REPORT TO THE COMMITTEE ON SCIENCE AND TECHNOLOGY HOUSE OF REPRESENTATIVES

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

Acquisition And Utilization Of Wind Tunnels By The National Aeronautics And Space Administration

GAO has reviewed a total of 74 wind tunnels costing about $309 million. During fiscal year 1975 the average use of NASA wind tunnels ranged from 59 percent for hypersonic tunnels to 76 percent for subsonic tunnels. Operating costs totaled about $18 million.

NASA is in the process of centralizing its aeronautical research activities and eliminating unneeded facilities. NASA plans to construct a new wind tunnel costing about $65 million and plans to modify others.

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-180466

The Honorable Olin E. Teague, Chairman
Committee on Science and Technology
House of Representatives

Dear Mr. Chairman:

As requested in your letter of June 25, 1975, we are reporting on the acquisition and utilization of wind tunnels by the National Aeronautics and Space Administration. The work was performed to assist the Subcommittee on Aviation and Transportation Research and Development in its review of the Nation's civil aviation research and development programs and facilities.

We believe that the contents of this report will be of interest to other committees, Members of Congress, and the National Aeronautics and Space Administration. We will be in touch with your office in the near future to arrange for release of the report.

Sincerely yours,

Comptroller General
of the United States

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COMPTROLLER GENERAL'S REPORT TO THE COMMITTEE ON SCIENCE AND TECHNOLOGY HOUSE OF REPRESENTATIVES

ACQUISITION AND UTILIZATION OF WIND TUNNELS BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

DIGEST

At the request of the Chairman, House Committee on Science and Technology, GAO has examined 74 wind tunnels and related special-purpose test facilities which cost about $309 million to obtain utilization, operation, and cost data. (See p. 6.) GAO has identified 45 wind tunnels that have been discontinued. They are either inactive, dismantled and stored, transferred to another Government or private user, or converted to other uses. (See p. 9.)

UTILIZATION OF WIND TUNNELS

Average utilization of National Aeronautics and Space Administration (NASA) facilities ranged from 59 percent for hypersonic wind tunnels to 76 percent for subsonic wind tunnels. (See p. 6.)

Several conditions limit utilization of certain wind tunnels. Cost and availability of energy creates inconveniences in that tunnel operations must be scheduled during "off-peak" hours to take advantage of lower rates or because adequate power is not available during regular working hours. Although no critical or high-priority projects have been delayed or canceled due to this practice, NASA officials foresee the availability and cost of energy as a growing problem. (See p. 7.)

Some locations have experienced difficulties due to the lack of available manpower. Ames Research Center officials stated that the principal constraint to their wind tunnel operation is the nonavailability of manpower and that more than 3,300 requested test hours were denied during fiscal year 1975 because of manpower shortages. (See p. 8.)

Tunnel instrumentation (equipment used to measure and process test data) for some facilities is inadequate. (See p. 8.) The best instrumentation and data processing equipment currently available could reduce the test time to as little as 25 percent of the time now required. The feasibility and cost of upgrading present tunnel instrumentation should be explored in greater depth.

NASA said that it was planning to initiate a study in the very near future on ways to reduce test time and energy usage and that improvements in tunnel instrumentation and data acquisition systems would be included. (See p. 10.)

NASA officials are in the process of eliminating facilities which are no longer needed because their capabilities are duplicated or superseded. In addition, NASA is centralizing its aeronautical research efforts, locating them primarily at Langley and Ames Research Centers. (See p. 8.)

NASA's current efforts to phase out unneeded facilities and centralize operations should further improve its utilization of available facilities.

OPERATING COSTS

The cost to operate NASA's wind tunnel facilities in fiscal year 1975 was about $18 million with personnel costs accounting for almost half of that amount. Electric power costs totaled more than $4 million. Maintenance costs also exceeded $4 million. (See p. 7.)

PLANNED PROCUREMENTS

At the Langley Research Center, NASA plans to construct a high Reynolds number facility--a wind tunnel capable of predicting with confidence full-scale aircraft performance and flow conditions at transonic speeds based on scale model investigations. The facility

ABBREVIATIONS

AACB	Aeronautics and Astronautics Coordinating Board
DOD	Department of Defense
DOT	Department of Transportation
FAA	Federal Aviation Administration
GAO	General Accounting Office
NAFEC	National Aviation Facilities Experimental Center
NASA	National Aeronautics and Space Administration
NTF	national transonic facility
R&D	research and development
RN	Reynolds number
USAF	U.S. Air Force

will be known as the national transonic facility and is estimated to cost $65 million. (See p. 11.)

The national transonic facility will be designed to achieve a 120 million Reynolds number capability, which represents a level about 10 times that of currently operational continuous flow transonic tunnels. According to aeronautical authorities, the lack of a high Reynolds number testing capability is the most critical deficiency in the operating characteristics of U.S. transonic facilities. They further state that extrapolation of data from present facilities has strained the limits of credibility and that viable alternatives to a high Reynolds number capability do not exist.

GAO's review did not include a determination or evaluation of the optimum Reynolds number capability for the proposed national transonic facility. However, based on the preponderance of evidence, increased capability in this area would enhance the technology base and assist in developing more efficient civil and military aircraft. (See p. 16.)

MODIFICATION COSTS

A planned modification to the 40- by 80-foot wind tunnel at Ames has been deferred until fiscal year 1978. The modification is currently estimated to cost about $85 to $90 million over a 5-year period. (See p. 21.)

About $3.8 million was appropriated during fiscal year 1976 for modifications to wind tunnels at Ames, and $755,000 was requested for fiscal year 1977. (See p. 19.)

AGENCY COMMENTS

NASA found the material in GAO's proposed report to be clear and basically factual. NASA also stated that GAO's opinions and conclusions were generally reasonable. (See p. 212.)

CHAPTER 1

INTRODUCTION

By letter dated June 25, 1975, the Chairman of the House Committee on Science and Technology asked us to assist the Subcommittee on Aviation and Transportation Research and Development in a review of the Nation's civil aviation research and development (R&D) programs and facilities. The request was directed toward programs and facilities managed by the National Aeronautics and Space Administration (NASA) and the Department of Transportation (DOT). Attached to the Chairman's letter was a work plan prepared by the Subcommittee Chairman, Congressman Dale Milford. (See app. I for copy of letter and work plan.)

The subcommittee's overall objectives are directed toward:

--Insuring that the United States retain its predominant role in world aviation.

--Insuring that U.S. governmental agencies and private industry are cooperating.

--Insuring that Federal expenditures for aeronautical R&D and facilities are being spent effectively.

To comply with the subcommittee's request, we initiated separate reviews of

(1) the Nation's civil aviation R&D programs and facilities and

(2) the acquisition and utilization of wind tunnels.

The results of our review of civil aviation R&D programs and facilities are being forwarded to the Chairman separately, as requested.

Concerning wind tunnels, we were specifically requested to:

--Inventory existing NASA and DOT wind tunnels, including data on acquisition cost and on cost and type of subsequent modifications.

--Obtain a description of the tunnels, including capabilities and limitations on uses.

--Obtain data on utilization, including identification of users, extent of use, and reimbursement procedures.

--Obtain data on operating costs, including costs of personnel, repairs and maintenance, and utilities.

--Look into planned construction of new wind tunnels and, if any, obtain cost data, description, and agency justification.

A WIND TUNNEL DEFINED

A wind tunnel is a tunnel-like passage through which air is blown at a known velocity, temperature, pressure, and turbulence level to determine the action of wind pressure on objects, such as aircraft, missiles, and space vehicles or components or models of these objects. Nitrogen, helium, or freon may be used in place of air.

Wind tunnels are most frequently used to predict or reproduce the phenomena that occur in flight. Their usefulness stems from the fact that test conditions can be closely regulated and important variables can be independently controlled. These accomplishments are difficult, if not impossible, with other testing methods, such as actual flight testing.

A stationary model is normally mounted in the test section of a wind tunnel and air (or other medium) is forced to flow past it by using propellers, compressors, or some other suitable means.

Obviously, many scale models of a particular configuration can be evaluated in wind tunnel tests at a relatively small cost compared to the cost of designing, fabricating, and flight testing full-scale prototypes. Configuration changes can be made rapidly, and a final design can be arrived at that has a considerably greater chance of success when the prototype is finally flown. The usefulness of wind tunnels in providing good aerodynamic design information has been demonstrated many times, both in the United States and abroad.

Wind tunnels have been in use for many years; in fact, they were already in use before the first powered airplane flight in 1903. Hundreds of wind tunnels have been built throughout the world. These wind tunnels range from simple, low-cost, low-speed tunnels used for testing subscale models to highly complex and expensive tunnels used for testing full-scale hardware at supersonic speeds.

TYPES OF WIND TUNNELS

Wind tunnels exist in a wide variety of shapes and sizes depending on cost, speed range, power requirements, and purpose. One tunnel design parameter of particular interest is airflow velocity. In practice, wind tunnel speed capabilities are generally categorized in terms of the speed of sound (referred to as mach 1) which is about 760 miles an hour at standard sea level conditions. Air speeds bordering the speed of sound are categorized as transonic. Subsonic speeds are those below the speed of sound. Supersonic speeds range from the speed of sound to about five times the speed of sound (mach 5), and hypersonic speeds are above mach 5.

Classification by speed capability is only one of several important characteristics of wind tunnels. Depending on the source and speed of the flow through the test section, wind tunnels are also referred to as:

--Intermittent: A wind tunnel that normally operates from a stored pressure source to achieve flow in the test section. Run times are usually in seconds.

--Continuous: A wind tunnel that operates from a continuously operating compressor or fan to achieve flow in the test section. It runs as long as necessary to obtain the data.

--Arc: A wind tunnel that operates from an electrical discharge that provides the temperature and pressure to achieve air flow in the test section. Run times are in milliseconds.

--Shock: A wind tunnel that operates from a shock tube discharge into a conical or contoured nozzle to achieve air flow in the test section. Run times are in milliseconds.

Wind tunnels are further described as having either an open or closed circuit, whether or not the tunnel is pressurized, and the Reynolds number (RN) that it is capable of simulating, if applicable. RN is a mathematical relationship that takes into consideration air speed, vehicle size, and air density and viscosity at the flight altitude. With proper mach number and RN, data obtained in a wind tunnel (using a model) can be used to predict actual flight conditions with a high degree of confidence. This is very important in the transonic speed regions and cannot be evaluated in present wind tunnels.

SPECIAL FEATURE TEST FACILITIES

In addition to the varying capabilities and characteristics of the wind tunnels discussed previously, many tunnels were designed and constructed with special features that serve a special purpose or function. Many of these special feature test facilities are also capable of general purpose testing, but they are usually classed according to the specialized function for which they were constructed.

SCOPE OF REVIEW

We obtained cost, utilization, and other pertinent data on 73 NASA active wind tunnel test facilities and 1 DOT test facility. We also obtained a limited amount of information on inactive or discontinued facilities. The NASA and DOT activities covered in our review are shown in appendix II.

Most of the information we obtained was provided by NASA. We subsequently verified the data in total or on a test basis. To verify acquisition costs we reviewed facility files, project files, and construction vouchers. We verified operating cost data by interviewing the individual responsible for compiling the data to determine the source and methods of compiling, and on a test basis, we examined logs, contracts, work orders, billings, data processing reports, personnel rosters, and wage scales.

Utilization data was verified on a test basis through discussions with operating personnel and examining tunnel log books, maintenance reports, and other related documents. Information was obtained on outside users, including reimbursement procedures. We also looked into the planned construction of new facilities or major modifications to existing facilities.

As previously noted, all the wind tunnels we reviewed are owned by NASA with the exception of one DOT facility. This is a special purpose wind tunnel known as the 5-foot fire test facility. It is located at the Federal Aviation Administration's National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey, and has a capitalized value of about $366,000. It was originally acquired from the Navy as surplus and became operational at NAFEC in 1961. The NAFEC tunnel is used primarily to conduct fire protection studies on small aircraft engines and components.

Information on this tunnel is shown in appendix III but is not included in our computations of overall utilization or operating costs.

CHAPTER 2

STATUS OF WIND TUNNEL OPERATIONS

We reviewed a total of 74 wind tunnels and related special purpose test facilities which cost about $309 million. Schedules and narrative descriptions showing acquisition costs, operating capabilities, planned use, and other pertinent data for each facility are contained in appendix III. Operating cost and utilization data were obtained for 52 of these facilities. The remaining 22 are special purpose test facilities which are included in appendix III for information purposes only.

In addition to obtaining utilization and cost data, we reviewed NASA's efforts to centralize its aeronautical research operations and dispose of underutilized and obsolete tunnels.

UTILIZATION

Average utilization of NASA's wind tunnels during fiscal year 1975 ranged from 59 percent for hypersonic tunnels to 76 percent for subsonic tunnels. Overall, NASA's wind tunnels were in use about 69 percent of the time, down for maintenance about 16 percent of the time, and idle about 15 percent of the time.

For comparison purposes we expressed utilization as a percentage of available time because the number of shifts, and consequently total hours, varied among tunnels and centers. The percentages cited represent occupied time, that is time that the tunnel was committed to a specific project and not available for other projects.

A summary schedule of wind tunnel utilization for all subsonic, transonic, supersonic, and hypersonic facilities is contained in appendix IV. Appendix IV also contains utilization data for each facility reviewed and shows the extent of use by non-NASA entities. For both Langley Research Center and Johnson Space Center we have shown a category (number/frequency of runs) as illustrative examples of the number of times the tunnels were actually operating (tunnel on) or the frequency of those intervals of operation. However, frequency or number of runs varies considerably from tunnel to tunnel due to basic differences in their capabilities and limitations, specific requirements of each project, speed of the automatic data-gathering and processing equipment available, and various other factors. For these reasons, we did not use the number or frequency of runs as a basis for measuring utilization.

efficiency, selected tunnels were to be put on a standby basis, converted, or dismantled. The same officials also stated that they were striving to "reduce the multicenter roles" in aeronautical research and were working on ways to minimize overlaps in the programs at Langley and Ames.

These matters were discussed with NASA officials, and we were told that NASA is centralizing its aeronautical research efforts. Langley has been designated as the primary center for "long-haul" aeronautical technology and Ames as the center for "short-haul" technology.

Discontinued facilities

We identified a total of 45 wind tunnels that have been inactivated or dismantled. Nine of the 45 tunnels are inactive. There are two inactive facilities at each of the following locations: Ames, Langley, Marshall, and the Jet Propulsion Laboratory. The ninth facility is located at Lewis. These facilities are identified in appendix III. (See pp. 47 to 59.) The remaining 36 facilities have been dismantled. They have either been stored, transferred to other Government or private users, or converted to other uses. Twenty of these were formerly located at Ames and 16 at Langley.

According to center officials, tunnels have generally been discontinued for the following reasons.

--Reduction in area of research that the tunnel was used for.

--Manpower and money constraints, in addition to breakdowns, made it economical to use different facilities.

--Tunnels became obsolete due to limited capabilities when compared to other facilities.

NASA headquarters personnel provided us with a listing of facilities showing various disposal actions taken or planned. Many of these facilities are wind tunnels. Only a small part of the information was verified due to time constraints, but we are including the listing as appendix VI.

ADEQUACY OF FACILITIES

We found that tunnels constructed over 25 years ago are still frequently used. With periodic maintenance and repair a wind tunnel should suffer little or no deterioration in its capabilities. Considerable effort and money is spent to keep the tunnels in usable condition. For example, at Langley capitalized expenditures for major repairs, rehabilitation, and modifications to the tunnels since their acquisition amounts to about $25 million. With the exception of the need for a high-Reynolds number transonic test capability and other modification programs discussed in chapters 3 and 4, NASA center officials generally agreed that their current inventory of wind tunnels is adequate to accomplish their testing requirements.

CONCLUSIONS

To improve utilization of existing facilities, NASA is centralizing its aeronautical research efforts at Ames and Langley, thereby reducing multicenter roles. In addition, NASA has taken action to eliminate unnecessary facilities with low utilization or overlapping capabilities.

In view of the potential savings in data acquisition and processing time, we believe NASA should explore the feasibility and cost of upgrading inadequate tunnel instrumentation.

AGENCY COMMENTS

In commenting on this report, NASA stated that it was planning to initiate a study in the very near future on ways to reduce test time and energy usage and that improvements in tunnel instrumentation and data acquisition systems would be included. (See app. VII, p. 212.)

OPERATING COSTS

The cost to operate NASA's wind tunnels during fiscal year 1975 was about $18 million. Personnel costs accounted for almost half of this amount with electric power and maintenance costs totaling over $4 million each. (See app. V.)

OPERATING PROBLEMS AND LIMITATIONS

We noted several conditions affecting utilization of certain facilities, such as cost and availability of electrical energy and manpower and inadequate tunnel instrumentation (equipment used to measure and process test data).

Electrical energy

The cost of energy creates inconveniences at some locations in that operation of the wind tunnels is scheduled to take advantage of lower rates during "off-peak" hours, as electrical power costs are based on demand as well as use. Although no critical or high-priority projects have been delayed or canceled due to lack of energy, NASA officials foresee the availability and cost of energy as growing problems.

Lewis Research Center officials told us that energy conservation and power costs are major deterrents to more frequent tunnel operation. Lewis depends on a local electric utility company for its power. The company controls the amount of power released for tunnel operations and when power will be made available. Lewis personnel must coordinate their runs with the utility company. For this reason, plus the availability of a less expensive off-peak night rate, Lewis normally operates its tunnels at night or early morning. Occasionally, power is not available when needed or anticipated and some runs have been delayed or canceled.

Ames Research Center officials also cited the availability and cost of energy as growing problems, although no tests were delayed or refused during fiscal year 1975. Because of the high cost and limited availability of electrical power during daylight hours, high-energy tests at Ames are generally undertaken during off-peak hours.

Manpower

Both Ames and Lewis have experienced difficulties due to lack of available manpower. At Lewis manpower ceilings have made it difficult to hire the personnel needed to expand tunnel operations.

Ames officials told us that the principal constraint to their wind tunnel operation is the availability of manpower. During fiscal year 1975, lack of manpower was given as the reason for turning down tests on the 3.5-foot hypersonic tunnel, the electric arc shock tube, the thermal protection laboratory, and the aerodynamic free flight facility. More than 3,300 requested test hours were rejected during fiscal year 1975 because of manpower shortages.

Officials at Langley feel tunnel utilization and data acquisition and publication could be improved with a balanced increase in personnel, such as technicians, scientists, and support personnel. Within the limitations imposed by manpower ceilings and funding, manpower is generally adequate to perform research in the priority established by management. Some inconveniences and delays are experienced because support personnel and technicians may not be available at the specific time desired by a facility manager.

Tunnel instrumentation

Tunnel instrumentation at some locations is inadequate. For example, Ames officials told us that tunnel instrumentation is outmoded for both the unitary facility and the 12-foot transonic tunnel. We were told that the best instrumentation and data processing equipment currently available could reduce the test time to as little as 25 percent of the time now required, thereby permitting an increase in the number of measurements possible during a given period. Current data processing time is as long as 24 hours.

CENTRALIZATION EFFORTS

In June 1975 NASA performed an in-depth review of its wind tunnels' utilization. According to NASA, the review indicated that some tunnels were underutilized and other facilities were no longer needed because their capabilities were duplicated or superseded by other facilities. NASA officials stated that facilities at Ames and Langley would substantially accommodate NASA's supersonic and hypersonic testing needs. As part of NASA's endeavor to increase

CHAPTER 3

PLANNED PROCUREMENT OF THE NATIONAL TRANSONIC FACILITY

The only major procurement of new wind tunnels planned by NASA is a high-Reynolds number transonic wind tunnel to be located at Langley Research Center. The tunnel is estimated to cost $65 million. The basic justification for the facility centers on the need for capability to test systems at a higher- or full-scale RN.

BACKGROUND

For nearly a decade, the aerospace community has recognized the need for better simulation of flight RN characteristics in ground-based facilities. The first facility in which test RN equaled those for full-scale aircraft went into operation in 1923. This tunnel used high-pressure air as the test medium in order to increase inertia forces. For the next 50 years, nearly all high-RN tunnels used this concept. The last major increase in the RN capability of high-speed tunnels occurred in the mid-1950s. Yet the need for proper simulation of flight RN has increased. This need was brought into focus in 1965 when large differences in wing shock location were noted between flight and wind tunnel results on the C-141.

Existing facilities adequately handle some aerodynamic characteristics of current aircraft, but RN simulation, according to numerous aeronautical authorities, still presents a serious problem, particularly in transonic testing. Because some aerodynamic characteristics do not behave in a predictable manner, the design engineer faces serious problems in extrapolating data to flight RN.

In recognition of this facility need, the U.S. Air Force (USAF) has been studying an intermittent flow, high-RN tunnel. NASA also has been studying both intermittent- and continuous-flow facility concepts to increase high-RN transonic capabilities. Concurrently, several advisory groups to USAF and NASA endorsed the high-RN transonic test facilities as having the highest national priority for aeronautical development.

NASA and USAF both developed firm plans for transonic facilities during fiscal years 1973 and 1974 to the extent that USAF had obtained congressional approval in the fiscal year 1975 budget for a high-RN tunnel, and NASA had planned for one to be included in the fiscal year 1976 budget. Both NASA and USAF tunnel projects encountered abrupt escalation of construction costs in 1974, causing USAF to defer construction and NASA to withhold the budget request.

Subsequently, the Department of Defense (DOD) and NASA agreed to undertake a joint study to seek other ways for satisfying the national transonic wind tunnel needs. Accordingly, the Aeronautics and Astronautics Coordinating Board (AACB)[1] organized a special Aeronautical Facilities Subpanel on November 1, 1974, to initiate the study and report to AACB by March 1, 1975.

AACB subpanel conclusions and recommendations

The subpanel's conclusions were contained in a report dated May 1975. An excerpt from that report follows.

> "A national and international concern exists over the inability of existing wind tunnels to provide accurate design information for maneuver and transport aircraft that must fly in or through the transonic flight regime. This deficiency has been dramatized during the past decade by aircraft problems which resulted in reduced aircraft performance and/or expensive redesign. A major cause for these design anomalies was identified as Reynolds number sensitive flow phenomena which had been inaccurately simulated in the wind tunnel. * * * Today's requirements for improved aircraft performance, efficiency, maneuverability, handling qualities, safety and environmental compatibility emphasize the need for good development wind tunnels.
>
> "The high costs of aircraft and aircraft development programs make it mandatory that more accurate information be provided at each stage of development to give confidence of a successful program before obligation of large program funds. This country cannot afford to develop expensive and sophisticated aircraft only to find out in flight that they cannot

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1/The AACB consists of NASA and DOD representatives and provides a close working relationship between the two agencies. More detail of its activities appears on page 24.

satisfy the needs. The lack of adequate development tools and a legacy of unsolved problems in the transonic flow regime have resulted in costly failures and embarrassments * * *. Reynolds number is believed to be one of the more important parameters that must be matched to full-scale values in order to resolve these anomalies."

The subpanel report also cited examples of previous aircraft development problems attributable largely to the inability of present facilities to accurately simulate full-scale aircraft performance. Examples included:

--C-141 transport: The flow over the wing during high-speed flight differed markedly from that observed in the wind tunnel and had an impact on stability, structural loads, and performance. The problems were eventually solved, but only after millions of dollars had been spent on extensive structural reevaluation, testing, and modification to the aircraft.

--F-102: Transonic drag rise caused a major reconfiguration, but, even then, it could not perform its mission and was replaced by the F-106. Base drag problems at transonic speeds were a concern on both fighters.

--Other: U.S. commercial transport development programs have also experienced RN-related transonic problems. Two aircraft required some redesign because of flow interactions between engines and wings. Uncertainties in predicting pitching moments, drag values, and maximum lift have been a concern in nearly all cases.

The subpanel recommended to AACB that a single, continuous-flow facility should be built at the earliest possible date to serve the needs of both NASA and DOD. The subpanel further recommended that the facility be located at the Langley Research Center and be known as the national transonic facility (NTF). NASA and DOD signed a memorandum of agreement accepting these AACB recommendations on June 2, 1975.

Regarding potential users the subpanel recommended:

--NTF is to be, in fact, a national aeronautical resource and, accordingly, should be used and managed in a manner that effectively serves the aeronautical and research needs of Government, industry, and scientific organizations.

--Operational funding or accommodations, therefore, will be provided to meet the needs of all prospective users, regardless of which organization has the management responsibility.

The principal prospective users of NTF and the estimated usage, as proposed by the subpanel, are:

User	Percent
NASA	40
DOD	40
Aerospace industry (proprietary)	15
Other Government agencies	5
Scientific community	Cooperative with NASA, DOD, or other Government agencies

Planned uses

According to aeronautical authorities, problems evidenced in today's development programs will become more critical as aircraft become larger and more complex. Additionally, an energy conservation transport is under consideration as an eventual replacement for the current wide-body jet transports. Proposed utilization of thick, supercritical wings will require high-RN testing.

Planning studies also recognize future transport aircraft in the 1.5 million- to 2.5 million-pound category, such as the heavy spanloader transport. Further, the planned new generation of short take off and landing aircraft also employs supercritical wing technology to maximize aerodynamic and structural performance.

Supersonic and hypersonic aircraft, launch vehicles, and reentry vehicles that must accelerate and decelerate through transonic flight regions require extensive testing in a high-RN transonic tunnel. Future space shuttle concepts which might include a single stage-to-orbit configuration would engender new demands on high-RN transonic testing capability.

Authorities have stated that any attempt to develop these advanced technologies without a high-RN transonic test facility is considered to be a high-risk venture.

Aircraft industry comments

The aircraft industry supports the need for higher RN testing capability. The majority of industry representatives recognized and shared the view that a higher RN capability was needed. Additionally, the majority felt that acquiring such a facility was a matter of considerable national urgency. The lack of advanced transonic experimental capability is expected to have an adverse effect on projected aerospace systems as indicated by the following comments from industry representatives.

--Inadequate technology will result in (1) less than optimum maneuverability in fighters and other aircraft and (2) conservative design in all vehicles to avoid problems.

--Risk of (1) overoptimistic design leads to system failures, redesign, late delivery, and higher costs and (2) less than optimum design leads to inferior performance and loss of strategic or competitive advantage.

--Development costs will increase due to greater reliance on full-scale flight testing.

--Some advanced systems will not be attempted due to technical risk.

--Excessive cost to correct deficiencies in new systems will occur or compromise in performance and effectiveness will have to be accepted.

DESCRIPTION OF NTF

The proposed NTF is to be a high-RN transonic tunnel designed to satisfy both the research and development needs of NASA and DOD. This facility is expected to provide a 120-million-RN capability to test a broad spectrum of military and commercial aircraft as well as space vehicles up to full-scale RN. This represents a level about 10 times that of currently operational continuous-flow transonic tunnels. According to NASA, NTF will incorporate a newly developed cryogenic approach for achieving a high RN; that is, using liquid nitrogen to obtain a low-temperature test medium. The basic performance characteristics of NTF are shown below.

Test section size	2.5 x 2.5 meters
Design shell pressure	130 pounds per square inch absolute
Mach range	0.2 to 1.2
RN (Maximum)	120×10^6 (120 million)
Test medium	Nitrogen
Operating temperature	-300° to +175° F.
Fan drive	120,000 horsepower electric motors
Run duration	Continuous (10 minutes limit at maximum horsepower)
Flow quality	Approach free air

Estimate of costs

NASA estimates that $25 million will be required during fiscal year 1977 for constructing NTF. To complete construction NASA estimates that an additional $40 million will be required in future years for a total cost of $65 million.

The preliminary estimates for the separate high-RN facilities initially planned by NASA and USAF totaled about $79 million; $44 million for USAF's high-RN tunnel and $35 million for NASA's transonic research tunnel. As previously noted, plans for both facilities were dropped when estimated costs for both facilities escalated to more than $130 million.

CONCLUSIONS

One of the major goals in wind tunnel testing is predicting full-scale aircraft performance with confidence based on scale-model investigations. Although there are many facets to accurate prediction of full-scale aerodynamic characteristics, the lack of high-RN capability is recognized as the most critical deficiency in the operating characteristics of U.S. transonic facilities.

Today, design engineers face serious difficulties when they extrapolate flight RNs from wind tunnel simulations, particularly in the transonic region. It is the opinion of authorities in aeronautics that extrapolation has strained the limits of credibility and that flight testing is not a viable alternative.

Our review did not include a determination or evaluation of the optimum RN capability for the proposed NTF. However, based on the preponderance of evidence, increased capability in this area would enhance the technology base and assist in developing more efficient civil and military aircraft.

CHAPTER 4

PLANNED MODIFICATIONS

The National Aeronautics and Space Administration plans to modify various wind tunnels located at the Langley, Ames, and Lewis Research Centers. The nature and cost of the modifications at each center are discussed below.

LANGLEY MODIFICATIONS

Langley's plans to convert its mach 6 high-Reynolds number tunnel to a mach 4 tunnel has been deferred for consideration until fiscal year 1979. The conversion is part of Langley's plan to rehabilitate its gas dynamics laboratory at an estimated total cost of $5.2 million.

Modifications that have been approved and for which funds have been appropriated in fiscal year 1976 are shown below.

Modifications	NASA's estimated total cost
Unitary plan wind tunnel rehabilitation. This project provides for replacement items for the main drive support equipment. (Pumps, valves, drive coupling, and controls.)	$490,000
Rehabilitation of the freon reclamation system, transonic dynamics tunnel. This project covers the replacement of the refrigeration system.	200,000
Modify the test section of the thermal protection test facility.	85,000
Rehabilitation of the mach 19 nitrogen tunnel. Primary purpose is to increase operating pressure.	95,000
Total	$870,000

NASA budgeted $810,000 for the transition period and fiscal year 1977 as follows.

Modifications	NASA's estimated total cost
Addition to 8-foot high-temperatures structure tunnel to provide additional office space for personnel conducting research in the tunnel.	$ 80,000
Constructing an addition to the transonic dynamics tunnel. This project will provide for the addition of an aeroelastic model laboratory. Construction costs are estimated at $545,000. The remaining $185,000 are estimated equipment costs.	730,000
Total	$810,000

AMES MODIFICATIONS

Ames has extensive plans for modifications, minor construction, and facility planning and design. These activities are estimated to cost about $4,560,000.

Authorized and appropriated in FY 1976	NASA's estimated total cost
11-foot unitary tunnel	$2,695,000
Unitary tunnel subsystems	385,000
7- x 10-foot wind tunnel #1	400,000
Electric power schedules	200,000
14-foot wind tunnel	65,000
Facility planning and design:	
12-foot wind tunnel	60,000
Total	$3,805,000

Budgeted for transition period and FY 1977	NASA's estimated total cost
Unitary tunnels improvement	$ 95,000
12-foot tunnel rehabilitation	415,000
Minor construction:	
Fluid dynamics laboratory	245,000
Total	$755,000

These projects are described in more detail below.

Authorized and appropriated
in fiscal year 1976

A total of $3,805,000 was authorized and appropriated in fiscal year 1976 for modifications and facility planning and design.

Modifications

The modifications are as follows.

--Eleven-foot unitary tunnel modification ($2,695,000). This project provides for improving the 11-foot tunnel's data acquisition system. NASA officials told us that this project is to be a pilot for modernization of data systems in other wind tunnels at Ames.

--Unitary tunnel subsystems rehabilitations ($385,000). This project provides for rehabilitating and upgrading the automatic model support system and associated position control systems in the 8- x 7-foot wind tunnel main drive compressor, replacing the rotor blade shrouds in the 11- x 11-foot wind tunnel main drive compressor, and modifying the cooling tower to prevent steam/water vapor drift.

--Acoustic modifications to 7- x 10-foot wind tunnel #1 ($400,000). This modification will provide 15,000 square feet of acoustically absorbent walls and baffles in one of the crosslegs, the diffuser, and the test section.

--Electric power schedules ($200,000). This project will provide for the installation of an electrical power scheduling system. The system will be used to schedule, monitor, and control the center's power usage to insure that energy is used most effectively.

--Elevator in 14-foot wind tunnel building ($65,000). The project consists of adding three aluminum power-operated car riding gates and other minor modifications.

Facility planning and
design--12-foot wind tunnel

Sixty thousand dollars has been authorized for a concept validation study for preparing a preliminary engineering report. This modification, if undertaken by NASA, would cost an estimated $6,572,000. Additionally, an estimated $350,000 would be required for the facility design. The proposed modification would increase the mach speed and substantially increase RN capability.

Budgeted for transition period

The project planned for the transition period (between fiscal year 1976 and 1977) calls for replacing the spray canopy and improvement of work-area lighting in the unitary wind tunnels. This project is estimated to cost $95,000.

Budgeted for fiscal year 1977

A total of $660,000 has been budgeted for fiscal year 1977 for modifications and minor construction.

Modifications

Rehabilitation and modification of 12-foot tunnel ($415,000).

Minor construction

The construction of a new test leg at the fluid dynamics laboratory (also called the high-RN channel) is the only minor construction related to wind tunnels planned for either fiscal year 1976 or 1977; it is budgeted for fiscal year 1977 at $245,000.

Modification of the 40- x 80-foot
wind tunnel

In addition to the projects previously described, the Congress authorized $12.5 million in fiscal year 1976 to begin modifying the 40- x 80-foot wind tunnel but no funds were appropriated. The Administrator, NASA, stated before the Senate Committee on Aeronautical and Space Sciences on January 26, 1976, that modification of the 40- x 80-foot wind tunnel would be deferred until fiscal year 1977.

Planning and design of this project began in fiscal year 1974 and has cost about $1,810,000. Construction was originally planned to begin in fiscal year 1976 and continue through fiscal year 1978 at an estimated total cost of $57.8 million. In September 1975 the estimated cost increased and ranged from $81 million to $86 million. The factors which influenced the revised estimate were as follows.

--Improved cost data.

--Changes in escalation rates.

--Delay to fiscal year 1977 start.

--Design changes.

--Change in funding from 3 to 5 years.

The latest update to the preliminary engineering report, completed on February 19, 1976, estimates a further increase in the construction cost to as much as $90 million. The latest increase is attributable to the delayed start--from fiscal year 1977 to fiscal year 1978. The modification calls for:

--Increasing the speed capability of the 40- x 80-foot test section from 200 to 300 knots by installing more powerful drive motors.

--Adding an 80- X 120-foot test section having a speed capability of 110 knots while using the same drive system.

--Relocating the electric substation to permit construction of the new test leg.

The expanded test section will allow full-scale testing of larger aircraft than now possible in the 40- x 80-foot tunnel. NASA justifies the project on the basis of technical and economic benefits the modified facility will provide.

The technical justification for the facility modification points to the interaction of aerodynamics and structural dynamics as a major reason why full-scale testing is superior to small-scale testing.

The economic benefits of the facility are expected to exceed the cost of the modification, according to a preliminary engineering report prepared for NASA by an independent contractor. The failure of the Cheyenne AH-56A helicopter program was cited to support the need for, and economic benefit of, large-scale testing.

> "This program for the development of an advanced rotary-wing attack aircraft ran into serious cost overruns when dynamic stability problems were encountered with the rotor system during flight tests. * * * By the time flight tests had exposed the technical problem, major funding commitments had been made, and delays in the program were extremely costly. The rotor dynamic stability problem was eventually solved. However, the program cost had exceeded $400,000,000, and the program was terminated. If this rotor system had been subjected to full-scale wind tunnel tests early in the development program, * * * these dynamic stability problems would have been discovered before the high cash-flow rate developed in the program, and the technical problem probably could have been resolved with a considerably lower cost."

LEWIS MODIFICATIONS

Lewis has three modifications to the 8- x 6-foot wind tunnel. Two projects were authorized and funded in fiscal year 1976. One project costing $170,000 consists of modifying the flexible wall hydraulic system. The second project is an $80,000 shop addition. A third project to rehabilitate the tunnel's air dryer is budgeted for the transition period at a cost of $110,000.

CHAPTER 5

COOPERATION BETWEEN NASA AND OTHER USERS

The Unitary Wind Tunnel Plan Act of 1949 authorized the National Advisory Committee for Aeronautics (the predecessor to the National Aeronautics and Space Administration) to construct and equip transonic or supersonic wind tunnels adequate for the conduct of experimental work. The act further specified that authorized unitary wind tunnels shall be available primarily to industry in connection with the development of aircraft and missiles.

The unitary wind tunnels are thus statutorily designated as development tunnels available primarily to industry. All other tunnels are designated as research tunnels. NASA policy also provides that other NASA wind tunnels, used primarily for research, may also be used for development work when it is in the public interest.

The Aeronautics and Astronautics Coordinating Board was established to provide a close working relationship between NASA and the Department of Defense. The board facilitates:

--Planning of activities by NASA and DOD to avoid undesirable duplication and to achieve efficient utilization of available resources.

--Coordinating activities of common interest to NASA and DOD.

--Identifying problems requiring solution by either NASA or DOD.

--Exchanging information between NASA and DOD.

NASA's Deputy Administrator and DOD's Director of Defense Research and Engineering serve as co-chairmen. An example of the activities undertaken by AACB is the study coordinated by AACB's facilities subpanel to arrive at recommendations regarding the construction of a high-Reynolds number transonic wind tunnel as discussed in chapter 3.

NASA also cooperates and participates jointly with other agencies that have common research and development interests. The program may be initiated by NASA or another agency and resources are provided by both parties. For example, five wind tunnels at Langley were used to support joint research programs during fiscal year 1975. Langley also has some written cooperative agreements with Federal agencies, universities, and private industries. Cooperative agreements are formed when there is a mutual interest in programs of national importance.

AVAILABILITY OF FACILITIES

NASA centers frequently make wind tunnels available to other NASA as well as non-NASA users. An illustrative example is Ames, where non-NASA users occupied wind tunnels approximately 24 percent of the time during fiscal year 1975. Of the 7,016 non-NASA test hours, 87 percent supported military testing. Other non-NASA users included the Department of Transportation and McDonnell-Douglas.

The Johnson Space Center, in connection with the space shuttle program, requested and received 2,912 test hours during a 6-month period from Ames.

NASA's policy does not require that tunnels be made available to industry, except for the unitary plan wind tunnels. Requests from industry that are deemed to have merit and can fulfill a need in the national interest would be scheduled, provided that the requestor agrees to relinquish proprietary interest. If tunnel use were requested for proprietary purposes and a similar tunnel was commercially available, the requestor would be referred to the commercial source.

Langley officials told us that no charges were made nor any reimbursement received during fiscal year 1975.

However, some reimbursements were noted at Ames. Users are charged the following occupancy rates (computed on a 40-hour-a-week basis).

Wind tunnel	Weekly rate
8- x 7-foot supersonic	$33,000
9- x 7-foot supersonic	33,000
11-foot transonic	33,000
6- x 6-foot supersonic	20,000
12-foot pressure	20,000
14-foot transonic	20,000

In addition to the above weekly occupancy charges, there is a charge for electric power and cost of data reduction (including automatic data processing equipment rentals), plus 15 percent of total charges for NASA and supervisory costs.

During fiscal year 1975, Ames received $332,522 reimbursement for use of its wind tunnels by private contractors for proprietary purposes.

We did not note any instances in fiscal year 1975 where NASA charged another Government agency for use of its wind tunnels. We were told that other Government agencies were rarely charged because the tests performed mutually benefit both NASA and the requesting agency. We did note one instance, in fiscal year 1976, where the Marshall Space Flight Center charged the Army Missile Command $7,200 for 24 hours of tunnel test time. The Army was charged for direct labor costs because Marshall officials felt that the test was of no benefit or interest to NASA.

The scope of our review did not include an evaluation of the propriety of NASA's policies and procedures regarding reimbursements.

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
SUITE 2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, D.C. 20515

June 25, 1975

Mr. Elmer B. Staats
Comptroller General of the United States
The General Accounting Office
441 G Street, N.W.
Washington, D.C 20548

Dear Mr. Staats:

As part of the Committee on Science and Technology oversight activity during the 94th Congress, the Subcommittee on Aviation and Transportation Research and Development, chaired by the Honorable Dale Milford, will examine in depth selected national aeronautical facilities and programs. In order to accomplish this task, additional assistance will be required. Therefore, I am requesting that you provide appropriate personnel in support of the Subcommittee's activity.

Attached is a Subcommittee program plan submitted to me by Mr. Milford. You will note that there are three items concerning GAO in this work plan:

(a) development of a selected data base on programs and facilities.

(b) examination of selected FAA/NASA centers.

(c) examination of specific types of facilities.

Under item (a), the Subcommittee wishes to accomplish a thorough review of the nation's civil aviation R&D programs and facilities. Assistance by the GAO for accomplishing the review would take the form of assembling information on selected programs and facilities to help achieve the objectives identified in the enclosed program plan. Primarily, these objectives are related to assuring that the U.S. retains its predominant role in world aviation, to insuring that U.S. governmental agencies and private industry are cooperating, and insuring that federal expenditures for aeronautical R&D and facilities are being spent effectively.

Mr. Elmer B. Staats June 25, 1975

Under item (b), the Subcommittee's first priority is an examination of the FAA's National Aviation Facilities Experimental Center (NAFEC). The Subcommittee has recently acquired jurisdiction over R&D activities of the FAA and is therefore extremely interested in the function of the NAFEC facility. In order to become thoroughly acquainted with the NAFEC operations, the Subcommittee needs definitive information concerning NAFEC personnel, facilities, equipment, and programs. It is requested that this information be furnished by February 1976, so that your report may be utilized during the annual authorization process. Subsequently, other centers would be examined during 1976.

Under item (c), the Subcommittee is primarily interested in obtaining an inventory and examining the status of the nation's wind tunnels. The Subcommittee has recognized that many of our wind tunnels were built in the 1940's and that this is of major concern to aviation interests in this country. Proposals have been made by NASA and the Department of Defense for a number of new, advanced aeronautical R&D facilities. If approved, these facilities would involve the expenditure of many hundreds of millions of dollars.

Therefore, a thorough understanding of our current wind tunnel resources is needed by the Subcommittee in order to act properly on the pending requests for new facilities. The preliminary phase of examination would consist of a study of NASA and FAA facilities, and the secondary phase would necessitate cooperation from DOD for examination of military facilities. It is requested that this information be furnished in a report by February 1976, in time for the authorization process.

My staff will be working with those people you assign to this task on a periodic basis. I would assume that you would designate a person to lead your effort and provide guidance to GAO personnel involved. Our expectation is that GAO assistance, in varying degrees, will be required until the end of the 94th Congress.

Since we wish to initiate these efforts at an early date, please provide me with your comments and recommendations at your earliest convenience.

Sincerely,

OLIN E. TEAGUE
Chairman

T/S/ps

Subcommittee on Aviation and Transportation R&D

June 20, 1975

SUBJECT: REVIEW OF NATIONAL AVIATION R&D FACILITIES AND PROGRAMS

Overall Objectives

1. Attain a broad perspective of the nation's policies and programs concerning aviation.

2. Understand the goals and objectives of the NASA and DOT aviation R&D programs.

3. Determine the inter-relationships between NASA, the DOT the Department of Defense and industry in establishing objectives and priorities in conducting aviation R&D.

4. Determine if overall aviation R&D objectives are being pursued in an effective manner.

Program Objectives

1. Identify NASA and DOT aviation R&D programs and review the relationship of these programs to agency objectives.

2. Identify major DOD aviation R&D programs (in cooperation with the Armed Services Committee).

3. Determine whether unwarranted duplication exists in R&D programs.

4. Determine if sufficient attention and resources are being devoted to aviation R&D programs.

Facilities Objectives

1. Identify NASA and FAA aviation R&D facilities and review the utilization of such facilities.

2. Identify DOD aviation R&D facilities and review the utilization of such facilities (in cooperation with the Armed Services Committee).

3. Determine whether unwarranted duplication exists in agency aviation R&D facilities.

4. Determine if sufficient attention and resources are being devoted to aviation R&D facilities and programs.

Approach

1. Review prior government examination of the nation's aeronautical programs.

2. Examine selected FAA/NASA Centers.

3. Compile data file on all FAA/NASA Centers.

4. Examine specific types of facilities (e.g. wind tunnels).

Basic Work Plan

GAO

1. Prepare file on each FAA/NASA center where aeronautical R&D is being performed.

2. Definitive examination of selected NASA/FAA Centers.

3. Examination of specific types of facilites, such as wind tunnels.

Library of Congress

1. Review prior government examinations of the nation's aeronautical programs.

2. Summarize major recommendations of such examinations.

NASA/FAA

1. Update Aeronautics and Space Engineering Board (ASEB) Study (Civil Aviation R&D).

2. Expand study as necessary (include facilities, safety, etc.)

Subcommittee Staff

Mr. Read -- to coordinate and control all phases of the study for the Subcommittee. Monitor items 1 and 4.

Mr. Staub -- Monitor items 2 and 3.

NASA RESEARCH CENTERS AND OTHER ORGANIZATIONS CONTACTED

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION:

Ames Research Center, Mountain View, California
Johnson Space Center, Houston, Texas
Langley Research Center, Hampton, Virginia
Lewis Research Center, Cleveland, Ohio
Marshall Space Flight Center, Huntsville, Alabama
Jet Propulsion Laboratory, Pasadena, California

DEPARTMENT OF TRANSPORTATION (FEDERAL AVIATION ADMINISTRATION):

National Aviation Facilities Experimental Center, Atlantic City, New Jersey

LANGLE

PROFILE OF

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test secti
Low turbulence pressure tunnel	1940	$ 729	$ 468	$ 1,197	3' x 7-1/2
Full-scale tunnel	1930	964	2,416	3,380	30' x 60'
V/STOL (note b)	1969	6,867	107	6,974	14-1/2' x
High speed 7- x 10-foot tunnel	1944	1,498	1,672	3,170	79" x 115"
Spin tunnel	1941	74	73	147	20' x 25'
Total		$10,132	$4,736	$14,868	

[a] Pounds per square inch absolute (PSIA).

[b] Vertical/short take-off and landing.

ize	Reynolds number	Pressure (PSIA)	Mach range	Type	Narrative description on page
	2×10^6	800 to 1,200	10.03	intermittent	100
	2.5×10^6	150 300	10 12	intermittent	102
	3.3×10^6	400 to 2,100	6.5 to 7.7	intermittent	104
	3×10^6	500 to 3,500	5.8 to 7.5	intermittent	106
	1.5×10^6	500 to 3,000	6	intermittent	108

LANGLE

PROFILE OF

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test secti
26-inch transonic blowdown tunnel	1950	$ 333	$ 93	$ 426	26"
6-inch x 28-inch transonic tunnel (note b)	1974	751	0	751	6" x 28"
6-inch x 19-inch transonic tunnel (note b)	1971	183	38	221	6" x 19"
8-foot transonic pressure tunnel	1952	5,585	2,528	8,113	7.1' x 7.1 (subsonic) 7.1' x 7.1 (transonic
Transonic dynamics tunnel	1961	12,336	1,087	13,423	16' x 16' (up to mac 16' x 16' (at mach 1
16-foot transonic tunnel	1953	9,512	4,906	14,418	15.5' octa 8' to 22'
Cryogenic transonic (model) tunnel	1973	175	48	223	13.5" octa 8" x 24"
Total		$28,875	$8,700	$37,575	

a/PSIA.

b/Life Expectancy is 10 years.

EARCH CENTER

AL PURPOSE FACILITIES

.ze	Reynolds number	Pressure (PSIA)	Mach range	Type	Narrative description on page
	(a)	200 to 700	2.9	continuous	109
	(a)	1 to 4	2.5 (1) 3.5 (2) 4.0 (3)	intermittent	110
	(a)	45,000	65,000 ft. per sec.	intermittent	112
	(a)	450	2.75 to 3.3	intermittent	113
	0.46×10^6	75 to 345	5.1 to 6.85	continuous	114
	$.605 \times 10^6$	36.8 to 75	2.50 to 2.70	continuous	115
	$.44 \times 10^6$	17.3 to 17.7	.48 to .54	continuous	117

ESEARCH CENTER

INACTIVE FACILITIES

size	Reynolds number	Pressure	Mach range	Type	Narrative description on page
	1×10^6	atmospheric	0 - 40 MPH	continuous	(a)
	33.8×10^6	b 50 to 200	3	intermittent	(a)

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:tion size	Reynolds number	Pressure	Mach range	Type	Narrative description on page
x 16'	2.3×10^6	atmospheric	0.33	continuous	120
x 15'	2.3×10^6	atmospheric	0.33	continuous	122
11.3' x 18'	9×10^6	atmospheric	0.98	continuous	124
1' x 80'	2.1×10^6	atmospheric	0.3	continuous	126
13.7' x 33.75'	4.2×10^6	atmospheric	0.6-1.2	continuous	127
x 5'	8.7×10^6	0.16-3.0 Atm.	0.2-1.4	continuous	129
' x 22'	9.4×10^6	0.5-2.25 Atm.	0.5-1.4	continuous	130
x 18'	6.5×10^6	0.3-2.0 Atm.	1.55-2.5	continuous	132
x 16'	5×10^6	0.3-2.0 Atm.	2.45-3.5	continuous	134
x 14.4'	5×10^6	0.3-1.0 Atm.	0.25-2.2	continuous	136

COST SUMMARY OF

ACTIVE WIND TUNNELS

	Subsonics		Transonics		Supersonics		Hypersonics		Special purpose		Total	
	No.	Cost (000 omitted)	No.	Cost (000 omitted)	No.	Cost (000 omitted)	No.	Cost (000 omitted)	No.	Cost (000 omitted)	No.	Cost (000 omitted)
Langley	5	$14,868	7	$37,575	4	$ 24,677	14	$31,904	8	$10,920	38	$119,944
Ames	4	23,900	3	25,008	3	29,350	1	16,343	6	22,331	17	116,942
Lewis	2	1,475	-	-	2	46,687	-	-	1	2,816	5	50,978
JPL (note a)	1	12	-	-	1	3,800	1	9,500	3	760	4	14,772
Johnson	-	-	-	-	-	-	-	-	2	4,438	2	4,438
Marshall	-	-	-	-	2	1,570	-	-	3	907	5	2,477
NAFEC (note b)	-	-	-	-	-	-	-	-	1	366	1	366
Total	12	$40,255	10	$62,593	12	$106,084	16	$57,747	24	$42,538	74	$309,217

[a]Jet Propulsion Laboratory.

[b]National Aviation Facilities Experimental Center.

APPENDIX III

PROFILES AND NARRATIVE DESCRIPTIONS OF WIND TUNNELS

RESEARCH CENTER

SONIC WIND TUNNELS

size	Reynolds number	Pressure	Mach range	Type	Narrative description on page
	15×10^6	[a]5 to 150	0.10 to 0.40	continuous	64
56'	1×10^6	atmospheric	0 to 0.14	continuous	65
-3/4' x 50'	2.1×10^6	atmospheric	0 to 200 knots	continuous	67
60"	4.1×10^6	atmospheric	0 to 1	continuous	69
	$.62 \times 10^6$	atmospheric	0 to 90 ft. per sec.	continuous	71

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PROFILE OF SUPERS

Facility name	Year built	Initial cost (ooo omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test section si
4-foot x 4-foot supersonic pressure tunnel	1946	$ 2,612	$ 597	$ 3,209	4.5' x 4.5' x 7
Unitary plan wind tunnel	1951	15,533	3,912	19,465	4' x 4' x 7' (1 4' x 4' x 7' (2
Ceramic heater	1957	346	114	460	11"
Thermal protection system test facility	1974	1,543	0	1,543	1' x 3'
Total		$20,054	$4,623	$24,677	

[a]Not applicable

RESEARCH CENTER

.NSONIC WIND TUNNELS

size	Reynolds number	Pressure	Mach range	Type	Narative description on page
	27 x 10^6	[a]20 to 75	0.6 to 1.45	intermittent	72
	10 x 10^6	30 to 90	0.2 to 1.2	intermittent	73
	3.0 x 10^6	[a]17 to 30	0.5 to 1.2	intermittent	74
15' 4'	6.2 x 10^6	[a].25 to 2.0	0.2 to 1.3	continuous	75
36' .7) 12')	8.5 x 10^6 (freon 12) 2.8 x 10^6 (air)	[a]0.1 to 14.7	0 to 1.2	continuous	76
nal ngth	4.2 x 10^6	atmospheric	0.2 to 1,3	continuous	77
nal	100 x 10^6	5 atmospheres	0 to 1.3	continuous	79

LANGLEY

PROFILE OF S

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test sectio
Supersonic materials environmental test system	1969	$ 100	$ 20	$ 120	3" x 5" x 1
High-enthalpy arc tunnel	1965	70	130	200	2.0" (1) 4.6" (2) 7.6" (3)
Hot gas radiation research facility	1964	4,025	375	4,400	6"
Supersonic combustion test stand	1970	287	38	325	16' x 16' x
Entry structures facility	1960	2,655	3,220	5,875	
Apparatus A: 10 megawatt arc tunnel (supersonic)	1961	(b)	(b)	(b)	6.30" diame
Apparatus B: 2-inch supersonic arc jet	1961	(b)	(b)	(b)	2" diameter
Apparatus D: high-enthalpy direct current plasma jet (supersonic)	1963	(b)	(b)	(b)	1" diameter
Total		$7,137	$3,783	$10,920	

[a]Not applicable.

[b]Costs included in those of the entry structures facility-- not practical to allocate.

LANGL

PROFILE

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test sect
12-foot low speed tunnel	1939	(a)	(a)	(a)	12' x 32'
9-inch x 6-inch model tunnel	1960	(a)	(a)	(a)	8.75" x 6'

[a] Not available.

[b] Pounds per square inch absolute.

RESEARCH CENTER

YPERSONIC WIND TUNNELS

n size	Reynolds number	Pressure (PSIA)	Mach range	Type	Narrative description on page
	5×10^5	30	6.0	intermittent	87
r	1×10^6	12,000	19	intermittent	88
.ter	11.3×10^6	200 to 3,000	17.6 to 22.2	intermittent	89
.'	11.3×10^6	200 to 3,000	20 to 40	intermittent	89
	9.0×10^6	45 to 550	6	intermittent	91
	(b)	10 to 600	3 to 5	intermittent	93
	200×10^6 (1) 1.2×10^9 (2)	50 to 3,200	6 (1) 6 (2)	intermittent	94
r	12×10^6	15 to 2,930	7.5 to 8.0	intermittent	96
.r (1) .r (2)	20.4×10^6 (1) 60.2×10^6 (2)	4,000 (1) 4,000 (2)	20 (1) 10 (2)	intermittent	98

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IC WIND TUNNELS

Reynolds number	Pressure (PSIA)	Mach range	Type	Narrative description on page
6.2×10^6	4 to 30	1.25 to 2.2	continuous	81
7.05×10^6 (1) 6.81×10^6 (2)	3.0 to 27 3.0 to 26	1.47 to 2.86(1) 2.29 to 4.63(2)	continuous	83
(a)	115 to 800	2 to 3.5	intermittent	85
1.6×10^6	.09 to 1.5	3.5 to 4.3	intermittent	86

LANGE

PROFILE OF

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test sect
SCRAMJET test facility	1974	[a] $ 4,250	$ 0	[a] $ 4,250	11" x 12"
Hypersonic nitrogen tunnel	1964	570	140	710	19" diam
22-inch helium tunnel	1960	997	315	1,312	22.5" dia
Open-jet helium tunnel	1973	275	0	275	9' x 6' x
20-inch hypersonic tunnel (mach 6)	1958	1,899	0	1,899	20" x 20"
Nozzle test chamber	1969	50	50	[a] 100	4" x 18"
Mach 6 high-Reynolds number tunnel	1967	248	0	248	12' (1) 12' (2)
Mach 8 variable-density hypersonic tunnel	1960	64	135	199	18" diame
High-Reynolds number helium tunnels	1967	3,148	0	3,148	60" diame 37" diame

[a]Estimated.

[b]Not applicable.

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test secti
Hypersonic flow apparatus	1959	$ 248	$ 267	$ 515	15" diamete
Continuous-flow hypersonic tunnel	1957	5,753	963	6,716	31" square
7-inch mach 7 pilot tunnel	1958	185	22	207	.5" diamete
8-foot high temperature structures tunnel	1964	11,029	1,046	12,075	8' diamete
20-inch hypersonic CF_4	1972	250	0	250	20" diamete
Total		$28,966	$2,938	$31,904	

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test
Profile of subsonic wind tunnels:					
7 foot x 10 foot (No. 1)	1941	$ 426	$ 330	$ 756	7' x
7 foot x 10 foot (No. 2)	1941	392	1,169	1,561	7' x
12 foot	1946	3,489	1,678	5,167	11.3'
40 foot x 80 foot	1944	7,139	9,277	16,416	40' x
Total		$11,446	$12,454	$23,900	
Profile of transonic wind tunnels:					
14 foot	1955	$ 1,881	$ 9,906	$11,787	13.5'
2 foot x 2 foot	1951	447	1,312	1,759	2' x
11-foot unitary	1956	[a]8,283	[b]3,189	11,472	11' x
Total		$10,611	$14,407	$25,018	
Profile of supersonic wind tunnels:					
9-foot x 7-foot unitary	1956	[a]$ 8,283	[a]$3,188	$11,471	7' x
8-foot x 7-foot unitary	1956	[a]8,283	[a]3,188	11,471	8' x
6 foot x 6 foot	1948	3,802	2,606	6,408	6' x
Total		$20,368	$8,982	$29,350	

[a]Estimated.

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test Se
Profile of hypersonic wind tunnels:					
3.5 foot	1961	$12,630	$3,713	[a]$16,343	3.5' di
Profile of special purpose facilities:					
Thermal protection laboratory	1962	$ 4,778	$6,132	$10,910	3.5' di
Aerodynamic free flight facility	1965	5,230	606	5,836	3.5' di
Electric arc shock tube	1966	(a)	(a)	(a)	4.0" di
Advanced entry heating simulator	1969	(c)	(c)	(c)	(b
Interaction heating facility	1974	2,800	0	2,800	(b
Fluid dynamics laboratory	1973	2,778	7	2,785	1' x 1'
Total		$15,586	$6,745	$22,331	

[a]Costs of the electric arc shock tube are included in the costs of the 3.5-foot hy

[b]Not applicable or not readily determinable.

[c]Costs of the advanced entry heating simulator are included in the costs of the 1-

AME

PROFILE (

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test sect
1-foot x 3-foot supersonic	1946	[a]$1,228	[a]$3,974	[a]$5,202	1.25' x
12-inch arc discharge, hypersonic	1964	1,899	0	1,899	1' diame
Total		$3,127	$3,974	$7,101	

[a]Not applicable or not readily determinable.

[b]Costs of the advanced entry heating simulator are included in the costs of the 1-f

APPENDIX III

:S RESEARCH CENTER

.on size	Reynolds number	Pressure	Mach range	Type	Narrative description on page
ter	6.9×10^6	(b)	5, 7, 10, and 14	intermittent	138
ter	(b)	(b)	(b)	intermittent	140
.ter	80×10^6	.005-.2 Atm.	45,000 ft. per sec	intermittent	141
.ter	(b)	(b)	40,000 meters per sec	intermittent	142
	(b)	.01-2.0 Atm.	2.5	intermittent	143
	(b)	(b)	3 and 5	intermittent	144
6'	200×10^6	(b)	0.5-1.5	intermittent	145

sonic.

t x 3-foot supersonic (see p. 146).

LEWI[S]

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test secti[on]
Profile of subsonic wind tunnels:					
Icing research tunnel	1944	$ 890	$100	$ 990	6' x 9' x
V/STOL wind tunnel	1968	485	0	485	9' x 15' x
Total		$1,375	$100	$1,475	
Profile of supersonic wind tunnels:					
8 foot x 6 foot	1949	$ 5,674	$4,959	$10,633	8' x 6' x
10 foot x 10 foot	1955	34,640	1,414	36,054	10' x 10'
Total		$40,314	$6,373	$46,687	
Profile of special purpose facilities:					
Space power chambers	1944	$2,597	$219	$2,816	30' and 50
Profile of inactive wind tunnels:					
Hypersonic facility	1971	$3,037	$3,051	$6,088	42" diamet[er]

[a]Not applicable or not readily determinable.

ESEARCH CENTER

NACTIVE WIND TUNNELS

size	Reynolds number	Pressure	Mach range	Type	Narrative description on page
x 5.5'	12×10^6	0.13-4.0 Atm.	0.4-6.0	continuous	146
	(b)	(b)	5-50	intermittent	147

x 3-foot supersonic (see p. 146).

MARSHA

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test se
Profile of supersonic wind tunnels:					
14-inch trisonic	1956	$ 550	$275	$ 825	14" x 1
High-Reynolds number	1969	494	251	745	32" x 3
Total		$1,044	$526	$1,570	
Profile of special purpose facilities:					
Impulse base flow facility	1963	$ 76	$130	$ 206	vacuum c
Thermal acoustic jet facility	1966	250	125	375	(b)
Plasma wind tunnel	1969	326	0	326	6' lengt 2' lengt
Total		$652	$255	$907	
Profile of inactive wind tunnels:					
Low density chamber	1966	$100	$35	$135	30" x 3
7-inch bisonic	1953	130	0	130	7" x 7"
Total		$230	$35	$265	

[a] Pounds per square inch absolute.

[b] Not applicable.

[c] One TOR equals one millimeter of mercury at 0^{O} centrigrade. It equals about 1.32

[d] Pounds per square inch.

:SEARCH CENTER

;ize	Reynolds number	Pressure/ altitude	Mach range	Type	Narrative description on page
	2.5×10^6	atmospheric	0-260 m.p.h.	continuous	150
.	1.3×10^6	atmospheric	50-175 m.p.h.	continuous	151
	5×10^6	atmospheric	0.36-2.0	continuous	152
)'	3.4×10^6	45,000-155,000 ft.	2.0-3.5	continuous	153
.ameter	(a)	100,000 ft.	(a)	(a)	154
	$.91\text{-}2.27 \times 10^6$	70,000 ft. plus	5-7	blowdown	155

JET PROP

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test sect
Profile of subsonic wind tunnels:					
Low turbulence wind tunnel	1966	$12	$0	$12	24" x 24"
Profile of special purpose facilities:					
6-inch arc heated shock tube	1962	$ 75	$325	$400	5' long-6
12-inch free piston shock tube	1963	75	175	250	2' long-1
43-inch shock tube	1964	50	60	110	215" long 43" diamet
Total		$200	$560	$760	
Profile of inactive supersonic and hypersonic wind tunnels:					
20-inch supersonic (note b)	1950	$2,800	$1,000	$3,800	20"-22" x
21-inch hypersonic (note b)	1959	6,500	3,000	9,500	15.8"-26.7 x 70"
Total		$9,300	$4,000	$13,300	

[a]Not applicable.

[b]Inactivated during FY 1976.

. SPACE FLIGHT CENTER

.on size	Reynolds number	Pressure	Mach range	Type	Narrative description on page
x 20"	$1\text{-}18 \times 10^6$	[a]105	0.25-5.0	intermittent	158
x 64"	$7\text{-}200 \times 10^6$	[a]45-686	0.3-3.5	intermittent	160
mber	(b)	[c]5×10^{-2} TORS 5×10^{-4} TORS	(b)	intermittent	161
	(b)	[d]100-3500 PSI 300-1500 PSI	(b)	intermittent	162
4' diameter 6' diameter	(b)	1×10^{-11} TORS 1×10^{-7} TORS	(b)	(b)	163
: 30"	(b)	[a]2-58.8	3.0	intermittent	164
12"	$1\text{-}4 \times 10^6$	atmospheric	0.4-0.9 1.55-4.39	intermittent	165

10^{-3} atmospheres.

JOH

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test sect
Profile of arc tunnels:					
1.5 megawatt arc tunnel	1963	$ 95	$ 136	$ 231	8' long-6
5 and 10 megawatt arc tunnel	[b]1966	2,537	1,670	4,207	variable
Total		$2,632	$1,806	$4,438	

NATIONAL AVIATIOI

Facility name	Year built	Initial cost (000 omitted)	Additions (000 omitted)	Total cost (000 omitted)	Test sect
Profile of special purpose facilities:					
5-foot fire test facility	[c]1961	[c]unknown	[c]unknown	$366	16'long-

[a]Not applicable.

[b]Ten megawatt capability added in 1974.

[c]Acquired from Navy in 1969 as excess, cost reflects capitalized value.

LSION LABORATORY

on size	Reynolds number	Pressure/ altitude	Mach range	Type	Narrative description on page
x 108"	0-1.1 x 10^6	atmospheric	0-80 ft. per sec.	continuous	168
diameter	(a)	0-5 mm. of mercury	12 to 48 kilometers per sec.	intermittent	169
diameter	.24-.72 x 10^6	0-20 mm. of mercury	5,000 - 40,000 ft. per sec.	intermittent	170
·r	.042 x 10^6	.455 PSI	12.5	intermittent	171
8" x 46"	0.01-0.6 x 10^6	15,000 - 185,000 ft.	0.4-5.0	continuous	172
x 19.8"	0.002-0.32 x 10^6	85,000 - 220,000 ft.	4.0-11.0	continuous	174

SON SPACE CENTER

on size	Reynolds number	Pressure/ altitude	Mach range	Type	Narrative description on page
diameter	(a)	.001-.06 Atm.	4-6	continuous	178
	(a)	0.01-0.2 Atm.	4-10	continuous	179

FACILITIES EXPERIMENTAL CENTER

:" diameter	(a)	13,000-15,000 ft.	about .85	continuous	180

LOW-TURBULENCE PRESSURE TUNNEL (LTPT) (SUBSONIC)

INITIAL OPERATION: 1941, reopened 1968.

DESCRIPTION: The tunnel is a single-return, closed-throat type. Air pressure may vary from 0.3 to 10 atmospheres absolute, giving a wide range of air densities. This is a low-speed tunnel, with a mach range of .1 to .4, but is uniquely capable of large test RNs up to 15 x 10^6/ft. Two-dimensional test models usually completely span the 3-ft-wide test section. Chords of models range from 6 to 100 in. Three-dimensional test models usually have a 2-ft span.

NARRATIVE: This is a one-of-a-kind test facility because of its high quality airstream and its capability to test at RN from .5 x 10^6 to 15 x 10^6 per foot with a single model. The LTPT is the principal low-speed test facility used to measure aerodynamic characteristics of all types of airfoils: supercritical, general aviation, and helicopters. It is also the principal low-speed support facility to the space shuttle program because it is the only low-speed facility in which near full-scale data can be obtained on a small shuttle model. Also, data with which to select the airfoil for the USAF A-10A aircraft was obtained in the LTPT. All of the new general aviation airfoils are being evaluated and developed in this tunnel. Low-speed aerodynamic characteristics of the NASA supercritical family of airfoils are planned for testing in the next year. Presently, the tunnel is scheduled into FY 1977 and operates much of the time on a two-shift basis. This tunnel time-shares with both the 6- by 28-inch transonic tunnel as well as the 26-inch transonic tunnel when the latter facility is required. One of the recent new exploratory research results obtained in the LTPT has been to show a marked skin friction drag reduction by using a so-called compliant wall.

AVAILABILITY: The facility is available for use by others, such as DOD or industry. Requests are worked into the tunnel as time and priority permit. Tests are made at no cost to the requesting agency, although models and any unique testing equipment are usually furnished by the agency requesting the tests.

Langley Research Center (LaRC)

Developing aerodynamic data base for theoretical stall/spin studies and piloted simulation of spin susceptibility.

Developing low-speed technology for advanced supersonic transports.

Identifying and solving stall problems of full-scale general aviation airplanes.

Aero-acoustic tests to determine noise of propulsion systems.

Evaluating acoustics, loads, and temperatures for large-scale, upper-surface blowing STOL model.

Future programs scheduled for the facility

Tests of advanced fighter concepts, such as supercruiser and HIMAT at high angles of attack.

Ongoing studies of low-speed characteristics of advanced supersonic transport concepts.

Aero-acoustic tests of general aviation airplanes.

Evaluating VTOL fighter concepts.

Drag cleanup and cooling drag tests for general aviation airplanes.

Developing low-speed technology for advanced subsonic transports.

AVAILABILITY: The facility is made available to other Government agencies if national interests are involved or if NASA is sufficiently interested in the proposed tests. If such tests can be integrated into the schedule, they are conducted with no reimbursable cost for tunnel operation. The greatest numbers of non-NASA projects involve support for DOD-related activities. Specific DOD requests account for an average of about 20 percent of the tunnel occupancy hours during a year. The requesting agency normally provides funding for models and equipment used in the tests.

FULL-SCALE TUNNEL (SUBSONIC)

INITIAL OPERATION: 1931

DESCRIPTION: The open-throat test section of the tunnel is 30 ft. high x 60 ft. wide x 56 ft. long. The test airspeed range is from 0 to 100 mph. Test capabilities include conventional static force tests of large-scale powered models or airplanes, free-flight dynamic model tests, aero-acoustic tests, and measurements of dynamic stability derivatives. The tunnel is equipped with shielded struts and a 6-component scale balance. The stagnation pressure is atmospheric and the test medium is air.

NARRATIVE: The full-scale tunnel has played a key part in the conception, development, and evaluation of many concepts which have resulted in a significant advance in the state of the art for low-speed aeronautics. The following list indicates some of the more important accomplishments associated with the facility.

Past

Drag cleanup tests of 30 critical military airplanes during World War II.

Developing technology for boundary-layer control and high-lift.

Developing the tilt-wing VTOL concept.

Evaluating most VTOL concepts, including proof of concept of the successful P-1127 design.

Tests of full-scale helicopters and rotor systems.

Evaluating low-speed characteristics of advanced research aircraft and reentry vehicles, such as the X-15 airplane and the M-2 and HL-10 lifting bodies.

Recent

Developing the upper-surface blowing and externally blown flap STOL concepts.

Analyzing high-angle-of-attack/stall characteristics of F-14, F-15, F-16, and F-17 configurations by means of free-flight tests and force tests.

AVAILABILITY: Many informal telephone queries for use of the V/STOL tunnel are received. The purely commercial requests are usually referred to an aircraft company or university tunnel with no formal records of requests. For the requests which support a Government-sponsored program, where this facility is the most appropriate and where the requested test is consistent with NASA research, a formal request or a joint program is encouraged. In the past year and a half, there have been four DOD formal requests which accounted for approximately 15 percent of the occupancy time and three joint programs in support of DOD and DOT (about 25 percent of occupancy time). All of the above tests involved aircraft aerodynamics. There are no reimbursable costs involved in any of these tests. However, if special models or test equipment are required, they are normally furnished by the requesting organization.

V/STOL TUNNEL (SUBSONIC)

INITIAL OPERATION: 1971

DESCRIPTION:

--0 to 0.30 mach number.
--14.5 feet high, 21.75 feet wide, 50 feet long.
--Moving-belt goundplane.
--Multiple wall configuration capability.
--High angle of attack and high sideslip angle sting.
--Movable floor and model support.

NARRATIVE: The V/STOL tunnel is used for low-speed aeronautical research. Specific programs include the takeoff, climb, and landing characteristics of all aircraft as well as subsonic aerodynamics. This work has included evaluation of aerodynamic and propulsion interaction effects for short takeoff and landing (STOL) powered-lift transport concepts for civil and USAF applications, such as jet flaps, externally blown flaps (YC-15 type), upper surface blown flaps (YC-14 type), and deflected thrust, as well as for vertical takeoff and landing (VTOL) high performance military combat aircraft (AV-8A and others) in support of the Navy. Additional work has been done in cooperation with DOT to develop test techniques for conducting wind tunnel studies of vortex wakes generated during the landing of a transport aircraft (B-747) and quantitative assessment of vortex attentuation devices. This work led to the development of a spoiler configuration which appears to be a very effective vortex attentuation device. The tunnel was also used to develop a simple retrofit device for the Army to relieve exhaust "hot spot" problems on two helicopters (AH-1G and OH-58A). Other rotorcraft work has included tilt-rotor and helicopter aerodynamics (RSRA). There have also been several shuttle orbiter support tests. In future work, there will be renewed emphasis on high-lift flap development for new general aviation aircraft and fuel conservation transports. Another area of work involves special wind tunnel tests for verifying appropriate theories for estimating the aerodynamic characteristics of flap systems, wing boundary layers, complete airplane configurations, and propulsion-induced effects. There will be a much greater emphasis on helicopter aerodynamics and power-induced effects with the recent completion of a joint NASA-Army generalized rotor model system which permits studies on complete rotorcraft configurations. Additional work is planned which will explore the use of this facility for acoustic measurement of airframe and propulsion noise.

AVAILABILITY: In addition to the in-house research and technology programs, the facility is being utilized for joint research programs, such as the NASA/DOD/General Dynamics advanced fighter program, NASA/NAVY missile dynamics studies, and specialized dynamic testing related to the space shuttle/B-747 ferry configuration. The facility is also in demand for specialized tests related to helicopter blade dynamics and aircraft rotary and oscillatory stability derivatives in support of other agencies and other Langley organizations.

Requests from other agencies for tests in this facility are considered in light of ongoing and planned in-house research programs. If the requested tests would augment the in-house research program or if they require a unique capability not available in other facilities and can be integrated into the facility schedule, they are performed at no reimbursable cost for tunnel operation. Any special models or equipment required are provided through the requesting agency. During fiscal year 1975, approximately 18 percent of the testing was related to either joint research programs or specific support requests from other agencies.

HIGH-SPEED, 7- by 10-FOOT TUNNEL (SUBSONIC)

INITIAL OPERATION: 1946

DESCRIPTION: This is a fan-driven, single-return atmospheric tunnel capable of operating at mach speeds of 0.20 to approximately 1.0. The test section measures 6'7" in height, 9'7" in width and 10' in length. In addition to static testing of complete and semispan models, it is equipped for both steady state roll and oscillatory stability testing.

NARRATIVE: This facility is used for a broad range of basic and applied aerodynamic research to provide the technology base for the development of advanced aircraft.

In the late 1940s, an interim method of testing at transonic speeds was developed for this tunnel, prior to the operation of transonic tunnels, and much of the early transonic research on stability and control characteristics was performed in this facility. In the late 1950s, researchers assigned to this facility performed the experimental and theoretical studies which provided the breakthrough in variable sweep wing technology on which the world's first operational variable sweep aircraft, the F-111, was based. This concept was later applied to the Navy F-14 and the Air Force B-1 variable sweep aircraft.

Over the years, the researchers utilizing this facility have also made important contributions to the understanding, prediction, and improvement of the stability, control, and maneuver performance of high-speed aircraft. For example, much of the research on spoiler type lateral control devices, now used on most modern aircraft, was carried out in this facility as was the research which solved the severe longitudinal stability problems of many high-speed military and commercial aircraft. This facility was utilized to provide the most comprehensive study of the effects of wing and airfoil geometry on the buffet onset characteristics ever performed.

Currently, the facility is playing an important role in a wide range of basic and applied aerodynamic research, such as advanced vortex lift concepts; fuel conservation aircraft design technology; highly maneuverable aircraft concepts; and the development of improved aerodynamic theories, including the difficult separated flow and jet interaction effects, needed for computer aided design and analysis methods.

26-INCH TRANSONIC TUNNEL

INITIAL OPERATION: 1950

DESCRIPTION: This tunnel is used primarily for flutter tests of model configurations of aircraft components. A supply of dry compressed air provides direct blowdown operation. The tunnel exhausts into atmosphere with independent mach and RN. The test section is octagonal and slotted for transonic testing to mach 1.45, and it is 26 inches between flats. Models are typically wall mounted on a reflection plane.

NARRATIVE: This wind tunnel is maintained on a stand-by-ready basis. Because of its unique capability to rapidly support projects in trouble, and because of its simple, low cost operation, it is considered a valuable asset. Although it has not been required in over a year, one USAF test on the F-111 is scheduled this fall. Previous USAF testing has included F-111, F-15, and F-16 flutter evaluations.

AVAILABILITY: The facility is available for use by others, such as DOD or industry. Requests are worked into the tunnel as time and priority permit. Tests are made at no cost to the requisitioning agency, although models and any unique testing equipment are usually furnished by the agency requesting the tests.

SPIN TUNNEL (SUBSONIC)

INITIAL OPERATION: 1941

DESCRIPTION: The test section is vertical with 12 sides, 20 ft. across the flats. The vertical test section is 25 ft. long with a closed throat and annular return passage. Tunnel speed is variable from 0 to 90 ft/sec with rapid acceleration of up to 15 ft/sec^2 and deceleration to 25 ft/sec^2. Stagnation pressure is atmospheric; the turbulence factor is 2; and the RN per ft. is 0 to 0.62 x 10^6. The test medium is air.

NARRATIVE: The Langley spin tunnel is the only operational spin tunnel in the United States. Tests are conducted with dynamically scaled models to determine the developed spin characteristics, spin recovery characteristics, and parachute size for emergency spin recovery for military and general aviation airplanes. The results of the tests are used for guidance in the flight program for full-scale airplane and for information on spin recovery for pilot's handbooks.

As a result of the uniqueness of the spin tunnel, virtually all highly maneuverable military airplane configurations are tested in the facility. Some of the well-known military designs previously tested include the P-38, P-39, P-40, F-2H, F-3H, F-5D, F-4D, F-8, F-6F, F-8F, F-4, F-5, F-101, F-105, F-111, F-14, F-15, F-16, and F-17. Configurations currently being tested include the F-5E and a series of general aviation research models. Future tests will include the F-16, F-18, HIMAT, and general aviation configurations.

AVAILABILITY: The facility has supported 12 different requests from DOD for tests on military aircraft in the past 6 years. These projects account for approximately 80 percent of the tunnel occupancy time. Most of the requests involve support for development programs for specific configurations. The facility is made available at no cost to DOD; however, the military services provide funds for most models tested in these projects.

6- BY 19-INCH TRANSONIC TUNNEL

INITIAL OPERATION: 1970

DESCRIPTION: This tunnel is a two-dimensional facility with solid parallel sidewalls and slotted top and bottom walls. A supply of dry, compressed air provides blowdown operation. Time to pressurize the supply tanks is about 1½ hours. The mach number is varied by changing the stagnation pressure; thus, there is no independent control of the RN. Angle of attack is set manually between runs. Typical models have a chord of 4 inches and span the 6 inch width of the tunnel. The mach number range is from about .5 to 1.2 with corresponding RN from 1.5×10^6 to 3.0×10^6.

NARRATIVE: This test facility is dedicated to airfoil research and to development of new two-dimensional test techniques. Except for specialized airfoil testing, such as an airfoil which used a jet of air as a flap, this wind tunnel is now used intermittently to develop new testing methods and new research hardware. The tunnel is presently scheduled for evaluating contoured wall boundaries and for exploring a special contoured rod wall to attenuate undesirable wall interference. This test facility is expected to be phased out by late calendar year 1978. A primary function of the tunnel has been to evaluate and develop new hardware and methods which have been applied to the 6- by 28-inch transonic tunnel now operational and to the 8- by 24-inch cryo test section now being installed. For example, the wake survey system was evaluated and the wall slot configuration was developed in this facility. The most recent airfoils tested were part of a joint USAAMRDL/NASA performance baseline program.

AVAILABILITY: The facility is available for use by others, such as DOD or industry. Requests are worked into the tunnel as time and priority permit. Tests are made at no cost to the requesting agency, although models and any unique testing equipment are usually furnished by the agency requesting the tests.

6- BY 28-INCH TRANSONIC TUNNEL

INITIAL OPERATION: 1974

DESCRIPTION: This tunnel is a two-dimensional facility with solid parallel sidewalls and slotted top and bottom walls. A supply of dry, compressed air provides direct blowdown operation. Mach number, angle of attack, and stagnation pressure are independently controllable so that data may be obtained at a constant RN. Mach number range is from about .2 to 1.2, and RN range is 2×10^6 to 10×10^6. Real-time visual displays of data being recorded are available. Typical airfoils have a chord of 6 inches and completely span the 6-inch width of the tunnel.

NARRATIVE: This test facility is dedicated to airfoil research and development; therefore, it is used to determine airfoil performance, evaluate airfoil design methods, and perform exploratory research on new airfoil concepts. Because of its flexibility and versatility, it is the mainstay of the transonic airfoil program and it can provide full-scale simulation for all helicopters and most small- to medium-speed transonic aircraft. The first program conducted after calibration was an intensive joint NASA/U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL) helicopter airfoil investigation to provide basic data with which to make evaluations for a military procurement. The facility is scheduled in fiscal year 1976 for tests of a series of new NASA-designed improved helicopter airfoils, and for performance evaluation of the entire new family of NASA supercritical airfoils. Present scheduling extends well into fiscal year 1977. This facility timeshares with the low-turbulence pressure tunnel and normally operates on a two-shift basis for maximum air use efficiency. At present, there are no outside agency requests for testing, but both USAAMRDL and several helicopter companies have indicated interest in future tests beyond the present schedule.

AVAILABILITY: The facility is available for use by others, such as DOD or industry. Requests are worked into the tunnel as time and priority permit. Tests are made at no cost to the requesting agency, although models and any unique testing equipment are usually furnished by the agency requesting the tests.

TRANSONIC DYNAMICS TUNNEL (TDT)

INITIAL OPERATION: 1960

DESCRIPTION: The TDT is a large, continuous-flow tunnel which operates from mach numbers near 0 to 1.2 at pressures from about 0.2 psia to atmospheric. The slotted test section has a 16' x 16' cross section and a usable length varying from 36 ft. at mach numbers up to 0.7 to 12 ft. at mach number 1.2. Either air or Freon-12 is used as a test medium. Freon-12 is a heavy gas with advantages over air for aeroelastic research. Other special features for aeroelastic research are a flutter stopper, a gust maker, a cable-mount system, protective screens, and a computerized data acquisition system tailored for dynamic data.

NARRATIVE: The testing capabilities of the TDT combine to make it a unique facility for work in support of the field of aeroelasticity. In particular, the TDT is used for aeroelastic research and to confirm the flutter and other aeroelastic characteristics of many high-speed aircraft designs. In the past, for example, TDT flutter investigations have included such aircraft as the C-141, F-111, C-5A, 747, SST, L-1011, F-14, DC-10, F-15, B-1, and YF-16. Also, ground-wind, load-clearance tests have been performed in this facility on nearly all U.S. launch vehicles. The demand for TDT use is very high with a current test backlog of over 2 years. Current tasks are in development of active controls technology, flutter clearance of specific aircraft, flutter and groundwinds clearance of space shuttle, and rotorcraft aeroelasticity testing. Future joint aeroelastic research programs are scheduled for the F-16, production B-1, F-4 with stores, Sikorsky and Bell rotors, Grumman DAST wing, and space shuttle.

AVAILABILITY: When requests for TDT usage by DOD and industry are received, they are screened against ongoing and planned research programs and other tests already scheduled. If these tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable costs for tunnel operation. In the past 18 months, the firms Bell, Rockwell International, Boeing, and General Dynamics have utilized the TDT in joint programs with NASA, such as flutter of Bell helicopter rotors, B-1 flutter tests, B-52 active controls technology tests, and F-16 flutter tests. Many of these models had repeated entries, taking up 45 percent of available testing time during this period. In these joint programs, industry or DOD furnishes the model, model instrumentation, model makers, and test engineers; NASA furnishes the wind tunnel facility, operators, NASA test engineer(s) and technicians.

8-FOOT TRANSONIC PRESSURE TUNNEL

INITIAL OPERATION: 1953

DESCRIPTION: The tunnel is a single-return, slotted test section, closed-circuit tunnel with mach number continuously variable from 0.2 to 1.3. The test medium is air. The test section is 7.1 ft x 7.1 ft x 15.0 ft long for subsonic speeds and 4.0 ft long for transonic speeds. It has a sting-type model support system with sidewall mounts available. Stagnation pressure, stagnation temperature, and dewpoint temperature are controlled.

NARRATIVE: The facility is primarily used for studies of the force, moment, pressure distribution, flutter, and buffet characteristics of aircraft and space vehicle configurations at transonic speeds. Research conducted in this facility has led to the discovery of the area rule; supercritical wing development; application to the T-2C, TF-8A, and F-111 aircraft; sonic transport design; and vortex diffusers (winglets). Currently, a major effort is underway in the area of drag reduction which will use approximately 50 percent of the available tunnel time. This research effort is directed toward the development of fuel-conservative aircraft technology, supercritical aerodynamics, and the application of vortex diffusers to various aircraft. The latter work is being conducted in a joint program with the USAF. The remaining tunnel time will be divided about equally in support of military aircraft advanced technology, missile aerodynamics, hypersonic aircraft, DOD assistance, shuttle support, and supersonic cruise aircraft aerodynamics.

AVAILABILITY: In the past 18-month period, three requests were made and filled for tests in the facility to determine the static stability, control, and performance characteristics of three widely different aircraft. Approximately 15 percent of the available tunnel time was spent on these investigations. The requests were made by the intelligence community, DOD, and industry. Requests for tunnel use are screened against ongoing and planned research programs for this facility. If these tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable cost for tunnel operation. However, specialized models and unique equipment and supplies associated with tests are normally furnished by the other Government agency or industry requesting the tests.

be conducted. The Navy, General Electric, and NASA will conduct another joint program to investigate the performance of an aircraft-integrated deflecting nozzle concept. The tunnel is fully scheduled with tests until shutdown for rehabilitation starting July 1976.

Future research programs in the post-rehabilitation period will be similar to the current work with emphasis on propulsion aerodynamics. A model now under construction will be available for studies of over-the-wing nacelle installations which may result in a more fuel conservative transport aircraft. New apparatus is being procured to enable powered model testing to be conducted at high angles of attack corresponding to attitudes of maneuvering fighter aircraft.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research programs for this facility. If the proposed tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable cost for the tunnel operation. However, specialized models and unique equipment associated with powered model tests are normally furnished by the other Government agency or industry requesting the tests. The following programs were requested by or conducted in the interest of DOD in the past 8 months.

1. Deflector nozzle tests. Navy request N-P-43, Sept. 1, 1972. Powered model propulsion aerodynamics investigation. Test scheduled for February 1976.
2. Integrated exhaust nozzle test. Navy request N-P-44, March 13, 1973. Powered model test of new nozzle concept. Phase I, single 2-D nozzle tests, February 11-March 24, 1974, 59 shifts. Phase II, twin 2-D nozzle tests, October 21-November 27, 1974, 54 shifts.
3. Upper surface blowing. USAF request AF-AM-187, May 23, 1973. Powered model aerodynamics. Tests Nov. 28-Dec. 21, 1973, 36 shifts.
4. Powered lift aerodynamics program. USAF-NASA Memorandum of Understanding, October 2, 1974. Propulsion aerodynamics investigation test scheduled for October 1975.
5. B-1 drag reduction. NASA research in the interest of USAF. Aerodynamic investigation. Tests December 9, 1974-January 31, 1975, 64 shifts.

16-FOOT TRANSONIC TUNNEL

INITIAL OPERATION: As subsonic tunnel - 1941
As transonic tunnel - 1950

DESCRIPTION: This is a closed circuit, single return, continuous flow, atmospheric tunnel. Speeds up to mach number 1.05 are obtained with a 60,000 horsepower main drive. Speeds from mach number 1.05 to 1.3 are obtained with a combination of main drive and a 35,000 horsepower compressor which provides test section plenum sunction. The slotted octagonal test section measures 15.9 feet between the walls and the test section length is 22 feet up to mach 1.0 and 8 feet for speeds above mach number 1.0. The tunnel is equipped with adjustable intake and exhaust vanes to provide some temperature control.

NARRATIVE: The Langley 16-foot transonic tunnel is one of the largest transonic wind tunnels operated by NASA. Its large size and transonic speed capability make this facility uniquely adapted to investigations of the aerodynamic, stability, and loading characteristics of aircraft and spacecraft and for studies of propulsion system interaction effects on large-scale, detailed, complex models of real vehicles.

The 16-foot transonic tunnel has produced a large share of the specialized National Advisory Committee for Aeronautics-NASA research in the transonic aerodynamics and propulsion system integration fields over the years. In the past decade, the transonic aerodynamics and/or propulsion system effects of the USAF's F-111 and F-15 fighters and Navy's F-14 aircraft have been evaluated in this facility. This research resulted in wind tunnel developed modifications being installed on the production military aircraft. The NASA Apollo Launch Escape Module rocket effects on stability and the LEM separation from the Apollo Command Module were predetermined in this wind tunnel.

The current program consists of powered model tests to investigate vectored thrust concepts for enhanced maneuvering capability and increased lift, studies to reduce drag by proper location of tails on fighter-type aircraft, investigation of the transonic wing loads and propulsion system interference on advanced supersonic technology aircraft, and research into the complex interactions between the jet exhaust and adjacent aircraft components. A joint USAF-General Dynamics-NASA research program to study the gains in aerodynamic performance by deflecting jets in combination with spanwise blowing will test section with a magnetic suspension system which will provide the unique conbination of high-RN testing free from support interference.

AVAILABILITY: The great majority of the work which has been accomplished in this tunnel has dealt with the development of the cryogenic tunnel concept. However, several projects were undertaken for other NASA Langley organizations which included the space shuttle, boattail drag, and instrumentation development work. These specific projects involved about 15 percent of the tunnel occupancy time during fiscal year 1975.

Requests from other agencies for tests in this facility will be considered in light of ongoing and planned in-house research programs. If the requested tests would augment the in-house research program or if they require a unique capability not available in other facilities and can be integrated into the facility schedule, they will be performed at no reimbursable cost for tunnel operation. Any special models or equipment are expected to be provided through the requesting agency.

1/3-METER TRANSONIC CRYOGENIC TUNNEL

INITIAL OPERATION: 1973

DESCRIPTION: The 1/3-meter transonic cryogenic tunnel has two test sections, a 3-dimensional (3-D) octagonal test section, (13.5 in. across flats) and an 8 in. by 24 in. 2-dimensional (2-D) test section. The 3-D test section can operate at mach number ranging from near 0 to 1.3 and the 2-D tunnel is designed for mach speeds up to about 0.90. Some of the unique features of this facility are the extremely high unit RN capability and the ability to independently vary temperature, mach number, and pressure. The temperature of the test medium can be reduced to about -320°F. by injecting gaseous nitrogen into the tunnel circuit as a means of increasing the RN and the tunnel pressure can be increased to about 5 atmospheres. The combination of increased pressure and reduced temperature provides a unit RN capability of slightly greater than 100×10^6 at transonic mach numbers which represents an increase of about a factor of 25 over ambient tunnel conditions.

NARRATIVE: At the outset of operation, this tunnel was used primarily as a "proof of concept" tunnel to validate at transonic speeds the cryogenic approach for achieving high-RN test results. The tunnel provided conclusive evidence that cryogenic nitrogen gas was a valid transonic test media. In addition, an extensive amount of knowledge was obtained regarding instrumentation, materials, and test techniques in a cryogenic environment. Accurate angle of attack, pressure, force, and moment measurements have been made at cryogenic temperatures approaching -320°F. The tunnel was designated as a facility in September 1974 and several specific research programs have been accomplished which have provided unique and enlightening high-RN results. A space-shuttle model was tested to evaluate base pressure drag. An afterbody boattail drag study was performed which provided results equivalent to flight RN conditions.

With regard to future plans, the 2-D test section will be installed during the fall of 1975 and will be used to provide high-RN data on advanced airfoils and the development of advanced test techniques. Further plans include additional use of the 3-D test section as required and the development of advanced test sections. The advanced test sections which are now being considered for the late '70 early '80 time period are an "adaptive wall" test section, which is aimed at eliminating wall effects and a larger 3-D

This was conducted on a nonreimbursable basis. It was an integrated exhaust nozzle test requested by the Navy on March 13, 1973. The tests were conducted from May 15 to June 28, 1974.

4-FOOT SUPERSONIC PRESSURE TUNNEL

INITIAL OPERATION: 1948

DESCRIPTION: Facility is a closed circuit, single return, continuous flow, variable density tunnel. Mach numbers from 1.25 to 2.2 are achieved by changing the test section by jacking the flexible upper and lower walls against interchangeable templates. The test section is nominally 4.5 feet square and 7 feet long. Test section height varies from 51 to 64 inches depending on mach number. Cooling coils and a dry air supply are used to change tunnel pressure and to maintain a low residual dewpoint. The tunnel is powered by a 45,000 horsepower main drive motor.

NARRATIVE: The 4-foot supersonic pressure tunnel was the first large supersonic wind tunnel at the Langley Research Center. Most of the early supersonic aerodynamic, stability, control, and fluid mechanics research was conducted in this facility. The responsibility for the facility was transferred to the Propulsion Aerodynamics Branch in 1968. The present research program is a combination of propulsion aerodynamics research and fluid mechanics research which is conducted by other organizations in the aeronautics directorate. Some of these projects included space shuttle configurations; the F-14 and F-15 aircraft; sonic boom research; missile configurations; and work on probes, wings, compliant surfaces, and basic research powered models.

The current program consists of aerodynamic investigations of lightweight fighter configurations, studies of supersonic aftbody closure, the supersonic performancy of aircraft with jets exhausting over the wings, and the supersonic performance of models with deflected jets and two-dimensional nozzles. Future program planning is limited by the start of the national transonic facility on the site of the 4-foot supersonic pressure tunnel.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research programs for this facility. If these tests can be integrated into the planned programs for this facility or if there is a special requirement for the capabilities the facility can provide, requests are granted on a nonreimbursable cost for tunnel operation. However, specialized model and unique equipment associated with tests are normally furnished by other Government agencies or industry requesting the tests. Only one investigation has been requested in the last 2 years by DOD.

program underway to expand the aerodynamic technology base for missile design. This will enable the missile industry to take maximum advantage of aerodynamic effects in missile performance. Emphasis is also being placed on the development of new and innovative experimental techniques to provide an expanded data base on basic flow phenomena at supersonic speeds.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research programs for this facility. If tests can be integrated into the planned programs of this facility, these requests are granted at no reimbursable cost for tunnel operation. However, the unitary plan wind tunnel is available on a fee basis for any agency or private industry. Specialized models and unique equipment and supplies associated with tests are normally furnished by the other Government agency or industry requesting the tests.

An estimate of future tunnel obligations for the next 2 or 3 years is as follows.

- --Shuttle support. (20 percent.)
- --Support on ongoing military programs. (10 percent.)
- --Assessment of foreign aircraft and missiles. (10 percent.)
- --Experimental studies of the application of SST technology to advanced supersonic cruise military aircraft. (20 percent.)
- --Experimental studies of advanced second generation SST concepts. (10 percent.)
- --Support of NASA HIMAT Program. (5 percent.)
- --Support of NASA X-24C Program. (5 percent.)
- --Provide experimental support of second generation aerodynamic controlled missiles. (20 percent.)

LANGLEY UNITARY PLAN WIND TUNNEL (SUPERSONIC)

INITIAL OPERATION: 1955

DESCRIPTION: The facility has two test sections which provide mach number ranges from 1.5 to 2.86 (test section 1) and 2.3 to 4.6 (test section 2). Both test sections are 4 feet high, 4 feet wide, 7 feet long, and permit variation of mach number at any desired increment throughout its range with the tunnel operating. Stagnation pressure and stagnation temperature may be controlled independently. The wind tunnel has a 100,000 horsepower compressor drive system which supplies air flow to only one test section at a time. (They cannot be operated simultaneously.) Maximum stagnation pressure is 60 psia for test section 1 and 150 psia for test section 2. The normal operating stagnation temperature is approximately 150°F. with heat bursts to 300°F. available for heat-transfer studies.

NARRATIVE: Technological area supported by the facility are aerodynamic, thermodynamic, stability and control, and fluid mechanics. This facility meets critical needs of industry, military, and other Government agencies in the development of high-speed aircraft and missiles. The demand on this facility for R&D activities is such that it has been in continuous operation with a test schedule backlog of over 6 months since 1955.

Essentially all supersonic configurations vital to DOD have been investigated in this wind tunnel. Recent examples include the F-111, F-14, F-15, and F-16 aircrafts and improved Hawk and SAM-D missiles with more than 5,000 test-occupancy hours devoted to the F-111 (TFX) R&D program. This facility has also played a major role in space systems development in the critical boost and reentry phases. It is the primary supersonic facility in the space shuttle R&D program. Nearly 40 percent of the test-occupancy time was devoted to the space shuttle in FY 1974. Approximately 30 percent of the tunnel's utilization has been for in-house basic research which has resulted in a 30 percent higher supersonic cruise lift to drag ratio, potential sonic boom reductions of 50 percent, and improved missile stability and control systems.

Future research and technology objectives and plans will provide basic aerodynamic technology for design and analysis of supersonic aircraft, including large commercial and military cruise aircraft as well as advanced fighters. The unitary plan wind tunnel is a major facility in the

SHUTTLE THERMAL PROTECTION SYSTEM TEST FACILITY (SUPERSONIC)

INITIAL OPERATION: Shakedown: 1974
Research: 1976

DESCRIPTION: The tunnel test region is 1 by 3 feet in cross section and 4 feet long. The gas speed is mach 3.7; however, the flowing gas is at an energy level simulating a hypersonic thermal environment. Test panels 2 by 3 feet in size are mounted in the sidewall of the tunnel and tests up to 25 minutes can be performed for simulating the aerodynamic loading and exposure time that the space shuttle will experience during reentry.

NARRATIVE: This facility will be used to explore aerodynamic problem areas associated with surface structure/thermal protection systems (TPS) when exposed to a hypersonic environment. The tunnel will have a relatively long test time and a high operational frequency for the rapid accumulation of cyclic environmental data in order that mission life of a TPS can be evaluated. Although this tunnel is being constructed for the immediate support of the space shuttle, it will also be used for development of new technology for advanced shuttles and hypersonic aircraft.

At present, this facility is undergoing shakedown and calibration. Future scheduled programs for validating space shuttle TPS include:

1. Investigation of lost tile effects.
2. Effects of high shear on surface deterioration.
3. Reusability of surface tiles with fabrication flaws.
4. Influence of gaps and joints.

Also, an in-house program is planned for advancing the technology base for TPS systems.

AVAILABILITY: A backlog of programs is already scheduled for the first 2 years of operation. However, in accordance with NASA's policy, this facility can be made available to other Government agencies or to industry depending on the priority of the program. For outside programs, there are no reimbursable costs; however, special models and equipment are furnished by the others.

CERAMIC HEATED COMBUSTION FACILITY (SUPERSONIC-HYPERSONIC)

INITIAL OPERATION: 1971

DESCRIPTION: The major component of the ceramic heated combustion facility is a matrix of ceramic material which is heated to high temperature by a propane-air-oxygen burner. This hot ceramic matrix is used to heat air (or nitrogen) to temperatures which simulate the temperature of hypersonic flight speeds. The heated air is expanded through a nozzle to supersonic velocities, where fuel (hydrogen) is injected to produce the desired experimental combustion flow field. Facility temperature simulates mach 5 to 7 flight speed, and nozzles produce test mach numbers of 2 and 3.5 with 2.5 inch and 3.5 inch diameter jets, respectively.

NARRATIVE: Hydrogen fueled, supersonic combustion ramjet (SCRAMJET) propulsion systems appear very attractive for various types of hypersonic aircraft. Since the residence time of fuel and oxidizer in such systems is on the order of milliseconds, rapid mixing and reaction can be the key to operating over a wide speed range. Basic research in turbulent, high-speed, reacting hydrogen/air flows is being conducted with the ceramic heated combustion facility to provide the basis for an analytical capability to design SCRAMJET combustors. Key problems addressed by this research include the interrelationships of turbulence, mixing and reaction, and the effects of pressure gradients, shock waves, injector and combustor configurations, walls, and jet interactions on combustion. Configurations for this research are small in size and have simple geometry. Papers describing results of the research are published by NASA and also presented in technical journals and at national technical society meetings.

AVAILABILITY: The facility could be made available to outside users. Infrequent inquiries concerning availability are received from industry (approx. 1 per year), but in the 1971-75 period, no commitment of test time to an outside user has resulted.

HYPERSONIC NITROGEN TUNNEL

INITIAL OPERATION: 1966

DESCRIPTION: The test medium is nitrogen which is heated to about 2500°F. before expanding through an axially symmetric, water cooled, contoured nozzle. The test gas exhausts into a 100-foot diameter vacuum sphere. The nozzle exit diameter is 19-inches, and the test core size is approximately 8-inches in diameter at high pressure. The mach and RNs range is 17 to 19.5 and 0.25 to 1.3 x 10^6/ft, respectively.

NARRATIVE: This facility provides mach and RN ranges that are essential to development of hypersonic high altitude vehicles, and it complements Langley air, helium, and CF_4 facilities in simulation studies of real gas effects. It is the only Langley facility in which basic studies (ideal gas, $\gamma = 1.4$) of cold wall thick turbulent boundary layers and free shear layers at mach 20 are possible. The facility is equipped with a model support and quick-injection system. The facility is used for research investigations in basic aerodynamics, fluid mechanics, and general configuration studies. These include measurements of pressure, aerodynamic forces, and heat transfer on candidate vehicle configurations. The electron beam technique is used for flow field visualization and direct measurements of density.

The facility has provided the only mach 20 ideal gas ($\gamma = 1.4$) data for shuttle orbiter and tank interference heating effects during peak heating conditions as well as aerodynamic force and moment data on the shuttle orbiter at entry conditions. These test programs were a joint research effort by North American Rockwell and NASA. The facility has also provided stability data in support of planetary entry programs.

Future plans include aerothermodynamic testing in support of planetary entry, advanced shuttle, advanced aerospace vehicle transportation, and space tug. The tests will be an integral part of an overall program involving three other Langley facilities using different test mediums and speed ranges.

AVAILABILITY: North American Rockwell requested two different shuttle test programs in the facility and these were granted by NASA in fiscal year 1975. The extent of utilization was from about 3 to 10 shifts each to perform heat transfer and aerodynamic force work. Rockwell provided assistance in data acquisition and reduction. Reimbursable costs were not involved. Future requests for shuttle and planetary entry programs are anticipated.

SCRAMJET TEST FACILITY (HYPERSONIC)

INITIAL OPERATION: 1975 (SCRAMJET test facility). It uses existing equipment of former Langley 4 ft. hypersonic arc tunnel, which began operations in 1961 for entry-oriented research.

DESCRIPTION: Test air is heated by an electric-arc from 20 megawatts d.c. power supply to duplicate flow ingested by engine when aircraft flies at mach 7. Air stagnation temperature is 4000°R; stagnation pressure is 30 atm. Nozzle exit of hot core flow is 12 in. by 10.7 in. Hot core flow is surrounded on 3 sides by supersonic shroud flow of unheated air increasing total nozzle exit size to 17.25 in. by 21.2 in.

NARRATIVE: The facility is specifically designed to test subscale SCRAMJET engine models which burn hydrogen fuel and are designed for integration with a hypersonic aircraft. SCRAMJET models are about 1/2 the size expected to be used on a research aircraft, such as the X24C. Subscale engine tests are a vital part of a more complete program to establish technology for this new engine concept. Other parts of the program include combustion research and research on individual engine components (inlet, combustor, and nozzle). Subscale tests are necessary to determine interactions between components. The subscale SCRAMJET models are essentially heat sink models, relatively inexpensive compared to flight-weight models, and are designed with high flexibility to allow changes in the internal engine contouring and method of fuel injection as indicated by research results.

AVAILABILITY: This facility is not yet operational. Shakedown tests are now underway. When the facility becomes fully operational, it will be made available for use by others. Requests for the tunnel will be screened against ongoing and planned research programs for this facility. If these tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable cost for tunnel operation. However, specialized models and unique equipment and supplies associated with tests are normally furnished by the other Government agency or industry requesting the tests.

advanced aerospace vehicle technology and planetary entry programs. Future studies will include support of programs that include the space shuttle, planetary entry, advanced shuttle, advanced aerospace vehicle technology, and atmospheric maneuvering space tug.

AVAILABILITY: Requests for tunnel use are measured against scheduled research programs in this facility. If the requests can be accommodated, they are granted at no reimbursable cost for tunnel operation. However, specialized models and/or unique equipment and supplies are normally furnished by the user. In fiscal year 1975, Rockwell International provided a space-shuttle orbiter model and a test engineer for 32 aerodynamic force and moment and flow visualization tests requiring 10 shifts of operation for 1½ weeks.

HYPERSONIC HELIUM 22" AND

HYPERSONIC HELIUM OPEN-JET

INITIAL OPERATION: The 22-inch aerodynamics leg - 1960.
The open-jet fluid mechanics leg - 1973.

DESCRIPTION: The facility uses helium gas in a 40-60 sec. blowdown mode with 2 hours between runs, and the gas is reclaimed for reuse. The 22-inch leg has three contoured nozzles (with mach design speeds of 18, 22, and 26), but only the mach 22 has been calibrated (actual range of mach 17.6 to 22.2). Unit RN range is 1 x 10^6 to 15 x 10^6 per foot. The test section is 22.5 inches in diameter and 30 inches long. The open-jet leg has two contoured nozzles (with mach design speeds of 20 and 40), but only the mach 20 has been partially calibrated. The test section length, width, and height is 9 x 6 x 8 feet with a nozzle exit diameter of 30 inches for mach 40 and 22 inches for mach 20. Both legs have an electron beam for flow illumination.

NARRATIVE: Aerodynamic characteristics, pressure, heating, and flow visualization studies are obtained on relatively small inexpensive models made from wood, plastic, and cast or machined metal. Past studies have provided data at entry flight mach numbers and RNs for manned entry programs which included Mercury and Apollo for the moon landing and Dyna Soar (dynamic soaring vehicle); HL-10; space shuttle for high- and medium-cross range entry, unmanned ballistic entry programs which included Polaris (submarine-launched missile), BGRV (boost-glide entry vehicle), and Reentry-F (state of boundary layer on entry cone); hypersonic bluntness and viscous-induced effects; and hypersonic body shaping effects. Also, flow-visualization studies were conducted on all major space-shuttle concepts during the phase B portion of the program. In the past, this facility has demonstrated a rapid response capability by obtaining force and moment data within 1-2 weeks after receiving a request by using quickly constructed wood and plastic models.

Present studies include viscous and real-gas effects on the aerodynamic characteristics of the space-shuttle orbiter over a range of mach numbers, RNs, and ratio of specific heats in conjunction with tests in three other facilities using different test gases. Presently, the orbiter characteristics from this facility represent the only data at entry mach numbers (mach 20) and flight RNs (2.5 x 10^6, based on length). These tests were conducted at the request of the shuttle contractor, Rockwell International. Tests are also being conducted in support of NASA's and unique equipment and supplies associated with tests are normally furnished by the other Government agency or industry requesting the tests. No records were maintained of number of requests for tunnel utilization before calendar year 1975. Outside users since calendar year 1972 include General Dynamics Corporation (NASA contract), Chrysler Corporation (NASA contract), and other NASA centers. Extent of utilization was generally less than 3 weeks per program. Outside programs involved shuttle, viking, hypersonic research vehicle, and missile systems.

20-INCH, MACH 6 HYPERSONIC TUNNEL

INITIAL OPERATION: 1958

DESCRIPTION: Test section mach number is 6; test section is rectangular (20 in. x 20.5 in.); total pressure is up to 550 psia and total temperature (using electric heaters) is up to 960°R giving RNs as high as 10^7 per foot. Unique features include rapid model injection, quick start, long run time (about 15 min.), accommodates long slender models (less than 5 ft.), and versatile test capabilities (including laser velocimeter and Raman scattering optical probing).

NARRATIVE: Tunnel is used primarily to achieve the following: Configuration aerodynamics of active vehicle systems (shuttle, viking, hypersonic research vehicles, etc.) and missiles; aerodynamic heating and skin friction drag for both basic and applied research programs; viscous and inviscid flow-field analysis for aircraft and propulsion systems; detailed experimental data on viscous flows--used as test cases for new numerical prediction methods; and general research support for active vehicle systems (shuttle, X-24C, DOD programs, etc.).

Past accomplishments include significant scientific input into the areas of high speed aerodynamics of missiles and rockets, aerodynamics and heating for flight vehicles (Mercury, Gemini, Apollo, Viking, Shuttle, etc.), interference flows at hypersonic speeds, alleviation of severe heating associated with lee-side flows, and concept development for high-speed flight vehicles.

Current program includes aerodynamics and heating for shuttle, hypersonic research airplane, and X-24C vehicle, fluid mechanics of turbulent free shear flows, high-speed missle development, three-dimensional interference heating, and development of noise shields for the quiet tunnel program.

Anticipate full-time utilization of facility in forseeable future. Upcoming programs include: X-24C aircraft, shuttle aerodynamics and heating, new optical system for defining three-dimensional flows, investigations of recirculating flows and three-dimensional turbulent flows, SCRAMJET engine development, and quiet tunnel development.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research programs for this facility. If these tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable cost for tunnel operation. However, specialized models

HIGH-RN MACH 6 (HYPERSONIC)

INITIAL OPERATION: 1967

DESCRIPTION:

Test conditions:
- --Stagnation pressure: 15 to 3000 psi.
- --Stagnation temperature: 400 F. to 800 F.
- --Mach 6.

Tunnel configuration	Test section size	RNs
I. Standard model tests	1 ft. dia. by 4 ft. long	25×10^4 to 50×10^6 ft.
II. Boundary layer channel	1 ft. dia. 13 ft. long pipe	Max. length Re about 1×10^9

NARRATIVE: Because of the model injection mechanism, this facility is particularly useful for heat transfer measurements by the standard transient technique on thin skin metal models and by the phase change paint technique on moded plastic models. Several investigations of this type with models of hypersonic aircraft and missiles have been completed including the shuttle, HRS, RAM, reentry F, and high-acceleration launch missiles. The high-RN capability was an important consideration for the last two investigations mentioned. In many of these investigations, flow field surveys and surface pressure data were also obtained. The wide RN range of the facility has been utilized in basic research investigations of boundary layer behavior, including transition from laminar to turbulent flow, on simple shapes like cones and cylinders.

One of the original design requirements of the facility was to provide for the detailed investigation of turbulent boundary layers at flight RN by the use of a 13-foot-long test section. This work has been reported in formal NASA publications and in American Institute of Aeronautics and Astronautics Journal articles. This capability is now being used to study the skin friction reduction and film cooling obtained by air injection at the wall through multiple flush slots. This technique may eventually reduce fuel consumption for hypersonic aircraft.

AVAILABILITY: This facility was shut down for repairs to the high-pressure piping system from 11/73 to 12/74. Since that time, it has been used for the NASA slot injection program. Before that time, the facility was used mainly

NOZZLE TEST CHAMBER (SUPERSONIC/HYPERSONIC)

INITIAL OPERATION: 1969

DESCRIPTION:

Mach 3 to 7 with different nozzles
Nozzle exit diameters: 3 to 6 inches
Open jet test section.
--Stagnation pressure: 15 to 550 psi.
--Stagnation temperature: 60°F to 450°F.
--Same high pressure air supply and vacuum system as 20-inch mach 6 tunnel plus auxiliary vacuum connections to 60 ft. sphere and 13 ft. tank.

NARRATIVE: During the first year of operation, the facility was used almost exclusively to determine the starting characteristics of a model of the hypersonic research engine. The full-scale engine was tested later in the NASA Lewis Plumbrook facility. The nozzle test chamber is small and the cost of test models and equipment is therefore less than for larger facilities. The operational costs are also moderate, so the facility is often used for facility development work as well as for basic research on supersonic turbulent free mixing and boundary layer transition. Since 1973 the facility has been used extensively in the testing and development of laminar flow nozzles and sound attenuation devices for the NASA Langley quiet tunnel development program. This program has led to the fiscal year 1977 construction of facility proposal to design and fabricate the 1/2-Meter mach 5 quiet tunnel.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research programs for this facility. If these tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable cost for tunnel operation. However, specialized models and unique equipment and supplies associated with tests are normally furnished by the other Government agency or industry requesting the tests.

MACH 8 VARIABLE DENSITY TUNNEL (VDT) (HYPERSONIC)

INITIAL OPERATION: 1959

DESCRIPTION: The mach 8 VDT test section is 18 inches in diameter. Models are mounted on an injection carriage which has the capability of injecting a model approximately 27 inches by 11 inches. Models used for force testing can be up to approximately 20 inches in length and will be used with the facility's procured angle of attack and angle of yaw mechanism which can vary the angle of attack during the tunnel operation. RN range is approximately 0.2×10^6 per foot to 12.0×10^6 per foot. The facility is used to obtain heat transfer, pressure, force, and flow visualization data with extended run times on the order of minutes.

NARRATIVE: The mach 8 VDT is one of the most versatile and productive hypersonic facilities in the nation. The results from the tunnel tests have had considerable impact on either the design of the configurations or the analysis of the data from such projects as: (1) Mercury, (2) Gemini, (3) Apollo, (4) lapdog, (5) sprint (6) reentry F, (7) viking, (8) space shuttle, (9) mariner (Radioisotope fuel cask), (10) project RAM, and (11) the HL-10 vehicle. In addition, there has been a great deal of basic fluid mechanics work done in the area of boundary layer transition, flow field studies, interference heating, shock-wave/boundary-layer interaction, shear layers, wakes, separation, and the acoustic properties of the tunnel wall boundary layer. Much of the basic fluid mechanic work in the area of transition (rod model) and "tunnel noise" have contributed considerably to the design concepts of the "quiet tunnel." The phase-change coating technique, for measuring quantitative heat transfer, which is used worldwide, was developed and refined in the mach 8 VDT. For the space shuttle program, no other facility in the country was able to generate the enormous amount of heat transfer and transition data over a wide range of RNs as was generated in the mach 8 VDT. In addition, the photographing of flow fields and heat transfer patterns in color simultaneously was developed in the mach 8 VDT. Finally, such programs as the forebody flow field study, the force testing of the HT-4 configuration, and the heat-transfer testing of the HYFAC configuration has all contributed to the optimization of the design of future hypersonic aircraft.

In the future, the mach 8 VDT is expected to continue its productive role in advancing hypersonic technology. One research program is focused on providing a data base for

for NASA research work; but, on at least two occasions, it was used by NASA contractors. Requests for tunnel use are screened against ongoing and planned research programs for this facility. If these tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable cost for tunnel operation. However, specialized models and unique equipment and supplies associated with tests are normally furnished by the other Government agency or industry requesting the tests.

HIGH-RN HELIUM TUNNELS (HYPERSONIC)

INITIAL OPERATION: 1967

DESCRIPTION: The high-pressure helium upstream of the tunnel can exhaust through either of two tunnel legs--one at mach 10 or one at mach 20. The two legs cannot be operated simultaneously. A description will be given of each tunnel leg separately.

Mach 10 leg: Test section is 37 inches in diameter; total pressure to 2400 psia at ambient total temperature giving RNs as high as 5×10^7 per foot; run time from 3 to 16 seconds. Unique features include very high-RN capability which can duplicate turbulent flight conditions at mach 10, unheated flow greatly simplifies problems with instrumentation, and clean unheated flow permits use of delicate hot wire probes for turbulence measurements.

Mach 20 leg: Test section is 60-inches in diameter; total pressure to 4000 psia at ambient total temperature giving RNs as high as 3×10^7 per foot; run time from 3 to 5 seconds. Unique features include very high-RN capability (highest of any conventional wind tunnel in United States) at mach 20 and large tunnel size, clean and unheated flow simplifies instrumentation problems and allows the use of delicate hot wire probes for detailed turbulence measurements.

NARRATIVE: Tunnels are used primarily to provide stringent experimental test cases for new and advanced numerical prediction methods for turbulent flows, to provide direct measurements of turbulence quantities in hypersonic flows (unique feature), and to provide configuration aerodynamics at high-RN/mach number.

Past accomplishments include unique unsteady flowfield studies for shuttle "Hypersonic Buzz," disturbance effects on boundary layer transition in high-speed flow, and investigations of two- and three-dimensional turbulent flow phenomena at high-RN/mach number.

Current program includes high-RN turbulent boundary layer investigation at mach 20, turbulence control methods for hypersonic boundary layer flows (drag reduction concept) and aerodynamics for hypersonic research aircraft.

Full-time use of the facility is anticipated for the foreseeable future. Upcoming programs include investigation of three-dimensional turbulent boundary layer at high RN, a hypersonic research airplane (prospective joint NASA/USAF project, X-24C). Areas of study will include (1) wing-elevon interactions, (2) forebody optimization, (3) heat transfer, (4) stability and control, (5) engine/airframe integration, (6) exhaust simulation, (7) induced pressures at various wall temperatures, and (8) vorticities.

AVAILABILITY: The mach 8 VDT has been used extensively by DOD, numerous companies, and other NASA centers. The DOD-requested tests on various blunt ballistic reentry configurations, the sprint project, the lapdog project (conducted by General Electric), and the SNAP 9A project. All requests for testing in the facility by DOD were complied with. The type of testing requested was primarily for pressure and heat-transfer data with complementing flow visualization pictures. In recent years ('69 to '73) about 23 test periods (approximately 1500 tunnel runs) for space shuttle testing were requested by various industry companies. The companies who requested and received test time in the facility were (1) Convair of General Dynamics, (2) Lockheed, (3) Martin, (4) McDonnell-Douglas, (5) Grumman, and (6) North American of Rockwell International. In addition to industry testing, specific shuttle configurations from the Johnson Space Center were tested extensively. Heat transfer was the major type of data obtained on the various space shuttle configurations. The testing method utilized was primarily the phase-change coating heat-transfer technique. In fiscal year 1973, after Rockwell International had been awarded the shuttle contract, they had 8 periods of testing (37 days) and during these periods made a total of 363 tunnel runs.

The models associated with the tests described above were normally furnished by the requesting agency or company. There were no reimbursable costs involved.

LANGLEY HYPERSONIC FLOW APPARATUS

INITIAL OPERATION: Original location - 1961
Present location - 1973

DESCRIPTION: This facility is a mach 10 blowdown wind tunnel with a test time of up to approximately 1 minute. It operates at stagnation pressures up to 1200 psia which provide unit RNs up to 2 x 10^6 per foot. The test medium is air heated to a maximum stagnation temperature of 1660°R by an electrical resistance heater. Model mounting consists of sting and circular arc strut. The tunnel has a contoured axially symmetric nozzle with a 15-inch diameter test section. The test core is 10 inches in diameter.

NARRATIVE: This tunnel can be used for a wide variety of tests. In its original location, it was used for force, heat transfer, and flutter testing and produced much valuable hypersonic aerodynamic data on configurations, such as minimum wave-drag bodies and wind-body reentry configurations. The results of these tests are presented in numerous NASA publications. In 1972 the research group that originally developed the tunnel changed work areas and no longer needed the facility for their work. Since the tunnel produces test conditions very similar to those produced in the continuous flow hypersonic tunnel (CFHT) (but with smaller models) and is much less costly to operate, it makes an excellent companion facility for the CFHT. Accordingly, it was moved to building 1251A where it shares utilities (electrical power, high-pressure air, vacuum spheres) with the CFHT. At present, the hypersonic flow apparatus (HFA) is used to complement the CFHT. Exploratory studies, using small, inexpensive models, are carried out at low cost in the HFA. Then more precise and extensive investigations, based on the HFA results, are carried out in the CFHT. Particular emphasis is placed on using the HFA for flow visualization studies (shadowgraph, schlieren, vapor screen) which are difficult in the CFHT because of its sidewall model injection system. The HFA supports the same programs that the CFHT supports, such as shuttle, advanced heavy lift orbiter, and fundamental hypersonic real gas effect studies. The HFA does not have a separate group of operating technicians. It is operated by the same group of technicians that operate the CFHT. The two tunnels cannot be operated simultaneously.

AVAILABILITY: While this tunnel is available to other agencies and research groups, no requests have been received in recent years. When requests are received, turbulent free shear layer development at high-mach number, and high-RN aerodynamics of hypersonic research aircraft.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research programs for this facility. If these tests can be integrated into the planned programs of this facility, requests are granted at no reimbursable cost for tunnel operation. However, specialized models and unique equipment and supplies associated with tests are normally furnished by the other Government agency or industry requesting the tests. Only outside user was Martin-Marietta Corporation (NASA contract) for approximately 2 weeks.

LANGLEY CONTINUOUS FLOW HYPERSONIC TUNNEL

INITIAL OPERATION: 1964

DESCRIPTION: This tunnel may be operated either in a continuous or blowdown mode at mach 10. The test medium is air heated by an electrical resistance heater. The test section is 31 by 31 by 72 inches with a 10- to 20-inch test core. Stagnation pressure is variable to a maximum of 150 atmospheres providing unit RNs from 3×10^5 to 2.25×10^6 per foot.

NARRATIVE: This tunnel is used for a wide variety of aerodynamic and heat transfer tests. It is equipped with a sophisticated model injection system which allows model changes to be made rapidly while the tunnel is running. This allows up to 38 heat transfer runs or 54 force test runs to be made in a single operating shift. In addition to the usual sting-mounted models, the flat test section side walls allow wall-mounted models to be tested in a thick turbulent boundary layer flow.

This facility has been used to carry out a wide range of aerothermodynamic research. Studies of fundamental heat transfer phenomena and aerodynamic characteristics carried out in this facility contributed significantly to the research data base which lead to the space shuttle concept. Over the past 5 years, the great majority of the tests run in the tunnel have been in direct support of the shuttle program. Aerodynamic and heat transfer characteristics were measured on various proposed shuttle configurations as well as on the final configuration, and extensive sidewall tests were carried out to accurately assess heat transfer distributions over the reusable surface insulation tiles that make the shuttle thermal protection system.

The current test program still contains a significant number of shuttle support tests, but the volume of these tests is decreasing as the shuttle approaches operational status. The major part of the current test program consists of investigations of advanced aerodynamic and heat transfer concepts that could provide greater payload capacity and lower operational costs for the present shuttle, and could lead to the design of advanced, heavy lift orbiters that will be required to make missions, such as nuclear waste disposal and orbital power stations feasible.

AVAILABILITY: This facility is available for use by industry and other Government agencies. During the shuttle program, the tunnel was used extensively by North American the scheduled testing times will be determined based on the priority of the tests and the impact on in-house research. No reimbursable costs will be involved. The requesting agency is expected to provide models, special supporting equipment, and engineering support.

7-INCH MACH 7 PILOT TUNNEL (HYPERSONIC)

INITIAL OPERATION: 1957

DESCRIPTION: This tunnel is approximately a 1/12 scale model of the 8-foot high-temperature structures tunnel (8' HTST). The test section is 7.5 inch diameter by 13 inches long, the test gas velocity is mach 7 and operates at total pressures and temperatures up to 2200 psi and 3000°F. The energy level of the stream is generated by burning methane in air under pressure and using the resulting combustion products as the test gas.

NARRATIVE: This tunnel was used initially to define design parameters for the 8' HTST, in particular:

1. The method of fuel injection and combustion process control for the combustor.
2. The feasibility of using an open jet type test section and influence of model insertion on test stream.
3. The operating performance of an air ejector to pump a hot gas when used as a down stream pump.
4. The feasibility of using an air film cooling process to prevent nozzle throat from overheating.
5. To verify the use of combustion product as a test medium--in relationship to air--such as aerodynamic forces, pressure, and temperature distribution.

In past years, the tunnel has been used as a research tool on such programs as:

1. The definition of temperature distribution on complex aerodynamic shapes.
2. The aerodynamic characteristics of decelerator shapes.

Also, in the past years, this tunnel has been used for flow and blockage studies of various research models to establish testing techniques for the 8' HTST, such as:

1. Development of panel holder fixture.
2. Large base cone model.

Current programs include investigations to determine suitable method for testing large models in 8' HTST, such as a wing leading edge employing heat pipes and a X-24C surface panel inclined at a high angle of attack.

Rockwell, the shuttle's prime contractor. Both heat transfer and force tests were carried out. Five requests were received and filled. A request was recently received from the Defense Nuclear Agency for tests of a "gas jet" nose tip. No reimbursable costs have been involved in any of these tests. The contractors have furnished models and engineering support.

8-FOOT HIGH-TEMPERATURE STRUCTURES TUNNEL (HYPERSONIC)

INITIAL OPERATION: 1967

DESCRIPTION: The tunnel test region is 8 feet in diameter and 14 feet long; hence, large models can be tested. The test gas speed is mach 7 and it is at the correct pressure and temperature to simulate flight conditions between 80,000 and 130,000 feet of altitude. A unique feature of the tunnel is the large high pressure combustor where fuel is burned in air and the resulting hot gases used as the test medium. In terms of electrical energy, this unit is capable of delivering 800 megawatts of power into the flowing air.

NARRATIVE: This facility is used to explore the unique problems of the interaction of structures with the aerodynamic heating and loading related to hypersonic flight. In the past, test programs have included:

1. Investigation of radiative thermal protection systems (TPS), including metallic and reusable surface insulation (RSI) concepts.

2. Structural performance of a hypersonic research engine when employing regeneratively cooled (fuel cooled structure) surfaces on the outside and inside the propulsion chamber.

3. Total aerodynamic thermal load to space shuttle RSI-type tiles, including side wall heating in gaps.

4. Aerodynamic produced grooved patterns on ablative nose cone of missile.

5. Aerodynamic heating and loading to a damaged reentry missile.

At the present, the tunnel supports a joint NASA-USAF program in evaluating candidate surface-structure/thermal-protection systems for the X-24C research airplane.

Future test programs will include:

1. Gaps and seals for shuttle control surfaces.

2. Wing leading edge concept employing heat pipes.

3. Actively cooled panels for airframes.

4. Advanced TPS concepts.

Future study will include:

1. Design parameters for a 3-dimensional test fixture for 8' HTST to permit investigation of wing or fin type structure with a control surface.
2. General preliminary investigation of testing methods and techniques for various models scheduled for 8' HTST.

AVAILABILITY:

Calendar year	Program	Agency	Contractor	Time in tunnel (months)
1963	equilibrium temperature contours on a reentry boost glide type vehicle	USAF	McDonnell Douglas	3

In accordance with NASA's policy, this tunnel can be made available to other agencies or to industry, depending on the priority of the program. For outside programs, there are no reimbursable costs; however, special models and equipment are furnished by others.

HYPERSONIC CF_4 TUNNEL

INITIAL OPERATION: 1972

DESCRIPTION: This facility is a mach 6 blowdown tunnel with a running time of up to 60 seconds. It has a contoured axially symmetric nozzle with an exit diameter of 20 inches and an open-jet test section with a rapid model insertion mechanism. The working gas is CF_4 (a freon) which is heated to 1500°R by a lead-bath, electrically heated, heat exchanger. The maximum free stream unit RN is 1.5×10^6 per foot. The use of CF_4 as the test gas provides a much better simulation of hypersonic shock wave geometry and vehicle heating and pressure distributions than is achievable in typical air wind tunnels. A reclaimer allows the freon gas to be reused rather than being exhausted to the atmosphere.

NARRATIVE: This tunnel is used for heat transfer, pressure distribution and aerodynamic force, and moment tests. In all instances, the reason for testing in this facility is to study hypersonic "real gas" effects by obtaining data at shock density ratios of approximately 12 which are close to actual flight values (10-16) whereas typical airwind tunnels produce shock density ratios that are too low (about 5.6). The facility has produced significant data for both the viking and shuttle programs. The current test program is about evenly divided between tests in support of the shuttle program, studies in support of advanced Earth orbital transportation systems, and studies of planetary probe configurations. Over the next several years, the facility will be heavily involved in defining the aerodynamic and heating characteristics of probe vehicles designed to enter the atmospheres of Venus and the giant planets.

AVAILABILITY: The facility is available to other Government agencies, industry, and university research groups. It has been used by the Martin Marietta Corporation to study the aerodynamic and heating characteristics (two separate requests) of the Viking entry vehicle, and it has been used by North American Rockwell to study heating distributions and aerodynamic characteristics (two requests) of the shuttle orbiter. In these tests, the contractor supplied models and support personnel. No reimbursable funds were involved.

AVAILABILITY:

Calendar Year	Program	Agency	Contractor	Time in tunnel (months)
1968	Study of aerodynamic produced grooves on ablative nose cone of missiles	USAF	General Electric	3
1969	Special materials wind tunnel test	USN	Lockheed Missiles & Space Co.	2
1971	Aerodynamic pressure and heat load to a damaged reentry missile	DNA	Aeronautical Research Associates	1
1975	Evaluation of ablative material proposed for X-24C	NASA-USAF	Martin Marietta	3

NOTES:

1. There were no reimbursable costs for above programs. Models and special support equipment were supplied by the other agency.

2. Within the past 3 years, there were many inquiries from various agencies regarding use of this facility; however, a formal request was never made. Our scheduled backlog during this period was for support of the space shuttle, which was of a high priority.

APPENDIX III

PLANETARY ENTRY RADIATION LABORATORY (PERL)

APPARATUS A & B (HIGH ENTHALPY ARC TUNNEL)

INITIAL OPERATION: 1971

DESCRIPTION: The apparatus utilizes a scanning monochrometer to measure the absorption of spectral electromagnetic radiation by ablation products similar to that which is produced by the high-speed entry of spacecraft (or probes) into the atmospheres of various planets. The emission of radiation is produced in the apparatus by heating a simulated atmospheric gas mixture to very high temperatures (10-20,000° K) by use of a high-powered electric arc.

NARRATIVE: Due to the shock wave produced by a spacecraft (or probe) during high-speed entry into a planetary atmosphere, gases adjacent to the spacecraft body are heated to a very high temperature. The hot gases transmit thermal energy to the body by conduction, convection, and radiation. In some instances, the radiant heat load is very large. Under this high heat load, a heat shield attached to the body will ablate (similar to vaporization) thus "using up" much of the energy and carrying more harmlessly into the wake of the vehicle. Theoretically, portions of the radiant energy at certain wavelengths will be absorbed or "blocked" by the ablation products and therefore will never reach the body. However, at other wavelengths, the ablation products may themselves present a radiant heat load to the vehicle. The PERL was designed to provide experimental verification of these theories, thereby reducing uncertainties in heat shild design. Optimum heat shield design is important because up to one-half of the total entry vehicle weight may be due to thermal protection materials. In the PERL, gases representative of the planetary atmosphere under investigation are heated to a very high temperature and the emitted radiation is measured with and without simulated ablation products. Investigations previously conducted have been with nitrogen (Earth atm.) and carbon dioxide (Venus atm.). Presently, hydrogen-helium mixtures (Jupiter atm.) are under investigation. The results of this investigation will be furnished to the Ames Research Center and the Jet Propulsion Laboratory (JPL) for inclusion into a Jupiter probe design.

To date, all work has been devoted to the stagnation region of the gas flow. Of equal, or even greater significance is the downstream flow region (on the flanks of a vehicle) where the ablation products and the emitting gas may mix,

SUPERSONIC MATERIALS ENVIRONMENTAL TEST SYSTEM (SMETS)--SUPERSONIC

INITIAL OPERATION: 1968

DESCRIPTION: The SMETS facility provides a unique capability for exposing small specimens to essentially continuous supersonic airflow for the purpose of assessing actual material surface physico-chemical response (rather than aerodynamic response) to simulated supersonic flight. The test section is nominally 3x5 inches in cross section by 12 inches long and has been used to expose small elemental test specimens both stressed and unstressed to simulated supersonic flight conditions for realistic exposure times and temperatures.

NARRATIVE: The SMETS facility has been used to assess the effects of hot salt deposits on candidate titanium alloys for airframe skin application on supersonic cruise aircraft. The effect of test-cycle duration and frequency on material degradation has been determined for two prime candidate alloys. The facility is capable of providing material physico-chemical surface response information on other types of materials considered for supersonic cruise aircraft application with the very low operating costs, both dollarwise and manpowerwise. There are essentially no fixed costs in maintaining the facility in the stand-by condition other than the minimal space it occupies. There are no immediate plans for additional tests.

AVAILABILITY: The facility is available on a request basis but has been used only on in-house R&D programs.

LANGLEY ARC-DRIVEN SHOCK TUBE (HYPERVELOCITY, IMPULSE)

(HOT GAS RADIATION RESEARCH FACILITY)

INITIAL OPERATION: 1969

DESCRIPTION: Facility is basically a stainless steel tube divided into two sections by a diaphragm. The driver (upstream) section is 0.6m in length, rated for pressures to 276 MN/m^2 and houses coaxial electrodes connected to a 5 MJ capaciter bank (largest capaciter energy source for impulse facilities in free world). Incident shock velocities from 5 to 21 km/s have been generated with various test gases and on arc-heated helium driver gas. These shocks propagate down the 15.2m long driven (downstream) section and test times range from 2 to 40 microseconds.

NARRATIVE: The Langley arc-driven shock tube has generated incident shock velocities in pure carbon dioxide from 9 to 13 km/s. This range of velocity encompasses the entry velocities into the atmosphere of Venus for which maximum total heating occurs to the aeroshell. Thermochemical properties of the high-temperature gas behind the incident shock were studied spectroscopically. (The gas behind the incident shock simulates the high-temperature gas immediately behind the normal portion of the bow shock about a blunt entry probe moving through a quiescent atmosphere which is simulated by the quiescent test gas.) This complex study greatly contributed to the determination of nonequilibrium radiative heating expected during Venusian entry and was in support of Pioneer Venus. Present and future studies in this facility will address radiation blockage (absorption) phenomena for carbon-hydrogen test gases. The purpose of this study is to provide experimental data pertaining to radiation blockage by the ablative layer of a probe entering the atmosphere of an outer planet, such as Jupiter or Saturn. (Radiation from the extremely hot gas behind the bow shock is incident upon the ablating aeroshell surfaces. Ablation products, primarily carbon, mix with the gas, primarily hydrogen for the outer planets, to form a carbon-hydrogen ablation layer. This layer tends to block radiant energy from the hot gas, thereby providing protection for the aeroshell.) Knowledge of the magnitude of this blockage is extremely important in probe design, hence mission success, and much of the technology required for assessment of this magnitude must be obtained experimentally.

AVAILABILITY: No requests from sources outside of NASA.

and the possible onset of turbulence make analysis even more difficult. Investigation of this region experimentally will require the formulation of design concepts and subsequent hardware modifications.

AVAILABILITY: The PERL is used by Langley personnel only.

HIGH-TEMPERATURE MATERIALS LABORATORY APPARATUS A (SUPERSONIC)

INITIAL OPERATION: 1961

DESCRIPTION: This apparatus uses one of several direct current electric arc gas heaters to heat air or nitrogen or mixture of these gases. The gas in the test section reaches temperatures of 15000°F. and velocities to 16,000 feet per second with test section pressures between 1 and 2 mm Hg. Blunt cylindrical models to 6 inches diameter can attain temperatures of 3200°F. and flat panels up to 12 inches by 12 inches can be heated to 2800°F. This apparatus has a demonstrated capability to produce a uniform heating and pressure distribution on a relatively large model in a high-energy flow.

NARRATIVE: The facility produces a hot air stream similar to that spacecraft encounter when they enter the Earth's atmosphere. Tests are run in the facility to find materials that will protect the spacecraft from the hot environment. Further tests are run to develop and verify design methods. Principal accomplishments include development of low-density heat shield materials, such as were used to protect Apollo, and verification of the theoretical methods which were developed to predict the heat shield thickness needed to protect Apollo. Current activities are directed largely to shuttle heat shield studies. Both basic materials behavior in shuttle environments, and the performance of complex systems, such as door seals, are being examined. Shuttle support requirements are expected to remain heavy for the next 2 years, at least. Thereafter, efforts must be directed to improved heat shields for the next generation of orbital vehicles after shuttle. Studies of the benefits man can acquire from space toward the end of the century typically start with the assumption that structural and heat shield weight can be reduced by 25 percent and that vehicle lifetime will be about 5000 flights. However, these goals will be unattainable without extended and intensive research and development studies, such as can be conducted in this facility. In addition to space-related work, high-temperature materials for a hypersonic research airplane are being tested as part of a joint NASA-USAF program.

AVAILABILITY: NASA requirements have generally precluded use of this facility to support tests for other agencies. This is one of three electric arc heated tunnels operating from the same utilities, so very little time is available for use by other agencies.

PROPULSION TEST CELLS (SUPERSONIC, HYPERSONIC)

(SUPERSONIC COMBUSTION TEST STAND)

INITIAL OPERATION: 1965

DESCRIPTION: The facility consists of two reinforced concrete test cells 16' x 16' x 52' long with atmospheric air entrance and exhaust towers at each end. The walls and structure are designed for 1 atmosphere differential pressure. Gas supplies include: air at 600 psi in a 16" line, hydrogen at 720 psi in a 3" line, and oxygen at 1200 psi in a 3" line. Cooling water and nitrogen purge gas are also available. A hydrogen-air-oxygen burner located in one cell provides hot test gas simulating air at temperatures to 4000°F. (equivalent to flight speeds of mach 8), pressures to 450 psi, and flow rates up to 50 lb/sec. Control systems for the various gas supplies and data recording equipment including special gas sample analysis instrumentation are located in a monitor room above the test cells.

NARRATIVE: Hydrogen fueled, SCRAMJET propulsion systems appear attractive for various types of hypersonic aircraft. Supersonic combustor technology and the evolution of engine designs with good performance potential over a broad flight speed range are two key items pacing the development of practical hypersonic engines. The propulsion test cells provide a general purpose facility capable of supporting a variety of research investigations into SCRAMJET combustor design, fuel injector configurations, and supersonic inlet and engine performance. Past accomplishments include research investigations on piloted flame propagation in supersonic premixed hydrogen-air flows, perpendicular and parallel fuel injection and mixing studies for several of cold-non-reacting and hot-reacting flow configurations, inlet concept development for an airframe integrated SCRAMJET engine configuration, and direct connection performance evaluation of candidate SCRAMJET engine combustor designs for this integrated engine configuration. Current research is focused on further development of fuel injector/combustor concepts for the integrated engine configuration emphasizing a range of speeds from supersonic to hypersonic. Future plans call for complete subscale engine tests at mach 4 to 5 speeds.

AVAILABILITY: The facility could be made available to outside users. No inquiries as to availability have been received.

Harry Diamond Laboratories, Department of the Army, was supported with about 3 weeks of testing in 1971. These tests were to compare the performance of antenna windows during reentry to the atmosphere.

HIGH-TEMPERATURE MATERIALS LABORATORY APPARATUS B

(SUBSONIC, SUPERSONIC)

INITIAL OPERATION: 1961

DESCRIPTION: This apparatus uses a three-phase alternating current electric arc to heat air or mixtures of air and nitrogen. The gas in the test section attains temperatures of 5500°F. and velocities of 9000 feet per second with minimum test section pressures of 2 mm of Mercury. Cylindrical models up to 5 inches in diameter can be heated to 2800°F and flat panels 5 x 5 inches can be heated to 2600°F. Test section dimensions are 6 feet diameter by 4 feet long.

NARRATIVE: The facility produces a hot air stream similar to that spacecraft encounter when they enter the Earth's atmosphere. Tests are run in the facility to find materials that will protect the spacecraft from the hot environment. Further tests are run to develop and verify design methods. Principal accomplishments include development of low-density heat shield materials, such as were used to protect Apollo, and verification of the theoretical methods which were developed to predict the heat shield thickness needed to protect Apollo. Current activities are directed largely to shuttle heat shield studies. Both basic materials behavior in shuttle environments and the performance of complex systems, such as door seals, are being examined. Shuttle support requirements are expected to remain heavy for the next 2 years, at least. Thereafter, efforts must be directed to improved heat shields for the next generation of orbital vehicles after shuttle. Studies of the benefits man can acquire from space toward the end of the century typically start with the assumption that structural and heat shield weight can be reduced by 25 percent and that vehicle lifetime will be about 5000 flights. However, these goals will be unattainable without extended and intensive research and development studies, such as can be conducted in this facility. In addition to space-related work, high-temperature materials for a hypersonic research airplane are being tested as part of a joing NASA/USAF program.

AVAILABILITY: NASA requirements have generally precluded the use of this facility to support other agencies. This is one of three electric arc heated tunnels which operate from the same utilities, so very little time is available for use by other agencies. One high priority request from

HIGH-TEMPERATURE MATERIALS LABORATORY APPARATUS D

(SUPERSONIC)

INITIAL OPERATION: 1963

DESCRIPTION: This apparatus uses a direct current electric arc to heat gas (oxygen and nitrogen). The gas in the test section reaches temperature of 15000°F. and velocities of 10,000 feet per second with test section pressures to 2 mm mercury. The test section is 6 feet in diameter and 4 feet long. Cylindrical models up to 4½ inches in diameter can be heated to 3000°F and flat panels up to 5 x 5 inches can be heated to 2700°F.

NARRATIVE: The facility produces a hot air stream similar to that spacecraft encounter when they enter the Earth's atmosphere. Tests are run in the facility to find materials that will protect the spacecraft from the hot environment. Further tests are run to develop and verify design methods. Principal accomplishments include development of low-density heat shield materials, such as were used to protect Apollo, and verification of the theoretical methods which were developed to predict the heat shield thickness needed to protect Apollo. Current activities are directed largely to shuttle heat shield studies. Both basic materials behavior in shuttle environments and the performance of complex systems, such as door seals, are being examined. Shuttle support requirements are expected to remain heavy for the next 2 years, at least. Thereafter, efforts must be directed to improved heat shields for the next generation of orbital vehicles after shuttle. Studies of the benefits man can acquire from space toward the end of the century typically start with the assumption that structural and heat shield weight can be reduced by 25 percent and that vehicle lifetime will be about 5000 flights. However, these goals will be unattainable without extended and intensive research and development studies, such as can be conducted in this facility. In addition to space-related work, high-temperature materials for a hypersonic research airplane are being tested as part of a joint NASA-USAF program.

AVAILABILITY: NASA requirements have generally precluded use of this facility to support tests for other agencies. This is one of three electric arc heated tunnels operating from the same utilities, so very little time is available for use by other agencies.

7- BY 10-FOOT SUBSONIC WIND TUNNEL

(NUMBER 1)

BUILDING NUMBER: N-215

INITIAL OPERATION: 1941

DESCRIPTION:

Speed	0 to 220 knots (continuously variable)
Stagnation pressure	1.0 atmospheres
RN	2.3 x 10^6 per foot (maximum)
Temperature	About 580°R (not controlled)
Height x width x length	7.0 x 10.0 x 16.0 feet
Access	Top hatch - 4.6 x 5.0 feet Side doors - 6.3 x 10.0 feet

NARRATIVE: The 7- by 10-foot subsonic wind tunnel (number 1) is a closed-circuit, atmospheric tunnel. Airflow is produced by a fixed-pitch fan powered by a variable-speed electric motor delivering a total of 1,800 horsepower. Model mounting capabilities include single and dual strut mountings on an external balance, sting mounting using an internal balance, and two dimensional mounts across the 7-foot dimension. Automatic data acquisition equipment (576 active channels plus output of external balance and fixed digital inputs) is located in the test chamber and is linked on-line with an IBM 1800 computer, output data from which is returned to an on-line data plotter in the chamber. Six component measurements can be made for external and sting mounting as well as three-component data for two-dimensional mounting. Data systems include scanivalve and strain-gage conditioning equipment. Various model motors are available with two, 100kw and 400-cycle, variable-frequency power supplies provided, as well as a 3,000 psi air system to power pneumatic drives.

AVAILABILITY: Operating on a one shift basis, the tunnel was 96 percent utilized during FY 1975; more than 89 percent of the testing supported NASA programs while the remainder represented Navy, USAF, and University of Michigan research.

More than 90 percent of the test hours requested by both NASA and non-NASA users during FY 1975 were scheduled for testing. Tests were generally rejected because the wind tunnel was too small for the model.

Ames Research Center (ARC)

7- BY 10-FOOT SUBSONIC WIND TUNNEL

(NUMBER 2)

BUILDING NUMBER: N-216

INITIAL OPERATION: 1941

DESCRIPTION:

Speed	0 to 220 knots (continuously variable)
Stagnation pressure	1.0 atmospheres
RN	2.3×10^6 per foot (maximum)
Temperature	About 580°R (not controlled)
Height x width x length	7.0 x 10.0 x 16.0 feet
Access	Top hatch - 4.8 feet diameter Side door - 6.3 x 10.0 feet

NARRATIVE: The 7- by 10-foot subsonic wind tunnel (number 2) has been under the jurisdiction of the U.S. Army since 1965. Because Ames Research Center had two somewhat identical tunnels experiencing low utilization, the Army agreed to operate the number 2 tunnel as an air mobility R&D laboratory.

The number 2 tunnel is a closed-circuit, atmospheric tunnel. Airflow is produced by a fixed-pitch fan powered by a variable-speed electric motor delivering a total of 1,800 horsepower. Test setups are flexible to allow installation of a wide variety of two- and three-dimensional models. Two-dimensional models are installed spanwise with supports at the floor and ceiling of the tunnel; continuous angle-of-attack variation from 0° to 180° is available. Three-dimensional models are generally supported on a single or dual pair of vertical struts, each with a trailing link which provides remote pitch control. Motion in the yaw direction of 360° is available. Various model motors are available with 100kw, 400-cycle, variable-frequency power provided. An external, six-component balance system is used to measure forces and moments.

AVAILABILITY: The tunnel was fully utilized on a one shift basis during FY 1975. More than 68 percent of the test time was dedicated to Army R&D projects with the balance supporting NASA (laser and oblique wing) research.

Because the tunnel is dedicated to research (in contrast to development) projects, it is generally unavailable for commercial development projects.

12-FOOT PRESSURE WIND TUNNEL (SUBSONIC)

BUILDING NUMBER: N-206

INITIAL OPERATION: 1946

DESCRIPTION:

Mach number	0 to 0.98 (continuously variable)
Stagnation pressure	0.17 to 5.0 atmospheres
RN	0 to 9.0 x 10^6 per foot
Stagnation temperature	500° to 625° R
Height x width x length	11.3 x 11.3 x 18.0 feet
Access	Top hatch - 5.0 x 11.0 feet

NARRATIVE: The 12-foot pressure wind tunnel is a variable-density, low-turbulence tunnel that operates at subsonic speeds up to slightly less than mach number 1.0. Airflow is produced by a two-stage, axial-flow, variable-speed fan powered by electric motors delivering a total of 12,000 horsepower. Eight fine-mesh screens in the settling chamber, together with the contraction ratio of 25 to 1, provide an airstream of exceptionally low turbulence.

A variety of tests can be accomplished using various model-support systems available. These include sting, semi-span, and two-dimensional-model type mountings. (A special mounting drive system is available for high angle of attack.) External and internal strain-gage balances are available.

Motion pictures of models can be taken by remotely operated cameras mounted in the balance chamber.

AVAILABILITY: This facility is one of three operated by contractor personnel at Ames Research Center. On a two-shift basis, the tunnel was 60 percent utilized during FY 1975. Approximately 63 percent of the testing supported NASA programs, while the remainder supported Navy, USAF, or McDonnell-Douglas programs.

Nearly 85 percent of the test hours requested by both NASA and non-NASA users during FY 1975 were scheduled for testing. Tests were rejected because they were considered unnecessary by Ames officials.

Approximately 93 percent of the test hours requested during FY 1975 were scheduled for testing. The Army reported that tests were rejected because there was a lack of available time, they were not of high research interest, and they did not require the unique capabilities of the facility.

40- BY 80-FOOT WIND TUNNEL (SUBSONIC)

BUILDING NUMBER: N-221

INITIAL OPERATION: 1944

DESCRIPTION:

Speed	0 to 200 knots (continuously variable)
Stagnation pressure	1.0 atmosphere
RN	0 to 2.1 x 10^6 per foot
Temperature	Ambient to 600° R
Height x width x length	40 x 80 x 80 feet
Access	Top doors - 49 x 80 feet

NARRATIVE: Being the largest tunnel in the United States, the 40- by 80-foot tunnel is considered unique and is in great demand. It is a closed-throat, closed-circuit wind tunnel used primarily for determining the low-speed aerodynamic characteristics of high-performance air craft and spacecraft (particularly landing and take-off and V/STOL aircraft and rotorcraft). Airflow is produced by six, variable speed, 40-foot-diameter fans, each powered by a 6,000 horsepower electric motor.

Power for operation of propellers, etc., can be obtained from either aircraft engines or electric motors. Either gasoline or JP-type fuel can be supplied for internal-combustion engines in the test section. A variety of electric motors are available for model propulsion systems (maximum electric power available for these is 3,000 horsepower).

In addition to a conventional support-strut system, a set of variable-height struts is available for ground proximity studies.

AVAILABILITY: Operated on a two-shift basis, the tunnel was fully utilized during FY 1975. Nearly 68 percent of the testing represented NASA programs while the balance primarily supported Army, Navy, and DOT research. More than 90 percent of the test hours requested by both NASA and non-NASA users during FY 1975 were scheduled for testing. Tests were generally rejected because of their incompatabilility with the facility.

Because the tunnel is dedicated to research (in contrast to development) projects, it is generally unavailable for commercial development projects. Only projects considered to have nonproprietary research merit are permitted to use the 40- by 80-foot tunnel.

The 12-foot tunnel is categorized as a research tunnel but, because of its uniqueness, NASA makes it available to non-Government users on a reimbursable basis. For example, McDonnell-Douglas Corporation ran proprietary DC-10 tests in this tunnel during FY 1975. Users are charged a $20,000 weekly occupancy rate plus actual utility and data reduction costs and a 15 percent NASA management surcharge.

The 14-foot transonic tunnel is categorized as a research tunnel but it can be used for development work on a reimbursable basis when such work is in the public interest, according to NASA policy. During FY 1975, no reimbursable work was undertaken in the facility. However, if such work had been done, users would have been charged a $20,000 weekly occupancy rate plus actual utility and data reduction costs and a 15-percent NASA management surcharge.

14-FOOT TRANSONIC WIND TUNNEL

BUILDING NUMBER: N-218

INITIAL OPERATION: 1956

DESCRIPTION:

Mach number	0.6 to 1.2 (continuously variable)
Stagnation pressure	1.0 atmosphere
RN	2.8×10^6 to 4.2×10^6 per foot
Stagnation temperature	Generally 650° R
Height x width x length	13.5 x 13.71 (upstream) and 13.92 feet (downstream) x 33.75
Access	Side doors - 6.7 x 8.0 feet

NARRATIVE: The 14-foot transonic wind tunnel is a closed-circuit tunnel equipped with an adjustable, flexible-wall nozzle and a test section with four slotted walls. (The air circuit is closed except for the air exchanger, in a low-speed section, which is controlled to maintain suitable air temperature.) Airflow is produced by a three-stage, axial-flow compressor powered by three variable-speed, electric motors mounted in tandem outside the tunnel, rated at 110,000 horsepower continuously or 132,000 hp for 1 hour.

For conventional, steady-state testing, models are generally supported on an adjustable sting. Internal, strain-gage balances are used for measuring forces and moments. Additional facilities are available for measuring multiple steady or fluctuating pressures, as well as variable-speed compact model motors with a variable-frequency power source.

AVAILABILITY: This tunnel is one of three operated by contractor personnel at Ames Research Center. On a one-shift basis the tunnel was utilized more than 140 percent during FY 1975. Fifty-six percent of the testing supported NASA programs while the balance supported Navy (static stability characteristics) and USAF (jet flap effectiveness) studies.

More than 84 percent of the test hours requested by NASA and other users were scheduled for testing during FY 1975. Tests were generally rejected because the facility was not capable of accomplishing the test objectives.

11- BY 11-FOOT TRANSONIC WIND TUNNEL

BUILDING NUMBER: N-227a

INITIAL OPERATION: 1956

DESCRIPTION:

Mach number	0.4 to 1.4 (continuously variable)
Stagnation pressure	0.5 to 2.25 atmospheres
RN	1.7 x 10^6 to 9.4 x 10^6 per foot
Stagnation temperature	580° R
Height x width x length	11.0 x 11.0 x 22.0 feet
Access	Top hatch - 7.0 x 22.0 feet

NARRATIVE: This tunnel is one of three comprising the Ames unitary plan facility; a 9- by 7-foot supersonic tunnel and an 8- by 7-foot supersonic tunnel are also a part of this facility. The major common element of the tunnel complex is its electric powerplant consisting of four intercoupled motors capable of generating a total of 180,000 horsepower continuously.

The 11- by 11-foot transonic wind tunnel is closed-return, variable density tunnel with a fixed geometry, ventilated throat and a single-jack flexible nozzle. Airflow is produced by a three-stage, axial-flow compressor powered by four variable-speed motors.

For conventional steady-state testing, models are generally supported on a sting. Internal strain-gage balances are used for measuring forces and moments. (Additional facilities are available for measuring multiple steady or fluctuating pressures.)

A schlieren system for studying flow patterns by direct viewing or photography, and a system for obtaining 20- by 40-inch shadowgraph negatives are available.

AVAILABILITY: Operating on a two-shift basis, the tunnel was more than 95 percent utilized during FY 1975. Nearly 78 percent of the testing supported NASA programs while the remainder supported USAF and McDonnell-Douglas programs. Both USAF and McDonnell-Douglas were testing aircraft static stability characteristics.

Nearly 79 percent of the test hours requested by both NASA and other users during FY 1975 were scheduled for testing. Of the remaining tests requested, approximately 5 percent were postponed and 16 percent rejected by Ames officials because they were considered to be of low priority.

2- BY 2-FOOT TRANSONIC WIND TUNNEL

BUILDING NUMBER: N-222

INITIAL OPERATION: 1951

DESCRIPTION:

Mach number	0.2 to 1.4 (continuously variable)
Stagnation pressure	0.16 to 3.0 atmospheres
RN	0.5×10^6 to 8.7×10^6 per foot
Stagnation temperature	580° R
Height x width x length	2.0 x 2.0 x 5.0 feet
Access	Side doors - 2.0 x 5.0 feet

NARRATIVE: The 2- by 2-foot transonic wind tunnel is a closed-return, variable-density tunnel equipped with an adjustable, flexible wall nozzle and slotted test section. Airflow is produced by a two-stage, axial-flow compressor powered by four, variable-speed induction motors mounted in tandem, delivering a total of 4,000 horsepower. For conventional steady-state testing, models are generally supported on a sting. Internal, strain-gage balances are used for measuring forces and moments. (Additional facilities are available for measuring multiple steady or fluctuating pressures.)

This facility is also used for panel-flutter testing (one test-section wall is replaced with another containing the test specimen).

AVAILABILITY: Operating on a one-shift basis, the tunnel was utilized more than 140 percent during FY 1975. All of the testing undertaken was in support of NASA research.

More than 93 percent of the test hours requested by NASA and other users were scheduled for testing during FY 1975. The remaining tests requested were postponed until FY 1976.

Because this tunnel is dedicated to research (in contrast to development) projects, it is generally unavailable for commercial development projects. Only projects considered to have nonproprietary research merit are permitted to use the facility.

9- BY 7-FOOT SUPERSONIC WIND TUNNEL

BUILDING NUMBER: N-227B

INITIAL OPERATION: 1956

DESCRIPTION:

Mach number	1.55 to 2.5 (continuously variable)
Stagnation pressure	0.3 to 2.0 atmospheres
RN	1.5×10^6 to 6.5×10^6 per foot
Stagnation temperature	580° R
Height x width x length	7.0 x 9.0 x 18.0 feet
Access	Top hatch - 6.0 x 9.0 feet Side door - 3.0 x 6.5 feet

NARRATIVE: This tunnel is one of three comprising the Ames unitary plan facility; an 8- by 7-foot supersonic tunnel and an 11- by 11-foot transonic tunnel are also part of this facility. The most common element of the tunnel complex is its electric powerplant consisting of four intercoupled motors capable of generating a total of 180,000 horsepower continuously.

The 9- by 7-foot supersonic wind tunnel is a closed-return, variable density tunnel equipped with an asymmetric, sliding-block nozzle and a flexible upper plate. Variation of the test section mach number is achieved by translating, in the streamwise direction, the fixed contour block that forms the floor of the nozzle. Airflow is produced by an 11-stage, axial-flow compressor powered by 4 variable-speed induction motors.

For conventional steady-state testing, models are generally supported on a sting. Internal strain-gage balances are used for measuring forces and moments. (Additional facilities are available for measuring multiple steady or fluctuating pressures.)

A schlieren system for studying flow patterns by direct viewing or photography and a system for obtaining 20- by 20-inch shadowgraph negatives are available.

AVAILABILITY: Operating on a three-quarter shift basis, the tunnel was 99 percent utilized during FY 1975. More than 93 percent of the test time supported NASA programs while the remainder supported a USAF-sponsored inlet drag study.

Eighty percent of the test hours requested by NASA and other users during FY 1975 were scheduled for testing.

The unitary plan tunnels, including the 11- by 11-foot, are classified as development tunnels (in contract to research tunnels) and are therefore available to non-NASA users on a reimbursable basis. Users, such as the McDonnell-Douglas Corporation, are charged a $33,000 weekly occupancy rate plus actual utility and data reduction costs and a 15 percent NASA management surcharge.

8- BY 7-FOOT SUPERSONIC TUNNEL

BUILDING NUMBER: N-227c

INITIAL OPERATION: 1956

DESCRIPTION:

Mach number	2.45 to 3.5 (continuously variable)
Stagnation pressure	0.3 to 2.0 atmospheres
RN	1.0 x 10^6 to 5.0 x 10^6 per foot
Stagnation temperature	580° R
Height x width x length	8.0 x 7.0 x 16.0 feet
Access	Top hatch - 2.0 x 4.5 feet Side door - 8.0 x 10.0 feet

NARRATIVE: This tunnel is one of three comprising the Ames unitary plan facility; a 9- by 7-foot supersonic tunnel and a 11- by 11-foot transonic tunnel are also included. The most common element of the tunnel complex is its electric powerplant consisting of four intercoupled motors capable of generating a total of 180,000 horsepower continuously.

The 8- by 7-foot supersonic wind tunnel is a closed-return, variable-density tunnel equipped with a symmetrical, flexible-wall throat (the sidewalls are positioned by a series of jacks operated by hydraulic motors). The upper and lower surfaces are fixed. Airflow is produced by an 11-stage, axial-flow compressor powered by 4 variable-speed induction motors.

For conventional steady-state testing, models are generally supported on a sting. Internal, strain-gage balances are used for measuring forces and moments. (Additional facilities are available for measuring multiple steady or fluctuating pressures.)

A schlieren system for studying flow patterns by direct viewing or photography, and a system for obtaining 20- by 20-inch shadowgraph negatives are available.

AVAILABILITY: Based on a one-quarter shift basis (which is its normal utilization level), more than 83 percent of the test time during FY 1975 supported NASA programs. The balance supported the Army's testing of a missle's static stability characteristics.

Another 4 percent of the requested tests were postponed until FY 1976 and the balance were rejected. Tests were rejected by Ames officials because they were considered to be of low priority or unnecessary.

The unitary plan tunnels, including the 9- by 7-foot, are classified as development tunnels (in contrast to research tunnels) and are therefore available to non-NASA users on a reimbursable basis. During FY 1975 no reimbursable work was undertaken in the facility. However, if such work had been done, users would have been charged a $33,000 weekly occupancy rate plus actual utility and data reduction costs and a 15 percent NASA management surcharge.

6-BY 6-FOOT SUPERSONIC WIND TUNNEL

BUILDING NUMBER: N-226

INITIAL OPERATION: 1948

DESCRIPTION:

Mach number	0.25 to 2.2 (continuously variable)
Stagnation pressure	0.3 to 1.0 atmospheres
RN	1.0 x 10^6 to 5.0 x 10^6 per foot
Stagnation temperature	580° R
Height x width x length	6.0 x 6.0 x 14.4 feet
Access	Side doors - 5.0 x 5.0

NARRATIVE: The 6- by 6-foot supersonic wind tunnel is a closed-circuit, single-return tunnel equipped with an asymmetric sliding-block nozzle and a test section with a perforated floor and ceiling. Airflow is produced by an eight-stage, axial-flow compressor powered by two electric motors mounted in tandem outside the tunnel delivering a total of 60,000 horsepower.

For conventional steady-state testing, models are generally supported on a sting. Internal strain-gage balances are used for measuring forces and moments. (Additional facilities are available for measuring multiple steady or fluctuating pressures.)

A schlieren system for studying flow patterns by direct viewing or photography and a system for obtaining 20- by 20-inch shadowgraph negatives are available.

AVAILABILITY: Operating on a two-shift basis, the tunnel was fully utilized during FY 1975. More than 70 percent of the testing supported NASA programs while the balance supported the Army and USAF.

Approximately 84 percent of the test hours requested by NASA and other users during FY 1975 were scheduled for testing. Another 3 percent of the test hours requested were postponed until FY 1976 and the balance was rejected by Ames officials because they did not qualify as development tests.

The 6- by 6-foot tunnel is categorized as a research tunnel but it is made available to non-NASA users on a reimbursable basis. During FY 1975 no reimbursable work was undertaken in the facility. However if such work had been done, Ninety percent of the test hours requested by NASA and other users during FY 1975 were scheduled for testing. The remaining tests were rejected by Ames officials because they were considered to be of low priority or unnecessary.

The unitary plan tunnels, including the 8- by 7-foot, are classified as development tunnels (in contrast to research tunnels) and are therefore available to non-NASA users on a reimbursable basis. During FY 1975 no reimbursable work was undertaken in the facility. However, if such work had been done, users would have been charged a $33,000 weekly occupancy rate plus actual utility and data reduction costs and a 15 percent NASA management surcharge.

3.5-FOOT HYPERSONIC WIND TUNNEL

BUILDING NUMBER: N-229

INITIAL OPERATION: 1961

DESCRIPTION:

Mach numbers	5, 7, 10, and 14
RN	0.3×10^6 to 7.4×10^6/ft.
Dynamic pressure	1,600 psf, maximum
Stagnation pressure	122 atmospheres, maximum
Stagnation temperature	3,460° R, maximum
Length and diameter	10 feet and 3.5 feet

NARRATIVE: The 3.5-foot hypersonic wind tunnel is a closed circuit, blow-down, wind tunnel, utilizing interchangeable contoured axisymmetric nozzles. Heat is supplied to the test gas by a storage heater containing aluminum oxide pebbles which are heated by burning natural gas during the recycle period. Usable test time, dependent upon test conditions, varies from 1/2 to 3 minutes, and the time between test runs averages 1½ hours. The test region is of the open jet type. The effective test section core is an open jet 3.5 feet in diameter and approximately 10 feet in length. A model support inserts and retracts models from the test stream and has a remotely actuated angle of attack range from -20 to +20 degrees. Shadowgraph and cameras are contained within the test chamber. Data is normally recorded in digital form on magnetic tape at a rate of 2,500 samples per second.

AVAILABILITY: Operating on a two-shift basis, the tunnel was fully utilized during FY 1975. Approximately 94 percent of the testing supported NASA research (primarily related to the space shuttle program) while the balance of time was used to test the Phoenix Missile for the Navy.

In August 1975 the 3.5-foot tunnel was damaged by the rupture of a flange. It is estimated the tunnel will be repaired by January 1976. Most of the ongoing space shuttle work was transferred to Arnold Engineering Development Center in Tennessee.

Sixty-five percent of the test hours requested by NASA and others were scheduled for testing during FY 1975. The balance of test requests were rejected because of lack of manpower.

users would have been charged a $20,000 weekly occupancy rate plus actual utility and data reduction costs and a 15 percent NASA management surcharge.

THE THERMAL PROTECTION LABORATORY

(HYPERSONIC)

BUILDING NUMBER: N-234

INITIAL OPERATION: 1962

DESCRIPTION:

Mach number	2.5 to 15*
Steam enthalpy	500 to 15,000 btu/lb.*
Plenum pressure	15 to 1200 PSI*

*Varies by facility (see below).

NARRATIVE: The thermal protection laboratory is used to research materials for heat shield applications and for aerodynamic heating and materials studies of vehicles in planetary atmospheres. This laboratory is comprised of five separate facilities: an aerodynamic heating tunnel, a heat transfer tunnel, two supersonic turbulent ducts, and a high-power CO_2 gasdynamic laser. All these facilities are driven by arc-heaters, with the exception of the large, combustion-type laser. The arc-heated facilities are powered by a 20 megawatt DC power supply. Their effluent gas stream (test gases; air, nitrogen, helium, and mixtures) discharges into a five-stage steam-ejector-driven vacuum system. The vacuum system and power supply are common to the test facilities in building N-238. All of the facilities have high-pressure water available at flow rates up to 4,000 gals./min. The data obtained from these facilities are recorded on magnetic tape or oscillographs. All forms of data can be handled whether from thermocouples, pressure cells, pyrometers, or radiometers, etc. In addition, closed circuit T.V. monitors and various film cameras are available.

AVAILABILITY: Operating on a one-shift basis, the thermal protection laboratory was fully utilized during FY 1975. All of the testing supported NASA research.

Nearly 67 percent of the test hours requested by NASA and others were scheduled for testing during FY 1975. The balance of test requests were rejected because of lack of manpower.

The thermal protection laboratory is classified as a research facility (in contrast to a development facility) and is therefore generally unavailable for commercial development projects.

The 3.5-foot facility is classified as a research tunnel (in contrast to a development tunnel) and is therefore generally unavailable for commercial development projects.

ELECTRIC ARC SHOCK TUBE FACILITY (HYPERSONIC)

BUILDING NUMBER: N-229

INITIAL OPERATION: 1966

DESCRIPTION:

Speed	30 to 40 Km/sec.
Maximum	6000 psi
RN	Not applicable
Maximum temperature	20,000°C
Length and diameter	40 feet and 4 inches

NARRATIVE: The electric arc shock tube facility is used for investigations, such as gas laser development, radiation and ionization studies for outer planetary entries, chemical reaction rate measurements, and diagnostics in high-energy flows requiring a high-performance electric arc driven shock tube facility. Shock velocities of 30 to 40 Km/sec. can be attained with quick succession operation (3 to 5 tests per day) utilizing the conical arc chamber. Energy for the driver is supplied by a one-megajoule capacitor storage system. It can be charged to a preset energy at either a 0 to 40 kV mode (1,250 μ f) or a 0 to 20 kV mode (5,000 μ f). The unique capability to change circuit capacitance for a particular energy storage permits control of the current pulse width (time constant) of the arc discharge.

AVAILABILITY: Operating on a one-shift basis, this facility was fully utilized during FY 1975. Fifty-two percent of the testing supported NASA research while the balance of time was dedicated to studying the interaction of water droplets with reentry vehicle shock waves for the Defense Nuclear Agency.

Nearly 82 percent of the test hours requested by NASA and others were scheduled for testing during FY 1975. The balance of tests were rejected because of a lack of manpower.

The electric arc shock tube is classified as a research facility (in contrast to a development facility) and is therefore generally unavailable for commercial development projects.

AERODYNAMIC FREE-FLIGHT FACILITY (HYPERSONIC)

BUILDING NUMBER: N-237

INITIAL OPERATION: 1965

DESCRIPTION:

Stream mach number	7.0
Stream enthalpy	4,000 btu/lb., maximum
RN	80 x 10^6 per ft., maximum
Stream static pressure	0.005 to 0.2 atmospheres
Model speed	30,000 ft./sec. maximum
Model launching acceleration	1.5 x 10^6 g, maximum
Length and diameter	75.0 feet x 3.5 feet

NARRATIVE: The aerodynamic free-flight facility is used for research on gas dynamic problems of atmospheric entry. High relative speeds are achieved by launching models (in sabots if necessary) from high-speed guns into a countercurrent hypersonic air stream (14,000 ft/sec) driven by combustion-powered shock tube. Parameters derived from observations of model flights include lift, drag, static and dynamic stability, flow characteristics (including absolute spectral emissive power of shock layers and wakes), and model ablation. Models up to 37 mm in diameter and weighing 45 grams maximum can be accommodated. Shadowgraphs can be obtained at 16 stations spaced every 5 feet along the test section.

AVAILABILITY: Operating on a one-shift basis, this facility was utilized approximately 60 percent during FY 1975. All of the testing supported NASA research--primarily research relating to planetary landing vehicles.

Nearly 88 percent of the test hours requested by NASA and others were scheduled for testing during FY 1975. The balance of test requests were rejected because of lack of manpower.

The aerodynamic free-flight facility is classified as a research tunnel (in contrast to a development tunnel) and is therefore generally unavailable for commercial development projects.

INTERACTION HEATING FACILITY (SUPERSONIC)

BUILDING NUMBER: N-238

INITIAL OPERATION: 1973

DESCRIPTION:

	20MW pilot test facility	60MW interaction heating facility
Enthalpy	4,000 to 14,000 Btu/lb	4,000 to 14,000 Btu/lb
Plenum pressure	1 to 10 atmospheres	1 to 10 atmospheres
Conical nozzle exit diameter (mach 5)	16 inches	41 inches
Semi-elliptic width (mach 3)	15 inches, flat side	30 inches, flat side

NARRATIVE: The interaction heating facility and the 20 megawatt pilot test facility are used for studies of aerodynamic heating in the thermal environment resulting from the interaction of a flow field with an irregular surface. Both facilities are essentially identical, except for scale, and are driven by constricted arc-heaters rated at 60 MW and 20MW, respectively. Power is furnished by two DC power supplies; a 40MW power supply serving building N-238, and a 20MW power supply common to building N-234. The effluent gas stream (test gas is air with flow rates from 0.1 to 5.0 lb/sec) discharges into a five-stage steam-ejector-driven vacuum system, also common to building N-234. Two nozzles are available for each facility, a conical nozzle (mach number 5), and a semi-elliptic nozzle (mach number 3). Data is recorded by digital printout paper tape and by punched paper tape from pressure cells, calorimeters, thermocouples, and optical pyrometers. Run-time is 30 minutes for each facility.

AVAILABILITY: We did not gather detailed utilization data for several specific-purpose facilities, including the interaction heating facility. However, because it is classified as a research facility (in contrast to a development facility) it is generally unavailable for commercial development projects.

ADVANCED ENTRY HEATING SIMULATOR (SUPERSONIC)

BUILDING NUMBER: N-207

INITIAL OPERATION: 1969

DESCRIPTION:

Stream enthalpy	2,000 to 15,000 btu/lb.
Mach numbers	2 to 5
Stagnation pressure	0.1 to 3.0 atmospheres
Arc chamber pressure	1.0 to 15.0 atmospheres
Nozzle exit pressure	0.0005 to 0.02 atmospheres
Nozzle exit diameters	1.6 to 7 inches

NARRATIVE: The advanced entry heating simulator is used for aerodynamic-heating and thermal-protection-materials studies of vehicles entering planetary atmospheres. It consists of a 3 megawatt arc-heated supersonic wind tunnel employing vortex and magnetic field methods of arc stabilization and operates in conjunction with a broad band radiative heating system which can furnish an additional 3,000 btu/ft.^{2}/sec. to 0.6-inch diameter models. Test gases include air and nitrogen with flow rates from 0.05 to 0.5 lbs/sec. Data is recorded on oscillographs or magnetic tapes utilizing calorimeters, pyrometers, and pressure cells. Models with specimen diameters from 0.5 to 2.0 inches can be accommodated. Run-time is 5 minutes maximum.

AVAILABILITY: We did not gather detailed utilization and programmatic data for several specific-purpose facilities, including the advanced entry heating simulator. However, because it is classified as a research facility (in contrast to a development facility) it is generally unavailable for commercial development projects.

1- BY 3-FOOT SUPERSONIC WIND TUNNEL

BUILDING NUMBER: N-207

INITIAL OPERATION: 1946

DESCRIPTION:

Mach number	0.4 to 0.9 and 1.4 to 6.0
RN	0.5×10^6 to 12×10^6 per foot
Stagnation pressure	0.13 to 4.0 atmospheres
Stagnation temperature	520° to 600° R
Height x width x length	2.8 (max.) x 1.0 x 5.5 feet
Access	Both sides - 2.0 feet diameter Downstream hatch - 2.0 x 1.5 feet

NARRATIVE: The 1- by 3-foot supersonic wind tunnel is closed-circuit and can be operated continuously at mach numbers from 0.4 to 0.9 and from 1.4 to 6.0. The air is driven by 4 compressors operated in parallel for mach numbers lower than 2.2. For the higher mach numbers, 2 or 3 of the same compressors connected in parallel are operated in series with a larger compressor (No. 5). Models for conventional, steady-state tests are generally sting-mounted. The sting-support system provides for large simultaneous variations in the vertical-plane angle and the roll angle. The vertical-plane angle can be varied ± 45°.

Special equipment is available for supersonic air-inlet testing. Flow-visualization equipment is available and schlieren photographs are readily obtained, but special arrangements must be made for shadowgraph pictures.

AVAILABILITY: This is a relatively small facility which has been primarily used for research testing. However, during FY 1975 the 1- by 3-foot tunnel was not utilized because of lack of demand. Because it is classified as a research facility (in contrast to a development facility), it is generally unavailable for commercial development projects.

FLUID DYNAMICS LABORATORY (SUPERSONIC)

BUILDING NUMBER: N-231

INITIAL OPERATION: 1973

DESCRIPTION:

Mach number	0.5 - 0.8 and 1.2 - 1.5
RN	40.0×10^6 and 200.0×10^6 per foot
Height x width x length	10 x 15 x 60 inches

NARRATIVE: The facility is of the blow-down type and uses a large settling tank with various throttling plates and screens for conditioning the flow. The facility is designed for operation at RNs per foot up to 40 million for subsonic flows and to 200 million for supersonic flows. Interchangeable test channel configurations are to be used, each designed specifically for the test flow to be studied.

AVAILABILITY: This facility is presently being used in conjunction with the ILLIAC IV computer to compare and contrast measured (by physical testing) and numerically simulated airfoil pressure distributions. Ames scientists believe that computer simulation will eventually reduce the level of wind tunnel testing presently necessary. We did not gather detailed utilization and programmatic data for this specific-purpose facility. However, because it is classified as a research facility (in contrast to a development facility) it is generally unavailable for commercial development projects.

12-INCH ARC DISCHARGE SHOCK TUBE (HYPERSONIC)

BUILDING NUMBER: N-230

INITIAL OPERATION: 1964

DESCRIPTION:

Speed	2 to 25 km/sec.
Stagnation pressure	Unstated
RN	Unstated
Stagnation temperature	Unstated
Length and diameter	50 feet and 12 inches

NARRATIVE: The 12-inch arc discharge shock tube is used for high-speed gas physics and chemical kinetics research. It consists of an exploding wire arc discharge driver which can be powered by a capacitor discharge of 1250, 2500, 3750, or 5000 u F at voltages between 10 and 20 kV, 10^6 joules at maximum. This energy in the driver can produce shock velocities in the 12-inch-diameter driven tube between 2 and 25 km/sec. The tube is 50 feet long and is made of type 304 stainless steel.

AVAILABILITY: Detailed utilization and programmatic data was not gathered by GAO for several specific-purpose facilities, including the 12-inch arc discharge shock tube. However, this facility has been inactive since January 1973. Because it is classified as a research facility (in contrast to a development facility) it is generally unavailable for commercial development projects.

Lewis Research Center (LeRC)

ICING RESEARCH TUNNEL (SUBSONIC) (IRT)

BUILDING NUMBER: 11

INITIAL OPERATION: 1944

DESCRIPTION: With a test section size measuring 6' high, 9' wide and 20' long, this is the largest icing tunnel in North America and NASA's only such facility. It has a maximum speed range of 260 mph and can simulate icing conditions to -40 degrees. The IRT allows testing with full-scale models. It can run longer than the other Lewis Research Center (LeRC) tunnels.

NARRATIVE: The IRT is used for low-speed testing of icing condition effects on full-scale wings and empennages, inlets, radomes and antennas, propellers and fans, and instruments. In the past it was used for basic research to solve icing problems experienced in slow-speed aircraft. Icing technology is now well documented, so the IRT is no longer needed as a research tool.

In fiscal year 1975 only one project was conducted in the tunnel, a study of icing conditions on turbine engine inlets of a Sikorsky helicopter. This aircraft is part of the Army's multi-million dollar UTTAS program.

There is no long-range usage schedule for the IRT.

AVAILABILITY: The IRT is available on a first-come-first-serve basis. It fulfilled the only request it received in fiscal year 1975. Even though it is used primarily by industry, no reimbursable costs are involved because projects tested usually have Government sponsorship.

After the Sikorsky project the IRT was used to test a Boeing-Vertol model, a competitor to the Sikorsky helicopter. Both projects were sponsored by the Army.

V/STOL WIND TUNNEL (SUBSONIC)

BUILDING NUMBER: 39

INITIAL OPERATION: 1968

DESCRIPTION: The test section measures 9' high, 15' wide and 20' long. The V/STOL is used for research on scale models of vertical and short take-off and landing engine components. Situated in the return leg of the 8' x 6' tunnel, the V/STOL facility has a speed range of 50 - 175 mph. It was recently equipped with highly sensitive noise detection and suppression devices to enable it to study noise abatement problems. It duplicates Rn between 300,000 and 1.3 million/ft, lowest of any LeRC wind tunnel.

NARRATIVE: The tunnel was originally built to perform low-speed propulsion tests of wing-mounted model V/STOL liftfans for the Army's liftfan, lift-cruise fan demonstrator program. Currently, and for the next couple years, the tunnel will test inlets and other engine components of STOL-type aircraft. As was the case in 1974, the tentative 2 year usage schedule shows the tunnel doing in-house research only. It is being used to develop propulsion technology for NASA's multi-million dollar quiet, clean, short-haul experimental engine (QCSEE) program. This program is expected to benefit civil short-haul planes (primarily) and military helicopters and ground support aircraft.

AVAILABILITY: The tunnel is primarily an in-house research facility not ordinarily used by outsiders. No requests were received or filled for out-of-house work during the period reviewed. Since most testing is NASA-oriented, no reimbursements are involved.

The tentative future tunnel obligations (next 2 to 3 years) are as follows.

Type of test	Percent
Directional acoustic validation	5
Inlet aerodynamics & acoustics	5
Turboprop & turbofan aero/acoustics	15
Thrust reversers aero/acoustics	15
Inlet aerodynamics	15
20" STOL simulator for QCSEE program	45
Total	100

8- BY 6- FOOT RESEARCH TUNNEL (SUPERSONIC)

BUILDING NUMBER: 39, 46, 53-55, 57, 61, and 138

INITIAL OPERATION: 1949

DESCRIPTION: The test section is 8' high, 6' wide, and 39' long. Its mach number range is 0.36 to 2.0--which enables it to test in the subsonic, transonic, and supersonic regimes. The 8' x 6' is the only LeRC tunnel that has this capability. It is a continuous-flow tunnel whose running time is somewhat restricted (depending on type of test, weather, etc.) by the capacity of its air dryer.

NARRATIVE: Propulsion and aerodynamic tests in three speed regimes are conducted in this wind tunnel. At one time it was used to test ramjet engines at supersonic speeds. Since the tunnel was modified about 15 years ago most of the testing is done at high subsonic, low transonic speeds --desirable speeds for energy conservation and low noise levels.

The 8' by 6' has been used for NASA's Titan-Centaur launch vehicle, the USAF's YF-16 air combat fighter, and USAF B-I and F-106 test models. During 1974 the tunnel was occupied 37 percent of the time with out-of-house projects--all for USAF.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research projects. If tests can be integrated into the planned programs, these requests are granted at no reimbursed costs, since they are normally Government sponsored. Specialized models and unique equipment are provided by outsiders when such projects are accepted. This is LeRC's most popular wind tunnel. Nine DOD requests (5 Navy and 4 USAF) were either rejected or tentatively denied during the first 6 months of 1975. Most of the tunnel's time is expected to be devoted to in-house projects as shown in the tentative 2-to-3 year schedule below.

Type of test	Percent
Ongoing military programs (e.g., YF-16 and Sonobouy)	8
In-house research on suppressor nozzles	8
NASA HIMAT program	8
Outside aerodynamic tests	8
CTOL program (in-house)	16
Isolated turboprops & Airframe integration study (in-house)	52
Total	100

10- BY 10-FOOT SUPERSONIC WIND TUNNEL

BUILDING NUMBER: 85-94, 113, and 114

INITIAL OPERATION: 1955

DESCRIPTION: This is LeRC's largest and fastest wind tunnel. Its test section is 10' high, 10' wide, and 40' long. The speed range is from mach 2.0 to 3.5, with continuous air flow as long as the air dryer is able to absorb moisture. Running times vary between 1 and 8 hours.

NARRATIVE: Propulsion and aerodynamic tests primarily in the supersonic regime are conducted in this tunnel. It was initially designed for dynamic testing of power plant systems of aircraft and missiles. Current and future work will help advance propulsion technology on NASA's supersonic cruise aircraft research program. The tunnel has been used to test models of the YF-12, TF-30, Trident missile, space shuttle, and the Zuni. During the period reviewed out-of-house projects occupied 12 percent of the tunnel's time. Thirty-two percent of the occupied hours were devoted to advancing the state of the art of engine inlets to be used on future high-speed planes.

AVAILABILITY: Requests for tunnel use are screened against ongoing and planned research programs. If tests can be integrated into the planned programs, these requests are normally granted at no reimbursable costs. However, because it is a "unitary wind tunnel" it is available to industry on a fee basis--something that has never happened. Out-of-house work included tests related to the USAF's J-85, the Navy's Trident missile, and the USAF's Zuni project.

The tentative schedule (2 to 3 years) for tunnel time is as follows.

Type of test	Percent
Outside aerodynamic tests	19
Development of inlet engine compatability and control criteria for supersonic cruise aircraft (in-house)	36
Improved analytical and experimental design methodology for inlets to achieve higher performance and stability (in-house)	45
Total	100

SPACE POWER CHAMBERS

OWNER: NASA

STATUS: Inactive

INITIAL OPERATION: 1944

NARRATIVE: The facility was originally built in 1942 as a subsonic altitude wind tunnel and converted to an environmental test chamber in 1961. It is capable of altitude simulation up to 100,000' and its chambers measure 30' and 50' in diameter each. It had been used primarily for space flight experiments.

HYPERSONIC TUNNEL FACILITY

OWNER: NASA

STATUS: Inactive

INITIAL OPERATION: 1971

TEST SECTION SIZE: 42" diameter

SPEED RANGE: 3,500 - 4,900 m.p.h.

TYPE: Blow down

ALTITUDE OR PRESSURE RANGE: 70,000' plus

RN (max.): 2.27 million/ft. at mach 5
1.86 million/ft. at mach 6
0.91 million/ft. at mach 7

NARRATIVE: The tunnel was originally built as a hydrogen heat transfer facility at a cost of $3 million in 1966. After a $3.1 million conversion project, the hypersonic tunnel became operational in 1971.

With a test section of 42" diameter, this is NASA's largest hypersonic wind tunnel and the only one capable of doing propulsion work with full-scale model engines.

The heart of the facility, an electrically heated graphite core, heats nitrogen to mix with oxygen. This produces the tunnel's own supply of synthetic air. Three interchangeable nozzles produce mach 5, 6, and 7 speeds in the test chamber. Altitudes in the 70,000' range can be simulated.

The hypersonic tunnel is a blow-down type not capable of continuous operation. Because the pebble bed must be reheated and the stored gases recharged, the tunnel can only be run every 24 hours and then for only about 3 minutes.

The tunnel was placed in a standby status in July 1974. No tests have been made in that facility since then. If NASA headquarters decides to reactivate the tunnel, it will take about 6 months longer to restore to operation.

Marshall Space Flight Center (MSFC)

14- BY 14-INCH - TRISONIC

INSTALLATION: 1956

TEST SECTION: Height - 14 inches
Length - 20 inches
Width - 14 inches

MACH NUMBER RANGE: 0.25-5.00, intermittent

RN: 1 to 18 x 10^6

NARRATIVE: The facility was constructed for the purpose of providing static and dynamic stability and pressure distribution data required for the aerodynamic design of Army missiles. After its transfer to NASA in 1960, the tunnel was used to produce static and dynamic stability and unsteady and static pressure distribution data for the development of the Saturn vehicles. The facility is curently being used in the development of the space shuttle.

During fiscal year 1975, MSFC received eight requests for tests. Six of the requests were from the Johnson Space Center (JSC) and its prime contractor for the space shuttle, and the other two requests were from the U.S. Army Missile Command (MICOM). The requests from JSC and its prime contractor totaled 1,000 hours, and the Army's requests totaled 120 hours.

One of the Army's requests for 80 hours was denied because of the heavy test load for the space shuttle program during the time period requested. The other Army request for 40 hours was reduced to 24 hours and deferred to fiscal year 1976 because of the shuttle testing schedule. MSFC charged MICOM $7,200 for the 24 hours of test time. The rate charged MICOM was computed using estimated labor, power, maintenance, and consumable costs. The computed rate was then applied to the 24 hours of test time.

The tests made for JSC and its prime contractor consisted of static stability and load distribution tests of the orbiter vehicle and the space shuttle launch configuration. The actual test time required totaled 496 hours which represent 24.8 percent of the 2,000 hours available and 27.1 percent of the 1,824 hours of occupied time. The tests were made on a nonreimbursable basis.

Of the 1,800 occupied hours projected for fiscal year 1976, the following schedule shows the anticipated users.

User	Hours	Percent
MSFC	1,376	77
JSC	400	22
MICOM	24	1
Total	1,800	100

HIGH-RN (TRISONIC)

INSTALLATION: 1969

TEST SECTION: Height - 32 inches
Length - 64 inches
Width - 32 inches

MACH NUMBER RANGE: 0.3 - 3.5, intermittent

RN: 7 - 200 X 10^6

NARRATIVE: The facility was constructed for the purpose of providing a special test capability in support of the Saturn vehicle development. The primary tests consisted of static stability and pressure distribution tests. The facility achieved an RN in the transonic speed range which was greater than any available ground test capabilities. According to MSFC officials, its transonic RN test capability is four times higher than any other facility in the Western World.

The tunnel is currently being used in support of the development of the space shuttle and its components. Static stability and pressure distribution tests have been made on the Solid Rocket Booster. In addition, changes in the nose shape of the external tank have been investigated. A critical wing investigation for USAF and a missile test for the Navy have also been made.

MSFC was the only user of the facility during fiscal year 1975, but MSFC received two requests for a total of 700 hours of test time during fiscal years 1976 and 1977. Ames Research Center requested 220 hours, and the Johnson Space Center and its prime contractor for the space shuttle requested the remaining 480 hours. MSFC approved both requests on a nonreimbursable basis.

Of the 1,800 occupied hours projected for fiscal year 1976, the following schedule shows the anticipated users.

User	Hours	Percent
MSFC	1,200	66
JSC	480	27
ARC	120	7
Total	1,800	100

IMPULSE BASE FLOW FACILITY

INSTALLATION: 1963

VACUUM CHAMBER: Diameter - 18 feet, length - 26 feet

PUMPDOWN TIME: 5×10^{-2} torr - 25 minutes
5×10^{-4} torr - 125 minutes

NARRATIVE: This facility was built to provide a specialized capability needed because of MSFC's responsibility for the development of launch vehicles. This special requirement was to evaluate experimentally the base heating rates of launch vehicles on stages at altitudes sufficiently high for the external flow field to be neglected.

The facility provided valuable test data through the life of the Saturn program. Stages tested were SIC, SII, and SIV. Base heating and plume (high-pressure nozzle flow) impingement heating tests were conducted in phase A-B of the shuttle program. Orbiter base heating tests were also conducted in phase C.

In fiscal year 1975, 17.9 percent of the occupied time was used by Rockwell International/Johnson Space Center for base heating tests of the 250 shuttle orbiter configuration. There were no funds transferred for the tests as they were covered by task agreements between MSFC and JSC.

The projected utilization of this facility in the next year is uncertain. Availability of manpower for its operation and a decision concerning a pending shuttle orbiter base heating test are the primary factors causing this uncertainty. The utilization by others depends on the decision to be made concerning orbiter base testing.

THERMAL ACOUSTIC JET FACILITY

INSTALLATION: 1966

OPERATING PRESSURE: 100-3500 psi- cold flow leg
300-1500 psi - hot flow leg

NARRATIVE: The intended use of this facility was to produce a controlled high-pressure air supply which would be exhausted through single or multiple nozzles to the atmosphere for the purpose of evaluating the acoustic characteristics of the flow field thus generated.

The facility has been used for acoustic investigations and for the development of specialized instrumentation for unsteady aerodynamic applications. Since 1973 it has been inactive. There are no specific tests planned for the immediate future. There is potential application for nozzle calibration testing in association with activities in space shuttle plume (high-pressure nozzle flow) technology. Pending the completion of current testing, data evaluation, and design impact evaluation from the acoustic model test program for shuttle rocket engine acoustics, there exists a potential use for this facility for jet flow and rocket engine noise investigations using cold and/or warm (heated) air.

PLASMA WIND TUNNEL

INSTALLATION: 1968-69

TEST SECTIONS:

1. Ultrahigh-vacuum plasma wind tunnel
   4 feet diameter x 6 feet length
   1×10^{-11} torr ultimate pressure
2. High-vacuum plasma wind tunnel
   2 feet diameter x 6 feet length
   1×10^{-7} torr ultimate pressure

NARRATIVE: The facility was built to conduct experimental studies of low-density space plasma problems, including the interaction of flowing plasma with bodies of arbitrary shape, size, and surface material; the effect of contamination on electrostatic plasma probes; and the development of new and/or improved probes and diagnostic techniques in order to understand spacecraft-space plasma interactions and to develop concepts for future space experiments.

In the opinion of MSFC personnel, the facility is being well utilized in support of several NASA projects. In the past 5 years, 19 publications have resulted from the efforts in the facility.

LOW-DENSITY CHAMBER (SUPERSONIC)

INSTALLATION: 1966

TEST SECTION: Height - 30 inches
Length - 30 inches
Width - 30 inches
Other - tank diameter 3.5 feet
- tank length 14 feet

MACH NUMBER RANGE: 3.0, intermittent - 2 to 5 minutes (The facility is basically a vacuum chamber, but it can be equipped with a nozzle for low-density flow work.)

RN: Not applicable

NARRATIVE: The facility was constructed for the purpose of providing a capability for gaseous and liquid plume (high-pressure nozzle flow) diagnostic at orbital altitudes, low-density aerodynamics for orbital decay studies, and instrumentation evaluation at low pressures. The chamber has been used for these purposes but most of the work has been in the gaseous and liquid plume diagnostics area.

The facility has not been used since late 1973. There are no tests planned for fiscal year 1976; however, plans call for its use in fiscal year 1977 as follows.

--Long duration testing of cool jet flows for plume probing, plume impingement, and plume flow fields resulting from gases stored on board spacecraft and spacecraft leaks.

--Investigating fuel and liquid waste discharges from spacecraft and payloads at near orbital conditions.

--Conducting low-density, high-velocity investigations to determine force and moment characteristics on spacecraft at simulated altitudes ranging from 200,000 to 400,000 feet.

--Investigating the "free field" definition and boundaries for free flying or remotely controlled space probes.

7 BY 7 INCH (BISONIC)

INSTALLATION: 1953

TEST SECTION: Height - 7 inches
Length - 12 inches
Width - 7 inches

MACH NUMBER RANGE: 0.4 - 0.9
1.58 - 4.39
Intermittent

RN: $1 - 4 \times 10^6$

NARRATIVE: The facility was constructed for the purpose of providing static and dynamic stability and pressure distribution data required for the aerodynamic design of Army missiles. It was used for this purpose between 1953 and 1960. The tunnel was transferred to NASA in 1960, and until 1972 it was used to provide static stability, instrumentation development, and pressure distribution data in support of the Saturn vehicle development.

The facility has not been used since 1972, is not presently committed to any specific test project, and no future requirements are foreseen. It had not been dismantled previously because of its potential use in the space shuttle program. MSFC officials have now determined, however, that no shuttle testing will be done in the facility.

Jet Propulsion Laboratory (JPL)

LOW-TURBULENCE WIND TUNNEL

BUILDING NUMBER: 183

INITIAL OPERATION: 1966

DESCRIPTION: Speed range: 0 to 80 ft/sec
Test section size: height - 24 inches
width - 24 inches
length - 108 inches

NARRATIVE: Since its construction in 1966, the tunnel has been used primarily for turbulence research. Several projects have used the tunnel as follows.

--Boundary layer transition (1966-74). Researched the properties of laminar and turbulent boundary layers and the transition between the two types.

--Air/sea interaction program (1971). Determined how energy is passed from wind to ocean waves.

--Air frame noise (current). Obtaining a basic understanding of why air produces noise when passing over a plane's surfaces.

--Compliant wall boundary layer research (current). Devising a flexible surface to extend the laminar boundary.

The tunnel has not been available to other users except for three California Institute of Technology Ph. D. candidates who have used the tunnel over the years for their research. No reimbursement was required because of the low operating costs.

6-INCH ARC-HEATED SHOCK TUBE

BUILDING NUMBER: 188

INITIAL OPERATION: 1962

DESCRIPTION: Speed range: 39,372 to 157,488 ft/sec (12 to 48 KM/sec)
Test section size: diameter - 6 inches
length - 60 inches

NARRATIVE: This shock tube has been totally committed to the planetary probe design/outer planets program since its construction. JPL officials indicate that it will remain committed to this R&D program for the next 3 to 5 years.

The tube is used in research to study the heat transfer problems encountered by planetary probes.

This facility has not been available to non-JPL users in the past nor will it be in the foreseeable future.

12-INCH FREE-PISTON SHOCK TUBE

BUILDING NUMBER: 188

INITIAL OPERATION: 1963

DESCRIPTION: Speed range: 18,000 to 30,000 ft/sec into air or CO2 or 5,000 to 40,000 ft/sec into hydrogen
Test section size: Diameter - 12 inches
Length - 24 inches

NARRATIVE: This shock tube has been totally committed to the planetary probe design/outer planets program since its construction. JPL officials indicate that it will remain committed to this R&D program for the next 3 to 5 years.

The tube is used in research to study the heat transfer problems encountered by planetary probes.

This facility has not been available to non-JPL users in the past nor will it be in the foreseeable future.

43-INCH SHOCK TUNNEL

BUILDING NUMBER: 188

INITIAL OPERATION: 1964

DESCRIPTION: Speed range: 12.5 mach
Test section size: Diameter - 43 inches
Length - 215 inches

NARRATIVE: This shock tunnel was used for the Mars entry portion of the planetary probe design research and development program. In September 1972, once the research had been completed, the tunnel was dismantled and placed in storage. Officials say it would only be used again should there be further need to research the entry to Mars.

The shock tunnel was not available for use by non-JPL agencies or on other projects during its use for Mars entry problems.

20-INCH SUPERSONIC WIND TUNNEL

BUILDING NUMBER: 79

INITIAL OPERATION: 1950

DESCRIPTION: Speed range - 0.4 to 5.0 mach
Test section size - height 20" to 22"
width 18"
length 46"

NARRATIVE: JPL authorities state this tunnel has qualities unique within NASA: (1) continuous, high-quality (uniform) air flow and (2) low-turbulence (quiet) air flow. It also has the capability to vary the mach number during operation or within 5 minutes while in a bypass mode.

A limiting factor, however, is the relatively small test section size which restricts the types of tests to those involving small-scale models.

Models may be tested mounted in several ways or may be pneumatically launched into free flight. Air pressure altitude is variable from 15,000 to 185,000 feet.

Some of the more significant test programs conducted in the 20-inch tunnel are as follows.

--Boundary layer research (1952-75). Research into the properties of laminar and turbulent boundary layers and the transition between the two types.

--Apollo command module (1962). Tests were conducted to determine pressure and temperature distributions and the static aerodynamic characteristics of the command module.

--Voyager configuration studies (1964). Tests were made of a series of capsule configurations at different mach numbers from 2.2 to 4.5.

--Near field sonic boom pressure tests (1968). A series of tests was performed to determine the near field sonic boom characteristics of shapes related to SST designs.

--Shuttle orbiter sonic boom tests (1973-75). Tests to determine the pressure pattern of various shuttle orbiter configurations.

The 20-inch tunnel has been available for use by various non-JPL users through the years. There has been a decreasing use of the wind tunnel and during FY 1975 it was used for only three projects. The U.S. Army Missile Command conducted "Developmental Force Tests" during 64.5 hours of occupancy and Ames Research Center used 58.4 occupancy hours for its "Space Shuttle Sonic Boom" program. A third test was conducted by JPL during 144 occupancy hours.

Tunnel users are required to reimburse JPL for all direct test-related costs plus a share of the maintenance costs because the tunnel operation is not directly funded by NASA.

The tunnel was scheduled for deactivation on February 27, 1976.

21-INCH HYPERSONIC WIND TUNNEL

BUILDING NUMBER: 80

INITIAL OPERATION: 1959

DESCRIPTION: Speed range: 4.0 to 11.0 mach
Test section size: height 15.8" to 26.7"
width 19.8"
length 70"

NARRATIVE: JPL authorities state this tunnel has qualities unique within NASA. It has a continuous high-quality (uniform) air flow and low-turbulence (quiet) air flow. It also has the capability to vary the mach number during operation while in the bypass mode. Mach number changes require about an hour to accomplish but do not require a nozzle change. All other hypersonic tunnels do require a nozzle change, according to JPL authorities.

As in the 20-inch tunnel, the relatively small test section size restricts the types of tests to those involving small-scale models. Models may be test mounted in several ways or may be pneumatically launched into free flight. Air pressure altitude can be varied from 85,000 to 220,000 feet and air temperature can be varied from 100 degrees to 1350 degrees F.

Some of the more significant test programs which have utilized the 21-inch tunnel are listed below.

--Boundary layer research (1960-75). Research into the properties of laminar and turbulent boundary layers and the transition between the two types.

--Apollo command module (1962). Tests were conducted to determine pressure and temperature distributions and the static aerodynamic characteristics of the command module.

--Voyager configuration studies (1964). Tests were made of a series of capsule configurations at different mach numbers from 4.0 to 9.5.

--Near field sonic boom pressure tests (1968). A series of tests were performed to determine the near field sonic boom characteristics of shapes related to SST designs.

--Saturn launch vehicle (1970). Test program conducted to determine how closely static wind tunnel data would compare with flight data.

--Shuttle orbiter sonic boom tests (1973-74). Tests to determine the pressure pattern of various shuttle orbiter configurations.

The last test conducted in the tunnel was a 6-hour operation (14-hour occupancy) test for Ames Research Center in July 1974. The tunnel has remained idle since then.

The 21-inch tunnel has been available for use by various non-JPL users. The recent use of this tunnel by JPL and other users has decreased significantly as shown by the following.

Fiscal year	Total operating hours	Non-JPL (other) use: Operating hours	Non-JPL (other) use: Percent of total operating hours
1973	278.8	148.4	53.2
1974	72.9	22.0	30.2
1975	6.0	6.0	100.0

Tunnel users are required to reimburse JPL for all direct test-related costs plus a share of the maintenance costs.

The tunnel was scheduled for deactivation on December 31, 1975.

Johnson Space Center (JSC)

1.5 MEGAWATT ARC TUNNEL FACILITY

LOCATION: Building 262

OWNER: NASA

STATUS: Active

INITIAL OPERATION/COMPLETION: 1963

TEST SECTION SIZE: Test chamber - 6' diameter x 8' length. One supersonic conical nozzle with a 5" diameter.

SPEED RANGE: Not meaningful on this type of facility. A JSC official stated that, if applicable, it would be approximately 4 to 6 mach.

TYPE: Continuous

GAS STREAM ENTHALPIES: 2,000 to 57,000 Btu's per pound of mass.

ALTITUDE OR PRESSURE RANGE: Model stagnation pressure range .001 to .06 atmospheres.

STAGNATION POINT CONVECTIVE HEATING RANGE: 10 to 1,500 Btu's per square foot per second.

NARRATIVE: The 1.5 MW facility and the 5 MW test chamber of the 5/10 MW facility were originally acquired for testing materials and structures used in the Apollo program. Currently, all of the arc tunnel facilities are exclusively engaged in performing tests supporting the development, evaluation, and verification of thermal protection materials and systems for the space shuttle vehicle.

We were advised that other activities have been made aware that these facilities are "booked solid" for this program, and as a result, no official inquiries from other activities for testing have been received during the past 12 to 18 months.

ATMOSPHERIC RE-ENTRY MATERIALS AND STRUCTURE EVALUATION FACILITY (ARMSEF)

(5 MW AND 10 MW ARC TUNNEL FACILITY)

LOCATION: Building 222

OWNER: NASA

STATUS: Active

INITIAL OPERATION/COMPLETION: 5 MW facility - 1966
10 MW facility - 1974

TEST SECTION SIZE: 5 MW test chamber--8' diameter x 10' length. Hypersonic conical nozzles with diameters ranging from 5" to 25" at 5" increments. 10 MW test chamber--10' diameter x 12' length. Hypersonic conical nozzles--5" to 40" diameter at 5" increments. Rectangular nozzles with maximum 2' x 2' test model capacity.

SPEED RANGE: Not meaningful on this type of facility. A JSC official stated that if applicable, it would be approximately 4 to 10 mach.

TYPE: Continuous

GAS STREAM ENTHALPIES: 2,000 - 25,000 Btu's per pound of mass.

ALTITUDE OR PRESSURE RANGE: Model stagnation pressure range .01 to 0.2 atmospheres.

STAGNATION POINT CONVECTIVE HEATING RANGE: 10 to 1,000 Btu's per square foot per second.

NARRATIVE: The 1.5 MW facility and the 5 MW test chamber of the 5/10 MW facility were originally acquired for testing materials and structures used in the Apollo program. Currently, all of the arc tunnel facilities are exclusively engaged in performing tests supporting the development, evaluation, and verification of thermal protection materials and systems for the space shuttle vehicle.

We were advised that other activities have been made aware that these facilities are "booked solid" for this program, and as a result, no official inquiries from other activities for testing have been received during the past 12 to 18 months.

SPECIAL PURPOSE FACILITY AT THE NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER

BACKGROUND: The wind tunnel, technically known as the 5-foot fire test facility, was acquired as excess from the U.S. Naval Missile Range, Point Mugu, California. The engines providing the thrust were obtained from the USAF and the facility first became operational at NAFEC in May 1961. The capitalized value of the facility at the time of our review was $365,529.

PURPOSE OF FACILITY: The NAFEC tunnel is used primarily to conduct fire protection studies on small aircraft engines and components which simulate actual in-flight fires. The facility is also used to test and evaluate fire detection and fire extinguishing systems of the types used to test and extinguish in-flight fires that are subjected to high-velocity air movement. These tests are performed in the 5-foot diameter test section of the wind tunnel by using either the actual components or scale models.

DESCRIPTION: The 5-foot fire test facility is a subsonic, open-circuit, induction-type wind tunnel using a continuous pressurized flow. It is capable of providing an environment for testing small aircraft engines, aircraft components, and aircraft equipment under conditions which simulate typical in-flight air flow conditions. The tunnel is 165 feet in length with a test section size of about 64 inches. It is powered by two Pratt and Whitney turbojet aircraft engines. Maximum thrust provides an air speed in the test section of about 660 miles per hour.

UTILIZATION OF THE WIND TUNNEL: We found, through discussion with the wind tunnel manager, that no logs or records were maintained on the utilization of the wind tunnel. However, he did state to us that, in the 14 years since it became operational at NAFEC, the aircraft engines used to provide the wind thrust had accumulated almost 500 hours of operating time. The facility manager estimated that the facility would be 50 percent utilized each year through fiscal year 1978.

We were able to identify, by means of documentation and interview, instances in which the wind tunnel was used.

A description of projects completed in fiscal year 1974 and their objectives is listed below.

Improved fire warning system

A new fire warning system developed by McGraw Edison Company under contract with USAF was tested in the NAFEC wind tunnel. The purpose of the system, which was flight tested in the NAFEC-based FAA Convair 880, was designed to resolve a longstanding problem of false fire warnings in aircraft operations.

Modified turbine fuel

A modified turbine fuel program was established by FAA to investigate the use of modified fuels for commercial transport aircraft in an effort to reduce the likelihood and severity of a post-crash fire as well as to extend the time available for passenger evacuation. The objective was to obtain a fuel that would burn properly in a jet engine but would not cause a large fireball following an accident.

A mathematical model was developed to predict ignition and flame propagation rates in modified fuel mists. Tests were made in the NAFEC wind tunnel to measure the modified fuel breakup and ignition characteristics.

Kennedy blast fence tests

At the request of the Eastern Region of FAA, NAFEC investigated the jet blast flow field at John F. Kennedy Airport in New York. Pilots had complained of jet blast effects when they landed behind other aircraft ready to take off on other runways.

The wind tunnel at NAFEC was used to check techniques to reduce this air flow field.

National Oceanic and Atmospheric Administration tests

The National Oceanic and Atmospheric Administration used the NAFEC wind tunnel on at least two projects. One involved development and evaluation tests on an "Airborne Snow Crystal Receiver" to determine its ability to trap snow crystals in flight. The other involved an evaluation of an experimental "Ice Nuclei Generator" for cloud seeding.

OPERATING COSTS: Accounting Division personnel informed us that in the development of a new project cost accounting system in 1973 the various divisions at NAFEC were permitted to select either staff-hours or facility hours as the unit of measure for cost purposes. The Aircraft and Airports

Safety Division, which has the responsibility for the wind tunnel plus 13 other facilities, selected the staff-hour basis as their unit of measure.

The consolidation of the 14 facilities into a single cost center and the absence of utilization records precluded any determination of the operating costs of the wind tunnel.

NONAVAILABILITY OF ADEQUATE TEST FACILITIES: We noted only one instance in recent years where FAA had to go to another agency because test facilities were not available to conduct the project requirements. We noted one other instance that may require the use of outside test facilities. These are summarized below.

Investigation of icing characteristics

The purpose of this project was to test commercially available low-cost materials under dynamic icing conditions in order to evaluate the effectiveness of the materials to passively prevent ice accumulation on the external surfaces of general aviation-type aircraft.

To accomplish this project, NAFEC made arrangements with NASA to use their icing research wind tunnel located at their Lewis Research Center, Cleveland, Ohio.

Piston engine emissions

We were informed that a project to investigate general aviation piston engine emissions is currently being contemplated by FAA. A decision, expected in January 1976, has to be made to conduct either flight tests or wind tunnel tests. In the latter, NAFEC will attempt to negotiate with either Boeing Vertol, Eddystone, Pennsylvania, or NASA-Lewis Research Center, Cleveland, Ohio, for the use of their wind tunnel facilities.

PROPOSED PROCUREMENTS OR MODIFICATIONS OF WIND TUNNELS: NAFEC personnel informed us that they were not aware of any future wind tunnel procurements or modifications to the existing wind tunnel.

UTILIZATION OF WIND TUNNELS

UTILIZATION TERMINOLOGY

The following definitions and explanations of the terminology used in the schedules are important to a clear understanding of tunnel utilization.

Percentage distribution

To simplify comparison of utilization data we have used a percentage distribution of time rather than the actual number of hours for each category. We believe that using percentages makes it easier to compare tunnel utilization because the number of shifts, and consequently total hours, varies among tunnels and centers.

Total tunnel time

The percentage of time shown as being occupied, in maintenance, and idle adds to 100 percent in each instance. A 100 percent "total" column is shown for Langley for illustrative purposes but has been omitted from all other schedules. (See p. 187 .)

A shift is 8 hours a day, 5 days a week, excluding weekends (104 days) and holidays (9 days). This amounts to 252 days, or 2,016 hours a year. For a two- and three-shift operation the number of hours a year are 4,032 and 6,048, respectively.

Occupied time

We defined occupied time as the time during which the tunnel is committed to a specific project and not available to other projects. It includes:

--Operating time, that is the time the tunnel is running.

--Tunnel and model setup time.

--Tunnel and model configuration.

--Test-related calibrations.

--Data acquisition and reduction time.

--Preventive or minor maintenance performed by tunnel operators.

Maintenance time

Maintenance time is the time devoted to scheduled or nonscheduled (emergency) maintenance, repairs, alterations, and rehabilitation. All of these require the tunnel to be shut down for a period of time during which it is not available to any projects.

Idle time

This category includes all the time during which the wind tunnel is not assigned to any given project and is now down due to maintenance; the tunnel is waiting for work.

Percentage of occupied time initiated by out-of-house

This represents the amount of time the tunnel was occupied as a result of a request for tunnel time from a non-NASA entity, such as DOD or a private firm.

Number/frequency of runs

For both Langley and Johnson we have shown a category, number/frequency of runs, as illustrative examples of the number of times the tunnels were actually operating or the frequency of those intervals of operation.

Frequency or number of runs varies considerably from tunnel to tunnel due to basic differences in their capabilities and limitations, specific requirements of each project, speed of the automatic data gathering and processing equipment available, and various other factors. For these reasons, we did not use the number or frequency of runs as a basis for measuring utilization.

SUMMARY OF NASA-WIDE WIND TUNNEL UTILIZATION

BY TUNNEL TYPE

(fiscal year 1975)

	No. of tunnels	Percent distribution of time: Occupied	Maintenance	Idle	Percent of occupied time initiated by out-of-house
Subsonic	12	76	13	11	27
Transonic	10	74	17	9	17
Supersonic	12	64	20	16	31
Hypersonic	16	59	15	26	1

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SUMMARY OF WIND TUNNELS UTILIZATION

BY LOCATION AND TUNNEL TYPE

(fiscal year 1975)

Location/type	No. of tunnels	Percent distribution of time: Occupied	Maintenance	Idle	Percent of occupied time initiated by out-of-house
Langley:					
Subsonic	5	84	13	3	12
Transonic	7	68	19	13	14
Supersonic	4	63	26	11	24
Hypersonic	14	52	18	30	0
Total weighted utilization	30	65	18	17	9
Ames:					
Subsonic	4	72	14	14	36
Transonic	3	85	14	1	22
Supersonic	3	65	32	3	23
Hypersonic	1	98	2	0	6
Total weighted utilization	11	78	16	6	26
Lewis:					
Subsonic	2	52	14	34	50
Supersonic	2	88	12	0	31
Total weighted utilization	4	76	13	11	37
Marshall:					
Supersonic	2	70	28	2	14
JPL:					
Subsonic	1	100	0	0	40
Supersonic	1	13	2	85	43
Hypersonic	1	1	3	96	100
Total weighted utilization	3	38	2	60	61
Johnson:					
Arc tunnel	2	80	20	0	0
Total weighted utilization all tunnels	52	69	16	15	19

APPENDIX IV

LANGLEY RESEARCH CENTER

SUBSONIC WIND TUNNEL UTILIZATION

(fiscal year 1975)

Wind tunnel name	Percent distribution of time: Occupied	Maintenance	Idle	Total	Percent of occupied time initiated by out-of-house	Number of runs
Low-turbulence pressure (note a)	66	28	6	100	0	661
Full-scale (CY '74) (note b)	96	1	3	100	2	821
V/STOL (note b)	93	6	1	100	8	3,170
High-speed 7' x 10' [c]	56	[c]/44	0	100	0	551
Spin (note d)	85	6	9	100	61	9,200

[a] Operating shifts vary with the low-turbulence pressure tunnel because it shares time with the 6" x 28", 26", and the 6" x 19" transonic wind tunnels. Projects have been scheduled through September 1976. The tunnels may run simultaneously depending upon the amount of air and power needed.

[b] The full-scale and V/STOL normally operate on a two-shift schedule. Calendar year 1974 data is shown for the full-scale because it was down for rehabilitation in 1975. Future projects have been scheduled through calendar year 1976 for the full scale and through fiscal year 1979 for the V/STOL.

[c] Majority was planned maintenance for replacing blades.

[d] The 7' x 10' and the spin tunnels normally operate on a one-shift basis. Future projects have been scheduled through fiscal year 1976 for the 7' x 10' and spin tunnel. No records are maintained for the number of runs for the spin tunnel and this estimate could not be verified.

APPENDIX IV

LANGLEY RESEARCH CENTER

TRANSONIC WIND TUNNEL UTILIZATION

(fiscal year 1975)

Wind tunnel name	Percent distribution of time: Occupied	Maintenance	Idle	Total	Percent of Occupied time initiated by out-of-house	Number of runs
26" transonic blowdown (note a)	0	0	100	100	0	0
6" x 28" transonic (note a)	69	17	14	100	0	793
6" x 19" transonic (note a)	16	4	80	100	0	149
8' transonic pressure (note b)	72	27	1	100	11	641
Transonic dynamics (note b)	83	17	0	100	11	311
16' transonic (note b)	77	23	0	100	29	319
Cryogenic transonic (note c)	-	-	-	-	-	-

[a]The 26", the 6" x 28", and the 6" x 19" transonic tunnels, and the low-turbulence pressure tunnels normally shared a two-shift per day operation during fiscal year 1975. These tunnels may run simultaneously depending upon the amount of air and power needed. The 26" transonic was not scheduled during fiscal year 1975 and is not expected to be used very often during the next several years. Projects have been scheduled for testing through September 1976 for the other tunnels.

[b]The 8' transonic, transonic dynamics (TDT), and the 16' transonic tunnels normally operated on a two-shift per day basis during fiscal year 1975. Future projects have been scheduled through March 1976 for the 8', through fiscal year 1976 for the TDT, and through June 1976 for the 16'.

[c]No records available.

APPENDIX IV

LANGLEY RESEARCH CENTER

SUPERSONIC WIND TUNNEL UTILIZATION

(fiscal year 1975)

Wind tunnel name	Percent distribution of time: Occupied	Maintenance	Idle	Total	Percent of occupied time initiated by out-of-house	Number of runs
4' x 4' supersonic pressure (note a)	50	12	38	100	0	128
Unitary plan (note b)	70	30	0	100	51	2,088
Ceramic heater (note c)	61	28	11	100	0	(d)
Thermal protection system test facility (note e)	-	-	-	-	-	-

[a]The 4' x 4' shares time with the 16' transonic tunnel and was operated on a 5-hour shift per day. Future projects have been scheduled through April 1977.

[b]The unitary plan normally operated 1-3/8 shifts per day during fiscal year 1975. Future projects have been scheduled through fiscal year 1979.

[c]The ceramic heater normally operated on a one-shift schedule. Projects have been planned through April 1977.

[d]No records maintained.

[e]The facility is planned to be operational for testing in January 1976. Future programs have been scheduled into 1977. The facility will share operational time with the 8' high temperature structures tunnel.

APPENDIX IV

LANGLEY RESEARCH CENTER

HYPERSONIC WIND TUNNEL UTILIZATION

(fiscal year 1975)

Wind tunnel name	Percent distribution of time: Occupied	Maintenance	Idle	Total	Percent of occupied time initiated by out-of-house	Number of runs
SCRAMJET test facility (notes a and b)	-	-	-	-	-	-
Hypersonic nitrogen (note a)	14	30	56	100	0	51
22" helium (note c)	91	5	4	100	0	659
Helium open-jet (note c)	4	0	96	100	0	21
20" hypersonic, mach 6 (note d)	83	14	3	100	0	934
Nozzle test chamber (note d)	44	19	37	100	0	378
Mach 6 high-RN (note e)	46	1	53	100	0	522
Mach 8 variable-density (FY 73) (note e)	95	5	0	100	0	1,338
High-RN helium (note f)	73	27	0	100	0	70
Hypersonic flow apparatus (note g)	21	1	78	100	0	39
Continuous-flow apparatus (note g)	66	12	22	100	0	906
7" mach 7 pilot (note h)	17	0	83	100	0	54
8' high-temperature structures (note i)	89	11	0	100	0	81
20" hypersonic CF_4 (note j)	20	80	0	100	0	63

[a] The SCRAMJET and the hypersonic nitrogen will share operational time. The SCRAMJET is planned to be operational for the first test in December 1975. Future projects have been planned through calendar year 1976 for the SCRAMJET and through September 1976 for the hypersonic nitrogen.

[b] New facility, not yet operational for testing.

APPENDIX IV

[c]The 22" helium and the open-jet share operational time. This helium tunnel facility normally operates one 8-hour shift per day. Future projects have been scheduled through fiscal year 1976 for the facility.

[d]The 20" hypersonic mach 6 and the nozzle test chamber (NTC) share operational time and can normally operate two shifts per day if required. Future projects have been planned for the 20" hypersonic mach 6 that may occupy the tunnel through 1980, and testing in the NTC is planned through calendar year 1976.

[e]The mach 6 high-RN and the mach 8 variable-density (VDT) tunnels share operational time. Each tunnel can normally operate an 8-hour shift. Future projects have been scheduled to 1979 for the VDT, and testing in the mach 6 high-RN is foreseen during calendar year 1976.

[f]The high-RN helium complex normally operates one 8-hour shift each day. Future projects are planned that may occupy the tunnel to 1979.

[g]The hypersonic flow apparatus and the continuous flow hypersonic tunnels share one shift each day. Future projects have been scheduled into February 1976 for the hypersonic.

[h]The 7" mach 7 pilot model is used when needed to provide preliminary test data on projects that may be tested in the 8' high-temperature structures tunnel (HTST).

[i]The 8' HTST was normally operated one shift each day during fiscal year 1975. The 8' HTST will share time with the thermal protection test facility when it becomes operational. Future projects have been scheduled through calendar year 1976 for the 8' HTST.

[j]The CF_4 was idle for installing a Freon gas reclaimer during fiscal year 1975. The tunnel normally operates one shift each day. Future projects have been scheduled through September 1976.

APPENDIX IV

AMES RESEARCH CENTER

UTILIZATION OF WIND TUNNELS

(fiscal year 1975)

Name of facility	Percent distribution of time: Occupied	Maintenance	Idle	Shifts	Percent of occupied time initiated by out-of-house
Subsonic:					
40 x 80 foot	78	22	0	2	32
7 x 10 foot (1)	79	16	5	1	11
7 x 10 foot (2)	95	5	0	1	68
12 foot	52	8	40	2	37
Transonic:					
14 foot	68	32	0	1	44
2 x 2 foot	96	4	0	1	0
Unitary (11 foot)	88	10	2	2	22
Supersonic:					
Unitary - (9 x 7 foot)	69	24	7	0.75	7
Unitary - (8 x 7 foot)	43	45	12	0.25	17
6 x 6 foot	66	34	0	2	30
Hypersonic:					
3.5 foot	98	2	0	2	6

APPENDIX IV

UTILIZATION OF WIND TUNNELS

(fiscal year 1975-except as noted)

Name of facility	Percent distribution of time: Occupied	Maintenance	Idle	Shifts	Percent of occupied time initiated by out-of-house
Lewis Research Center:					
Subsonic:					
Icing research	13	18	69	1	100
9 x 15 foot V/STOL (note a)	91	9	0	1	0
Supersonic:					
8 x 6 foot research (note a)	87	13	0	3	37
10 x 10 foot supersonic (note b)	88	12	0	0	12
Marshall Space Flight Center:					
Supersonic:					
14-inch trisonic	91	9	0	1	27
High-RN	50	46	4	1	0

[a]Calendar Year 1974.

[b]Averaged over 39 month period ending September 1975.

APPENDIX IV

JET PROPULSION LABORATORY

UTILIZATION OF WIND TUNNELS

(fiscal year 1975)

Name of facility	Percent distribution of time: Occupied	Maintenance	Idle	Shifts	Percent of occupied time initiated by out-of-house
Subsonic:					
Low turbulence	100	0	0	1	40
Supersonic and hypersonic:					
20-inch supersonic (note a)	13	2	85	1	43
21-inch hypersonic (note a)	1	3	96	1	100

[a]Scheduled for deactivation.

APPENDIX IV

JOHNSON SPACE CENTER

UTILIZATION OF WIND TUNNELS

(6-month period ending June 30, 1975)

Name of facility	Distribution of Time: Occupied	Operating	Calibration (note a)	Maintenance (note b)	Idle (note c)	Occupied time initiated by out-of-house (note d)	Frequency of running time
1.5 megawatt facility	63	22	1	14	0	0	1 hour per test with an average of 4 tests per 8-hour shift. Facility operates one 8-hour shift per day. A total of 127 8-hour shifts worked.
5/10 megawatt facility	59	19	1	21	0	0	1 hour per test with an average of 2 tests per 8-hour shift. Facility operates two 8-hour shifts per day. A total of 246 8-hour shifts were worked.

[a] Relates specifically to determining the operational characteristics of new test equipment. Any other calibration is considered to be a part of the test set-up and is not broken out separately.

[b] Primarily for refurbishing arc heaters.

[c] Relates to actual time for no scheduled tests. These facilities always have tests to run for NASA. They are booked solid for the next 18 months.

[d] These facilities are fully programmed and utilized for the NASA space shuttle program. Facilities are not available to other activities.

APPENDIX IV

OPERATING COSTS OF WIND TUNNELS

OPERATING COSTS TERMINOLOGY

The following definitions and explanations of the terminology used in the schedules are important to a clear understanding of tunnel operating costs.

Personnel

Two categories of personnel costs are identified in the schedules: NASA and contractor.

NASA personnel costs consist of civil service tunnel operators and maintenance personnel; however, it does not include scientific or engineering personnel costs. At Langley, Lewis, and Marshall only NASA personnel are involved in tunnel operations and maintenance.

Contractor personnel costs consist of non-NASA operators and maintenance personnel. Operating costs at Ames include the use of contractor personnel to augment their manpower capabilities. JPL being a NASA-owned, contractor-operated center uses its own personnel. Johnson's wind tunnels are operated and maintained by NASA personnel and contractor personnel from Rockwell International, the prime contractor for the space shuttle.

Maintenance

Maintenance costs, unless otherwise indicated by footnotes to the schedules, includes supplies and equipment which are replaced during scheduled and nonscheduled maintenance and repairs.

Other

This final category includes such items as natural gas, helium, nitrogen, and freon.

SUMMARY OF OPERATING COSTS

(fiscal year 1975)

Location/type	Number of tunnels	Personnel NASA	Personnel Contractor	Electric power	Maintenance	Other	Total
		(000 omitted)					
Langley:							
Subsonic	5	$ 508	$ 0	$ 88	$ 405	$ 106	$1,107
Transonic	7	844	0	588	862	199	2,493
Supersonic	4	518	0	612	363	36	1,529
Hypersonic	14	835	0	120	410	382	1,747
	30	2,705	0	1,408	2,040	723	6,876
Ames:							
Subsonic	4	595	522	66	749	0	1,932
Transonic	3	675	640	573	310	0	2,198
Supersonic	3	882	658	995	348	0	2,883
Hypersonic	1	204	354	192	175	19	944
	11	2,356	2,174	1,826	1,582	19	7,957
Lewis:							
Subsonic	2	171	0	161	48	0	380
Supersonic	2	852	0	631	217	45	1,745
	4	1,023	0	792	265	45	2,125
JPL:							
Subsonic	1	0	29	1	0	6	36
Supersonic	1	0	45	8	9	3	65
Hypersonic	1	-	4	4	0	0	8
	3	0	78	13	9	9	109
Marshall:							
Supersonic	2	271	0	34	48	37	389
Johnson:							
Arc	2	25	335	40	90	109	598
Total	52	$6,479	$2,487	$4,113	$4,034	$942	$18,054

APPENDIX V

LANGLEY RESEARCH CENTER

OPERATING COSTS OF SUBSONIC WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel costs	Power costs	Maintenance costs	Other costs	Total operating costs
	-----	-----	(000 omitted)	-----	-----
Low-turbulence pressure tunnel	$ 59	$29	$ 31	[a]$ 0	$ 119
Full-scale tunnel (note b)	119	6	51	66	242
V/STOL tunnel	198	31	152	37	418
High-speed 7- x 10-foot tunnel	113	4	167	3	287
Spin tunnel	19	18	4	0	41
Total	$508	$88	$405	$106	$1,107

[a]Costs of high-pressure air included in electrical power cost.

[b]Data based on calendar year 1974. Down for a major rehabilitation beginning January 1975.

APPENDIX V

LANGLEY RESEARCH CENTER

OPERATING COSTS OF TRANSONIC WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel costs	Power costs	Maintenance costs	Other costs	Total operating costs
	(000 omitted)				
26-inch transonic blowdown tunnel (note a)	$ 0	$ 0	$ 32	$ 0	$ 32
6- x 28-inch transonic tunnel (note b)	55	27	16	[c] 0	98
6- x 19-inch transonic tunnel (note d)	[e] 16	7	8	[c] 0	31
8-foot transonic pressure tunnel	247	221	96	[c] 0	564
Transonic dynamics tunnel	234	102	250	78	664
16-foot transonic tunnel (note f)	245	228	452	12	937
Cryogenic transonic (model) tunnel	47	3	8	109	167
Total	$844	$588	$862	$199	$2,493

[a] Tunnel on standby during period July 1974 through June 1975.

[b] Operational 86 percent of practical capacity.

[c] Facility has its own air compressor. Costs for operating are included under electrical power costs.

[d] Operational 20 percent of practical capacity.

[e] Tunnel in operation 4 months, July through October 1974.

[f] Operational 106.7 percent of practical capacity.

APPENDIX V

LANGLEY RESEARCH CENTER

OPERATING COSTS OF SUPERSONIC WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel costs	Power costs	Maintenance costs	Other costs	Total operating costs
	----	----	----(000 omitted)	----	----
4- x 4-foot supersonic pressure tunnel (note a)	$ 98	$ 53	$ 52	[b]$ 0	$ 203
Unitary plan wind tunnel	273	559	268	26	1,126
Ceramic heater	36	[d]0	7	10	53
Thermal protection system test facility (note a)	111	0	36	0	147
Total	$518	$612	$363	$36	$1,529

[a]4' x 4' supersonic operational 61.9 percent of practical capacity.

[b]Cost of high pressure air rounded to less than $1,000. 72,000 pounds of air times $.0047 equals $338.

[c]Facility is currently undergoing shakedown and calibration. It is scheduled to begin research in 1976.

[d]Electrical power costs do not round to $1,000. 1100 KWH times .0253 equals $28.

APPENDIX V

LANGLEY RESEARCH CENTER

OPERATING COST OF HYPERSONIC WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel costs	Power costs	Maintenance costs	Other costs	Total operating costs
	----	----	----(000 omitted)	----	----
SCRAMJET test facility (note a)	$ 61	$ 16	$ 22	$ 4	$ 103
Hypersonic nitrogen tunnel (note b)	25	2	5	6	38
22-inch helium tunnel	60	8	12	30	110
Open-jet helium tunnel (note c)	17	[d] 0	7	3	27
20-inch hypersonic tunnel (mach 6)	60	14	26	62	162
Nozzle test chamber (note e)	56	4	24	17	101
Mach 6 high RN tunnel (note f)	52	4	21	16	93
Mach 8 variable-density hypersonic tunnel (note g)	5	9	19	16	49
High-RN helium tunnels	106	20	9	68	203
Hypersonic flow apparatus (note h)	9	[i] 0	23	[j] 0	32
Continuous-flow hypersonic tunnel (note k)	101	[i] 40	101	4	246
7-inch mach 7 pilot tunnel (note l)	17	0	1	2	20
8-foot high-temperature structures tunnel	230	1	104	106	441
20-inch hypersonic CF_4 tunnel (note m)	36	2	36	48	122
Total	$835	$120	$410	$382	$1,747

APPENDIX V

LANGLEY RESEARCH CENTER

[a]SCRAMJET under shakedown operations in April, May, and June 1975.

[b]Operational 43.8 percent of practical capacity. The tunnel was down in October and November for maintenance due to failure of the cryopump.

[c]Open-jet operational 3 months during fiscal year 1975.

[d]Electrical power cost does not round to a thousand. 14,224 kilowatt hours times $.0253 equals $360.

[e]Nozzle test chamber operated 63.4 percent of practical capacity.

[f]Mach 6 high-RN operated December 1974 through June 1975.

[g]Mach 8 figures based on fiscal year 1973 figures. Tunnel inoperable since March 1974 due to piping defects. Scheduled to resume operations in August 1976.

[h]Hypersonic flow operated 21.8 percent of practical capacity.

[i]Power costs for continuous flow also includes power costs for hypersonic flow apparatus. These facilities are metered together.

[j]Cost of high pressure did not round to $1,000. 106,000 pounds of air times $.0047 equals $499.

[k]Continuous flow operated 78.1 percent of practical capacity.

[l]Operated April through June 1975. This is 17 percent of practical capacity. The mach 7 is used for pretests of tests to be made by the 8' high-temperature structures tunnel. Its usage is based on the tests currently being done in the 8' structure tunnel.

[m]Tunnel was down 8 months of fiscal year 1975 for installation of a CF_4 reclaimer.

APPENDIX V

AMES RESEARCH CENTER

OPERATING COSTS OF WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel NASA	Personnel Contractor	Electric Power	Maintenance	Other	Total
	(thousands)					
Subsonic:						
40- x 80 foot	$ 386.7	$ 0	$ 32.1	$ 532.0	$ 0	$ 950.8
7- x 10 foot (1)	38.5	0	0.4	23.0	0	61.9
7- x 10 foot (2)	117.7	0	0.9	82.2	0	200.8
12 foot	52.5	521.8	32.7	112.0	0	719.0
	595.4	521.8	66.1	749.2	0	1,932.5
Transonic:						
14 foot	52.5	521.8	144.8	112.0	0	831.1
2- x 2 foot	206.3	50.0	3.3	80.5	0	340.1
Unitary (11 foot) (note a)	416.0	68.2	424.8	117.9	0	1,026.9
	674.8	640.0	572.9	310.4	0	2,198.1
Supersonic:						
Unitary - 7' x 9' (note a)	415.0	68.2	424.8	117.8	0	1,025.8
Unitary - 8' x 7' (note a)	415.0	68.1	424.8	117.8	0	1,025.7
6' x 6' supersonic	52.5	521.8	145.7	112.0	0	832.0
	882.5	658.1	995.3	347.6	0	2,883.5
Hypersonic:						
3.5 foot	203.7	353.8	192.0	175.0	18.5	943.0
Total	$2,356.4	$2,173.7	$1,826.3	$1,582.2	$18.5	$7,957.1

[a]Costs of these three tunnels not available separately. We allocated total costs.

APPENDIX V

LEWIS RESEARCH CENTER

OPERATING COSTS OF WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel NASA	Personnel Contractor	Electric Power	Maintenance	Other	Total
	-----	-----	-----	(thousands)	-----	-----
Subsonic:						
Icing research	$ 19.9	$0	$ 9.4	$ 34.4	$ 0	$ 63.7
9' x 15' V/STOL (note b)	150.7	0	151.8	13.2	0	315.7
	170.6	0	161.2	47.6	0	379.4
Supersonic:						
8' x 6' research (note b)	405.6	0	214.0	85.3	28.2	733.1
10' x 10' Supersonic (note b)	446.5	0	416.7	131.8	17.2	1,012.2
	852.1	0	630.7	217.1	45.4	1,745.3
Total	$1,022.7	$0	$791.9	$264.7	$45.4	$2,124.7

[a]Also includes time technicians spent on routine and annual maintenance and repair work.

[b]Calendar year 1974.

[c]Averaged over 39-month period ending September 1975.

APPENDIX V

MARSHALL SPACE FLIGHT CENTER

OPERATING COSTS OF WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel NASA	Personnel Contractor	Electric power	Maintenance	Other	Total
	(thousands)					
14-inch trisonic	$162.7	$0	$25.4	$29.3	$17.7	$235.1
High-RN	107.9	0	9.0	18.2	19.0	154.1
Total	$270.6	$0	$34.4	$47.5	$36.7	$389.2

APPENDIX V

JET PROPULSION LABORATORY

OPERATING COSTS OF WIND TUNNELS

(fiscal year 1975)

Name of facility	Personnel NASA	Personnel Contractor	Electric Power	Maintenance	Other	Total
	--------	--------	--------	(thousands)	--------	--------
Subsonic:						
Low turbulence	$0	$28.9	$ .5	$ 0	$6.0	$ 35.4
Supersonic and hypersonic:						
20-inch supersonic	0	45.5	7.9	8.7	2.9	65.0
21-inch hypersonic	0	4.1	3.7	0	0	7.8
	0	49.6	11.6	8.7	2.9	72.8
Total	$0	[a] $78.5	[b] $12.1	$8.7	$8.9	$108.2

[a]Includes operating and maintenance, labor expense, and labor burden.

[b]Estimated; normally part of labor burden.

APPENDIX V

JOHNSON SPACE CENTER

WIND TUNNEL OPERATING COSTS

(6-month period ending June 30, 1975)

Name of facility	Personnel NASA (note a)	Personnel Contractor (note b)	Electric power (note c)	Maintenance (note d)	Other (note e)	Total
1.5 megawatt facility	$ 6,157	$ 59,800	$ 6,600	$15,000	$ 5,500	$ 93,057
5/10 megawatt facility	18,470	275,080	33,000	75,000	103,586	505,136
Total	$24,627	$334,880	$39,600	$90,000	$109,086	$598,193

[a] Computations based on an average hourly rate of $11.84 for JSC civil service employees. This rate does not include any add-on costs (overhead, etc.).

[b] Computations based on an average hourly rate of $11.50 for the contract under which the personnel are working.

[c] Based on estimates by JSC officials because these two facilities are not metered separately for electrical power. These estimates are based on demand and usage.

[d] Primarily material costs for refurbishing arc heaters.

[e] Test gases and natural gas.

APPENDIX V

DISPOSITION OF NASA FACILITIES

Center	Facility	Status	Approximate date Built	Approximate date Deactivated
LaRC	hot shot tunnel	demolished	1962	1969
Do.	1-ft. hypersonic arc tunnel	demolished	1963	1971
Do.	cyanogen facility (part of 1-ft Hyp Arc)	demolished	1963	1971
Do.	300-mile-per-hour 7' x 10' tunnel	demolished	1945	1970
Do.	integrated life support tank	demolished	1966	1971
Do.	water immersion simulator	demolished	1968	1973
Do.	pilot model expansion tube	demolished	1963	1973
Do.	tactical effectiveness simulator	demolished	1968	1973
Do.	60' sphere dynamic research laboratory	demolished	1966	1974
Do.	landing display generator	demolished	1969	1975
Do.	dynamic bearing zero-G simulator	demolished	1966	1975
Do.	20" mach 8.5 tunnel	dismantled	1961	1974
Do.	9' x 6' hot structures tunnel	dismantled	1955	1972
Do.	micrometeoroid impact simulator	dismantled	1965	1973
Do.	20 Mw linear plasma accelerator	dismantled	1966	1973
Do.	life support research system	dismantled	1966	1973
Do.	planetarium	dismantled	1948	1973

APPENDIX VI

Center	Facility	Status	Approximate date	
			Built	Deactivated
LaRC	visual task zero-g simulator	dismantled	1966	1975
Do.	11" hypersonic tunnel	surplused	1949	1973
Do.	space radiation effects laboratory	surplused	1966	1973
Do.	400' optical tunnel	standby	1965	1974
Do.	real time dynamic simulator	standby	1965	1975
Do.	4' arc tunnel	converted to SCRAMJET engine test facility	1964	[a]1975
Do.	2' hypersonic facility	converted to transonic test section/diffuser test apparatus	1961	[a]1974
Do.	4' supersonic pressure tunnel	[b]demolish	1947	1976
Do.	impact basin	demolish	1942	1976
Do.	150-cubic ft. space vacuum simulator	surplus	1965	1976
Do.	6" x 19" tunnel	standby--phase out by June '77	1934	1977
Do.	mach 15 helium tunnel	mothball	1967	1970
ARC	42" shock tunnel	demolish	1955	[c]1972
Do.	28" helium tunnel	dismantled	1960	

APPENDIX VI

Center	Facility	Status	Approximate date Built	Deactivated
ARC	24" prototype hypervelocity free-flight facility	dismantled	1955	1972
Do.	1" x 5" Mw arc	dismantled	1970	1974
Do.	Monte Carlo arc	dismantled	1972	1975
Do.	4-Mw combined convective radiative heating facility	dismantled	1966	1970
Do.	pilot pulsed arc	dismantled	1969	1975
Do.	8cm heat sink pilot facility	dismantled	1971	1975
Do.	satellite attitude control simulator	dismantled	1968	1975
Do.	hypervelocity ballistic range	dismantled	1955	1972
Do.	1 x 3-ft. wind tunnel	standby	1945	1972
Do.	material research facility	standby	1967	1972
Do.	7' x 10' subsonic tunnel	surplused	1945	
Do.	20' helium tunnel	Converted to high-Reynolds channel	1960	[a]1972
Do.	14" helium wind tunnel	demolished		1969
Do.	14-ft. transonic	to USAF or mothballed	1941	1978

APPENDIX VI

Center	Facility	Status	Approximate date	
			Built	Deactivated
ARC	42" hypervelocity free-flight facility	standby	1967	1972
Lerc	altitude rocket test facility	standby	1961	1974
Do.	nuclear rocket dynamics facility	standby	1965	1974
Do.	nuclear test reactor facility	standby	1959	1973
Do.	hypersonic tunnel facility	standby	1966	1974
Do.	cryogenic propulsion research, K site	standby	1960	1974
Do.	dynamic research site	standby	1960	1973
Do.	space power	standby	1967	1975
JPL	20" supersonic	standby	1948	1976
Do.	21" hypersonic	standby	1954	1976

[a] Converted.

[b] Make room for national transonic facility.

[c] Originally 1-ft. shock tunnel--converted 1967.

APPENDIX VI

FACILITY DISPOSITION TERMINOLOGY

Demolish--Facility scrapped and removed.

Dismantle--Facility inoperable, equipment reassigned, basic structure in place.

Mothball--Preserve, no staff required.

Standby--Maintain in Working order, operate infrequently, no permanent staff required.

Surplus--Make available for reuse elsewhere.

APPENDIX VII

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Attn of W

March 24, 1976

Mr. R. W. Gutmann
Director, Procurement and
Systems Acquisition Division
U. S. General Accounting Office
Washington, DC 20548

Dear Mr. Gutmann:

Thank you for the opportunity to review and comment on GAO's draft report to Chairman Olin E. Teague, House Committee on Science and Technology, on the acquisition and utilization of wind tunnels that was transmitted with your letter to the Administrator, dated March 18, 1976.

We found the material in the draft report to be clear and basically factual. The GAO opinions, recommendations, and conclusions are in general reasonable. There are, however, a few instances in which the report should be modified or corrected.

Enclosed are NASA's detailed comments that are keyed, by paragraphs and pages, to the specific portions of the draft report that should be modified. Also enclosed are the documents containing the descriptions of certain projects at Langley Research Center and at Lewis Research Center that were not included in the report, as identified in our detailed comments.

In view of the reporting deadline mentioned in your above-cited letter, we suggest that Mr. John M. Alvis of the Headquarters Office of Facilities staff be contacted on telephone number 755-3285 if it is necessary to clarify or discuss the enclosures.

Sincerely,

William W. Snavely
Assistant Administrator for
DOD and Interagency Affairs

Enclosures: A/S

Comments on Draft GAO Report on
Acquisition and Utilization of Wind Tunnels
National Aeronautics and Space Administration

1. Page ii, second paragraph.

The GAO states that the feasibility and cost of upgrading present tunnel instrumentation should be explored in greater depth. In this regard, NASA is planning to initiate a study in the very near future to identify candidate energy reduction projects. This study is part of a NASA wide "Energy Management Multiyear Action Plan" approved January 5, 1976. In addition to looking at improving our instrumentation and data acquisition systems, we also plan to investigate other time/energy "saving" candidate areas; such as: automatic model positioning and model changeover, logic scheduling of test runs, improve computerized monitoring displays, and improvement of basic wind tunnel flow efficiency. The period of performance for this study is one year.

2. Page 12, Conclusion, last paragraph.

Refer to comment #1 above.

3. Page 18, Estimates of Costs, second paragraph.

The preliminary estimates for the two separate facilities should be changed to $79 million from $74 million, $44 million for the Air Forces high RN tunnel and $35 million for the NASA transonic research tunnel.

4. Page 21, Langley Modifications.

a. Langley's current plan for conversion of the existing Mach 6 High Reynolds Number Tunnel into a Mach 4 tunnel is now planned for FY 1979 consideration as part of an overall rehabilitation of the Gas Dynamics Laboratory, Building 1247, at an estimated cost of $5.2 million.

b. The report does not include the CofF projects related to wind tunnels for Langley that are authorized and appropriated in FY 1976 and budgeted for in the transition period and FY 1977. Specifically they are:

Authorized and Appropriated in FY 1976

- Unitary Plan Wind Tunnel Rehab	$490,000
- Rehab of Freon Reclamation System, Transonic Dynamics Tunnel	200,000
- Modify Test Section of Thermal Protection Test Facility	85,000
- Rehab of Mach 19 Nitrogen Tunnel	95,000
TOTAL FY 1976	$870,000

Budgeted for Transition Period and FY 1977

- Addition to 8-Ft. High Temperatures Structure Tunnel	$ 80,000
- Construction for Addition for Aero elastic Model Laboratory	730,000
TOTAL TRANSITION PERIOD AND FY 1977	$810,000

A description of these projects is attached.

5. Page 21, Ames Modifications.

a. The estimated cost amount in the fourth line of the first paragraph should be changed to $4,560,000 from $4,650,000 which reflects the changes noted below.

b. Increase the amount authorized and appropriated for Facility Planning and Design for the 12-Foot Wind Tunnel to $60,000 from $50,000.

c. Increase the Total FY 1976 amount to $3,805,000 from $3,795,000.

d. The total amount budgeted for the transition period and FY 1977 should be changed to $755,000 from $855,000 and delete the entry - Vacuum Systems Piping for Building N-207, $100,000. This project is not budgeted.

6. Page 23, Facility Planning and Design.

The first two sentences should be changed to read: Sixty thousand dollars has been authorized for a concept validation study and for the preparation of a Preliminary Engineering Report. This modification, if undertaken by NASA, would now cost at least an estimated $6,572,000, with an additional presently estimated $350,000 as being required for the facility design.

7. Page 24, Budgeted for FY 1977.

The total amount budgeted for FY 1977 should be changed to $660,000 from $760,000 and delete paragraph #2 - Vacuum Systems Piping for Building N-207 ($100,000). Refer to comment #5 above.

8. Page 24, Modification of the 40x80-Foot Wind Tunnel.

Change $125 million in the second line of the first paragraph to $12.5 million.

9. Page 25, first paragraph.

Change $2,607,000 in the second line to $1,810,000.

10. Page 26, Lewis.

The GAO's statements concerning the Lewis planned projects may be misleading. The rehab of 8x6-ft. tunnel's air dryer is budgeted for in the Transition Period. The shop addition to 8x6-ft. tunnel has been authorized and funded in FY 1976. In addition, a project to modify the flexible wall hydraulic system of the 8x6-ft. wind tunnel has also been authorized and funded in 1976 at a total estimated cost of $170,000. A description of this latter project is enclosed.

11. Page 30, fourth paragraph.

We feel that this paragraph should be changed to read: "During FY 1975, Ames Research Center received $332,522 reimbursement for use of its wind tunnels which was deposited in the U.S. Treasurer's miscellaneous receipt account".

12. Pages 38-53, Appendix III, Cost Summary

It should be noted that the initial cost and total cost values being used by GAO do not in all cases agree with the NASA real property recorded book values. In those cases, it is understood that the GAO did not include items included as part of the NASA book value which was not directly related to the specific technical facility item.

R. H. Curtin 3/24/76

R. H. Curtin
Director of Facilities

Date

GAO note: Page references in this appendix refer to the draft report and do not necessarily agree with the page numbers in final report.

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