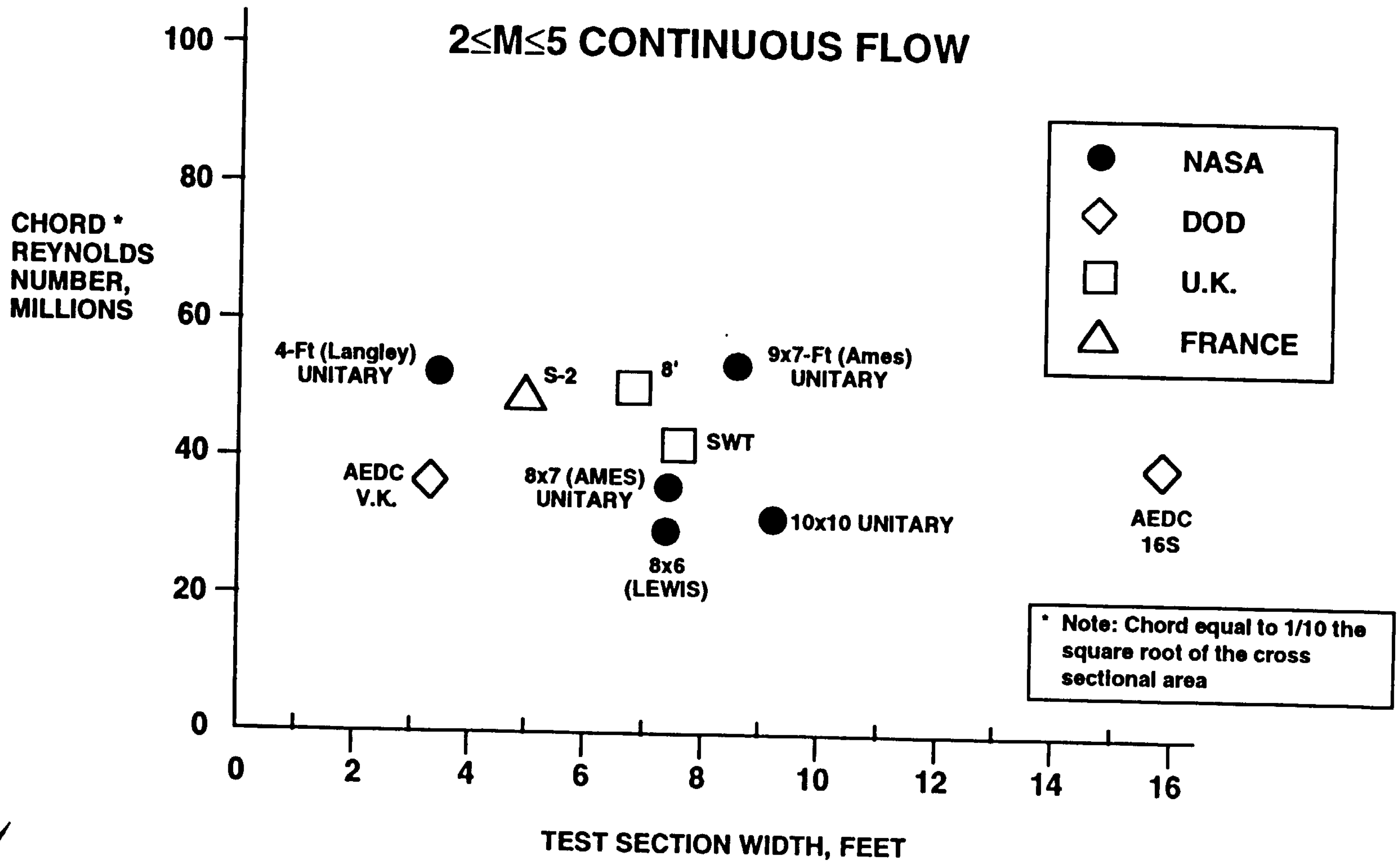
Major Supersonic Wind Tunnels



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Supersonic Tunnels - Capabilities

The primary demand for supersonic facilities has been from the Department of Defense and from its military aircraft manufacturers. Based on the input of those customers, today's facilities satisfy the requirements for fighter aircraft and missile product development. In the future, the civil aircraft industry has plans for a supersonic airliner, currently referred to as the high-speed civil transport (HSCT), which would cruise at Mach 2.0 to 2.4. It was also concluded that the requirements for the HSCT could be met with the supersonic facilities of today, supplemented by flight testing, until a new, low-turbulence supersonic tunnel can be designed.

Supersonic Tunnels - Capabilities

- Mach no. range sufficient to cover all applications - Fighters, HSCT, and Missiles
  - Mach overlap with transonic tunnels
  - Maximum Mach sufficient for transition to Hypersonics
- Tunnels available for testing models with large jet engines installed
- Many tunnels available for weapon integration testing using captive trajectory systems
- High Reynolds no. capability of intermittent blowdown tunnels important for HSCT applications

Most Supersonic Aerodynamic Testing Needs are Satisfied by Using Existing U.S. Supersonic Wind Tunnels

Shortfalls

Although the capabilities of the facilities are adequate, the ability to get data quickly and reliably was identified as a significant shortfall. Improvements will also be needed to enhance the productivity of the AEDC 16S wind tunnel and of the industry-owned blowdown tunnels.

In assessing the future needs of supersonic flight, the group identified laminar flow as a high-leverage technology. The ability to develop supersonic laminar flow control (SLFC) technology from the "laboratory" to operational status was seen as crucial to maintaining U.S. technology leadership. It was also determined that the existing tunnels have levels of turbulence greater than is acceptable for SLFC technology research and development.

Shortfalls

- Productivity & reliability potential of AEDC 16S not realized because system upgrades are needed
- Poor productivity exists for those industry-owned blowdown tunnels needed for HSCT high-Reynolds no. testing
- Pressure turbulence intensity for all existing tunnels is too high for suction LFC model tests - laminar tunnel wall boundary layer required

AEDC 16S System Upgrades

In order to correct the deficiencies of the AEDC 16S wind tunnel, the following list was developed as recommended upgrades. These upgrades directly address the reliability and productivity shortfalls identified and would be implemented over a period of 4 years.

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AEDC 16S System Upgrades

(Dollar values are rough estimates used to facilitate discussions)

- Proposed Upgrades
  - Drive motor system
  - Nozzle upgrade
  - Data acquisition
  - Pressure system
  - Reliability upgrades
- Improvements
  - Major reliability improvements
  - Reduced energy & staffing requirements
  - Faster data acquisition
  - Reduced test installation time
  - Increased availability & throughput
  - Reduced cost of data
- Minimal Impact on 16S or 16T operations
  - Upgrade incrementally
- Cost
  - Drive system (16S and 16T) $24M
  - Other upgrades $18M
- Schedule
  - Incrementally over 4 years

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Supersonic - Recommendations

The primary assessment of the working group is that a new supersonic facility with greater capability is not warranted at this time.

An investment to bring existing facilities up to the productivity standards needed for commercial product development is recommended specifically as identified for the 16S.

The working group does, however, recommend that research and development be funded for ‘quiet’ flow supersonic wind tunnels. This capability is indispensable to assure the development of SLFC technology for future aircraft. The working group also felt that the Russian Tu-144 supersonic aircraft should be evaluated as a testbed for certain SLFC research.

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Supersonic - Recommendations

- Use existing U.S. supersonic wind tunnels
- Improve productivity & reliability of AEDC 16S by system upgrades ($42M)
- Conduct R&D for M = 2.0 to 2.4 Quiet Tunnel ($12M)
- Evaluate use of a supersonic laminar flow control flying laboratory, such as the Tu-144

Matrix of Priorities

The working group assembled the following matrix in order to prioritize the various recommendations for facility upgrade and construction of new facilities. It is important to note that the dollar values shown here are engineering estimates which were derived prior to the cost estimating efforts of the Facility Study Office and were used as a means of assessing relative cost versus benefit.

It was clear that the first option, which calls for new subsonic & transonic facilities and upgrades to existing tunnels, had the greatest support of the working group members.

The lower case letters refer to specific upgrades identified in the section: Potential for Modifications to Existing Wind Tunnels.

Matrix of Priorities

(Dollar values are rough estimates used to facilitate discussions)

OPTIONS	SUBSONIC	TRANSONIC	SUPERSONIC	TOTAL $	ADVANTAGES	DIS-ADVANTAGES	OTHER FACTORS
#1 New Cap Mods Studies	NTS (800M-1B) H.G. Test (10M)	NTT ($800M-$1.2B) NTF (abhi) (44M) 11' (abd) (24M)	16S (24M) Pilot/Studies (40M)	$1.7 - $2.3B	High Reynolds CAP High Producivity World Leadership/ Capability Future Flexibility Competitiveness	Cost Schedule	New Legistration Strong Support Boeing, MDC, Northrop, AEDC, LaRC, ARC, NAWC, DOD? Mod Support Lockheed
#2 New Cap Mods Studies	NTS (800M-1B) H.G. Test (10M)	NTF (abhij) (304M) 11' (abd) (24M)	16S (24M) Pilot/Studies (40M)	$1.2 - $1.4B	High Reynolds Low Speed High Productivity Low Speed World Leadership Low Speed Incr. Prod. Trans. (Not World Class)	Inadequate Prod. Trans. Subst. Incr. Risk to Indus. Higher Cost/Data Pt. Trans. NTF Downtime Cost Schedule	Strong Support Northrop Mod Support MDC, Lockheed, AEDC, LaRC, ARC, NAWC, DoD?
#3 New Cap Mods Studies	H.G. Test (10M)	NTT+ ($800M-$1.2B) NTF (abhi) (44M) 11' (abd) (24M)	16S (24M) Pilot/Studies (40M)	$0.9 - $1.3B	High Reynolds Trans High Product. Trans World Leadership - Transonic	No Incr. Subsonic Cap. Cost Schedule	Stong Support AEDC, NAWC Mod Support ARC, DoD?
#4 Mods Studies	H.G. Test (10M)	NTF (abhij) (304M) 11' (abd) (24M)	16S (24M) Pilot/Studies (40M)	$400M	Cost Minor Improvement	No New Cap. Non Solution to Re & Prod.	Strong Support Lockheed/GD
#5 Mods Studies	All H.G. Test (10M)	All	All Pilot/Studies (40M)	$416M			

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Summary

The payoffs to the aerospace industry and to the U.S. economy for producing more efficient aircraft than our competitors is of immense proportions. Wind tunnel test and evaluation is a critical element of the product development process and must not be left at the standards of the 1950's.

The working group's conclusions, after assessing current capabilities and review of options to modify existing facilities, is to construct new subsonic and transonic wind tunnels. The subsonic tunnel must be capable of achieving a Reynolds number of 20 million at Mach 0.2 - 0.3 with a productivity of 5 polars of data per hour, and the transonic tunnel with a Reynolds number of 30 million at approximately Mach = 1.0 with productivity of 8 polars per hour.

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Summary

- Assessed existing capabilities and future needs
  - U.S. capability seriously falling behind European
- Reviewed options for modifying existing wind tunnels
  - Insufficient enhancement potential
- Defined goals for new subsonic and transonic tunnels
  - Established consensus on technical requirements
  - Subsonic tunnel with Rn = 20 million & 5 polars/hr.
  - Transonic tunnel with Rn = 30 million & 8 polars/hr.
- Recommended 16S supersonic tunnel upgrade and R&D efforts

Appendix 4

Report of the Strategy Working Group

STRATEGY WORKING GROUP FINAL REPORT

SUBMITTED TO

AERONAUTICS R&D FACILITIES TASK GROUP

Robert Rosen, Chair
January 3, 1994

Outline

The Strategy Working Group (SWG) was chartered by the Aeronautics R&D Facilities Task Group to address policy issues related to the National Wind Tunnel Complex (NWTC).

The SWG was chaired by Dr. Robert Rosen of NASA Ames Research Center. The other members were Sally Bath, Dept. of Commerce, John Bolino, Dept. of Defense, Mark Brenner, Dept. of Commerce, Tom Edwards, NASA Ames, Parker Horner, USAF, Arvid Larson, Walcoff and Assoc., Lynn Laster, USAF/AEDC, and Doug Nation, USAF.

This report presents findings of the SWG for three policy issues of importance to the NWTC. First, possible business arrangments that would allow the government to team with the US aerospace industry in the construction and operation of the NWTC were investigated. In evaluating financing options for the NWTC, three alternatives merit consideration: 1) government only; 2) industry only; and 3) government and industry together. The first alternative is the conventional approach that has extensive precedent within NASA and DoD. This process of obtaining financing from the government is well understood and does not require further analysis. The second alternative, industry only, has been put aside at this time based on the industry's own assessment of its ability to finance such a large capital outlay. The third alternative, government and industry teaming together, has limited precedent but is becoming an increasingly popular means of financing projects that share benefits with public and private interests. Hence, the SWG focused its effort on looking at government/industry teaming arrangements - what both parties seek in a partnership, how the management structure would look, and what impact this would have on the operations of the NWTC.

The next two issues were considered together by the SWG. These were user access priority (particularly with respect to international customers) and charge policy. The SWG assessed current practices and policies regarding these issues and developed proposed policies appropriate for the NWTC.

Outline

- Government-industry consortium options
- Foreign access and user priority policy
- Charge policy

Background

Government-Industry teaming arrangements were developed first within the SWG, then with input from the US aerospace industry. The first step in the process was to make an initial characterization of possible government/industry business arrangements. Features such as source of capital and operating expenses, ownership, user access and fees, and management structure were considered. The results of these discussions were presented to the Aeronautics R&D Task Group. Recognizing that any viable government-industry partnership would require endorsement from industry, the SWG then continued developing the concepts with input from the US aerospace industry.

Background

- Strategy Working Group tasked to develop government/industry scenarios
- Preliminary report briefed to:
  - Strategy Working Group – March 10, 1993
  - Aeronautics R&D Facilities Task Group – March 11, 1993
- Task Group directed further development with inclusion of industry inputs
- Workshop on Government-Industry Wind Tunnel Consortia conducted April 13-14, 1993

Consortium Workshop

To develop a combined government-industry position on possible wind tunnel consortium arrangements, a two-day workshop was held at NASA Ames Research Center April 13-14, 1993. Government representatives included Tom Edwards, Lado Muhlstein, Bob Rosen and Frank Steinle (NASA Ames Research Center), Blair Gloss (NASA Langley Research Center), Frank Graham (Arnold Engineering Development Center/USAF), and Step Tyner (Walcoff and Associates, representing the Office of the Undersecretary of Defense). The industry representatives included Art Fanning (The Boeing Company), Jerry Callaghan (McDonnell Douglas), Dabney Howe (Northrop), and John Guidone (Pratt & Whitney/United Technologies).

Consortium Workshop

- Held at Ames April 13-14, 1993
- Attendees:
  - ARC: Edwards, Muhlstein, Rosen, Steinle
  - LaRC: Gloss
  - AEDC: Graham
  - OUSD: Tyner
  - Boeing: Fanning
  - McDonnell Douglas: Callaghan
  - Northrop: Howe
  - Pratt & Whitney: Guidone

Workshop Objectives

The main objective of the workshop was to develop a government/industry consortium description that included input from both interest groups. The key features of the consortium to be defined were the capitalization scheme, debt repayment, design and construction, operation, and charge policy. The purpose of this activity was to identify the key features of consortia and to develop a conceptual consortium model. Thus, in addition to a primary consortium scenario, options that held promise were to be defined as well.

To facilitate the development of pros and cons for the consortium scenarios, a government-alone baseline model was adopted. In particular, the operating parameters of the NASA Ames Unitary Plan Wind Tunnels were used in comparing and contrasting the various consortium options. The results of this workshop were reported to the full SWG, and subsequently, to the Task Group.

Workshop Objectives

- Develop baseline consortium description
  - Capitalization
  - Debt repayment
  - Design and construction
  - Operation
  - Charge Policy
- Develop consortium options
  - Other promising scenarios
  - Pros and cons
- Use NASA Ames Unitary Plan Wind Tunnels as "Government Alone" baseline for comparison
- Report presented to Strategy Working Group and Aeronautics R&D Task Group

Government/Industry Consortia: Practical Considerations

Some practical considerations were discussed at the outset of the workshop that bounded the range of viable government/industry teaming arrangements. First, the aerospace industry cannot afford to provide the substantial funds necessary to construct the NWTC. This was determined by a comprehensive study by the aerospace industry of the cost of owning and operating a comparable facility by itself. The conclusion of this study was that the capital investment was too great to take on on their own. Furthermore, the cost of this investment would have to be recouped through a premium on the sale price of aircraft. The premium that this investment would place on aircraft prices would make the US aerospace industry noncompetitive with foreign manufacturers, who do not bear this burden.

Second, customers of the facilities should be represented in the management of them. This ensures that equitable, cost-effective decisions will be made regarding scheduling, maintenance, facility modifications, and other issues pertaining to the utility of the facility to its users.

Third, the facility should be self-sustaining to the greatest extent possible. This means that fees for commercial users should be set at a level that would cover all but the capitalization costs. Furthermore, there should be stable sources of funds to maintain a viable operation through periods of low demand, given the cyclical nature of the aircraft industry.

Finally, the compelling need for the NWTC is brought about by the appearance of the European Transonic Wind Tunnel. This facility, which will primarily benefit the European aerospace industry, changes the competitive position of the US industry relative to its foreign competitors. The impact of failing to produce comparable or superior facilities in the US, at similar cost to industry, could be loss of market share and a less favorable balance of trade in the aerospace industry.

Government/Industry Consortia: Practical Considerations

- Industry cannot afford initial capitalization and remain competitive (foreign competition doesn't pay this bill)
- Customers of facilities should be represented in management
- National facility should be self-sustaining to the greatest extent possible
- ETW changes competitive equation in commercial aircraft market

Option A:
Government Corporation

The workshop produced three government-industry teaming arrangements that will be referred to as Options A, B, and C for convenience. The first scenario, Option A, was like a government corporation. All funds for construction and working capital in this arrangement are generated through government appropriations. There is no direct repayment of debt to the government. On the other hand, indirect benefit accrues to the national economy from the continued competitiveness of the US aerospace industry.

The government would be responsible for the design and construction of the facility, but an advisory board of directors consisting of the primary customers of the facility would provide substantial input to the decision making process. Similarly, operations would be managed by the government but advised by a board of customer representatives. The facility could be operated by the government or by a government contractor.

The charge policy reflects a two-tiered rate structure. A standard rate for full cost recovery (excluding initial capital) is charged to members. Membership could be established by guaranteeing a minimum number of occupancy hours, nominally one-fourth of a shift year (approximately 500 hours). Members gain access to the standard charge rate and proportional representation on the advisory board. If members do not require all the hours they guaranteed, and there exists excess demand for tunnel occupancy, those hours may be sold to other members or non-members to defray membership costs. Alternatively, the board could be appointed to consist of representatives of key customers of the facility.

Non-members may purchase time (as available) at a rate that is market-based. The market rate is set according to demand for access to the facility, along with rates available at competing facilities. Thus, the market-based rate may represent either a premium or a discount to the standard rate.

User access priority would provide first priority to members, second priority to US non-members, then international teams with US participation, and finally foreign entities. In case of scheduling conflicts, the management board would adjudicate.

Option A: Government Corporation

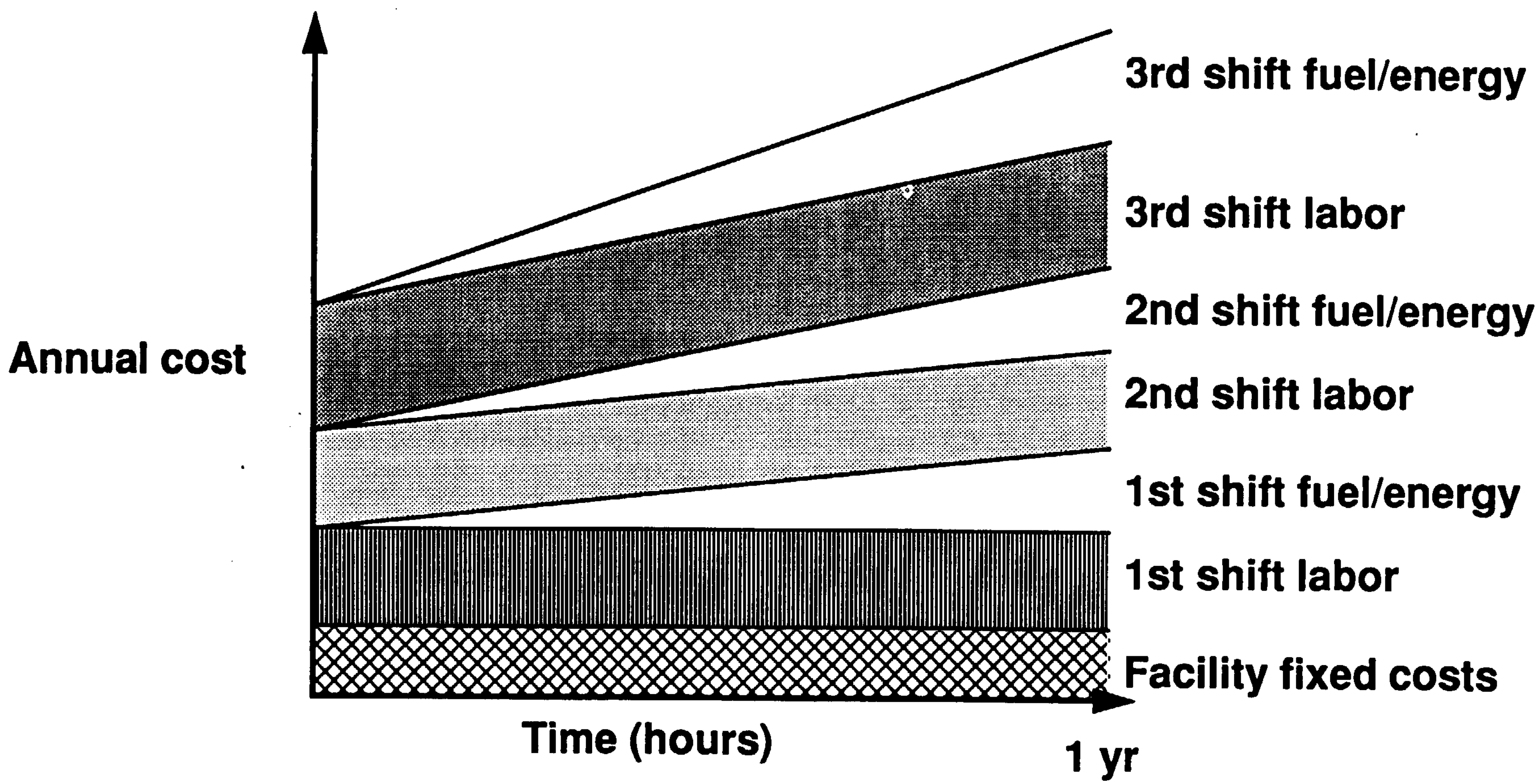
- **Initial capital:** government appropriation
- **Working capital:** government appropriation
- **Debt repayment:** none
- **Design/build:** advisory board of directors
  - > Industry
  - > NASA
  - > DoD
- **Operation:** advisory board of directors
- **Charge Policy:** members - direct + indirect
non-members - market-based

Wind Tunnel Operating Costs

As a primary customer of the facility, the government would purchase and guarantee all costs associated with one-shift operation of the facility. As shown in the figure, this represents the facility fixed costs, the fixed cost of one full shift of labor, and the variable costs of fuel and energy associated with operations. Because the facility would be built for the primary purpose of commercial transport development testing, the industry would be able to use the government's shift if the time was needed for this purpose.

The remaining two shifts would be sold for memberships or on the "open market" to non-members. The charge structure for the overall operation would include the facility fixed costs, so the government would recover a proportional share of the fixed costs to the extent that the facility operated a second and third shift. Only in a period of low facility usage would the government assume total responsibility for facility fixed costs.

Wind Tunnel Operating Costs



Pros and Cons
Option A - Govt. Corporation

Option A features user representation in the design, construction and operation of the facility. There is also precedent for this form of government-industry relationship, such as the Tennessee Valley Authority. The government, by guaranteeing one shift-year of operations, lends stability to the availability of the facility. Finally, this arrangement is supportive of cooperative research in that the government owns an entire shift-year and retains the right to perform research considered to be in the national interest.

Weaknesses of the government corporation described here are that it must create its own entire infrastructure for procurement, administration and other functions intrinsic to an independent corporation. This is in contrast to the government baseline, where that infrastructure already exists, and to the private corporations in Options B and C, which may draw upon the resources of members' parent companies to perform necessary functions. Also, because there is no long-term investment required for membership – just occupancy guarantees for a given year – the membership may be less stable than the other alternatives.

Pros and Cons
Option A - Govt. Corporation

PRO	CON
Some user representation	Must create infrastructure for procurement, administration, etc.
Some precedent (TVA, etc.)	
Stable operating funds	
Supportive of cooperative research	

Option B: Private Corporation/Govt. Loan

Option B can be described as a private corporation that is financed by a government loan. However, a loan forgiveness mechanism is built into the operations so that a profitable industry is rewarded by reduced liability.

First, a private corporation is formed consisting of government and industry wind tunnel customers. The government then provides a loan sufficient to design and build the facility. The corporation members contribute to a reserve fund, representing roughly two years' operating costs, for repairs, improvements and operational readiness during low demand periods. The corporation then manages the design, construction and operation of the facility. The user access and charge policy are patterned similar to Option A.

Recognizing that debt service presents an uneconomical burden on industry members, a mechanism was developed to defray this expense. The annual debt service would be forgiven based on the favorable balance of trade generated by the aerospace industry for the national economy. A level of 1% of trade surplus was proposed as credit against the debt service. This would offset the significant capital costs associated with owning such a facility, while creating an incentive to maintain a favorable balance of trade for the national economy.

Option B:
Private Corporation/Govt. Loan

- **Initial capital:** government loan
- **Working capital:** member investment
- **Debt repayment:** annual loan forgiveness
- **Design/build:** consortium members
- **Operation:** consortium manages,
contractor operates
- **Charge Policy:** members - direct + indirect
non-members - market-based

Pros and Cons
Option B - Private Corp./Govt. Loan

Option B, the private corporation financed by a government loan, features the advantage of giving complete responsibility for construction to the ultimate customers of the facility. This creates an integrated design process that maximizes the utility of the final product to its customers. Also, with capital investments by all members including the government, there are more sources of capital to draw upon, lending financial soundness to the operation. Users bear all the operating costs, so the viability of the business is directly related to the demand.

Because a private corporation represents a source of tax revenue, there exists the opportunity that local governments will offer incentives to locate the facility within their jurisdiction, potentially defraying the cost of construction or operation. The members retain more authority in this operation than in the government corporation. Also, these members have the opportunity to reach back to their parent companies for support in functions such as procurement, making for a smaller, more efficient operation. The government doesn't guarantee one-shift operations in this situation, avoiding the taxpayer burden associated with that cost. Obtaining the buy-in of industry in this arrangement confirms the value of the investment. Also, the debt forgiveness feature creates an incentive to improve the balance of trade and retain jobs domestically.

On the negative side, the private corporation will be liable for taxes and insurance (unlike a government-owned facility), increasing operational costs. There is also less precedent for this kind of government-industry business relationship. The debt forgiveness has the appearance of a government subsidy which may complicate international trade agreements. Also, the cost of testing in the facility will greatly restrict its accessibility to the aerodynamics research community, which generally does not have sufficient funding to pay for wind tunnel testing. The private enterprise makes the facility the least accessible to national security needs, too, which may be of concern in times of significant military need. The high buy-in level limits membership to entities with significant capital resources, and the operating funds (recovered from user fees) fluctuate with demand for the facility. Finally, creating a viable consortium in this case adds the difficulty of obtaining a unilateral commitment from industry.

Pros and Cons
Option B - Private Corp./Govt. Loan

PRO

Integrated product design process

More sources of capital

User bears operating cost

Local govt. incentives (for tax revenue)

More user representation

Use corporate procurement infrastructure

Less taxpayer burden

Industry working capital committed

Creates incentive for balance of trade and domestic job retention

CON

Increased tax and insurance liability

Less precedent

Appearance of govt. sweetheart deal

Less accessible to research community than A

Least national security orientation

Appearance of exclusivity in membership

Less stable operating funds than A

Must get unilateral commitment from industry

Option C:
Private Corporation/Govt. Lease

The third arrangement, Option C, represents a variation on the private corporation concept described in Option B. In this arrangement, the government would appropriate the funds for the design and construction of the facility. The process would be managed by a consortium of members, where membership would again be purchased through investments in working capital and occupancy guarantees. Upon completion of construction, the facility would be leased at a nominal rate to the corporation, which would then manage the operation of the facility. The actual operations would be carried out by a contractor to the corporation. The same access and charge policies would apply as in the preceding examples.

Option C:
Private Corporation/Govt. Lease

- Initial capital: government appropriation, lease to consortium
- Working capital: member investment
- Debt repayment: none
- Design/build: consortium members
- Operation: consortium manages, contractor operates
- Charge Policy: members - direct + indirect
  non-members - market-based

Pros and Cons
Option C - Private Corp./Govt. Lease

Option C features essentially the same pros and cons as Option B. In addition, the arrangement appears to favor the current agenda in the federal government to provide infrastructure to enable private industry to compete in the world marketplace. On the negative side, the construction of the facility is complicated by the fact that the government will finance construction on behalf of a private entity.

Pros and Cons
Option C - Private Corp./Govt. Lease

PRO	CON
Same as B, plus:	Same as B, plus:
Terms favor Clinton agenda	Customer for design/build process unclear - govt. pays, but built for private corporation

Summary of Consortium Workshop Findings

This chart summarizes the business arrangements described above. The existing mechanism, government-owned and government- or contractor-operated, is used as a baseline to compare the relative merits of the alternative business arrangements. The strengths and weaknesses developed by the SWG for Options A, B, and C help determine which of these alternatives offers the best taxpayer investment and best meets the customer needs.

Summary of Consortium Workshop Findings

Component	Baseline	Option A	Option B	Option C
Business Arrangement	NASA or DoD	Govt. Corporation	Private Corporation Consortium of Facility Users Commercial - Boeing, Douglas, NASA Defense - DoD	Private Corporation Consortium of Facility Users Commercial - Boeing, Douglas, NASA Defense - DoD
Initial Capitalization	Govt. Appropriated Funds	Govt. Appropriated Funds	Govt. Loan 20:1 Debt:Equity Interest - Low or Free, secured by tunnels	Govt. Appropriated Funds, then Govt. leases to private corporation ($1/yr)
Equity Source (Working Capital)	Govt. Appropriated Funds	Govt. Appropriated Funds	Govt./Industry investment, e.g.: $25M Boeing, Douglas, NASA $25M DoD; Appropriated Funds	Govt./Industry investment, e.g.: $25M Boeing, Douglas, NASA $25M DoD; Appropriated Funds
Debt Repayment	None (value recovered by improved national defense and balance of trade)	None (value recovered by improved national defense and balance of trade)	Annual Loan Forgiveness: Commercial: Percent of trade surplus (e.g., 1%) DoD: Years of availability	None (value recovered by improved national defense and balance of trade)
Design, Site Selection and Construction Decisions and Methods	NASA or DoD via FAR	Govt. Corp. Advisory Board of Directors: * Industry * NASA * DoD	Consortium members	Consortium members
Operation	NASA: GOGO/GOCO DoD: AEDC - GOGMCO	Govt. Corp. Advisory Board of Directors: * Industry * NASA * DoD	Consoritum manages, contractor operates	Consoritum manages, contractor operates
Charge Policy	Tiered sponsored: free or direct nonsponsored: direct + indirect	Members* - direct+indirect others - market-based *Buy-in via guaranteed test time	Members* - direct + indirect others - market based *member usage - 1 year commit 3 year 50% commit 5 year look-ahead	Members* - direct + indirect others - market based *member usage - 1 year commit 3 year 50% commit 5 year look-ahead

Feedback from Task Group

These findings were reported to the Aeronautics R&D Facilities Task Group. This resulted in further direction to the SWG to develop another option, "Option D," that featured more industry investment in the capitalization of the NWTC. Scenarios that involved 25%-50% industry participation were targeted, and the SWG was directed to define desirable business arrangements, member rights and responsibilities, and user access and charge policies.

To accomplish this, the SWG again went to the industry representatives (the same ones that participated in the original workshop) and developed a consensus of how to structure such a business.

Feedback from Task Group

- Investigate Option D: a government-industry consortium with some industry investment in capitalization
- Seek industry capitalization of 25%-50%
- Develop member rights and responsibilities
- Develop buy-in and usage costs
- Identify return on investment for industry

Option D:
"Government/Industry Partnership"

This chart summarizes the key features of Option D. It is largely the same as Option B (the private corporation with government loan), but in this case corporate membership is gained through a substantial equity investment. The member's representation in the management of the facility is proportional to the initial capital investment. The government's share comes from appropriations, while industry shares are established with a 25% down payment. This was done to reduce the actual capital outlay by industry and more closely follow industry practices for financing such a project. The partnership uses this equity to borrow the balance of the industry contribution. In addition to participation in the management of the facility, members gain guaranteed access up to the percentage of their ownership of the facility.

Unlike Option B, there is no debt forgiveness in this scenario. The debt service becomes part of the charge structure to non-government customers (the government's capital was appropriated and thus has no debt service associated with it). Initially, 100 shares would be offered for sale. The desired level of industry participation in the initial capital would be achieved by selling at least 25 shares to industry.

Option D: "Government/Industry Partnership"

- Like Option B in member rights and responsibilities
  - Members buy in with initial capital - government pays its share up front, industry pays 25% up front, partnership borrows balance
  - Independent entity formed
  - Members manage design, construction and operation
  - Guaranteed access, preferential rate, management representation
- No annual debt forgiveness
- 100 shares of facility for sale
- Require >25% private ownership, e.g.,
  - DoD 33 1/3
  - NASA 33 1/3
  - Industry 33 1/3

Option D
Investment Example

It is illuminating to look at the effect of debt service on the cost of using the facility. This and the following charts work through a hypothetical $1 billion wind tunnel facility that is planned to operate three shifts a day. Financing this capital outlay with 100 shares sets the price of a share at $10 million. This one-percent share entitles the member to roughly 60 occupancy hours per year. Further suppose that the government elects to buy 67 shares (half for NASA and half for DoD) and the industry buys the remaining 33. The government would purchase its shares outright with a special appropriation of $667 million. These funds could be used first, for design and construction, if necessary to defer industry's capital outlay to nearer the operational date of the facility.

The industry shares are purchased on 25% margin, so each $10 million share is financed with $2.5 million up front. The partnership formed from the members then borrows the remaining $7.5 million per share with government guarantee. The debt is repaid through annual membership dues or, equivalently, user fee premiums. Thus, the 33 industry shares require a margin payment of $82.5 million, and an additional $247.5 million would be borrowed by the consortium.

Option D
Investment Example

- For $1B facility, 1 share costs $10M
  - One share provides for 60 occupancy hours
  - Government investment (67 shares=2 shift years): $667M
  - Industry investment (33 shares=1 shift year): $333M
- Government buys its shares outright (special appropriation)
  - Government funds used for initial design and construction
  - Permits industry to defer investment until nearly operational
- Industry buys shares on 25% margin
  - One industry share costs $2.5M up front
  - Partnership borrows balance
  - Government guarantees loan of $7.5M per share
- Debt service repaid through annual membership dues or user fee premiums

Option D
Working Capital Example

In addition to the initial capital for design and construction, the partnership also requires two years' operating funds to maintain cash flow, to provide a contingency fund for repairs and to maintain operational readiness in low demand periods. If the annual cost of operations is $25 million, then the reserve account requires $50 million, or $500,000 per share. The government's share of this account is $33.3 million and the industry share is $16.7 million.

Option D
Working Capital Example

- Need approximately 2 years' operating funds in partnership account
  - working capital for cash flow
  - contingency fund for repairs
  - maintain operational readiness in low demand periods
- Projected annual cost of operations is $25M
- Prior to start of production operations, members assessed $0.5M per share
  - Government: $33.3M
  - Industry: $16.7M

Option D
User Cost Example

Under this scenario, an approximation for the user fees can be made with a few further assumptions: assume that the facility is supported by 50 operations staff paid $60 per hour (including their direct and indirect costs). Utilities (water and electricity) will cost $1500 per hour. For the industry construction loans, the assumed rate is 12% with 30 year amortization. This leads to the following breakdown of hourly operating costs:

Labor (L)	$3000
Utilities (U)	$1500
Debt service (D)	$24,000

Thus, the fully burdened rate - that paid by industry members and non-members - amounts to $28,500 per occupancy hour (L+U+D). The unburdened rate paid by government members is $4500 per occupancy hour (L+U).

Option D
User Cost Example

- Consider transonic facility
- Assume:
  - $1B capitalization
  - 50 operations staff (estimates vary from 40 to 100) at $60/hr direct+ indirect
  - Utility (water + elect.) cost $1500 per occupancy hour (estimates vary from $1000 to $2000, based on typical commercial test program)
  - Loan rate 12%, 30-year amortization (current industry rate)
  - Two shift operations - 4160 occupancy hours per year
- Labor = $3000/occupancy hour
- Utilities = $1500/occ. hr
- Debt Service = $24,000/occ. hr
- Fully burdened rate = Labor + Utilities + Debt Service

  = $28,500/occ. hr

Option D
User Cost per Polar

A more accepted basis of comparison is the cost per drag polar. This figure accounts for the productivity of the facility in the cost of obtaining data. The productivity goal for the new transonic facility is eight polars per occupancy hour. The unburdened rate is thus $560 per polar, while the fully burdened rate is $3560 per polar. The sensitivity of this burdened rate to some of the assumptions can be evaluated for a worst-case and best-case situation. In the best case, the interest rate is reduced to 6% and the productivity is increased to 8.5 polars per hour with three-shift operations. This results in a rate of $1650 per polar. If, on the other hand, the facility runs only two shifts and the productivity drops to 5 polars per hour, the resulting rate is $6000 per polar.

It is typical business practice to use an accelerated depreciation schedule, which would significantly increase the amortization cost over that used in this simple example, perhaps tripling it.

Option D
User Cost per Polar

- **Assume 8 polars per occupancy hour (typical commercial test program)**
- **No capitalization (L+U): $560/polar**
- **Full burden (L+U+DS): $3560/polar**
- **Possible variation (due to utility cost, staff level/ cost, interest rate, productivity)**
  - **Lowest likely: $1650/polar (3 shifts, i=6%, 8.5 polars/hr)**
  - **Highest likely: $6000/polar (2 shifts, i=12%, 5 polars/hr)**
- **Actual accounting procedures require accelerated depreciation**
  - **<u>Triples</u> (or greater) straight-line amortization cost in early years**

Option D Summary

To summarize the findings from the Option D study, the arrangement is largely the same as Options B and C. However, Option D requires substantial industry capital outlay and the user cost example shows the impact this has on user rates. Options B and C showed two examples of ways to defray these capital expenses, though many other options are possible, such as public stock offerings, tax credits or other special accounting procedures.

Upon completion of this study, the Aeronautics R&D Facilities Task Group directed industry members of the Task Group to obtain an unofficial position on the viability of the industry participating in an arrangement such as Option D. As of the date of this report, no industry feedback has been offered to the Aeronautics R&D Facilities Task Group.

Option D
Summary

- Member rights & responsibilities same as Option B (loan w/debt forgiven) and Option C (government build/lease)
- Options B&C show ways to defray capital expenses to industry - many other means possible
  - public stock offering
  - tax credits
  - special accounting procedures

National Aeronautical Facilities
Foreign Access, User Priority, and Charge Policy

Two other issues that the SWG addressed concern policy for the operation of the NWTC. The first is how to assign user priority. Customers for the facility include government - military and civilian - along with domestic industry, foreign military and foreign industry. The second issue is charge policy. The foregoing examples put forth a tiered charge structure that was developed for a hypothetical government-industry business arrangement. Many variations are possible and it is best to have a rationale up front regarding a proposed charge structure.

National Aeronautical Facilities

Foreign Access, User Priority, and Charge Policy

Objective

Of particular concern in the area of user access is the likely prospect of foreign customers requesting access to the NWTC. The SWG was requested to research the policy issues involved with this subject.

Objective

Propose policy regarding international customers for national aeronautics facilities

Background

Current legislation pertinent to international access to government wind tunnel facilities is unclear. There are examples within the government of facilities that have permitted access to international customers, and others that have not.

The SWG's interpretation of the Uruguay round of GATT is that international access will be required. To ensure that the primary customers - US government and US aerospace industry - obtain as much access as they require before reserving time for international entries, a priority system is proposed for scheduling test entries.

Background

- Under current laws, it is unclear whether we must allow foreign entities to test in US facilities

- Under Uruguay round of GATT, indications are that we will be required to do so

- SWG tasked with investigating current policies and proposing international access and charge structure policy for new aeronautical facilities

Proposed User Priority Structure

The SWG was tasked to develop a user priority policy that would serve the nation's interests for access to the NWTC. The SWG proposes that all potential customers be offered access and prioritized as follows: first, wind tunnel consortium members (if the facility were operated as a consortium); next, other US industry customers, then US government, international teams, and finally, foreign entities (government or industry). In the case of a government-owned facility, the priority would begin with US industry, then US government, and so on.

Proposed User Priority Structure

1. Wind tunnel consortium members (if applicable)
2. Other US industry
3. US government
4. International teams with US membership
5. Foreign entities

Capital Recoupment Policy

There are disparities in the charge policies throughout government facilities. For example, both NASA and the Air Force Arnold Engineering Development Center (AEDC) exclude recovery of initial capital costs in the charge structure. However, NASA does include in the charge structure a premium to recoup costs for major improvements and modernization, while AEDC does not..

The Strategy Working Group put forward a proposal to apply the AEDC charge policy to the NWTC (i.e., no recoupment of initial capital nor modernizations) for domestic customers. This proposal was adopted by the Task Group.

Capital Recoupment Policy

- Current policy does not require recoupment of initial capitalization at either AEDC or NASA
- Recoupments of major improvements and modernization are required at NASA facilities, but not AEDC
- We propose policy consistent with AEDC
- For a consortium, policy would be dependent on particular consortium business structure

Proposed Charge Structure

The proposed charge structure for the NWTC will recover from all customers the direct and indirect operations expenses. Government testing requirements would be funded institutionally. Industry consortium members and non-members would pay a premium for debt service on industry loans (if applicable), although government members would not pay this premium because the government capital was appropriated, not borrowed. Foreign customers would pay a premium representing full debt service (initial capital and improvements). The justification for this premium is that domestic customers contribute to the capitalization costs through tax payments, while foreign entities do not.. However, it was noted that in a consortium arrangement with industry the charge policy would be determined by the consortium.

Proposed Charge Structure

Customer	Direct	Indirect	Debt service on industry shares	Full debt service
Government	X	X		
Non-govt. Members*	X	X	X*	
US non-member	X	X	X*	
Foreign	X	X		X

*if applicable

Appendix 5

Report of the Propulsion Facilities Working Group

PROPULSION FACILITIES WORKING GROUP

FINAL REPORT

FOR

AERONAUTICS FACILITY TASK GROUP

DECEMBER 2, 1993
DAVID J. POFERL
DIRECTOR OF TECHNICAL SERVICES
NASA LEWIS RESEARCH CENTER

Continued advances in engine technology are key to major improvements in aircraft performance and therefore to the U.S. competitiveness in the world commercial transport markets. The Nation's propulsion facilities infrastructure has been a major factor in U.S. competitiveness in the area of commercial aircraft engines. Continued advances in propulsion technology are critical to improving cruise economy and minimizing environmental impact in terms of noise and emissions and in general reducing aircraft acquisition and operating costs. Recognizing the continued importance of propulsion advances, the Aeronautics R&D Facilities Task Group established the Propulsion Working Group on January 11, 1993, and chartered it to address facility needs in the Nation's propulsion facility infrastructure.

In assessing potential propulsion facility shortfalls, the Propulsion Working Group focused primarily on development facility requirements for future subsonic and supersonic commercial transports. To determine an appropriate timeframe for assessing facility needs for subsonic aircraft propulsion systems, the Working Group felt it necessary to look at propulsion systems beyond the current GE90 and PW4000 series of engines (i.e., post year 2000). In the area of engines for supersonic commercial aircraft, the Working Group focused on the propulsion system facility requirements for the High Speed Civil Transport (HSCT).

INTRODUCTION

- PROPULSION TECHNOLOGY KEY TO AIRCRAFT PERFORMANCE
  - CRUISE ECONOMY
  - ENVIRONMENTAL IMPACT
- PROPULSION FACILITY INFRASTRUCTURE
  - CURRENT CAPABILITY
  - FUTURE REQUIREMENTS

In order to assess propulsion facility requirements for the development of future engines, a team consisting of NASA, DOD, and industry participants was formed. This team represented a broad range of expertise covering propulsion research, development, and facilities.

PROPULSION WORKING GROUP MEMBERSHIP

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Altitude engine test facilities, propulsion wind tunnels, and engine/propulsion component facilities address the full range of facilities needed to develop and continually improve both civil and military aircraft engines. Our assessment covers propulsion facility requirements for future subsonic and supersonic aircraft. Hypersonic facility requirements were addressed by the Hypersonic Working Group. The Propulsion Working Group assessed the existing capabilities of the U.S. propulsion facilities including those at the engine companies, airframers, universities, DOD, and NASA installations related to subsonic and supersonic applications. In addition, foreign capabilities were reviewed.

Our overall assessment is that with a few exceptions, the U.S., through industry and government laboratories, owns the largest and most capable propulsion facilities in the free world. The existing propulsion facilities, with several exceptions that will be discussed in the charts that follow, are adequate to support future research and development testing. However, due to the high costs of maintaining industries' aging facilities and the severe financial pressure industry is experiencing, dependence on government test facilities is expected to significantly increase. To be competitive, industry will need timely access to reliable, highly productive, and high data quality facilities. Increased support for existing facilities is strongly supported by this Working Group and continuation of selected rehabilitation and upgrade efforts, along with an enhancement in maintenance activities, is recommended. An area of increasing concern is the need for timely replacement and upgrade of facility instrumentation, controls and data systems, and the development of advanced instrumentation systems to ensure high testing productivity.

ASSESSMENT OF CURRENT PROPULSION FACILITY CAPABILITIES

- ALTITUDE ENGINE TEST FACILITIES
- PROPULSION WIND TUNNELS
- ENGINE/PROPULSION COMPONENT FACILITIES

The Working Group identified and addressed three key areas with regard to future propulsion system requirements and the adequacy of current facilities infrastructure to adequately support the development of these systems. These areas included high engine mass flow for subsonic transports, inclement weather simulation, and full scale engine development for HSCT. In the process of assessing the impact of future technology development in these areas on facility requirements, it was necessary to obtain input from the airframe industry. Specifically, the Working Group obtained input from Boeing and McDonnell Douglas on the largest anticipated subsonic transport engines in terms of size and thrust, future cycle times from product launch to market, new certification processes, and full scale engine test requirements for HSCT.

In addition, the Propulsion Working Group provided inputs to the Aero-Aeroacoustics Working Group to ensure that the proposed new subsonic and transonic tunnels met propulsion system test requirements in the area of acoustics and propulsion simulator capabilities.

REQUIREMENTS

- FUTURE PROPULSION FACILITY REQUIREMENTS
  - ENGINE MASS FLOW FOR SUBSONIC TRANSPORTS
  - INCLEMENT WEATHER SIMULATION
  - FULL SCALE HSCT ENGINE DEVELOPMENT

- PROPULSION REQUIREMENTS FOR PROPOSED NEW SUBSONIC AND TRANSONIC WIND TUNNELS
  - ACOUSTICS
  - PROPULSION SIMULATORS

Development of today's new generation high mass flow subsonic engines is accomplished by utilizing sea level static facilities, simulated altitude facilities, and/or flying test beds that already exist or will be available soon. The ASTF facility at AEDC is the only test site that can satisfy most simulated altitude conditions for large engines currently under development. The current PW4084 has a thrust of 84,000 lbs. and a flow of about 2800 pps at sea level take-off conditions. At a cruise altitude of 30,000 ft., the flow is approximately 1200 pps. Since ASTF is currently limited by exhauster capability to a maximum flow of 2200 pps, this world-class facility is limited to tests above 10,000 ft. simulated altitude for engines in the PW4084 class. This test capability is considered adequate for the development of engines in this thrust class at their current thrust levels.

Based on CF6 and JT9 history, derivative engines are developed over 20 to 25 year periods. If this holds true for GE90 and PW4000 series, development derivatives of these engines up to 120,000 lbs. thrust can be expected. At thrust levels of 120,000 lbs. engine airflow at sea level, take-off conditions will approach 4000 pps. Tests at simulated cruise conditions in ASTF will then be limited to altitudes above 25,000 ft.

Only one new engine program beyond the PW4000/GE90 series was identified by the Working Group. This engine, the P&W ADP, could require mass flows in excess of 3000 pps at sea level take-off conditions. Preliminary AEDC cost estimates range from \$100M to \$200M to increase the flow capability of ASTF to 2950 pps. Upgrades to 3500 pps capability is currently estimated to cost about \$400M to \$600M. Since these estimates are of the magnitude of the entire ADP engine development costs, the Working Group decided that a mass flow upgrade to ASTF was not justified at this time.

REQUIREMENTS (CONTINUED)

MASS FLOW UPGRADES TO GROUND BASED ENGINE FACILITIES

(NEAR TERM)

- ASTF (AEDC) MASS FLOW "ADEQUATE" FOR PW4000/GE90 SERIES SIZE ENGINES
- ONLY ONE NEW ENGINE PROGRAM IDENTIFIED BEYOND PW4000/GE90 SERIES (PW ADP)
  - LARGE VERSIONS OF ADP COULD REQUIRE MASS FLOWS OVER 3000 PPS
  - ASTF CAPACITY IS 2200 PPS
  - COST TO INCREASE ASTF MASS FLOW TO 2950 PPS ESTIMATED AT $100M TO $200M
  - COST TO INCREASE ASTF MASS FLOW TO 3500 PPS ESTIMATED AT $400M TO $600M

Projections by Boeing and Douglas result in a wide range of engine mass flows estimated for future engines over the next 20 to 30 years. Fan diameter estimates range from 11 to 18 ft. with engine thrusts projected to reach 120,000 lbs. Fan-corrected airflows consistent with the airframers projections range from 3500 to over 9000 pps. Comparing these projections with the current capability at AEDC (ASTF) indicates a major upgrade if engines having these mass flows require development testing in a ground-based altitude facility. An aircraft testbed may be a preferred option for airflows substantially in excess of today's altitude ground test capabilities. In light of the present uncertainty with regard to future propulsion system requirements, the Working Group has identified a need for further refinement of post PW4000/GE90 series engine facility requirements. Since NASA is presently configuring the Advanced Subsonic Technology (AST) initiative, it would be appropriate to coordinate a study of future engine facility requirements with the ongoing AST activities.

REQUIREMENTS (CONTINUED)

MASS FLOW UPGRADES TO GROUND BASED ENGINE FACILITIES

(FAR TERM)

- AIRFRAMER PROJECTIONS FOR ENGINES OVER THE NEXT 20-30 YEARS

	BOEING	DOUGLAS
FAN DIAMETER (FT.)	14-18	11-14
ENGINE THRUST (LBS.)	>100,000	120,000

- FAN CORRECTED AIRFLOWS AT THESE FAN DIAMETERS RANGE FROM 3500 TO OVER 9000 PPS
- MASS FLOW UPGRADE REQUIREMENT ANTICIPATED

The ASTF is currently being fitted with an engine icing system that will provide the simulation for conditioned airflows up to approximately 1600 pps. This upgrade falls short of meeting the need for testing large engines over the full range of conditions expected in flight (primarily high thrust engines operating at low altitudes). A second phase is required to expand the system to match a capacity of 2200 lbs. m/sec. It is recommended that this phase be implemented in FY95 and FY96. The need to upgrade rain and hail simulation capabilities at altitude test conditions was also addressed. Existing sea-level capabilities (with some future upgrades) combined with analytical codes may be adequate to satisfy certification testing for rain and hail ingestion at altitude. The Propulsion Working Group was unable to reach a consensus on this issue.

The NASA LeRC Icing Research Tunnel (IRT) is currently being upgraded to increase simulation speed 25% (300 MPH with 20% model blockage) and to increase productivity. Additional improvements are required to more accurately test industry-provided aircraft components, sub-scale models and small engines over the full range of climbout, hold and descent conditions. The proposed project when implemented in FY97 will further increase airspeed to 400 MPH (with 20% model blockage), improve airflow quality (with performance consistent with modern low-speed aerodynamic wind tunnels), and provide a 30% increase in the uniform icing cloud size.

This project is supported by the Propulsion Working Group and the Aero/Acoustic Working Group due to IRT's unique role in basic research of icing phenomena in support of code verification, certification of ice protection systems, and development of new ice protection systems.

REQUIREMENTS (CONTINUED)

INCLEMENT WEATHER SIMULATION

- ICING
  - ASTF UPGRADES
  - LERC ICING RESEARCH TUNNEL UPGRADE
- HEAVY RAIN
  - ASTF UPGRADE
- HAIL
  - ASTF UPGRADE

The currently planned program requirements for the subscale HSCT effort can be satisfied by existing test facilities (NASA, AEDC, and industry). However, full scale inlet/engine operability validation before flight for the full scale HSCT development program could economically be satisfied by adding supersonic freejet capability to AEDC's ASTF. Subsonic freejet capability, if needed, already exists in this facility for current engines or those presently under development. In addition, ASTF modification will be required to adequately test engine/nozzle performance for HSCT propulsion systems.

REQUIREMENTS (CONTINUED)

HIGH SPEED CIVIL TRANSPORT (HSCT) ENGINE FACILITY NEEDS

- ASTF SUPERSONIC FREEJET FOR INLET/ENGINE DEVELOPMENT
- ASTF TEST CELL MODIFICATIONS FOR ENGINE/NOZZLE DEVELOPMENT

The Propulsion Working Group interfaced extensively with the Aero/Aeroacoustics Working Group to ensure that propulsion related requirements were included in the proposed new subsonic and transonic wind tunnels. Since advanced engine inlets are projected to have acoustic signatures in the range of tunnel background noise, it was critical to the propulsion community that the subsonic tunnel background noise be minimized. Desired background tunnel noise levels are 70 db at 0.3-1.0 kHz and 55 db at 10 kHz. It was also essential that the subsonic tunnel provide an anechoic chamber with an open jet capability for isolated tests of large scale models and for installed effects. These requirements have been accepted by the Aero/Aeroacoustics Working Group and have been incorporated in the design requirements for the new subsonic tunnel.

A review of the existing Turbofan Propulsion Simulators (TPS) used in propulsion integration testing in wind tunnels with atmospheric total pressure result in a required facility auxiliary pressure for the turbine drive air of 300 psi to 450 psi at a flow rate of up to 7 lbs. m/sec. For the proposed new high Reynolds number wind tunnels these values would approximately increase proportionally with the tunnel total pressure. Therefore, for TPS testing in a tunnel with a total pressure of five (5) atmospheres the facility auxiliary air requirement would be up to 2250 psi at a flow rate of 35 lbs. m/sec. Advanced TPS designs having interchangeable fans to permit simulating a variety of engine by-pass ratios with a single drive turbine require flow rates of up to 4 lbs. m/sec. at 200°F and pressures up to 1000 psi. For a tunnel operating at five (5) atmospheres total pressure, advanced simulators would require up to 5000 psi and 20 lbs. m/sec. facility auxiliary air. A facility auxiliary air capacity of 3000 psi (desired up to 5000 psi) with a capability of heating the air to 400°F at a flow rate of 35 lb. m/sec. would satisfy the propulsion simulator requirements. Of course, new wind tunnel force balances will be required with capability to handle this airflow across the balances for TPS testing and to handle the increased loads associated with the higher tunnel total pressures/dynamic pressures.

TPS units are currently calibrated in a test chamber which is evacuated to obtain simulated Mach numbers with the fan inlet airflow being atmospheric (same total pressure as most current wind tunnels). In order to simulate TPS inlet conditions comparable to those of the new high Reynolds number wind tunnels (i.e. five (5) atmospheres inlet total pressure), a calibration capability is needed. Flow through nacelle calibration could also be accomplished in this TPS calibration facility without any additional facility requirements.

Finally, to adequately assess HSCT nozzle jet noise the auxiliary air supply must be able to provide 40 pps at 500°F and 40 pps at 1500°F at a pressure of approximately 150 psi. The heater to provide the high temperature air supply to the nozzle should be uniform and suppressed to ensure that heater noise is not being measured as nozzle acoustics.

REQUIREMENTS (CONTINUED)

NEW WIND TUNNELS - PROPULSION REQUIREMENTS

- ACOUSTICS (SUBSONIC TUNNEL)
  - LOW TUNNEL BACKGROUND NOISE LEVELS
  - ANECHOIC CHAMBER WITH OPEN JET
- PROPULSION SIMULATORS (TPS AND UPS)
  - AUXILIARY HIGH PRESSURE AIR SUPPLY FOR TURBINE DRIVES
  - FORCE BALANCES TO HANDLE INCREASED FLOWS
  - TPS CALIBRATION FACILITY
- HSCT NOZZLES
  - HIGH TEMPERATURE AIR FOR NOZZLE ACOUSTICS
  - NOISE SUPPRESSION DOWNSTREAM OF HEAT ADDITION

Long range studies for engines beyond the GE90 and PW4000 series to define facility requirements beyond the year 2000 need to be conducted with engine companies, aircraft companies, airlines, and FAA involvement. Emphasis in these studies should be focused on the optimum approach to developing future propulsion systems and the concomitant facility requirements. We recommend that these studies be initiated in FY94 and that they be coordinated with NASA's Advanced Subsonic Technology initiative.

While the Propulsion Working Group believes that a mass flow upgrade to ASTF may be required in the future, we do not recommend proceeding at this time. We believe that ASTF marginally supports the near term GE90/PW4000 series of engines and recommend that any upgrade be deferred until the studies are completed to better define propulsion system and facility requirements associated with future engines beyond growth versions of the current GE90 and PW4000 engine series.

Program requirements for the subscale HSCT effort can be satisfied by existing test facilities (NASA, AEDC, and industry). However, full scale inlet/engine operability validation before flight for the full scale development program could economically be satisfied by adding supersonic freejet capability to ASTF. Subsonic freejet capability, if needed, already exists in this facility for current engines or those presently under development. In addition, ASTF modifications will be required to adequately ground test engine/nozzle performance for HSCT propulsion systems.

Icing is becoming an increasingly important issue to both commercial and military aircraft. For example, operational and regulatory issues applied to twin-engine overwater flight will require better and more productive icing test capability. Therefore, the Propulsion Working Group endorses the planned upgrades to the existing NASA Icing Research Tunnel and the icing upgrade to ASTF. While heavy rain and hail are also concerns, the Propulsion Working Group has not achieved consensus on the need for additional facility capability in these areas.

The development of future propulsion systems must consider both national and international noise standards to ensure commercial competitiveness of U.S. aircraft. It is therefore essential that the new large subsonic tunnel design include an anechoic chamber with open jet test capability. In addition, the desired background tunnel noise levels are 70 db at 0.3-1.0 kHz and 55 db at 10 kHz in order to accurately evaluate engine inlet and nozzle acoustics.

RECOMMENDATIONS

- CONDUCT A STUDY TO REFINE POST PW4000/GE90 PROPULSION SYSTEM FACILITY REQUIREMENTS
- DEFER DECISION ON MASS FLOW UPGRADE TO ASTF UNTIL RESULTS OF STUDY TO DEFINE FUTURE DEVELOPMENT FACILITY REQUIREMENTS ARE AVAILABLE
- UPGRADE ASTF TO SUPPORT HSCT ENGINE DEVELOPMENT
- COMPLETE PROPULSION SYSTEM ICING MODIFICATION TO ASTF AND PROCEED WITH PLANNED UPGRADES TO NASA LERC ICING RESEARCH TUNNEL
- INCLUDE AN ANECHOIC CHAMBER WITH OPEN JET TEST CAPABILITY AND LOW TUNNEL BACKGROUND NOISE LEVELS IN THE DESIGN OF THE PROPOSED LARGE LOW SPEED WIND TUNNEL

For TPS testing in a tunnel with a total pressure of five (5) atmospheres the facility auxiliary air requirement would be up to 2250 psi at a flow rate of 35 lbs. m/sec. In addition, advanced simulators are currently being designed that could require up to 20 pps at 4000 psi for tunnels operating at 5 atmospheres. The Working Group therefore recommends a facility auxiliary air capability of 3000 psi (desired up to 5000 psi) with a capability of heating the air to 400°F at a flow rate of 35 lbs. m/sec. Of course new wind tunnel force balances will be required with capability to handle this airflow across the balances for TPS testing and to handle the increased loads associated with the higher tunnel total pressures/dynamic pressures.

TPS units are currently calibrated in a test chamber which is evacuated to obtain simulated Mach numbers with the fan inlet airflow being atmospheric (same total pressure as most current wind tunnels). A new TPS calibration facility capable of simulating TPS inlet conditions comparable to those of the new high Reynolds number wind tunnels (i.e., five (5) atmospheres inlet total pressure) is recommended. Flow-through nacelle calibration could also be accomplished in this TPS calibration facility without any additional facility requirements.

For accurate HSCT nozzle jet noise simulation, auxiliary air supplies of 40 pps at 500°F and 40 pps at 1500°F are required. It is essential that the noise suppression be accomplished downstream of the heat addition to the auxiliary air supply to ensure that heater noise is not measured as nozzle acoustics.

Development of advanced engine and airframe materials paces technological advances in commercial aircraft and is key to the economic success and U.S. leadership in this market. Engine performance represents the greatest single contribution to aircraft economics during cruise and the rate at which new engine materials are developed and transitioned to production determines the propulsion system technology level (and level of risk) that can be incorporated into new commercial aircraft ventures. Reducing the cycle time from basic materials research to introduction into production can result in a major U.S. competitive advantage in the commercial transport market. Although the Propulsion Working Group was not able to identify unique national facility needs for materials, we do recommend that a materials workshop be held to address national facility needs for expediting the transition of materials technology from R&D to production capability. We recommend that the workshop address both propulsion and airframe materials and that this workshop be conducted under the auspices of the Aeronautics Advisory Committee.

Increased support for maintaining existing propulsion facilities in the U.S. is strongly supported by this Working Group. Continuation of selected rehabilitation and upgrade efforts, along with an enhancement in maintenance activities, is recommended. An area of increasing concern is the need for timely replacement and upgrade of facility instrumentation, controls and data systems, and the development of advanced instrumentation systems.

RECOMMENDATIONS (CONTINUED)

- **PROVIDE AUXILIARY HIGH PRESSURE AIR SUPPLY FOR TURBINE DRIVES AND A CALIBRATION FACILITY TO SUPPORT PROPULSION INTEGRATION TESTING**
- **PROVIDE HIGH TEMPERATURE AIR SUPPLY WITH NOISE SUPPRESSION FOR HSCT NOZZLE ACOUSTIC TESTING**
- CONDUCT A PROPULSION SYSTEM MATERIALS WORKSHOP TO ADDRESS REDUCED CYCLE TIMES FOR TRANSITION OF MATERIALS TECHNOLOGY FROM R&D TO PRODUCTION CAPABILITY
- MAINTAIN AND UPGRADE EXISTING NATIONAL PROPULSION FACILITIES

PROPULSION DEVELOPMENT FACILITY FUNDING REQUIREMENTS ($M)

TASK	FY94	FY95	FY96	FY97	FY98	BTC
INCLEMENT WEATHER SIMULATION (INLET/ENGINE)						
• ICING - IMPROVED CLOUD PATTERNS/PRODUCTIVITY (AEDC) (INITIAL CAPABILITY ON-LINE IN 1994)	-	1.0	1.0			
• ICING TUNNEL UPGRADE (LERC/COF)			2.0	18.0		
MASS FLOW UPGRADE (ASTF)						
• REFINE POST-GE90/PW4000 PROPULSION SYSTEM AND FACILITY REQUIREMENTS	0.3	0.8				
• CONCEPTUAL DESIGN OF ASTF UPGRADE OPTIONS (AEDC)	0.1	0.5				
• MASS FLOW UPGRADE	-	-	TBD	TBD	TBD	TBD
ASTF MODIFICATIONS TO SUPPORT HSCT						
- SUPERSONIC FREEJET		0.2	0.8	6.0	5.0	8.0
- C1 MODS FOR ENGINE/NOZZLE TESTS		0.2	0.8	5.0	4.0	5.0
TOTALS ($M)	0.4	2.7	4.6 + TBD	29.0 + TBD	9.0 + TBD	13.0 + TBD

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Appendix 6

Report of the Hypersonic Facilities Working Group

NATIONAL FACILITY STUDY

HYPERSONICS WORKING GROUP REPORT

DECEMBER 1993

Dr. Keith Richey, Chairman
USAF/Wright Laboratory

Dr. M. L. Laster
USAF/AEDC

AF-94-247

Hypersonics Working Group

The hypersonic working group was chaired by Dr. Keith Richey, Chief Scientist of the Air Force Wright Laboratory. The group consisted of experts in hypersonic testing and facilities from NASA, DOD, and industry. All of the members of this working group also served on a joint Air Force, NASA study begun in 1992 to develop a proposed hypersonic test investment plan (HTIP). HTIP, which served as the basis for this working group study, is discussed in more detail later in this report.

HYPERSONICS WORKING GROUP

• Dr Keith Richey/Chair	Wright Laboratory
• Dr Marion L. Laster	Arnold Engineering Development Center
• Carlos Tirres	Arnold Engineering Development Center
• Robert L. P. Voisinet	Naval Surface Warfare Center
• Dennis M. Bushnell	Langley Research Center
• Dr Paul J. Waltrup	Johns Hopkins University
• V. Michael DeAngelis	Ames Dryden Flight Research Facility
• Dr John Erdos	General Applied Science Laboratory
• Dr. James O. Arnold	Ames Research Center

AF-94-262

Hypersonic Facilities Rationale

The use of hypersonic flight in the earth's atmosphere and potentially that of other planets in the post-2000 era will require major advances in hypersonic technology. Ground test facilities which provide hypersonic flight conditions will be absolutely necessary for understanding the fluid flow physics, the thermal environment, structural and material requirements, and the subsequent development of flight systems, just as they were for subsonic flight (1910-) and supersonic flight (1950-). Current hypersonic facilities are very primitive relative to needed capability. The inherent nature of hypersonic flight simulation means that very high energy flows must be created and sustained for a sufficient period of time. Although the needed facilities do not exist, we do know how to proceed (The Plan) toward acquiring the needed technology and ground test facilities. The facility development process will require 10-20 years. A plan has been developed and is ready for execution.

HYPERSONIC FACILITIES RATIONALE

- Beneficial access to the hypersonic flight regime in post-2000 era will require hypersonic technology infrastructure
  - Ground test facilities will be the keystone, just as they have been for subsonics (1910 -), and supersonics (1950 -)
  - Current hypersonic facilities are primitive relative to needed capability
  - We know how to proceed (The Plan)
  - We need to begin now

AF-94-250

Ground Facility Developed Subsonic Advances

Practically every aspect of subsonic aerodynamics, propulsion, and even structures and materials advances have been developed and verified by the used of ground facilities. This is a list of some of the more major areas where ground test facilities have been essential for reducing risk in aircraft developments. Literally, hundreds of ground test facilities have been built throughout the world to satisfy the test needs including wind tunnels, propulsion cells, and structures and materials facilities.

GROUND FACILITY DEVELOPED SUBSONIC ADVANCES

- Nacelles
- Propellers
- NACA series airfoils
- High lift systems
- Swept wings
- Turbofan engines
- High-bypass-ratio engines
- Supercritical airfoils
- Winglets
- Vortex lift configurations
- Organic composite materials and structures
- Reduced/negative static stability
- Active controls/gust load control
- Boundary layer control/laminar airfoils

AF-94-248

Ground Facility Developed Supersonic Advances

Similarly, ground test facilities have played an important role in the development of supersonic flight vehicles. This is a partial list of some of those developments areas. Aeronautics would not be where it is today without these investments.

GROUND FACILITY-DEVELOPED SUPERSONIC ADVANCES

- Variable geometry/sweep wings
- Area rule
- Highly swept wing leading edges
- Double delta wings
- Variable geometry inlets
- Mixed compression inlets
- High-temperature materials and structures

AF-94-249

Hypersonic Facilities Rationale

Therefore, it is reasonable to expect that hypersonic facilities are needed as much and perhaps even more, considering the more severe flight environments, than for subsonic and supersonic testing.

HYPERSONIC FACILITIES RATIONALE

- Beneficial access to the hypersonic flight regime in post-2000 era will require hypersonic technology infrastructure
  - Ground test facilities will be the keystone, just as they have been for subsonics (1910 -), and supersonics (1950 -)
  - Current hypersonic facilities are primitive relative to needed capability
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AF-94-250

Lessons From the National Aerospace Plane (NASP)

The NASP program was schedule driven and could not wait for needed new facilities. The best that could be accomplished was to modify some existing facilities with program funds, and this proved to be inadequate in most instances. This experience demonstrated that ground-based facilities are essential, and that existing facilities were inadequate. Notably, the facilities needed to develop airbreathing propulsion technologies and cryogenic airframe structures were especially inadequate.

LESSONS FROM THE NATIONAL AEROSPACE PLANE (NASP)

- Program could not wait for new Milcon or CofF facility development – necessary to modify existing facilities
- Facility modification decisions were driven by the NASP program schedule
- Program funds were expended to upgrade facilities – most have proven to be inadequate for system development and certification
- Program experience demonstrated that ground-based research facilities are required, and existing facilities are inadequate to develop needed hypersonic technologies
  - Engine test facilities
  - Cryogenic tank test facilities

Facility availability must precede flight vehicle programs

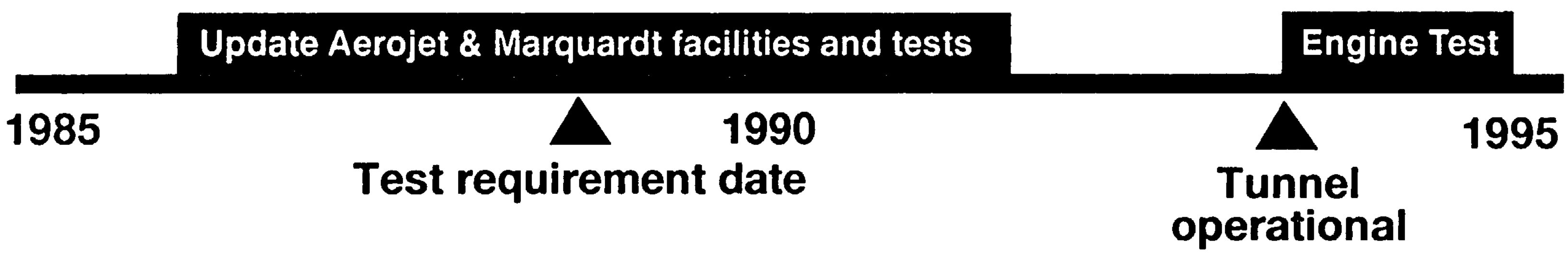
AF-94-251

NASP Engine Testing

In the case of NASP engine testing development, the program required an engine test to Mach 8 in 1989. Since no facility existed which would meet the test requirements, five facility modifications/upgrades were planned. The initial choice was to upgrade the Aerojet and Marquart facilities. These facilities could not support the test requirement, so it had to be waived. There were also technical difficulties with nonuniform temperature distributions in the flow. Finally, the NASA Langley 8 foot High Temperature Tunnel is being brought on line, after modification, for testing a subscale research engine in 1994.

NASP ENGINE TESTING

- Program requirement to test engine to Mach 8 in 1989
- All options required facility modifications or upgrades
  - NASA Langley 8-ft Hi Temp. Tunnel
  - NASA Lewis Hypersonic Test Facility
  - Aerojet Engine Test Facility
  - Marquardt Engine Test Facility
  - AEDC Aerodynamic and Propulsion Test Unit



- Interim facilities could not be upgraded to Mach 8 capability
- Nonuniform flow temperature distributions caused difficulty
- Facilities could not support original requirement
  - Requirement had to be waived
- NASA Langley Mach 8 tunnel is now being calibrated

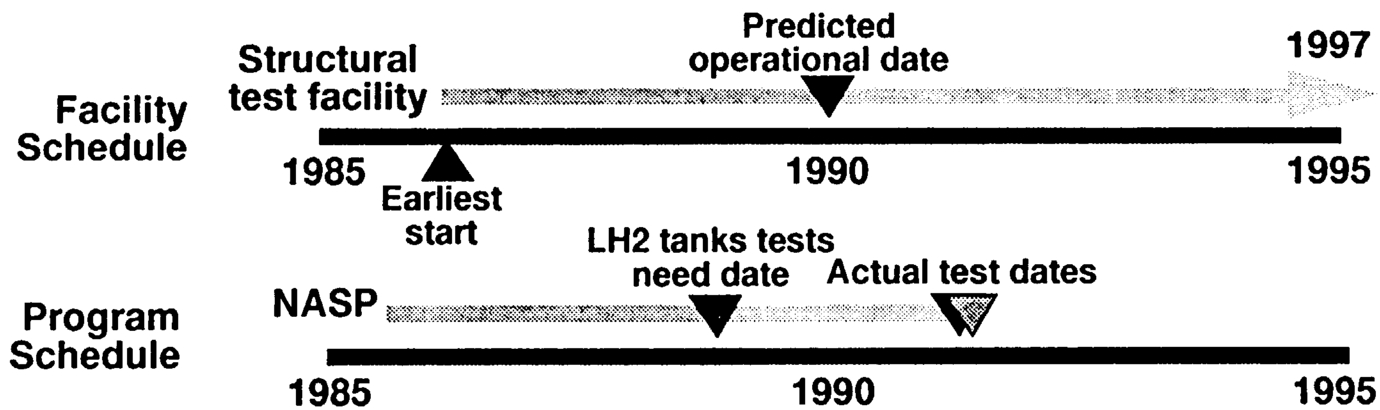
AF-94-264

NASP Structural Test Requirements

A structural test capability, needed for testing cryogenic hydrogen tanks, could not meet the development schedule. Therefore, the needed facility was not endorsed or built. Instead, testing was limited to small-scale test articles. There was no capability for slush (hydrogen) dynamics and flight profile simulation of the thermal environment. Existing facilities could not meet the required objectives.

In summary, adequate facilities could not be provided to meet the NASP schedule and, consequently, the risk reduction testing was inadequate. Any similar undertaking for future hypersonic airplanes requires developing facility technologies now so the test capabilities can be provided when needed.

NASP STRUCTURAL TEST REQUIREMENTS



- Facility schedule in conflict with program schedule
  - Program decision not to endorse facility
- Facility capability did not allow accomplishment of all objectives
  - Life cycle testing incomplete
  - No capability for slosh dynamics tests
  - No flight profile test capability
  - Limited small-scale test articles

Inadequate risk reduction testing to spend billions of taxpayer dollars on Hypersonic X-Airplanes

AF-94-263

Historical Aerothermal Shortfall

Hypersonic flight is characterized by the intense aerothermal heating of the flight vehicle. Apollo, Gemini, X-15, and Shuttle have experienced aerothermal problems in flight that had not been detected in ground testing. A number of these problems are listed here; practically all could have been detected with adequate ground test capability and would have avoided costly retrofitting.

HISTORICAL AEROTHERMAL SHORTFALLS

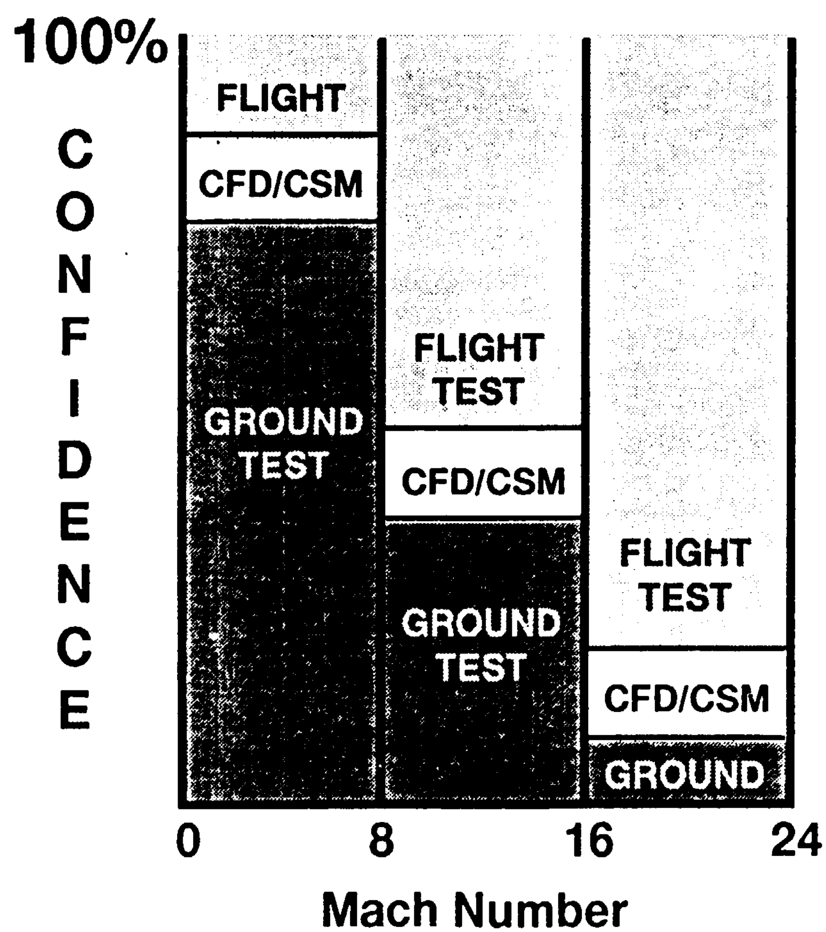
- Boundary-layer transition on essentially everything ever flown hypersonically; e.g., X-15, Space Shuttle, Apollo, etc.
- Gemini entry aerodynamics (Tw/Tt effects on afterbody separation)
- X-15 wing leading edge joints, landing gear hooks, and ramjet test shock impingement
- BMO MARV systems technology flight test (incorrect ablation simulation in low-pressure arc-jets)
- Apollo trim angle-of-attack and heat shield mass loss
- Shuttle entry aerodynamics requiring additional flap control
- Shuttle control jet interaction forces for M > 20 (elevated wind tunnel dynamic pressure vis-a-vis flight)
- Shuttle lee surface high Mach no. vortex-induced interference heating
- Shuttle OMS pod heating

AF-94-252

Hypersonic Systems Confidence Requires Excessive Flight Test

This figure illustrates the relative confidence level we have today in developing systems for flight. As the figure shows, the confidence level is high at the lower Mach numbers since the tools for ground testing and computations are reasonably well developed. This confidence is reduced dramatically at hypersonic Mach numbers primarily because of the lack of ground test capability. Confidence level can be interpreted as inversely proportional to systems development risk, i.e. the higher the confidence the lower the development risk. Therefore, the development risk of hypersonic flight systems is very high with today's ground test capabilities.

HYPERSONIC SYSTEMS CONFIDENCE REQUIRES EXCESSIVE FLIGHT TEST



AF-94-274

Hypersonic Facilities Rationale

Again, this illustrates the need for adequate hypersonic ground test facilities.

HYPERSONIC FACILITIES RATIONALE

- Beneficial access to the hypersonic flight regime in post-2000 era will require hypersonic technology infrastructure
  - Ground test facilities will be the keystone, just as they have been for subsonics (1910 -), and supersonics (1950 -)
  - Current hypersonic facilities are primitive relative to needed capability
  - We know how to proceed (The Plan)
  - We need to begin now

Hypersonic Test Investment Plan (HTIP) Background

The HTIP study had its genesis before the beginning of the National Facilities Study. In 1991 a DOD, NASA, industry, university working group was formed to develop a national hypersonic test investment plan (HTIP), published in March 1993. The charter for the activity was to "formulate a coordinated national investment strategy for the development of hypersonic test capabilities." The study recommended facility research and development of seven high priority facilities needed to maintain U.S. leadership in hypersonics. The HTIP study itself was preceded by several other recent studies, including two Air Force Scientific Advisory Board studies and two ASEB studies; all identified the inadequacies of the nation's hypersonic ground test capabilities. The HTIP working group transitioned to the Hypersonics Working Group of the National Facility Development Plan. The hypersonic development plan (based on the HTIP report) follows.

HYPERSONIC TEST INVESTMENT PLAN BACKGROUND

- NASA/DoD/Industry/University working group and executive council chartered in 1991
- Chartered to "formulate a coordinated national investment strategy for the development of hypersonic test capabilities"
- Five working group and five executive council meetings in 1992
- Study recommended facility research and development and seven high priority facilities needed to maintain U. S. leadership in hypersonics
  - Published as "Hypersonic Test Investment Plan (HTIP)" in May 1993
- HTIP Working Group transitioned to Hypersonic Working Group of the National Facility Development Plan
  - Developed the plan (based on the HTIP report) which follows

AF-94-253

Test Facility Characteristics

The seven facilities recommended are identified in this table along with their respective capabilities. Three of these facilities, the high energy expansion tube, the Mach 3-8 Clean Air Heater, and the structure/airframe test facility are low risk and can be built with today's technology. The other four will require new technology not currently available. The plan for acquiring the facilities and the needed technologies follows later in this report.

TEST FACILITY CHARACTERISTICS

FACILITY	RUN TIME	TEST SIZE	STAGNATION PRESSURE	TEMPERATURE	VELOCITY
High Energy Expansion Tube/Tunnel	Milliseconds	5 ft	> 100,000 atm	> 24,000°R (Equivalent)	> 24,000 fps
PGU/Multi-Shock Facility (Mach 10 – 16)	Seconds	5 ft	Up to > 10,000 atm	Up to 14,000°R	Up to 16,000 fps
Liquid Air Arc/Direct Energy Addition (Mach 10 – 30)	Minutes	10 ft	> 60,000 atm (Equivalent)	> 18,000°R (Equivalent)	> 20,000 fps
Mach 3-8 Clean Air (Mach 3 – 8)	Minutes	10 ft 4 ft	100-200 atm	1,200 – 4,500°R	3,000 – 8,000 fps
Arc Heater (Mach 6 – 12)	Minutes	3 ft	Up to 400 atm	Up to 10,000°R	Up to 12,000 fps
Structure/Airframe Test Facility (Mach 0)	Hours	250 x 125 ft x 100 ft	Ambient	Heat Load: 50 – 2,500 Btu/ft^2 sec	----
Large Ballistic Range	Milliseconds	10-in. diam	Planetary Entry Conditions		45,000 fps

AF-94-257

Summary of Systems and Facility Requirements

The basis for the seven recommended facilities are summarized here by identifying these six system classes and their key technical requirements. The working group is proposing a Phase I and Phase II program to acquire the needed test capabilities. The Phase I program proposes the three facilities which can be acquired within current technology. The Phase II program follows once sufficient facility technology has been developed. This chart shows the application of the seven recommended facilities to the respective systems and their key technical requirements.

SUMMARY OF
SYSTEMS AND FACILITY REQUIREMENTS

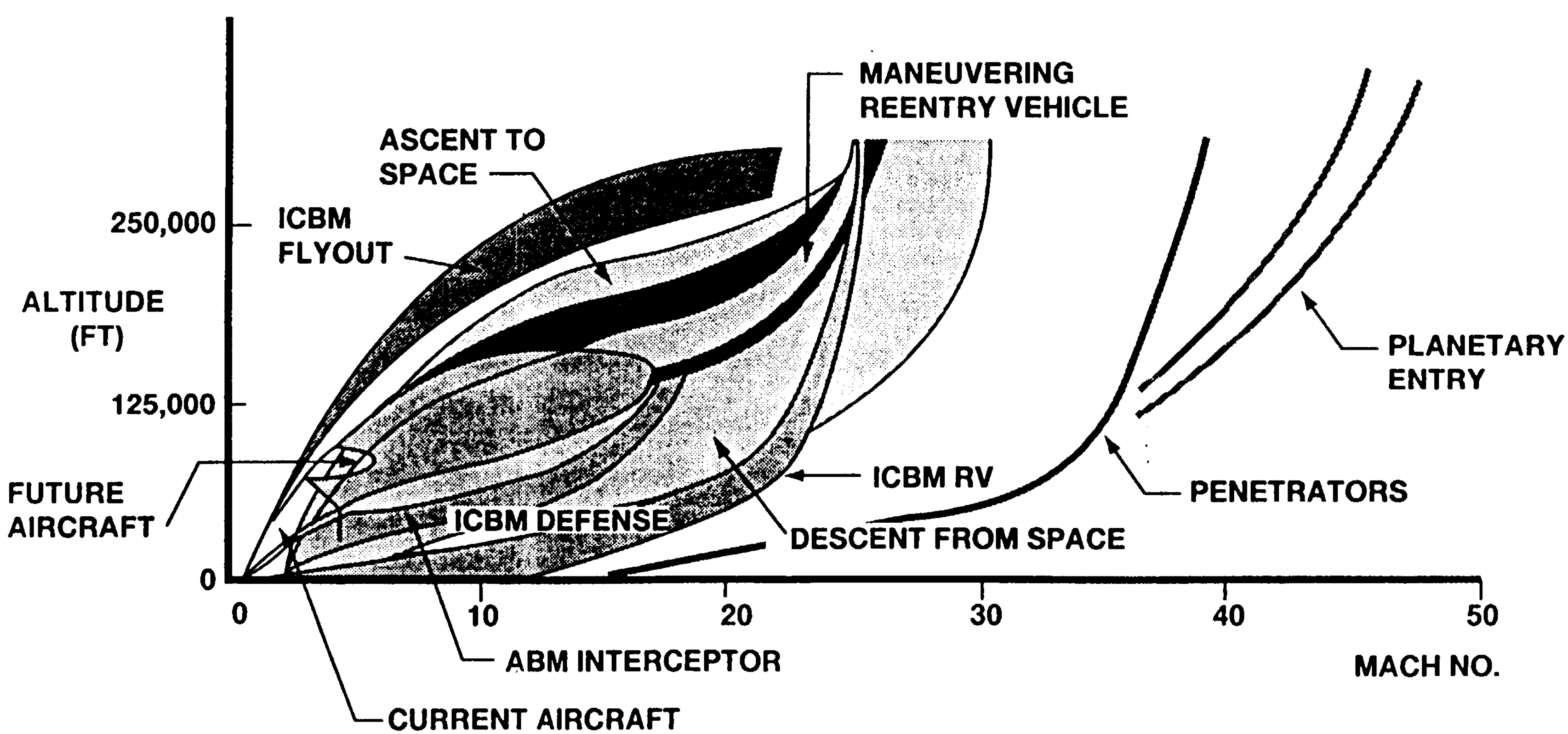
SYSTEM	MAX. MACH NO.	KEY TECHNICAL REQUIREMENTS	PHASE I TEST FACILITY	PHASE II TEST FACILITY
Space Launch and Rescue	25 – 30	• Mach 12-24 airbreathing propulsion • Real gas aerodynamics • Hot primary structure	• High=energy expansion tube/tunnel, M = 14 – 35 • Liquid H_2 structures test facility	• Liquid air arc/direct energy addition • PGU multi-shock • Large structures/airframe test facility
Cruise Aircraft	8 – 10	• Mach 4 – 10 airbreathing propulsion • Durable airframe/propulsion system	• Mach 3 – 8 clean air T&E facility • Liquid H_2 structures test facility	• Mach 3 – 8 certification facility • Large structures/airframe test facility
Interceptors	15 – 30	• Real gas aero/control • Thermal protection • Sensor performance/life	• High-energy expansion tube/tunnel, M = 14 – 35	• PGU multi-shock • Advanced Arc heater • Large ballistic range • Liquid air arc/direct energy
Missiles	10 – 30	• Sensor performance/life • Thermal protection • Real gas aero/control	• High-energy expansion tube/tunnel, M = 14 – 35	• Large ballistic range • Liquid air arc/direct energy • Advanced arc heater • PGU multi-shock
Planetary Entry Probe	30 – 50	• Thermal protection • Planetary gases • Sensor performance/life	• High-energy expansion tube/tunnel, M = 14 – 35	• Large ballistic range • Liquid air arc/direct energy • Advanced arc heater

AF-94-258

Hypersonic Fight Regime

This figure shows the flight regime of the six classes of systems just discussed plus that for current and future aircraft and the ICBM flyout. The speeds of the hypersonic systems essentially blanket the envelop to Mach 25. Even higher speeds are involved with planetary entry and earth penetrators.

HYPERSONIC FLIGHT REGIME



AF-92-862

Hypersonic Propulsion Test Capability

This chart presents the inadequacies of present facilities for testing hypersonic airbreathing engines. Three categories of facilities are proposed to cover the full range from Mach 3 to orbital velocity. Note that in each category, new facilities are proposed because serious inadequacies exist in the best available facilities in the U.S. The primary deficiencies of existing facilities are in their size, pressure capabilities, and test time. The minimum propulsion test capability for the required risk/cost reductions is *"adequate"* in all five categories.

HYPERSONIC PROPULSION TEST CAPABILITY

BLOW DOWN FACILITIES

FACILITY	RUN TIME	TEST SIZE, FT	STAG. PRESS., ATM	STAG. TEMP., °R	VELOCITY, FT/SEC
Proposed					
Mach 3-8 Clean Air Tunnel	Minutes	10	270	4,500	8,000
Existing					
Clean Air					
Vitiated					

IMPULSE TUNNELS

FACILITY	RUN TIME	TEST SIZE, FT	STAG. PRESS., ATM	STAG. TEMP., °R	VELOCITY, FT/SEC
Proposed					
Expansion Tube Tunnel	Millisec	5	100,000	24,000	24,000
PGU Multi-Shock Facility	Seconds	5	10,000	14,000	16,000
Existing Facilities					

ARC-HEATED FACILITIES

FACILITY	RUN TIME	TEST SIZE, FT	STAG. PRESS., ATM	STAG. TEMP., °R	VELOCITY, FT/SEC
Proposed					
Arc Heater	Minutes	3	400	10,000	12,000
Existing Facilities					

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AF-94-268

Hypersonic Aerodynamic Test Capability

The relative performance of proposed and existing facilities for aerodynamic and sensor testing is presented. Note that existing "Perfect Gas Facilities" are adequate , so new "cold" facilities are not being proposed. Three facilities are included in the program to simulate the hypervelocities where the temperatures in the flow over the vehicle are so hot that chemical reactions of the gases affect aerodynamic forces, heating rates, and sensor performance.

HYPERSONIC AERODYNAMIC TEST CAPABILITY

PERFECT GAS FACILITIES

FACILITY	RUN TIME	TEST SIZE, FT	STAG. PRESS., ATM	STAG. TEMP., °R	VELOCITY, FT/SEC
Existing Facilities					

REAL GAS FACILITIES

FACILITY	RUN TIME	TEST SIZE, FT	STAG. PRESS., ATM	STAG. TEMP., °R	VELOCITY, FT/SEC
Proposed					
Expansion Tube Tunnel	Millisec	5	100,000	24,000	24,000
PGU Multi-Shock Tunnel	Seconds	5	10,000	14,000	16,000
Existing					
Shock-Driven Tunnel					
Piston-Driven Tunnel					

AEROBALLISTIC FACILITIES

FACILITY	RUN TIME	TEST SIZE, FT	STAG. PRESS., ATM	STAG. TEMP., °R	VELOCITY, FT/SEC
Proposed					
Large Ballistic Range	Millisec	0.83	Planetary Entry		45,000
Existing Ranges					

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AF-94-266

Airframe Structures Test Facilities

Comparisons of proposed and existing facilities are shown for both static structures and flow facilities. Across the board, existing hypersonic facilities tend to be large enough for supporting research activities, but are too small for development and certification testing of flight systems. This became painfully evident during the NASP program. Building larger facilities is sometimes merely an economic issue, but oft times also a technical limit such as for arc heaters. Other parameters such as pressure, temperature and run times tend to be limited technically, which will require facility R&D to provide adequate performance.

AIRFRAME STRUCTURES TEST FACILITIES

STATIC FACILITIES

FACILITY	RUN TIME	TEST SIZE, FT	STAG. PRESS., ATM	STAG. TEMP., °R	VELOCITY, FT/SEC
Proposed Structures Test Facility	Hours	250 x 125	Ambient	2,500 Btu/ft^2 sec	-----
Existing					

ARC-HEATED FACILITIES

Proposed					
High-Pressure Arc	Minutes	3	400	10,000	12,000
Liquid Air Arc	Minutes	10	60,000	18,000	20,000
Existing Arc Heaters					

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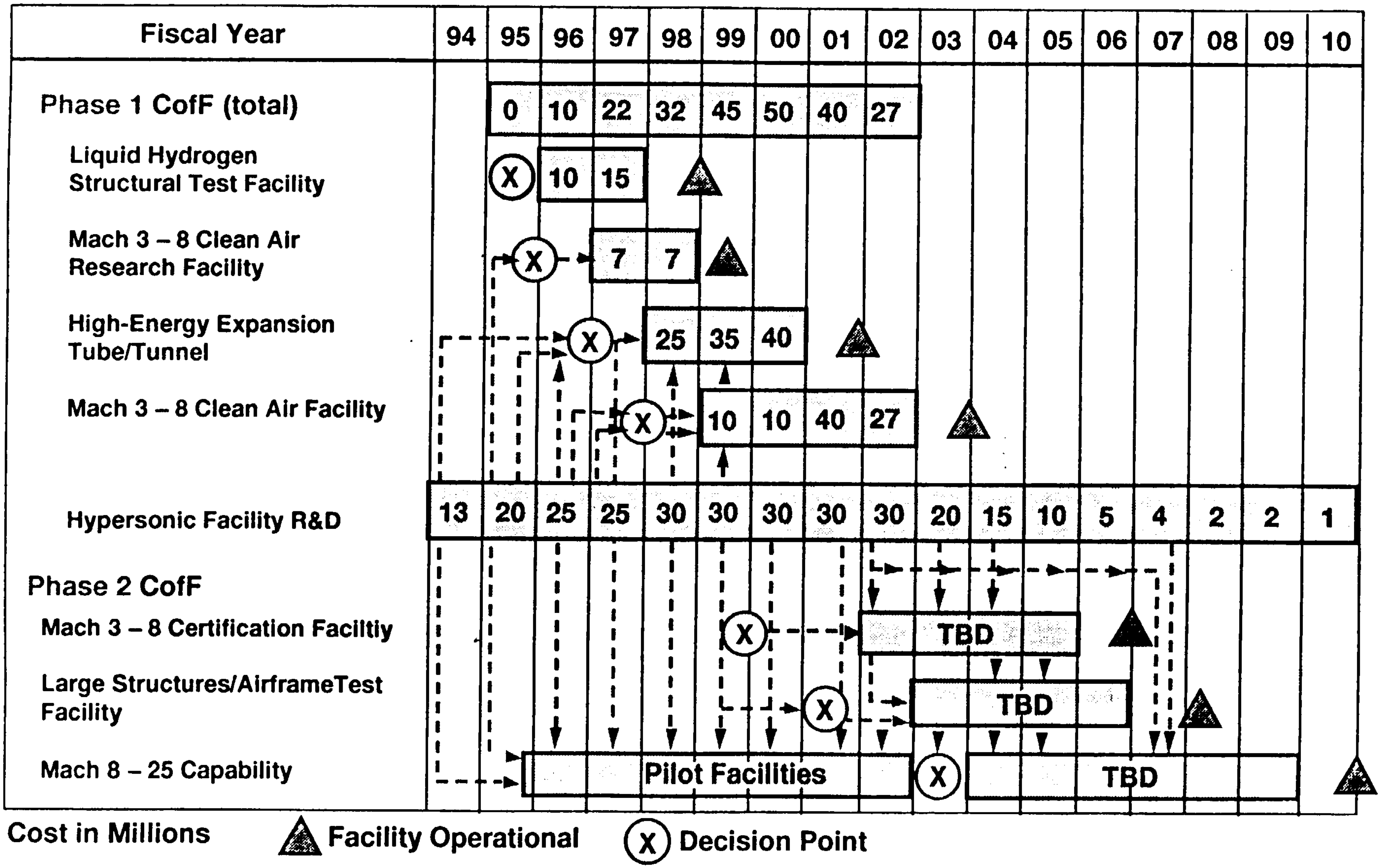
AF-94-269

Hypersonic Facility Development Plan

This chart summarizes and outlines the hypersonic development plan recommended by the working group. The Phase I and Phase II portions of the plan are shown along with the recommended hypersonic facility research and development program. The working group felt that the medium scale Liquid Hydrogen Structural Test Facility designed for the NASP program, but not built, would give the country a relatively inexpensive medium scale hydrogen tank test capability in the near term at modest cost. The Mach 3-8 research facility is recommended only if the existing NASA Plumbrook Hypersonic Test Facility (HTF) proves in current studies to be an inadequate "clean" air propulsion research facility. The hypersonic facility R & D plan calls for research to determine the credibility of using vitiation heated flows for propulsion testing. This will form the basis for deciding whether or not the Phase I medium scale Mach 3-8 Clean Air Facility is needed. If not the existing NASA Langley 8 foot vitiation tunnel can serve as a medium scale Mach 3-8 propulsion development test capability. Otherwise, upgrading the AEDC APTU facility is required. This decision also determines the test medium heater for the Phase II Mach 3-8 Certification Facility. The advantage of a vitiation heated facility is considerably lower cost. The Phase I High Energy Expansion Tube/Tunnel will be driven by either a combustion driver or a free-piston driver. Studies proposed in FY 94 will establish the approach. The Phase II Mach 8-25 test capability approaches will be determined by the most promising technology developments in the hypersonic facility R & D program and validated through pilot demonstrations.

HYPERSONIC FACILITY DEVELOPMENT PLAN



AF-94-275

Requirements for Facility Research and Development

Facility research and development is required because existing hypersonic facilities are essentially "maxed out" in terms of pressure, temperature, and test time. New approaches have been proposed to overcome these limitations, but facility research is required to explore these concepts. The chart lists four examples. In addition there are generic research requirements that apply to multiple facility approaches such as facility thermal protection, instrumentation, and CFD.

REQUIREMENT FOR FACILITY RESEARCH & DEVELOPMENT

- Current hypersonic facilities are "maxed-out" in terms of pressure, temperature, and test time
- Facility research is required to explore and provide proof of concept for the requisite new approaches to providing higher pressures and energy levels, longer test times, and testing cryogenically fueled structures, i.e.
    - Liquid Air Arc (6,000 vs. 200 atm)
    - High-Energy Expansion Tube (20,000,000 vs. 20,000 psi)
    - Multi-Shock Facility (2 sec vs. 2 msec)
    - Direct-Energy Addition

AF-94-254

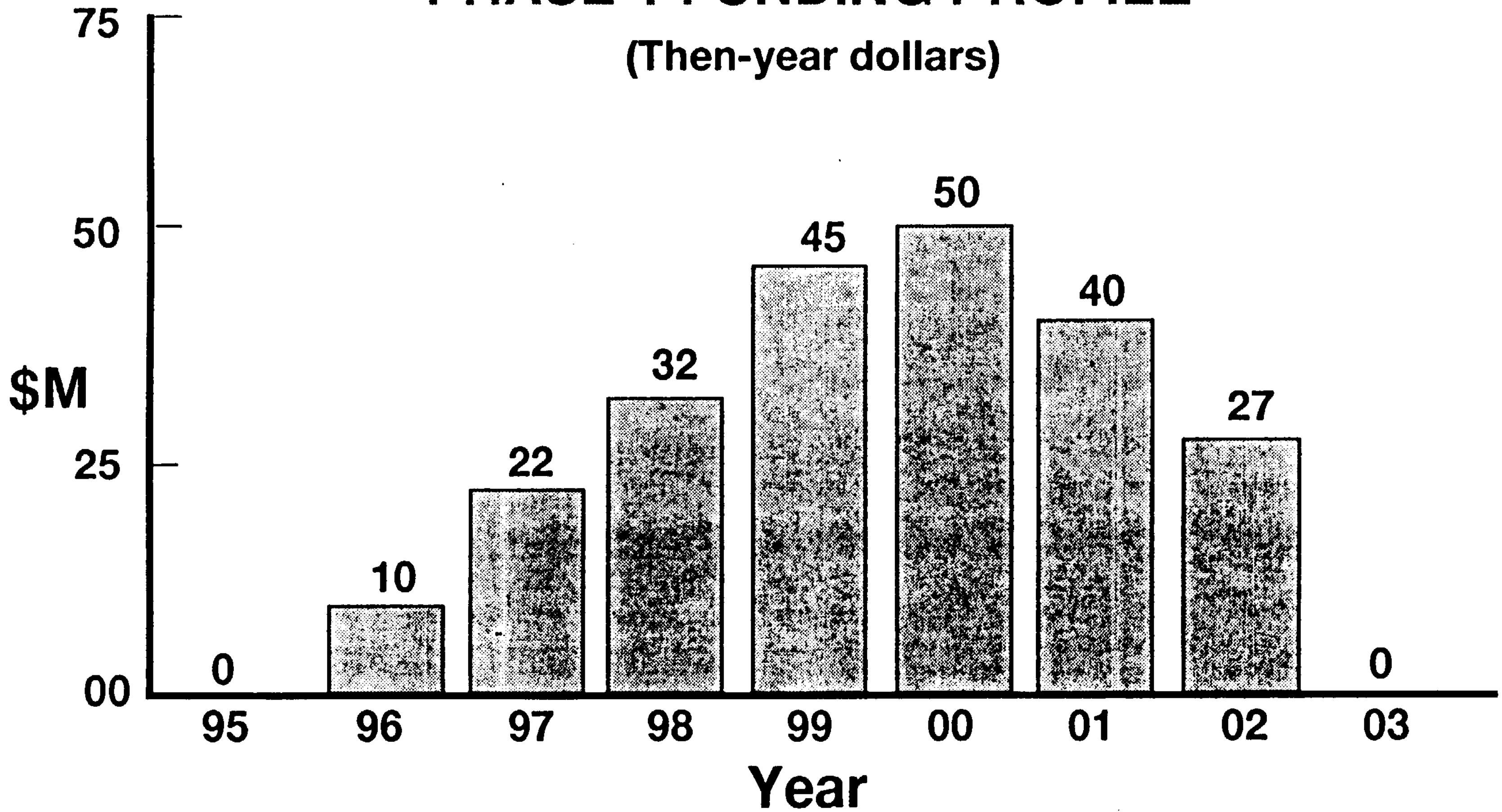
Hypersonic Facilities Construction

This chart shows the Phase I Facility funding profile recommended by the working group. It must be understood that this is a maximum funding profile, not the minimum which could result from the facility R&D studies. For example, if the expansion/tube tunnel is proven capable of being driven by a combustion driver rather than a piston driver, the cost of the facility reduces by $60M. Also, if vitiation heating is acceptable for the Mach 3-8 tests, the requirements for the Mach 3-8 "clean" air facility is eliminated, which could result is a reduction of $107 million. Therefore, the Phase I facility investment requirements could reduce from $226 million to $57 million.

HYPERSONIC FACILITIES CONSTRUCTION

PHASE 1 FUNDING PROFILE

(Then-year dollars)



AF-94-273

Hypersonic Research Activities for FY 94

This is a priority listing of the recommended research activities for FY 94, proposed funding, and the work source. The work source is the government center of expertise which the working group believes is most capable of managing and directing the research area. In all cases the work source is expected to acquire and utilize the best expertise that can be brought to bear on the task whether in government, industry, or academia. This research program is in the FY 94 NASA budget. A hypersonic advisory working group has been organized to advise on this program. Two meetings have been held, assignments given to the work sources, and work source project plans, including approach, schedule, and cost, have been reviewed. Program execution is pending release of the funds for execution of the program.

HYPERSONIC RESEARCH ACTIVITIES FOR FY94

R&D ITEM	AMOUNT $ IN MILLIONS	WORK SOURCE
High-Energy Expansion Tube/Tunnel	6.5	NASA
Clean Air Heater (HTF - NASA Lewis)	0.7	NASA
PGU/Multi-Shock Facility	0.5	NSWC
Facility Thermal Protection	0.5	AEDC
Ballistic Range launcher	0.6	NASA
Direct Thermal Energy Addition	0.9	AEDC
High-Temperature/Low-Pressure Arc	0.9	NASA
High-Pressure Arc	0.9	AEDC
Liquid Air Arc	0.8	AEDC
MHD Study	0.7	AEDC
TOTAL	13.0	

AF-94-259

Hypersonic Research Activities for FY 95

The research activities extend into FY 95 and one new start is added, i.e., instrumentation/CFD research. As seen in the development plan earlier, work in FY 95 is expected to identify the most promising facility approaches in preparation for acquisition of pilot facility demonstrations.

HYPERSONIC RESEARCH ACTIVITIES FOR FY95

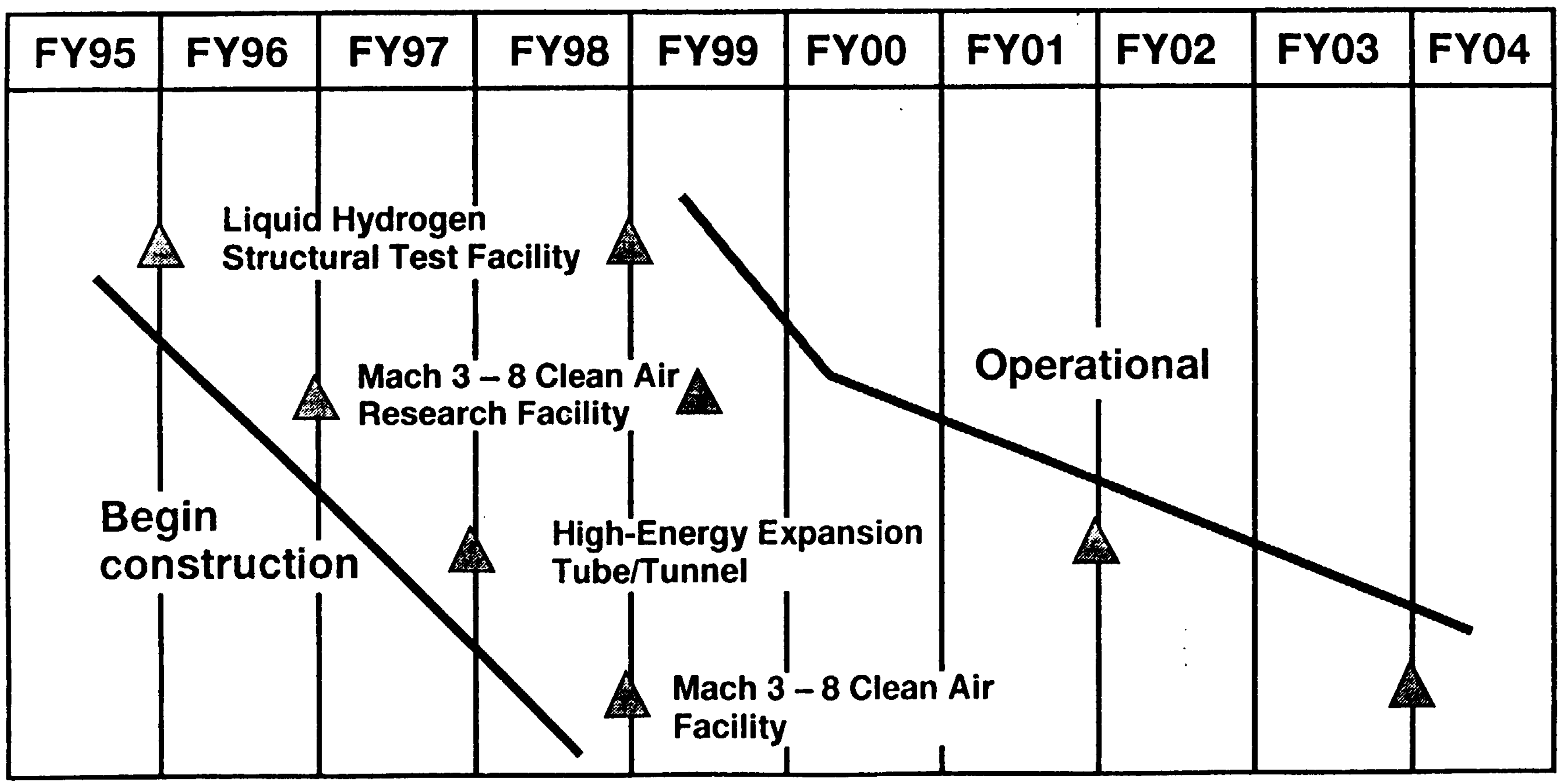
R&D ITEM	AMOUNT $ IN MILLIONS
Mach 8 Clean Air Heater	2.0
High-Energy Expansion Tube/Tunnel	2.0
Clean Air Heater (HTF - NASA Lewis)	1.0
PGU/Multi-Shock Facility	2.0
Facility Thermal Protection	1.0
Ballistic Range Launcher	1.0
Instrumentation/CFD	3.0
High-Temperature/Low-Pressure Arc	1.0
High-Pressure Arc	2.0
Liquid Air Arc	2.0
Direct Energy Addition (MHD, Other)	3.0
TOTAL	20.0

AF-94-260

Phase I Hypersonic Facilities Construction

The proposed Phase I facilities construction is shown here along with expected operational dates. This is a time-phased program driven in part by decision points based on technical information coming out of the research program. The necessary decisions were discussed earlier under "Hypersonic Facility Development Plan".

PHASE 1 HYPERSONIC FACILITIES CONSTRUCTION

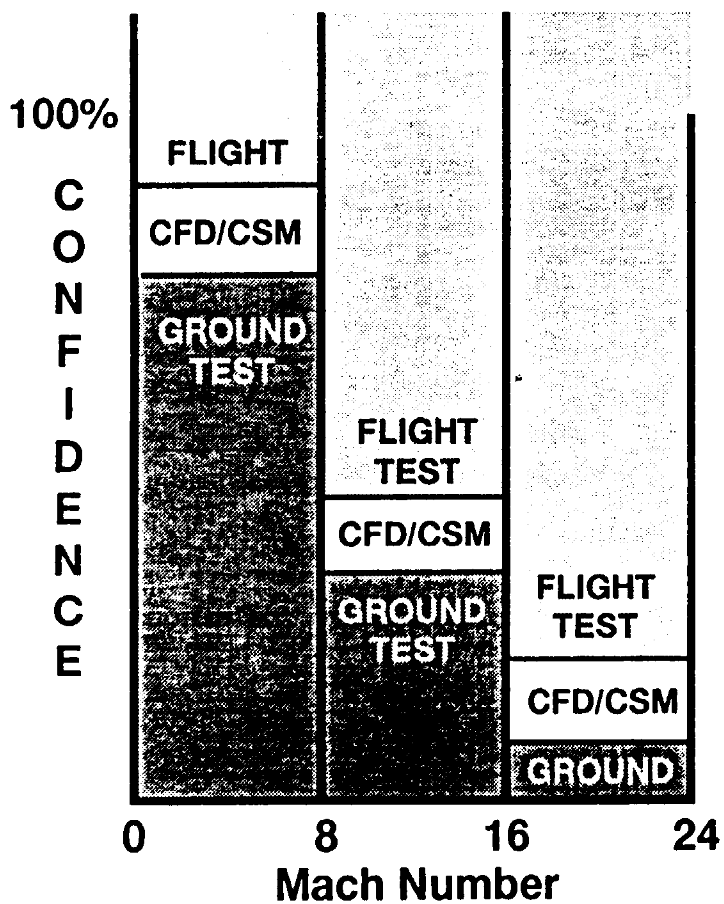


AF-94-278

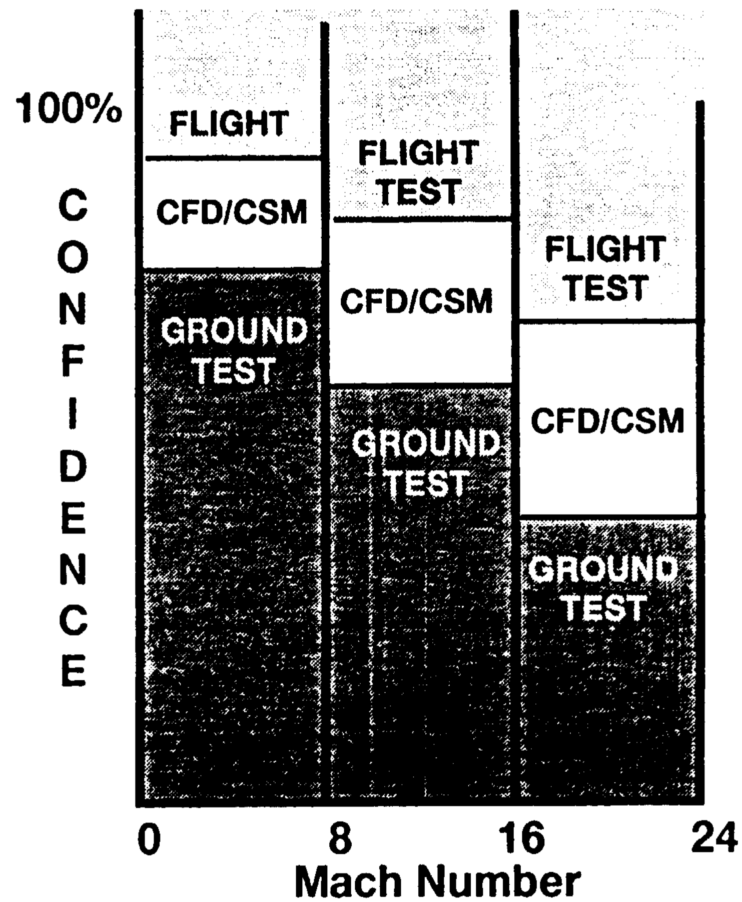
Plan Will Greatly Reduce Reliance on Costly Flight Test

The left portion of this chart was discussed earlier. Recall that it notionally represents current ground test capability and its relationship to confidence of fielding hypersonic systems before flight. The right side of the chart notionally illustrates how confidence (or reduced risk) would increase between now and 2015 if the plan is executed to completion. The estimated payoff on just one program such as an A/B launch vehicle from availability and use of this augmented ground test capability is in the order of several billion dollars simply by replacement of research flight tests with ground testing. Additional payoffs include enhanced system capability, efficiency, and greatly reduced system development cost and time.

PLAN WILL GREATLY REDUCE RELIANCE ON COSTLY FLIGHT TEST



Existing hypersonic facilities require excessive flight testing.



Advanced ground test facilities give higher confidence (lower risk) before flight.

AF-94-279

Advanced Hypersonic System Candidates

Of the six classes of advanced hypersonic systems discussed earlier, all have one or more specific systems which currently are funded either at the study or development stage. Some, but not all, of these systems are expected to emerge as full system programs for development.

ADVANCED HYPERSONIC SYSTEM CANDIDATES

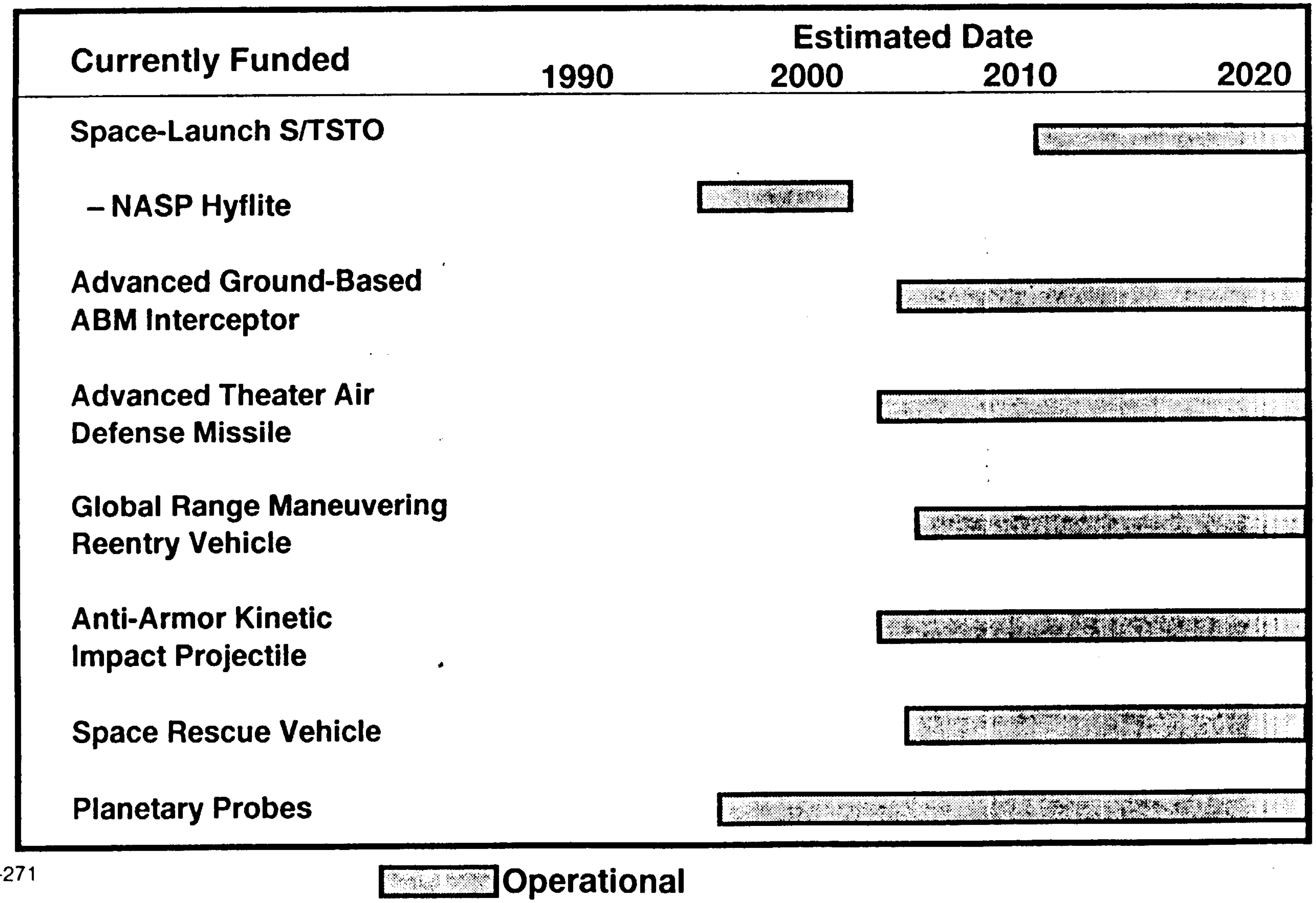
	DEV. FUNDS	STUDIES
• Space Launch		
• Single/two-stage-to-orbit launch vehicle (Mach 0 – 26)	X	X
• NASP Hyflite	X	
• Aircraft		
• Airbreathing cruisers (Mach 4 – 8; Mach 10+)		X
• Interceptors		
• Advanced ground-based ABM interceptor (Mach 10 – 15)	X	
• Advanced theater air defense missile (Mach 10 – 30)	X	
• Missiles		
• Hypersonic cruise missile (Mach 6 – 8)		X
• Global range maneuvering re-entry vehicle (Mach 12 – 26)	X	X
• Tactical boost-glide missile (Mach 4 – 6)		X
• Munitions		
• Anti-armor kinetic projectile (Mach 4 – 10)	X	
• Earth penetrator kinetic impact weapon (Mach 4 – 30)		X
• Space		
• Space rescue vehicle (Mach 25 – 30)	X	
• Planetary probe (Mach 30 – 50)	X	

AF-94-261

Candidate Hypersonic Systems Potential Operational Dates

The potential operational dates for some of the proposed advanced hypersonic facilities are shown in this chart. Notice that the dates are within ten years in most instances, although slippage is probable, given current national budget realities.

CANDIDATE HYPERSONIC SYSTEMS POTENTIAL OPERATIONAL DATES

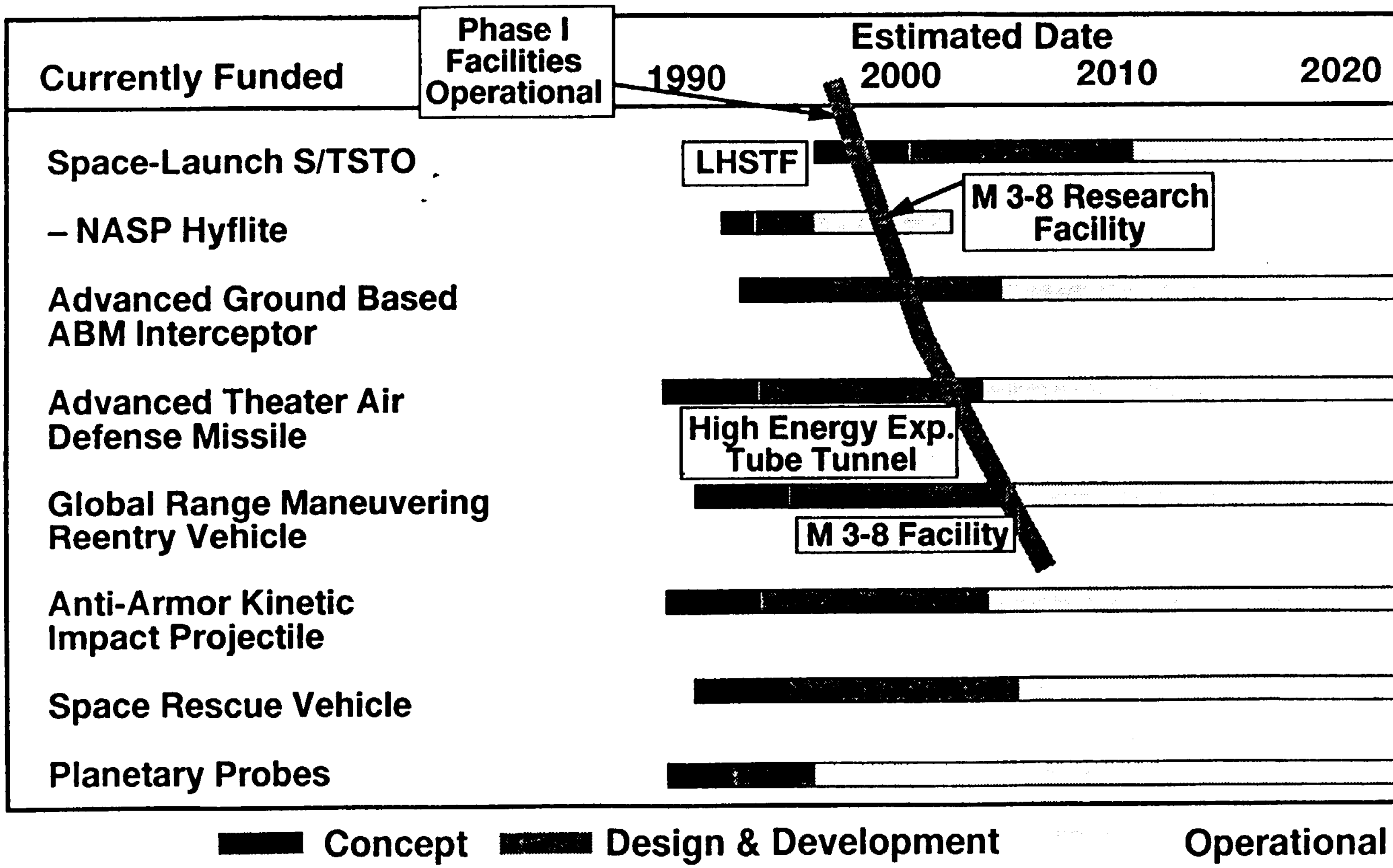


AF-94-271

Candidate Hypersonic Systems Development

By overlaying the operational dates of the Phase I facilities on the systems development and operational date schedule we must conclude that the systems developments are already occurring prior to facility availability. We must act now to keep from continually falling into the trap of not having ground test facilities available for systems development needs.

CANDIDATE HYPERSONIC SYSTEMS DEVELOPMENT



The situation gets worse each day

AF-94-272

Hypersonic Facilities

Hypersonic ground test facilities are needed for both military and civil applications. Hypersonic simulation above Mach 8 is very limited in the U.S. and is impeding technical progress in both military and civil applications. Foreign hypersonic capability is advancing and is already somewhat better than U.S. capability in a few limited areas, but still is not adequate. Japan is planning a very extensive and impressive set of new hypersonic facilities.

HYPERSONIC FACILITIES

- Both military and civil applications
- Hypersonic simulation above Mach 8 is very limited in U. S. A., and this situation impedes technical progress and military/civil applications.
- Some foreign facilities somewhat better than U. S., but still not adequate.

Hypersonic Facilities Conclusion

This chart is self explanatory.

HYPERSONIC FACILITIES CONCLUSION

- Capable hypersonic facilities are required to develop advanced systems at affordable cost and risk
  - Facilities need to be in place during concept and engineering development, and system deployment
  - Hypersonic facility investments are needed now – Phase I won't be complete until 2002; Phase II about 2010 if R&D starts in FY94
- There is an acknowledged legitimate need for hypersonic research & development facilities
- We have developed a reasonable, phased plan to satisfy the highest priority requirements
- It's time to do the right thing

AF-94-256