REPORT TO THE COMMITTEE ON APPROPRIATIONS HOUSE OF REPRESENTATIVES

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

The National Aeronautical Facilities Program: Issues Related To Its Cost And Need

Department of Defense

National Aeronautics and Space Administration

In its appropriations for fiscal year 1977, the Air Force has included $437 million for a facility to support development testing of future aircraft engines. NASA has included $25 million for a facility to support research and development testing of future aircraft. These two facilities are a part of a national aeronautical facilities program for which the Department of Defense and NASA are seeking congressional authorization and funds.

In this report, GAO discusses the cost and justifications for the engine and aircraft test facilities. It also points out unresolved issues related to the justifications which should be pursued by the House Committee on Appropriations before deciding whether or not to fund the facilities.

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

B-180766

The Honorable George H. Mahon
Chairman, Committee on Appropriations HSE00300
House of Representatives

Dear Mr. Chairman:

This is our report in response to your February 27, 1974, request that we assist the Committee in reviewing the cost and justification for two major aeronautical test facilities for which the Air Force planned to seek congressional authorization and funds. These two facilities were a part of the national aeronautical facilities program and were identified as the Aeropropulsion System Test Facility and the High Reynolds Number Transonic Tunnel.

In view of the urgency of reporting to the Committee at this time, we did not obtain and incorporate formal DOD and NASA comments in our report. However, we discussed our preliminary report with officials of these agencies and considered their informal comments in preparing the final report.

As agreed with your office, we are sending copies of this report to the Chairmen, House and Senate Committees on Armed Services; the Chairman, Senate Committee on Appropriations; the Chairman, Senate Committee on Aeronautical and Space Sciences; the Chairman, House Committee on Science and Technology; the Director, Office of Management and Budget; the Secretary of Defense; and the Administrator, National Aeronautics and Space Administration.

Sincerely yours,

Elmer B. Staats

Comptroller General
of the United States

Contents

ABBREVIATIONS

AACB	Aeronautics and Astronautics Coordinating Board
ASTF	Aeropropulsion System Test Facility
AEDC	Arnold Engineering Development Center
DOD	Department of Defense
FSST	Full-Scale Subsonic Wind Tunnel
GAO	General Accounting Office
HIRT	High Reynolds Number Transonic Tunnel
LETF	Large Engine Test Facility
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NTF	National Transonic Facility
PSIA	pounds per square inch absolute
TRT	Transonic Research Tunnel

COMPTROLLER GENERAL'S REPORT TO THE COMMITTEE ON APPROPRIATIONS HOUSE OF REPRESENTATIVES

THE NATIONAL AERONAUTICAL FACILITIES PROGRAM: ISSUES RELATED TO ITS COST AND NEED
Department of Defense
National Aeronautics and Space Administration

D I G E S T

In June 1974, the Air Force told the House Committee on Appropriations about a national aeronautical facilities program developed by the Aeronautics and Astronautics Coordinating Board which is jointly chaired by the Department of Defense and NASA. The program then included four test facilities.

The Air Force was to seek authorization and funds for two facilities: The Aeropropulsion System Test Facility for engine development testing and the High Reynolds Number Transonic Tunnel for aircraft development testing.

NASA was to seek authorization and funds for the other two facilities: the Transonic Research Tunnel for aircraft research testing and the subsonic wind tunnel modification for aircraft development testing.

In 1975, due to an increase in costs, the two planned transonic tunnels were dropped and the National Transonic Facility--to be used jointly by Defense and NASA--was added. As of February 1976, the estimated cost for the three facilities in the program totaled about $609 million, not including planned modifications to increase the test capability of the Aeropropulsion System Test Facility. (See pp. 7 to 10.)

In appropriations requests for fiscal year 1977, NASA is requesting about $25 million to start acquisition of the National Transonic Facility and the Air Force about $437 million for the Aeropropulsion System Test Facility. (See p. 9.)

Defense and NASA officials said the facilities in the program are necessary for U.S. manufacturers to develop superior civilian and military aircraft that will be competitive with foreign aircraft. (See pp. 11 to 15.)

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GAO recognizes the importance of the Nation maintaining superiority in aircraft development for both defense and export sales of commercial aircraft. Nevertheless, in GAO's opinion there are issues related to capability, use and cost effectiveness of the Aeropropulsion System Test Facility and the National Transonic Facility which should be pursued by the Congress.

AEROPROPULSION SYSTEM TEST FACILITY

The design of this facility includes two altitude test cells, one principally for subsonic engines for transport and cargo aircraft and the other mainly for supersonic engines for fighters, bombers, and potentially supersonic transports.

There are indications that its planned capability was based on the assumption that large engines would be required for the next generation of aircraft for civilian and military use. There is also evidence that the types of aircraft considered in selecting the planned capability included fighter-type aircraft operating at speeds up to 3.8 mach, supersonic bombers, and supersonic transports and cargo aircraft for military and civilian use. (See p. 16.)

The Air Force states the planned capability is needed to develop more efficient multimission supersonic engines in the 30,000 to 40,000-pounds-thrust range, or about the size currently planned for use in the B-1 bomber. (See p. 19.)

A National Science Foundation study said the facility's particular value to development testing would be to provide a means of minimizing costly flight testing and engineering modification of finished aircraft. (See p. 20.)

In February 1973, the Air Force contracted with a private contractor to estimate the economic benefits attributable to the facility. The contractor's report, revised through October 1975, concluded that only two new types of engines are likely to be developed within the next 20 years and that the facility would be cost effective if used in development of both new types of engines. However, most of the savings would accrue to the aerospace industry, including domestic and foreign airlines. (See pp. 21 to 27.)

The Air Force said that more than two new types of engines would be developed and that the contractor did not consider all savings and benefits associated with the use of the facility. (See p. 27.)

GAO believes the Committee, in deciding whether to fund the Aeropropulsion System Test Facility, should:

--Require the Air Force and NASA to identify the specific types of future aircraft developments, including engine thrust levels, requiring the facility's planned capability.

--Require the Air Force to clarify the importance of the facility in the development of combat aircraft as opposed to the development of larger military or commercial transport or cargo aircraft and to discuss the proposed use of the facility in the development of large engines.

--Obtain independent expert opinion as to whether the facility's capability is needed now if engines are not expected to grow in the next 20 years significantly above the current thrust ratings.

--Require the Air Force to identify all possible alternatives to the facility, including the construction of a shared-cost facility with our NATO allies, and to clarify why existing facilities could not be modified to permit development testing of military aircraft if there are no prospects for significant engine growths above current thrust levels.

--Ask the Air Force to provide specifics on new foreign technology developments, particularly by potential aggressor nations, supporting the view that the new facility is needed for U.S. military and civilian aircraft to remain superior and competitive.

--Obtain the Air Force's views on the essentiality to develop an engine with improved fuel economy, the expected improvements in fuel consumption for engines developed using the facility, and the practicality of such engines being installed in existing aircraft.

--Get the contractor's views on the reasonableness of his aircraft development projections and the significance of savings and benefits the Air Force says his study did not consider.

--Explore the possibility of funding the planned expansion of the facility now, rather than years later, if its planned capability is needed to test large engines and if the Congress elects to provide such capability.

NATIONAL TRANSONIC FACILITY

There appears to be support for an increase in the Nation's Reynolds number test capability but there is a difference of opinion as to what level the increased capability should be. (See p. 34.)

The facility will employ the newly developed cryogenic operational concept and its planned capability was selected from various facility options which were estimated to cost between $50 million and $80 million. The capability selected represents a compromise between the full scale capability the Air Force planned for the High Reynolds Number Transonic Tunnel and the lower capability NASA planned for the Transonic Research Tunnel. Because the planned capability for the facility represents a compromise and it cannot be later expanded, its usefulness is not clear. (See pp. 31 to 41.)

GAO believes the Committee, in deciding whether to fund the National Transonic Facility, should:

--Require NASA and the Air Force to specifically identify research and development programs for future aircraft that will require the facility's planned capability.

--Obtain independent expert opinion on whether the lower capability planned for the Transonic Research Tunnel would be adequate in the event there are no prospects for future development of large supersonic aircraft.

--Seek expert opinion as to whether test results from the facility can be extrapolated to higher levels in the event there are prospects for future development of large supersonic aircraft.

--Obtain independent expert opinion as to whether the newly developed cryogenic concept is sufficiently tested to insure that major construction and operational problems will not be encountered and that reasonable reliance can be placed on the present forecasts of cost, completion, and operational results.

CHAPTER 1

INTRODUCTION

On February 27, 1974, the Chairman of the House Committee on Appropriations asked us for assistance in evaluating the Air Force's appropriation requests for two new test facilities--the High Reynolds Number Transonic Tunnel (HIRT) and the Aeropropulsion System Test Facility (ASTF). These two facilities were a part of a proposed national aeronautical facilities program and were to be constructed at Arnold Engineering Development Center (AEDC), Tullahoma, Tennessee.

At the time of the Chairman's request, the Air Force estimated an approximate cost of $300 million to build HIRT and ASTF and about $30 million to design and activate them. About $6 million of the design cost had been financed from prior year Air Force appropriations received for military construction, and the remaining $324 million in unfunded cost was to be included in appropriation requests for fiscal year 1975 and subsequent years. Of the unfunded cost, the Air Force's fiscal year 1975 request actually included $54 million--$44 million for HIRT construction and $10 million for continuing ASTF design.

ORIGIN OF THE NATIONAL AERONAUTICAL FACILITIES PROGRAM

During testimony on its 1975 appropriation request, the Air Force said that the proposed program was initiated in the late 1960s with the objective of providing the Nation with the technical facilities needed to develop superior new aircraft and other aeronautical sytems. Facilities included in the program were to have operational scope and funding requirements exceeding the capability of any single agency under normal facility procurement procedures.

The Air Force referred to facilities in the program as "national aeronautical test facilities." This term also refers to the 22 wind tunnels that were authorized by the Unitary Wind Tunnel Plan Act of 1949 (Public Law 81-415). These wind tunnels were built throughout the United States for use by the military departments, Government civil agencies, private industry and universities. The Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA) began developing the presently proposed national aeronautical facilities program in 1967 in response to an Air Force suggestion for an orderly plan to expand test facilities constructed under Public Law 81-415.

DOD and NASA assumed the responsibility for developing the program under the auspicies of the Aeronautics and Astronautics Coordinating Board (AACB) which is jointly chaired by DOD and NASA. At the time of the Air Force's testimony, AACB was recommending that the Air Force and NASA seek congressional authorizations and funding for four large aeronautical test facilities in the program.

Air Force facilities:

1. HIRT--a wind tunnel to be constructed for aircraft development testing in the transonic speed regime to be located at AEDC.

2. ASTF--a wind tunnel to be constructed for development testing turbojet and turbofan aircraft engines, also to be located at AEDC.

NASA facilities:

1. The 40x80-ft. Subsonic Wind Tunnel--an existing wind tunnel to be upgraded for development testing in the subsonic speed regime to be located at NASA's Ames Research Center.

2. The Transonic Research Tunnel (TRT)--a wind tunnel to be constructed for aircraft research testing in the transonic speed regime to be located at NASA's Langley Research Center.

HIRT'S PLANNED TEST CAPABILITY

HIRT was planned as a transonic wind tunnel to produce aerodynamic flows closely simulating flight conditions of advanced, large, high-performance aeronautical systems. It was to be a special type of facility called a Ludwieg tube tunnel in which a model of an aircraft or aircraft part, such as a wing, could be tested. (See p. 4 for an artist's concept of the facility.)

As a transonic test facility, HIRT was being justified to allow testing in the range of speeds from slightly below the speed of sound (around 600 mph or 0.8 mach) to slightly above the speed of sound (around 900 mph or 1.2 mach). It was being designed, however, with an overall capability to test in speeds ranging from 150 to 1,000 mph (0.2 to 1.3 mach).

HIRT was also being designed with a high Reynolds number[1] test capability. A Reynolds number capability is a mathematical relationship of airspeed, vehicle size, and air density and viscosity at flight altitude. Some large aircraft such as bombers are currently operating at Reynolds numbers ranging up to 100 million, but the smaller, fighter-type, aircraft are attaining a maximum of about 60 million Reynolds numbers.

The Air Force said transonic test capability requirements cannot be stated just in terms of Reynolds number without some understanding of the size of the model. When testing near 1.0 mach it is necessary to use models that are smaller than those normally used. Smaller models, in turn, require increased tunnel capability to duplicate flight conditions.

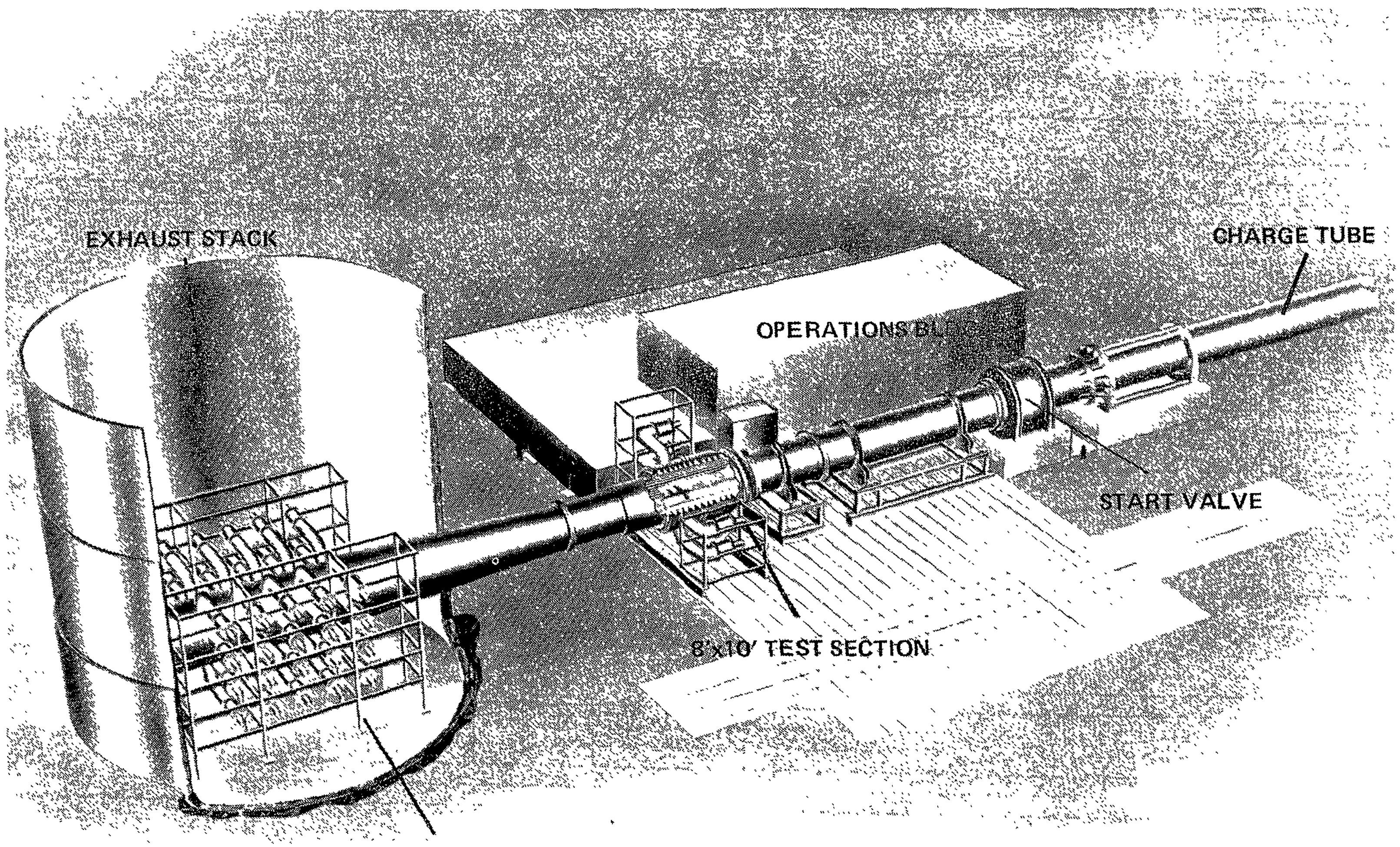
The mach number and the Reynolds number are the two parameters most frequently mentioned in discussions of HIRT's planned test capability. Existing wind tunnels in the United States possess the capability to test at the mach number range for which HIRT was being designed, but the capability to test aircraft models is around 10 to 12 million Reynolds numbers.

ASTF'S PLANNED TEST CAPABILITY

ASTF was planned as a large facility which would permit full development testing of subsonic and supersonic air breathing engines under simulated altitude conditions. It was to be a complex of compressors, heaters, refrigeration equipment, piping, valves, and exhausters. (See p. 6 for an artist's concept of ASTF.)

ASTF was being designed with two altitude test cells for full-scale testing of engines at conditions simulating the speed and altitude at which they are being developed to operate. One cell would accommodate the large mass flows of cold air at low pressure necessary for subsonic testing and the other cell would accommodate the higher pressures and temperatures associated with supersonic testing. However, the subsonic, or the turbofan, engine test cell was also being designed with limited capability for supersonic testing. Conversely the supersonic, or the turbojet, engine test cell was also being designed to have limited subsonic-test capability.

1/Reynolds numbers between 0 and 10 million are considered low; 10 to 50 million are considered moderate; and 50 to 200 million are considered high.



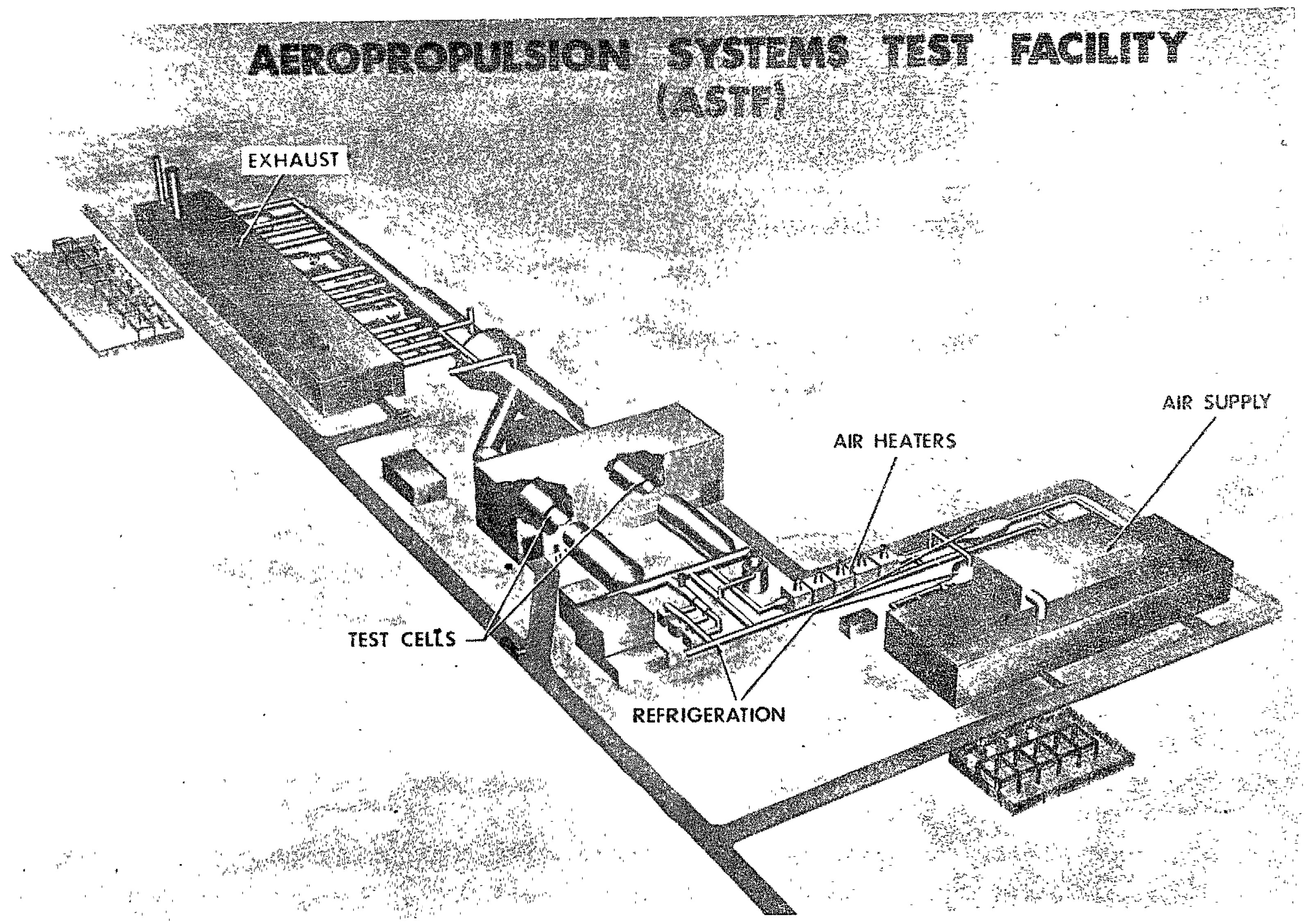
HIGH REYNOLDS NUMBER TUNNEL (HIRT) *Furnished by the Department of the Air Force

The altitude test cells were being designed to simulate conditions for different altitudes and speeds. The turbojet engine test cell was being sized to ultimately test engines with up to 100,000-pounds-rated thrust to speeds of mach 3.8 in a simulated altitude of 80,000 feet. This capability would be limited to "direct connect" mode of testing and the "freejet" test mode would be limited to engines with approximately 50,000-pounds-rated thrust.1/ The turbofan engine test cell was being sized to ultimately test engines up to 100,000-pounds-rated thrust for speeds up to 1.0 mach at altitudes to 50,000 feet in the direct connect test configuration. It also would have capability for freejet tests of some supersonic engine types with up to 50,000-pounds-rated thrust.

While both altitude test cells were to be constructed with physical dimensions to test 100,000-pounds-rated thrust engines, the initial air-handling capacity of ASTF was being planned to test only engines with up to 75,000-pounds-rated thrust. According to Air Force officials, existing engine facilities can only marginally test the 41,000-pounds-rated thrust high-bypass turbofan engine such as the one used in the C-5 aircraft. Commercial versions of these engines have now grown to around the 54,000-pounds-rated thrust level, which is beyond current testing capability.

ASTF was also being designed with an operational concept similar to engine test facilities existing in the United States which can simulate altitude conditions for development testing. In comparing ASTF's size with engine test facilities already existing, however, ASTF would have larger physical dimensions in its altitude test cells and greater capability to simulate altitude conditions.

1/ In direct connect testing the facility's air supply is directly connected to the engine inlet. In freejet testing, air supply is allowed to enter the engine inlet just as it would under actual flight conditions.



*Furnished by the Department of the Air Force

CHAPTER 2

ACQUISITION COST OF PROPOSED

NATIONAL AERONAUTICAL FACILITIES PROGRAM

In October 1974, following House Committee on Appropriations hearings on appropriation requests by the Air Force and NASA for fiscal year 1975, the total estimated construction cost for the four facilities in the program was increased from about $400 million to about $645 million. The increase was made to recognize a higher cost-escalation rate for all facilities, cost omissions in Air Force estimates, and increased cost for design refinements of HIRT and ASTF. As a result of the substantial increase, HIRT and the program's other transonic wind tunnel--TRT--were eliminated and a transonic wind tunnel was added to be used jointly by DOD and NASA. As of February 1976, the estimated cost for the three facilities remaining in the program amounted to about $609 million.

SUBSTANTIAL COST INCREASES CAUSING PROGRAM REVISIONS

In December 1973, AACB decided to seek congressional authorizations and appropriations for the four facilities then comprising the national aeronautical facilities program--HIRT, ASTF, TRT, and the 40x80-ft. Subsonic Wind Tunnel modification. Under the plan, the Air Force was to seek congressional authorizations and appropriations for HIRT and ASTF, and NASA was to seek congressional authorizations and appropriations for TRT and the wind tunnel modification. AACB instructed its aeronautics panel to develop the necessary briefings for joint presentations to congressional committee staffs, the Office of Management and Budget, and others on the acquisition of the four recommended facilities.

In March and May 1974, NASA and the Air Force, respectively, advised House appropriations subcommittees about the proposed national aeronautical facilities program during hearings on the 1975 appropriation requests. NASA gave estimates totaling about $400 million to acquire the facilities which was the total amount estimated in December 1973 by the Air Force for HIRT and ASTF and by NASA for TRT and the 40x80-ft. Subsonic Wind Tunnel modification. However, as shown in the following table, the total estimated cost was increased to about $645 million by October 1974.

	Estimated cost			
	December 1973	October 1974	Increased Amount	Increased Percent
	millions			
HIRT acquisition	$ 47	$100	$ 53	113
ASTF acquisition [note a]	285	452	167	59
TRT acquisition	23	35	12	52
40x80-ft. Subsonic Wind Tunnel modification	47	58	11	23
Total	$402	$645	$243	60

a/ Estimates do not include cost to provide for increasing ASTF's capability to test engines of the 75,000- to 100,000-pounds-rated thrust range. This expansion was estimated to cost $61 million before the high escalation was recognized.

REASONS FOR SUBSTANTIAL INCREASE IN ESTIMATED COST

NASA attributed the cost increases for the TRT acquisition and the 40x80-ft. Subsonic Wind Tunnel modification to escalation in construction costs. It also said that the estimates include the effect of decreasing TRT's planned test capability.

Because of the significance of cost increases for HIRT and ASTF--about $220 million--we studied these estimates and identfied the following specific reasons for the increases.

Reasons for increases	Amount (millions)
1. Use of historical escalation rather than arbitrary 6 percent rate used in initial estimates	$143
2. Addition of amounts for construction contingencies and contract award and management which were previously omitted	42
3. Increase of cost for design refinements	35
Total	$220

PROGRAM REVISIONS RESULTING FROM INCREASES

After being informed of the cost increases, the NASA official serving as cochairman of AACB told his DOD counterpart in a letter dated October 17, 1974:

> "In light of this trend in the cost of construction, it may not be possible for the country to acquire in the near future all of the facilities we jointly agreed were necessary, and perhaps we should seek a realistic compromise position by an immediate reexamination of the requirements and viable options for meeting those requirements. Agreement to a single transonic facility may well be a necessary step for solution of the cost problem we now face."

In his letter, the NASA cochairman proposed that AACB reassess the facility requirements and options and his DOD counterpart agreed with the proposal. AACB then reexamined the test requirements that led to formulating the national aeronautical facilities program.

AACB decided to eliminate HIRT and TRT and to add the National Transonic Facility (NTF)--a transonic test facility using the operational concept planned for TRT--to handle the testing requirements of the Air Force and NASA. A decision was made to leave ASTF and the 40x80-ft. Subsonic Wind Tunnel modification in the program.

AGENCIES' MOST RECENT ESTIMATES

As shown below, the Air Force and NASA in February 1976 were estimating a cost of about $609 million for the three facilities remaining in the program.

	(millions)
ASTF acquisition	$450
NTF acquisition	65
40x80-ft. Subsonic Wind Tunnel modification	94
Total	$609

The Air Force has included $437 million in its fiscal year 1977 request for appropriations to cover military construction and activation cost of the ASTF. The Congress has already appropriated about $13 million to cover design cost.

NASA has included $25 million in its fiscal year 1977 appropriation request to procure long leadtime items for construction of NTF. The remaining $40 million will be requested in future years. It also plans to start requesting funds for the 40x80-ft. Subsonic Wind Tunnel modification in fiscal year 1978.

CHAPTER 3

DEVELOPMENT OF THE PROPOSED NATIONAL AERONAUTICAL FACILITIES PROGRAM

Defense and NASA officials said the three new facilities in the proposed program are necessary for U.S. manufacturers to develop superior future civilian and military aircraft that will be competitive with aircraft developed by other countries. Certain North Atlantic Treaty Organization (NATO) countries and Russia are reported to already have or are planning to have facilities with capabilities similar to those that would be provided by the proposed facilities. The new facilities were selected by DOD and NASA after 8 years of study. The need for the facilities has been endorsed by several groups on which industry and the academic community are represented, including a group of consultants selected by the National Science Foundation.

APPROACH TO SELECTING FACILITIES FOR THE PROGRAM

In May 1967, AACB asked its aeronautics panel to identify major aeronautical facilities to develop military and civilian aeronautical vehicles during the next 10 to 15 years. Three working groups whose membership was composed of personnel from NASA, the Army, Navy, and the Air Force, were assembled to make the study.

The working groups first requested NASA, the military services and the Federal Aviation Administration to submit projections of future (covering a 10 to 15 year period) programs in the aeronautical area. No restrictions were placed on the projections other than for them to be atmospheric operating vehicles; however, some reentry vehicles and intercontinental ballistic missiles were included. The only other condition imposed was for the programs to be based on reasonable projections of the state-of-the art.

By August 1968, the working groups had developed a listing of all foreseeable facilities that they believed might be required for development of the future programs identified by the agencies. The listing contained 53 test facilities of which 7 were characterized as major national facilities because of their estimated cost. Included were ASTF and HIRT already planned by the Air Force, and those identified by the working groups as being needed to support development of projected aeronautical systems.

At its January 1969 meeting, AACB asked the aeronautics panel to briefly assess requirements for facilities in the listing and, among other things, to identify individual priorities for the major facilities. By September 1969, the aeronautics panel had concluded that five of the seven major facilities previously classified as national facilities should receive a priority rating and should be given further consideration. A facilities working group composed of members from NASA, the Army, Navy, and the Air Force was then formed to make detailed engineering and funding examinations of the five proposed national facilities. The five facilities, in order of priority, were as follows:

1. A Large Engine Test Facility (now ASTF) at AEDC.

2. A Large-Scale V/STOL (vertical takeoff aircraft) Wind Tunnel (later called the Full-Scale Subsonic Tunnel-FSST) at NASA's Ames Research Center.

3. A High Reynolds Number Tunnel (HIRT) at AEDC.

4. A 40x60-ft. Transonic Wind Tunnel at NASA's Lewis Research Center.

5. A Hypersonic True Temperature Tunnel (Tripletee) at AEDC.

These facilities were proposed to AACB in July 1970, and, since then, AACB has decided to support as national facilities:

--ASTF for development testing of turbojet and turbofan aircraft engines.

--HIRT and TRT for development and research testing, respectively, of aircraft models and parts in the transonic speed range. These facilities were dropped in favor of NTF, a single facility for both research and development testing, whose cost is estimated to be about one-half of that estimated for the two facilities. NTF will have a greater test capability than that planned for TRT, but only about one-half the capability planned for HIRT.

--FSST for subsonic and vertical takeoff aircraft research. This facility was dropped in favor of the 40x80-ft. Subsonic Wind Tunnel modification which was stated to provide one-half of the capability planned for the FSST at about one-eighth of the cost.

After facilities were selected for consideration in the program, discussions were held with the aerospace industry and the academic community to obtain views on technical capabilities and assistance in justifying the facilities.

CRITERIA USED IN FACILITY SELECTION

In its study, the aeronautics panel adopted the following criteria as the bases for selecting facilities for the latest program.

--The facility would be too large or expensive to be handled by one agency through routine channels and would require special enabling legislation.

--The facility would provide a unique capability that would not duplicate an existing facility.

After facilities were selected, AACB decided that authorization and appropriation for each facility must be sought by either the Air Force or NASA through established budgetary channels. This approach was selected because it afforded review and approval by those in Government agencies and the Congress most familiar with requirements of the military services.

ACTIVITIES ENDORSING THE PROGRAM

In September 1971, the aeronautics panel prepared a memorandum for AACB which, among other things, discussed reaction by industry, the academic community, and Government agencies to the program. According to minutes of the October 1, 1971, AACB meeting the memorandum stated that:

> "although knowledgeable DOD and NASA elements are convinced of the need for large facilities (LETF, FSST, and HIRT), other elements of the government, industry, and universities are not necessarily so convinced."

Because of this, the aeronautics panel recommended developing a plan to inform industry, educational institutions, and appropriate elements of the Government of the proposed national aeronautical facilities program. Other objectives of the proposed plan were to get reactions to the proposed program and to obtain additional information for the continued evaluation of aeronautical facility requirements.

In February 1972, AACB approved such a plan which provided for a NASA and a DOD representative to brief selected congressional committees, Government agencies, professional societies, and certain DOD and NASA advisory committees on aeronautical matters. It also provided for articles to be published in technical journals discussing the need for facilities in the program.

Since the plan was implemented, several activities have endorsed the need for one or more of the facilities in the program, including those listed below.

--The Aerospace Industries Association agreed to support the need for the two NASA facilities now in the program. The association represents over 40 of the Nation's leading manufacturers of aircraft, spacecraft, missiles and related components.

--The aerospace vehicles panel of the Air Force Scientific Advisory Board agreed to support ASTF and HIRT. This panel is composed of representatives from the academic community, industry, DOD and NASA.

--NASA's Research and Technology Advisory Council agreed to support the need for NTF and the 40x80-ft. Subsonic Wind Tunnel modification. This council is composed of representatives from the academic community, industry and other Government agencies.

NATIONAL SCIENCE FOUNDATION STUDY ENDORSING FACILITIES IN THE PROGRAM

In December 1975, the National Science Foundation released a report summarizing the findings of five consultants that it selected to study the need for the three proposed new aeronautical test facilities--ASTF, NTF, and the 40x80-ft. Subsonic Wind Tunnel modification. The study was made in response to a request from the Office of Management and Budget in late April 1975 for an independent analysis to assess the requirements and alternatives for aeronautical facilities modernization.

According to the report, the five consultants individually examined in depth the need for one or more of the three facilities; the findings summarized in it were a general consensus of the individual consultant's findings. The more important findings summarized in the report were:

--Adequate U.S. facilities do not exist to carry out tests on present and projected aircraft and engines.

--NTF has been proposed as an important design tool to provide the basic information needed to develop more efficient commercial aircraft and more combat-effective military aircraft by refinements in aerodynamic design. ASTF, along with the 40x80-ft. Subsonic Wind Tunnel modification, would also be of assistance in the design stages, but their particular value would be to provide a means of minimizing costly flight testing and engineering modification of a finished aircraft.

--Facilities equivalent to ASTF already exist in Great Britain, France and the Soviet Union. No facility equivalent to NTF is known to exist anywhere, but intensive studies are underway in several NATO countries, including France and Great Britain, and it is expected that such a facility will be developed in Europe about the same time or before NTF.

--The construction of the three proposed new aeronautical test facilities would be cost effective for the Nation at this time.

The report recommended constructing all three facilities as soon as practical.

CHAPTER 4

JUSTIFICATION FOR ASTF'S PLANNED TEST CAPABILITY

The ASTF's test capability appears to have been initially based on the assumption that large engines would be required for future aircraft. ASTF's test capability is now being justified on the basis that it is needed primarily to develop a high-performance supersonic engine in the 30,000 to 40,000-pounds-thrust range that would have a multimission capability. Also, there is frequent mention of the facility being an economic investment for the Nation but the results of the contractor's cost-effectiveness study raises doubt about whether the facility can be justified strictly on the cost savings accruing directly to the U.S. Government.

LARGE ENGINE DEVELOPMENT CAPABILITY CONSIDERED

In July 1970 the AACB considered a recommendation by its aeronautics panel on facilities to be included in the proposed program. In referring to the Large Engine Test Facilities (LETF), now the ASTF, the minutes of the July 1970 AACB meeting state:

> "* * * the LETF is very much dependent on a growth in engine thrust levels beyond the present SST [Supersonic Transport] requirements. There is a question as to whether civil and military systems will demand such larger engines in the future. It was noted that when the original Unitary plan was constructed, it was clear that supersonic engines would be required. However at this time there is no strong conviction that the nation will go to these larger size engines."

Later, in October 1970, AACB considered the initial effort by its aeronautics panel to justify the need for facilities in the proposed program. This proposed justification said there were approximately 15 military and 7 civilian projected aircraft systems that would require an ASTF capability in order to be built. It also conceded the possibility that some of these systems would not be built, but emphasized that any system built would require testing in a facility such as ASTF. The projected military and civilian aircraft systems were:

Military systems:

1. airborne warning and control system

2. advanced subsonic tanker

3. advanced airborne command post
4. advanced subsonic transport
5. air defense interceptor
6. advanced supersonic trainer
7. hypersonic scramjet vehicle
8. hypersonic interceptor
9. military supersonic transport
10. airborne ballistic missile intercept system
11. antisubmarine warfare aircraft
12. long-range strike aircraft
13. vertical takeoff fighter
14. air target aircraft
15. reconnaissance system

Civilian systems:

1. airbus
2. jumbo jet
3. super jumbo jet
4. jumbo cargo transport
5. super jumbo cargo transport
6. growth supersonic transport
7. jumbo supersonic transport

After ASTF was included in the program, its initial test capability was changed as follows:

--The turbofan engine test capability was increased from 60,000 to 75,000-pounds-rated-thrust.

--The turbojet engine test capability was increased from 3.0 to 3.8 mach.

--The pressure for the turbojet cell was increased from 100 to 146 pounds per square inch absolute (PSIA).

--The size of the turbofan and turbojet test cells was increased from 24 and 20 feet in diameter, respectively, to 28 feet in diameter.

The reasons for these changes were explained in a document presented to AACB at its February 1972 meeting. This document indicates that the increases affecting the turbofan test cell were made to accommodate testing of large engines. For example, the document says:

"The rapid and extensive growth of the present generation of large turbofan engines just within the past year indicate that LETF (with a 60,000 lb test capability) would, upon facility completion, be inadequate to test the next generation of engines expected at that time. * * * Based on projected needs and planning information the engines for the 1980's will be in the 70,000 to 90,000 lb class."

The document also indicates that the changes affecting the turbojet test cell were made primarily to accommodate testing of large, high-speed engines. For example, the document says:

"The military requirement to fly aircraft above Mach 3.0 in the 1980 time period appears certain. Reconnaissance, fighter, and interceptor aircraft will be needed to counter the military threat at speeds considerably above Mach 3. The choice of Mach 3.8 * * * is based upon considerations for both facility technology and engine testing requirements."

Other documents we reviewed indicating ASTF was sized to test large engines included

--a record of a briefing the Deputy Commander of AEDC gave to the Secretary of the Air Force in September 1971 and

--an executive summary on the national aeronautical facilities program which was presented to the AACB at its February 1972 meeting.

In December 1975, an article appeared in a trade publication, Astronautics and Aeronautics, which contained NASA's views on the future aircraft that would require ASTF's test capability. Such aircraft were identified as

--a large subsonic cargo transport for civil use,

--a very large subsonic logistic transport for military use,

--an advanced supersonic transport for civil use,

--a supersonic vertical takeoff aircraft for military use, and

--an advanced fighter/bomber for military use.

EFFICIENT HIGH PERFORMANCE ENGINE JUSTIFICATION

After a decision was made to include ASTF in the program, the Air Force began developing the justification package that would be submitted to the Congress supporting the appropriation and authorization request. The Air Force formed a group to advisors from industry and the academic community to, among other things, provide views on ways ASTF could be justified. In summarizing the views of one scientific advisor, the minutes of the group's first meeting in December 1972 states:

"(a) If we persist in making the larger-and-larger aircraft argument we will lose since few people may be convinced;
(b) We should persist in the argument of need for complete freejet testing of inlet, engine, nozzle, and vehicle portion in the tunnel as our main justification for more air flow and larger test cells. We must be ready to answer how F-14, F-15, and B-1 engines are being successfully developed without ASTF."

The Air Force is emphasizing the need for complete freejet testing of aircraft engines in its justification for ASTF. It is also emphasizing the ASTF's transient testing capability which permits simulation of such things as changes in engine power, changes in aircraft altitude and speed, or any combination of these changes.

Air Force officials said that the primary requirement for ASTF was to permit development of a high-performance multimission supersonic propulsion system in the range of 30,000 to 40,000-pounds thrust. Such an engine was said to be a follow-on engine to the one being currently developed for the B-1 bomber.

As explained by Air Force officials, ASTF's initial freejet test capability will accommodate testing of engines in the 37,000-pounds-thrust range over the full flight conditions at which it is designed to operate. Such an engine would be about the size of the one planned for the B-1. Any larger supersonic engines could not be tested over all the flight conditions at which they would be designed to operate unless ASTF's capability is increased. In short, the ASTF's capability for freejet testing probably would have to be increased shortly after the facility is constructed if the next generation of fighters or bombers uses a higher rated thrust engine than is currently available.

ECONOMIC JUSTIFICATION FOR THE FACILITY

As mentioned on page 15, the National Science Foundation's study said ASTF's particular value will be to provide a means of minimizing costly flight testing and engineering modification of finished aircraft. Economies attributed to the ASTF were also mentioned in Air Force testimony before the House Committee on Appropriations in June 1974. In recent testimony an Air Force official stated that the use of the ASTF would result in development of more reliable, more effective, and safer weapons systems at lower cost.

In February 1973, the Air Force contracted with Analytic Services Inc. for a cost-effectiveness study to estimate the benefits. The results of the analysis are supposed to be an important part of the justification package to be submitted to the Congress.

RESULTS OF THE COST-EFFECTIVENESS STUDY

Analytic Services Inc. issued a draft report to the Air Force in June 1974. At the Air Force's request, the study was updated and a revised draft was issued in October 1975. The Air Force had not accepted the revised draft as of January 1976. The contractor's latest draft raises several issues related to the cost effectiveness of the facility, including those discussed below.

Limited market for large engines

According to the Air Force, airflow capacity and transient test capability are the principal differences between the capabilities of ASTF and the capabilities of existing engine test facilities. In its report, Analytic Services Inc. used the term "large engines"1/ to distinguish between engines that need ASTF airflow capacity for development testing and engines whose airflow demands can be satisfied by at least one existing engine test facility.

In the cost-effectiveness study, the contractor considered new engine families that he believed might be developed in the next two decades. As shown below, a total of nine different engine families were considered possible candidates for use in new subsonic and supersonic aircraft that might be developed in the same time frame.

1/ In testing, an afterburning engine demands a greater airflow than a nonafterburning engine with a similar thrust rating. For simplicity in this study, the contractor considered a large engine to be either a nonafterburning engine whose thrust rating exceeded 35,000 pounds or an afterburning engine whose thrust rating exceeded 20,000 pounds.

Forecast of Large Engine Developments
In the United States from 1982 Through 1993

	Number of engine families: New models	Number of engine families: Follow-on models	Thrust class (pounds)	Quantity of engines: Per model	Quantity of engines: Total
Type of engines:					
Supersonic					
Fighter	2	4	30,000	500	3,000
Bomber/ fighter	1	2	50,000	500	1,500
Commercial transport	1	1	75,000	500	1,000
Subsonic					
Commercial transport	2	6	a/30,000	b/1,500	7,500
Military air-lift	1	1	60,000	500	1,000
Commercial transport/ freighter	2	6	75,000	c/1,200	6,000
Total	9				20,000

a/ ASTF capabilities not required for development.

b/ For new models, 750 for follow-on models.

c/ For new models, 600 for follow-on models.

Analytic Services Inc. forecast a substantial market within the next two decades for existing or new subsonic commercial transport engines with 25,000 to 30,000-pounds-rated thrust. U.S. representatives of the aircraft industry gave a similar forecast to the Air Force in December 1972. These engines will be used on twin-engine, three-engine, and four-engine transports. According to Analytic Services Inc., existing altitude test facilities are adequate to test such engines.

After eliminating the two families of engines not requiring ASTF's test capability, seven engine families remained for consideration in the study. The contractor concluded that five of these new engine families probably would not be developed within the next two decades, for the following reasons.

--A commercial supersonic transport requiring one of the new engine families would, in his opinion, not be financed by the U.S. Government within the next two decades because of increased fuel costs, high fuel consumption per passenger mile and possible environmental limitations.

--A new engine family for advanced supersonic military bombers is unlikely because the experience with the B-1 bomber shows high development and procurement costs, development running behind schedule, and the B-1 program may be canceled. The contractor also expressed doubt about developing a follow-on bomber before 1995 because future U.S. strategic policies are not clear and because of a possibility that strategic arms agreements may limit future development of supersonic bombers.

--A new engine family for a large subsonic military transport aircraft with long-range capability is doubtful in the contractor's opinion, because it considered that the requirement would more likely be satisfied by an existing or follow-on engine to those already approaching a 60,000-pounds-rated-thrust capacity.

--A new engine family for one of the advanced supersonic fighters was considered unlikely because the contractor concluded that the engine family in current fighters, such as the F-15, would remain in production until the late 1980s and that this would be encouraged by higher costs of acquiring new fighters and operating and maintaining them.

--A new engine family for a new commercial freighter with a gross takeoff weight of 1 million pounds was considered unlikely because, in the contractor's opinion, it depends upon DOD to partially fund its acquisition costs. The market for the new transport is uncertain because of inflation, higher fuel costs, and fuel availability.

Two new engine families would then remain for consideration of their market potential within the next decade: one for an advanced supersonic military fighter and one for a subsonic commercial transport/freighter. With a reasonable degree of certainty, the contractor predicted that those two engine families would be developed in the next two decades even without the ASTF capability.

Alternatives to constructing ASTF

The Air Force plans to use ASTF for subsonic and supersonic engine development and certification testing. There are two generally recognized methods to accomplish this: one is ground testing in a ground altitude test facility and the other is flight testing in prototype aircraft. The availability of a ground level test facility for altitude simulation does not eliminate the need for flight testing; it only reduces the number of required flight tests.

The contractor pointed out that there are about 14 altitude test facilities already in operation in the United States which are capable of testing engines with a rated thrust of 20,000 pounds or more. Many of these facilities can test engines in either the direct-connect or freejet mode. One facility also has the capability for transient testing which involves simulation of such things as changes in engine power, changes in aircraft altitude and speed, or any combinations of those changes.

The Air Force, however, told us that the existing altitude cells are inadequate to fully test subsonic and supersonic engines for future development or to even test some of the engines now being developed.

The contractor's study addresses the problem of developing large engines without fully adequate facilities for simulated altitude testing. It discusses large engine programs that have been completed during the last decade by the only three companies in the United States and Europe--General Electric Co., Pratt & Whitney Aircraft, and Rolls Royce--now capable of designing, developing, and producing large engines requiring ASTF's test capability. The study concludes that:

> "The histories of the * * * programs demonstrate that engines can be developed in the absence of facilities that are fully adequate for simulated-altitude testing."

The Air Force said history also demonstrates that advancing engine test requirements have deviated markedly from the capabilities of existing 20 to 25-year old facilities. It also said ASTF was not designed to provide full environmental simulation for all propulsion systems, but rather to bring the test capability more in line with testing requirements for various propulsion systems.

In the cost-effectiveness study, only flight testing was considered as an alternative to ASTF for development and certification testing of large subsonic and advanced supersonic engines.

Another possible alternative would be to modify or expand test capabilities of existing facilities; however, the Air Force said that this possibility at AEDC was studied extensively and found not to be a viable alternative. Analytic Services Inc. concluded that it was highly unlikely that the two U.S. engine manufacturers capable of producing large engines would expand or augment capabilities in their existing test facilities because of a limited market being projected for engines requiring ASTF's capability.

The Air Force said U.S. engine manufacturers should not be encouraged to increase their test capability even to the level now available in Government. It said the Government pays for industry's test facilities through its engine development and research contracts, and the United States cannot afford duplicative test capability by allowing extensive test facilities in each contractor plant.

Benefits accruing from using ASTF

It is generally recognized that data obtained in flight tests is less precise, takes longer to acquire, exposes test aircraft and crew to greater risk of loss, and costs more than data acquired by simulation in ground test facilities. Thus the type of cost-avoidance benefits (savings) measured in the contractor's cost-effectiveness study were:

--Cost of additional flight testing and related engine development programs.

--Cost related to the risk of loss of prototype test aircraft and delay of aircraft development programs.

--Cost related to less than optimum performance (poorer fuel economy and reliability) of engines in operational services.

The contractor computed the present value of savings that would be realized from 1983 to 1995 for the seven engine families. These engine families were related to five different types of aircraft for which they would be needed. As shown below, a substantial amount of the savings that it computed will accrue to the aerospace industry:

	Benefits (millions)
Aerospace industry:	
Subsonic commercial transport/ freighters (2 engine families)	$515.6
Supersonic commercial transport	250.0
Total	$765.6
Federal Government:	
Supersonic fighters (2 engine families)	$ 72.3
Supersonic bomber	155.4
Subsonic transport	75.9
Total	$303.6

The Air Force said other benefits will also accrue to the U.S. Government, such as better military aircraft and the spinoff to civil aircraft which will enhance the U.S. position in world trade.

As previously mentioned, the contractor predicted only two engine families would be developed by 1995--one for the supersonic fighter and one for the subsonic commercial transport/freighter. Its present value computation of savings totals $425.7 million for these two families, compared to the $340.6 million present value assigned to acquire ASTF and operate it until 1995. About $44.4 million in savings was estimated for the Federal Government and the remaining $381.3 million was estimated as savings to either the engine manufacturers, aircraft manufactures, or foreign and domestic airlines.

Possibility of Government recovering its investment

Based on estimated benefits in the cost-effectiveness study and the fees normally received from the aerospace industry for use of test facilities, it does not appear that the Government would recover its investment in ASTF.

In its study, Analytic Services Inc. computed the present value of ASTF's acquisition and operating costs at $340.6 million. It estimated a savings of $303.6 million for the Government if ASTF was used in developing the four new engine families that it considered as candidates for military application. It concluded that three of the families would not be developed by 1995. (See pp. 21 to 23.)

The present rates that the Air Force charges engine manufacturers for use of test facilities will recover only part of the cost to operate and maintain facilities.

ALLEGED SHORTCOMINGS IN THE STUDY

In commenting on the contractor's draft report, Air Force officials responsible for developing ASTF said:

> "The draft report, as presently written, is incomplete and possibly misleading. It addresses only the benefits that would be derived in the area of new engine development, and then it is extremely conservative. We feel that more than two new engines would be developed in the referenced time period. The draft report does not consider the return associated with it's use in the area of inlet-engine-airframe matching nor does it consider the improvements in efficiency and performance of existing engines that could be obtained."

These officials told us that they believe six engine families will be developed within the next two decades, but did not provide any specific information on proposed new aircraft programs to support their position.

The Air Force said it was asking the contractor to recognize, in its report, the types of savings and benefits that the Air Force believes were omitted. We understand that the contractor's final report, which will be issued by about March 15, 1976, is expected to recognize such savings and benefits. However, according to Air Force officials, the estimated savings attributed to using ASTF will probably remain the same as those contained in the contractor's draft report of October 1975.

SOME GENERAL CLARIFICATIONS AND DISTINCTIONS NECESSARY IN DECIDING WHETHER TO CONSTRUCT ASTF

As previously discussed, the early emphasis on ASTF was its use for testing in the development of supersonic transports or potential successors to large cargo aircraft, such as the C-5A and the Boeing 747. Although the early documents we examined showed emphasis on big engines, later studies pointed out the usefulness of the ASTF in developing high-speed, highly maneuverable aircraft. Also, although fuel economy was not a primary factor in engine designs at the time ASTF was initially proposed, the international oil problem made fuel economy more important. NASA and Air Force officials recently said that ASTF would be useful in designing engines needing less fuel, even if thrust levels were not increased.

We believe that the relative usefulness of ASTF to the development of future generations of military combat aircraft, contrasted with the development of new or larger military or commercial transport or supersonic transports, may be important in deciding whether ASTF should be built.

For instance, if ASTF's usefulness is primarily directed to large-engine improvement or development--and only incidental to smaller combat engine--it seems the Congress would want to establish policy on whether the larger or supersonic transports should be built before large investments are made in the facilities to develop and test the engines which are characteristic of those transports.

Conversely, if ASTF is essential to the development of combat aircraft, independent of their utility in the development of large aircraft, the Congress would want to determine the need for a new generation of military aircraft and whether a lower cost facility might satisfy the combat development needs as distinguished from transport development needs.

According to Air Force officials, new generations of fighter aircraft will be needed to maintain air superiority and ASTF is important to aircraft development. Also the fact that ASTF will be useful in both combat and large engine development is incidental or coincidental.

Although the Air Force and NASA recently told us that the test facilities would be useful in both the development of aircraft with large engines and combat aircraft with smaller engines, we could not discern a clear delineation of the relative importance of the test facilities to the development of both types of aircraft. We believe that answers to these types of problems can only be answered by experts in aircraft design and construction. The scope and time requirements of our study did not permit this type of independent evaluation.

MATTERS FOR CONSIDERATION BY THE COMMITTEE

We believe the Committee, in deciding whether to fund ASTF, should:

--Require the Air Force and NASA to identify the specific types of future aircraft developments, including engine thrust levels, requiring the facility's planned capability.

--Require the Air Force to clarify the importance of the facility in the development of combat aircraft as opposed to the development of larger military or commercial transport or cargo aircraft and to discuss the proposed use of the facility in the development of large engines.

--Obtain independent expert opinion as to whether the facility's capability is needed now if engines are not expected to grow in the next 20 years significantly above the current thrust ratings.

--Require the Air Force to identify all possible alternatives to the facility, including the construction of a shared-cost facility with our NATO allies, and to clarify why existing facilities could not be modified to permit development testing of military aircraft if there are no prospects for significant engine growths above current thrust levels.

--Ask the Air Force to provide specifics on new foreign technology developments, particularly by potential aggressor nations, supporting the view that the new facility is needed for U.S. military and civilian aircraft to remain superior and competitive.

--Obtain the Air Force's views on the essentiality to develop an engine with improved fuel economy, the expected improvements in fuel consumption for engines developed using the facility, and the practicality of such engines being installed in existing aircraft.

--Get the contractor's views on the reasonableness of his aircraft development projections and the significance of savings and benefits the Air Force says his study did not consider.

--Explore the possibility of funding the planned expansion of the facility now, rather than years later, if its planned capability is needed to test large engines and if the Congress elects to provide such capability.

CHAPTER 5

JUSTIFICATION FOR JOINT-USE TRANSONIC WIND TUNNEL

In January 1975, AACB decided to include one transonic wind tunnel in its proposed national aeronautical facilities program rather than both HIRT and TRT. The single facility, NTF, is being designed around the cryogenic operational concept planned for TRT but with a capability to simulate 120 million Reynolds numbers. This level of Reynolds numbers would stay within a dollar limitation established several years ago for both HIRT and TRT.

There appears to be considerable support within DOD, NASA, and the aerospace industry for construction of a transonic wind tunnel with the basic operational concept now being planned. However, we noted

--there is no unanimity of agreement on what capability NTF would need to permit reliable testing of future civilian and military aircraft,

--NTF's relationship to specific future aircraft design requirements is not clear, and

--there may be no insurance that NTF can be constructed at the estimated cost of $65 million.

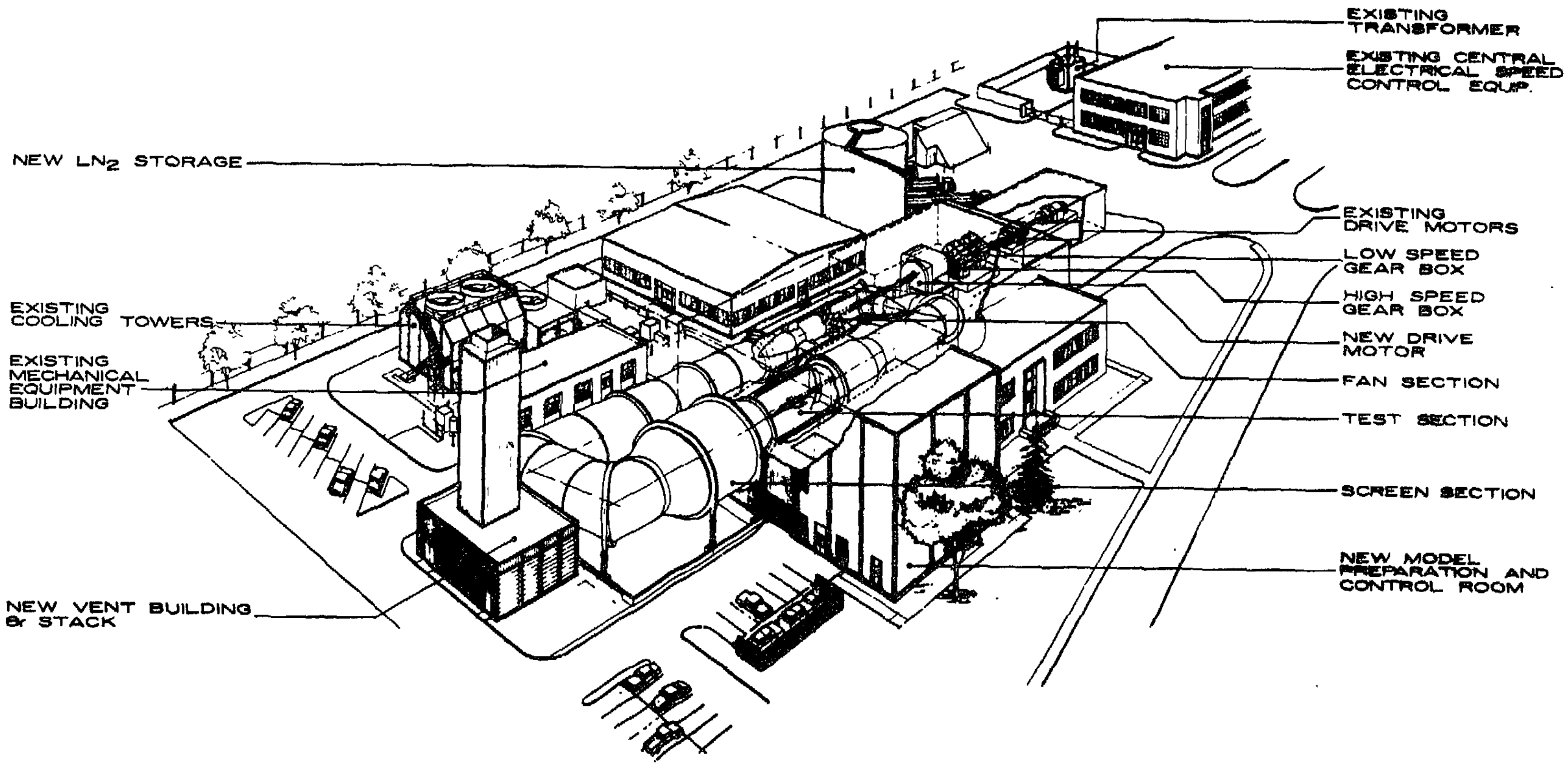
OPERATIONAL CONCEPT PLANNED

HIRT and TRT were to be entirely different wind tunnels. HIRT was to be a tube-type facility that relies on extreme air pressure--700 PSIA--to achieve high Reynolds numbers. Conversely, TRT was to be a conventional fan-driven facility that relies on the cryogenic approach whereby liquid nitrogen is used to lower temperatures in the test cell to simulate high Reynolds numbers. (See p. 32 for an artist's concept of NTF.)

After the increase in estimated costs for the two facilities, AACB asked its aeronautics panel to identify a single facility which could provide a compromise of the overall capabilities that were planned for HIRT and TRT. The aeronautics panel concluded that NTF using the cryogenic concept would be capable of testing in the transonic range. A brief comparison of characteristics of HIRT, TRT, and the proposed NTF is provided below.

BEST DOCUMENT AVAILABLE

NATIONAL TRANSONIC FACILITY
LANGLEY RESEARCH CENTER, NASA



*Furnished by the National Aeronautics and Space Administration

	HIRT	TRT	NTF
Design concept	Ludwieg tube	Cryogenics	Cryogenics
Cost (in millions)	$100	$35	$ 65
Reynolds number (in millions)	200	50 to 80	120
Mach number	0.2 to 1.3	0.2 to 1.2	0.2 to 1.2
Pressure	700 PSIA	14.7 to 80 PSIA	14.7 to 130 PSIA
Temperature	-30 F	155 to (-300F)	155 to (-300F)
Test section	8' X 10'	8' X 8'	8' X 8'
Run (data gathering) time per test	2.5 seconds	10 minutes	10 minutes
Type of testing	Development	Research	Development/ research

As proposed, NTF will have a capability for Reynolds number testing between that of the two originally planned facilities. The temperature and pressure of the airflow in NTF dictate the Reynolds number level that can be attained. A decision was made to increase the pressure beyond that envisioned for TRT to attain the Reynolds number desired.

The aeronautics panel chose the cryogenic concept because it offered possibilities to attain a rather high Reynolds number with a long run time for testing. HIRT, while capable of simulating the highest Reynolds number (200), had a run time of a few seconds in which test data could be gathered.

CAPABILITY ESTABLISHED BY DOLLAR LIMITATIONS

In July 1971 AACB agreed that upper limits for cost and requirements had to be established for facilities comprising the national aeronautical facilities program. This resulted in approximately $80 million being budgeted for HIRT and TRT. In October 1974, when the cost for both facilities escalated to $135 million, AACB asked its aeronautics panel to consider other viable facility options for meeting research and development requirements at a reduced cost. In carrying out this task the panel was encouraged to:

> "consider options costing about $45 to $55 million, but in no case more than approximately $80 million, about which had been originally budgeted for the two facilities. Emphasis on options representing a range in costs was regarded as most important."

In accordance with the above instructions, the aeronautics panel developed the following range of facility options within the specified limit that would be considered to replace HIRT and TRT in the program.

	Cost (millions)
Option for two facilities:	
1. HIRT with a smaller (8- X 8-feet) test section and less supporting equipment	$50
2. TRT with a smaller (6.5- X 6.5-feet) test section	25
	$75
Options for a single facility:	
1. TRT as is (see schedule on p. 33)	$35
2. HIRT with a smaller (8- X 8-feet) test section and less supporting equipment	$50
3. TRT with an increase in Reynolds number capability to 120 million	$50
4. HIRT with a smaller (8- X 8-feet) test section	$80
5. New facility with cryogenic concept and a 180 million Reynolds number capability	$80

After some review, the aeronautics panel reported at the January 1975 meeting of AACB its conclusion that a single transonic facility should be developed using the fan-driven cryogenic concept and having a Reynolds number capability of 120 million. The panel reported that such a facility should cost in the range of $60 to $75 million.

OPINIONS ON TEST CAPABILITY NEEDED FOR RESEARCH AND DEVELOPMENT TESTING

Within DOD, NASA, and the aerospace community, there is considerable support for a transonic wind tunnel capable of simulating high Reynolds numbers for future aircraft development. As discussed below, however, there is no unanimity of agreement as to what Reynolds number capability this transonic wind tunnel should possess.

Industry's position on capability

In a May 1975 report, the national aeronautical facilities subpanel to AACB's aeronautics panel recommended the acquisition of NTF to support research and development testing needs of NASA and the Air Force, respectively. The report says the subpanel concurred in testing needs as previously presented in the report of the ad hoc transonic tunnel study group to AACB's aeronautics panel which was issued on March 26, 1973.

The aeronautics panel formed the ad hoc group in mid-1972 to study national requirements of a high Reynolds number transonic tunnel. The study was to consider the level of testing capability and whether both a research and development tunnel was required.

Because the aircraft industry has the greatest overall experience in using wind tunnels for new aircraft development, the ad hoc group felt that the views of industry were highly important and should be known and understood. Accordingly, a group of industry advisors was selected to assist in the study in which the major segments of the aircraft industry experienced in the development of both fighter and large cruise were represented. The advisors were briefed on both the Air Force HIRT proposal and NASA's investigation of the cryogenic wind tunnel. In briefings, the advisors were presented with Air Force and NASA projections of Reynolds number levels that they believed the different classes of future aircraft would attain in flight. The projections were similar to those illustrated on p. 37, which show that the large supersonic aircraft, such as a supersonic transport, would incur Reynolds numbers between 170 to 225 million during flight.

A list of questions was submitted to advisors from industry in which their views were requested on such things as the Reynolds number capability needed and the amount of testing that would be done at various levels up to 100 million Reynolds numbers. The consensus of the advisors' views was that about 90 percent of the testing would be between values of 2 and 20 million Reynolds numbers and about 10 percent would be at about 100 million. As shown below the advisors had different opinions as to the capability needed, but only one industry advisor indicated a need for Reynolds number capability exceeding 100 million.

Company	Reynolds number capability (millions)
North American Rockwell, Los Angeles	40
North American Rockwell, Columbus	50
Lockheed, Georgia	100
Lockheed, Burbank	40
McDonnell-Douglas, Long Beach	50
McDonnell-Douglas, St. Louis	25
General Dynamics, Fort Worth/San Diego	100+
Boeing, Seattle	100

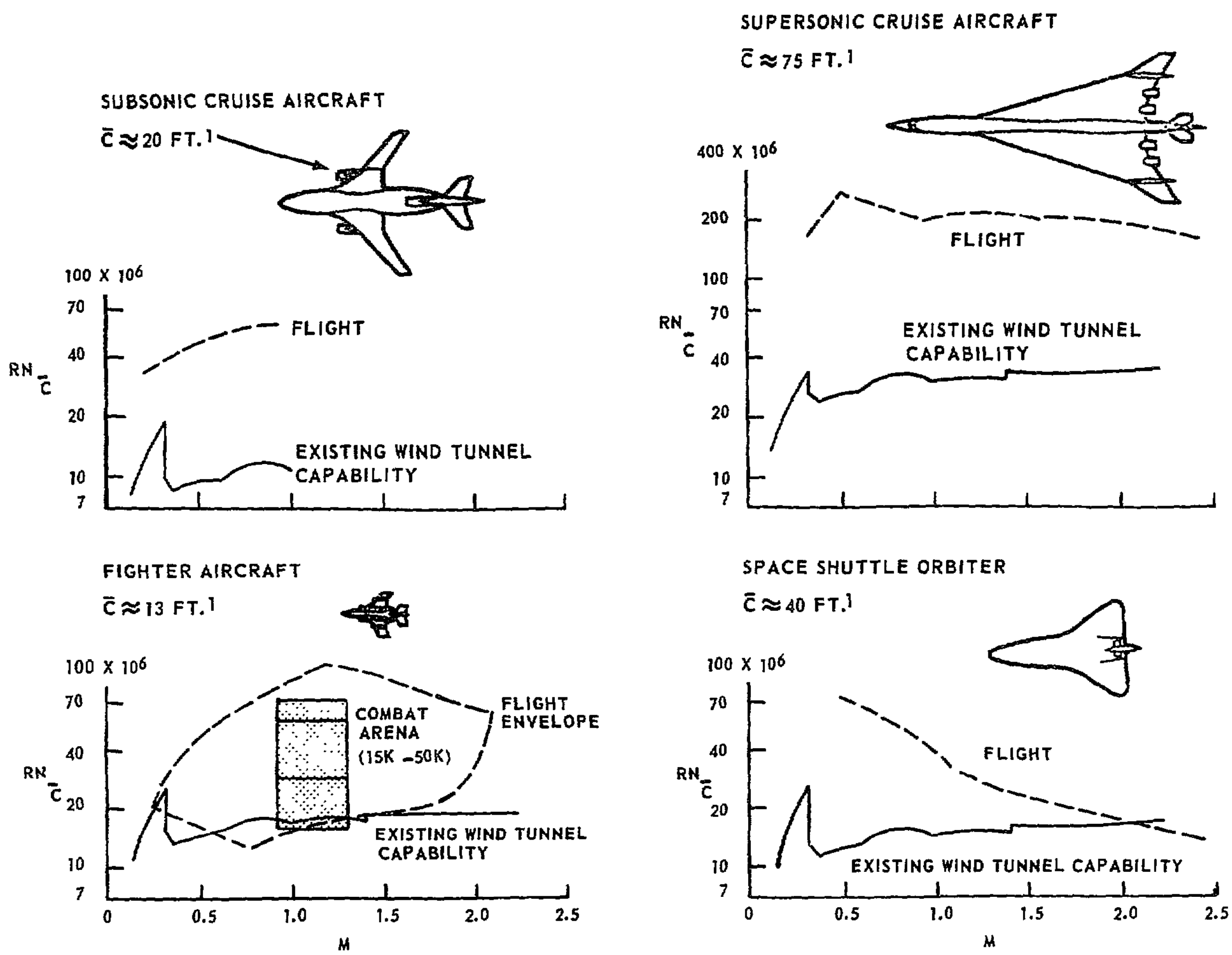
Agencies' views on development testing capability

In testimony before the House Committee on Appropriations in June 1974, the Air Force said it needed a 200 million Reynolds number test capability to support the development of future military aircraft. NASA officials also concurred that this level of capability was essential to the development testing of future military aircraft.

Because NTF will have only about one-half of the capability planned for HIRT, we asked the Air Force if the planned test capability for NTF would satisfy its known test requirements for future aircraft developments. In responding to our question on March 8, 1976, the Assistant Secretary of the Air Force (Research and Development) said:

> "The Air Force requirement for testing at 200 million RN [Reynolds number] is unchanged. It should be understood, however, that this is the maximum RN that we expect to see. There are several ways to accomplish this since RN is dependent not only on tunnel parameters but model size. We are currently investigating alternate testing techniques to obtain the desired results using the NASA National Transonic Facility (NTF). This includes several approaches such as half model and porous wall techniques. We expect several advances in this area to be realized by the time NTF becomes operational. Even if a breakthrough of technology does not occur in this area, a capability of 120 million RN will cover the vast majority of the Air Force testing requirements. The NTF will produce a tunnel pressure

PROJECTIONS OF FLIGHT REYNOLDS NUMBERS FOR VARIOUS CLASSES OF FUTURE AIRCRAFT



GAO Note: [1]This represents the average distance between the leading and trailing edges of the wing.
Furnished by the National Aeronautics and Space Administration.

of 130 psia which corresponds to approximately 120 million RN, depending upon model size and other factors. Using half model technology, for example, 240 million RN could be realized.

"A special panel was convened by the Aeronautics and Astronautics Coordinating Board (AACB) to determine the design criteria for the NTF. The panel decided to use an approach which used very cold nitrogen as the fluid and to make maximum use of existing air moving equipment. Based upon these and other considerations the design tunnel pressure was established at 130 psia. The alternate approach previously described, will be used to attain Reynolds Numbers above 120 million RN. The Air Force was represented on the special panel and concurs in its findings. Therefore, we support construction of the NTF with a maximum tunnel pressure of 130 psia and certify that it will meet Air Force requirements."

Reasons for different opinions

In March 1973 a NASA-Air Force-Navy ad hoc working group was formed to define research programs' needs to determine the minimum test Reynolds number test capability that would simulate or allow reliable extrapolation to full-scale aircraft flight characteristics. The ad hoc working group in January 1974 concluded:

> "evidence presently available to the Working Group is inadequate to permit any conclusions to be drawn on a wind tunnel test Reynolds number level required for acceptable simulation of full-scale aerodynamic flight."

The ad hoc group concluded that it should be possible within a few years to define a Reynolds number range in which predictable changes occur for relatively simplified flow fields. It said a more complete understanding of Reynolds number effects for a broad range of flow fields will be in hand upon the completion of existing and newly proposed research programs.1/

1/ The term "simplified flow fields" relates to the simplified airflow conditions on an aircraft wing, and the term "broad range of flow fields" relates to the broad range of airflow conditions on a complete aircraft.

NASA, on the other hand, said even if proposed research programs were to be accelerated, Reynolds number effects for only relatively simplified flow fields could possibly be defined within the next 2 years. NASA interpreted the study to say that

> "we [United States] never will be able to develop experiments which will provide generally applicable results for wing/body and control effects and the basis for the need for a high Reynolds number tunnel."

NASA said the fundamental and still unanswered question is how much Reynolds number capability should be designed into an advanced transonic facility which will be operational in the 1980 to 2000 time period and beyond. According to NASA, there are two conflicting schools of thought with strong advocates for each side.

--Design for full-scale Reynolds number and anything less than full-scale Reynolds number is a compromise because it is not possible to establish some lesser value as being technically adequate.

--Design for a range of Reynolds numbers which, if not extending to full-scale, allows extrapolation to flight conditions to be made with confidence.

NASA said that, from a research standpoint, the basic desire was for a test capability covering the complete span to full-scale flight Reynolds numbers and beyond. However, the research scientist with longer time scales and with the benefits of advanced theoretical and experimental tools, can often attain his goals by indirect methods. For example, the researcher may test large-scale components of a flight vehicle to assess Reynolds number effects, or simulate high Reynolds number flows by elaborate techniques. Thus, with the technical optimism inherent in the scientific approach, the research scientist if required, can often settle for experimental capability at some threshold Reynolds number less than full scale.

In the area of development and evaluation, however, NASA said the engineer has the responsibility for defining the full-scale aerodynamic performance of perhaps a multibillion-dollar system in a relatively short time. He has little opportunity to add to the technology base; he can only use what exists at that time. The cruise range is not the only test area of interest. Military aircraft in particular are required to fly all over the available flight envelope. Reynolds number problems, on past military transport aircraft programs, were encountered at other than cruise conditions. Thus, from a development/evaluation standpoint, anything less than full-scale test Reynolds number is a compromise which makes his predictions of full-scale aircraft performance uncertain.

ADEQUACY OF PLANNED CAPABILITY FOR FUTURE AIRCRAFT RESEARCH AND DEVELOPMENT

NTF is being justified on the basis it is needed to test models of highly maneuverable fighter-type aircraft and large transport-and cargo-type aircraft that will operate in the future near or beyond the transonic speed range. NTF will also have the capability to test models of the space shuttle vehicles. However, the need for planned test capability has no clear relationship to projections of future aircraft.

Development of large future aircraft

As previously mentioned, only one advisor from industry indicated to the ad hoc group that a test capability exceeding 100 million Reynolds numbers would be needed. On the other hand, Air Force officials said that some aircraft have already been designed to operate at peak values of about 180 million Reynolds numbers. They said these would be aircraft operating at the extremes of their design and gave as an example the B-1 flying at sea level at a speed of around 1.2 mach.

As shown in the graphs on p. 37, the Reynolds number levels for the various classes of future aircraft at cruise ranges will be less than 100 million, except for large supersonic cruise aircraft. The Air Force, however, said:

> "Cruise range is not the only test area of interest. Military aircraft in particular are required to fly all over the available flight envelope. Reynolds number problems, on past military transport aircraft programs, were evidenced away from cruise conditions."

The ad hoc group recommended acquiring HIRT for development and evaluation. This facility was to be designed with a 200 million Reynolds number test capability. In discussing HIRT's planned capability, the ad hoc group's report on its study, issued in March 1973, says:

> "This proposed facility has as its objective the capability of producing a wide range of high

RNs [Reynolds numbers] up to and including full-scale values for the development of the largest flight vehicles that can be conceived for construction within the next 20 years."

In its May 1975 report, the national aeronautical facilities subpanel to the AACB addressed the flight envelopes projected for various classes of aircraft to be used in justifying the NTF's test capability. This report shows the test capability planned for the NTF will only permit full testing of the flight envelope for a future small bomber. However, in January 1976, the Ralph M. Parsons Company issued a preliminary engineering report indicating the NTF will not permit full testing of the flight envelope for any of the types of future civilian and military aircraft considered in sizing it.

NTF cannot be expanded to test at full scale the large types of aircraft considered in sizing it in the event that they are developed. The results of tests at NTF's peak Reynolds numbers could be extrapolated to the full-scale Reynolds numbers for such aircraft; however, the Air Force and NASA said that extrapolation of data was risky and was known to provide less than credible results in many cases.

Maneuverable and medium-sized aircraft developments

The ad hoc group also recommended continuing efforts to develop a smaller, less expensive test facility with capability to operate at intermediately high Reynolds numbers. In describing such a facility, the ad hoc group's March 1973 report says:

"Its purpose would be primarily to support NASA's research needs, but it would also be of great value in the development space shuttle vehicles, medium sized transports, and fighter aircraft."

Later, TRT was accepted by AACB as the facility to support NASA's research role. The facility was to be designed with a 50 million Reynolds number test capability.

The facilities subpanel of AACB's aeronautics panel said the need for the transonic test capability was established in the ad hoc group's report of March 1973. The subpanel's report does not say, however, why the test capability planned for TRT was not considered high enough for research and development testing of future aircraft.

ASSESSMENT OF THE CRYOGENIC CONCEPT

In November 1973, the aerospace vehicles panel of the Air Force's Scientific Advisory Board reviewed plans for HIRT. The panel also considered using the cryogenic operational concept as an alternative and concluded that, while the cryogenic working medium may ease major model and wind tunnel design problems, it may itself introduce others. The following is an excerpt from the panel's findings.

> "Instrumentation, bearings, seals, lubricants, and other ordinary mechanical appurtenances of wind tunnels and wind tunnel models will all have to be designed and developed for cryogenic temperature operation. And, although the use of cryogenic temperatures will effect a marked reduction in model and support stress levels, allowable stresses, particularly with respect to fracture mechanics, will also be lower for most high strength materials at these low temperatures. Although, undoubtedly there are engineering solutions (at a price) to all of these problems, until they are completely analyzed and subjected to the test of practical application, it is difficult to say what the net benefit/cost advantage of operation at cryogenic temperatures will be."

At that time, the panel said it would hardly appear prudent to commit resources to a large and expensive development facility until complete and detailed experiments and studies have been completed.

More recently, the May 1975 report has been prepared by the facilities subpanel of AACB's aeronautics panel and used as justification for NTF. According to NASA, this report clearly defines the needs for research and development in the transonic speed range and explains how NTF will fulfill them. The report, nontheless, does not specify whether complete and detailed experiments and studies on cryogenics have been conducted. It also indicates that two pilot cryogenic tunnels have been constructed and operated successfully by NASA but there is no indication that either of these pilot tunnels was operated at the level of test capability planned for NTF.

The estimated cost of $65 million for NTF is based on a contractor's preliminary engineering estimate as of January 1976. Until there is more definitive design, there are no reasonable insurances that NTF can be constructed with its planned test capability for $65 million.

APPROACHES TO HIGH REYNOLDS NUMBER TRANSONIC TESTING

A high Reynolds number wind tunnel is not the only method of transonic testing available to NASA and the Air Force. However, such a wind tunnel is considered to offer certain advantages in time and money over other alternatives available.

The oldest of these alternatives is the research aircraft. In 1949, during hearings to consider the unitary wind tunnel plan, the House of Representatives considered problems in building wind tunnels for testing in the transonic regime. In this regard, House of Representatives Report No. 81-1376 notes specifically:

> "The absence of any immediate prospect of solving the problems of transonic wind-tunnel operation led several years ago to the extensive development of alternative techniques for the observation and measurement of aerodynamic effects during transonic flight. One of these methods which has proven highly successful is the use of the research airplane * * *."

NASA said research aircraft is a valuable tool, but one that must be used at great cost. As an example, NASA cited a recent Air Force/NASA program which involved work with a modified F-111. It said the answers obtained in flight cost $25 million whereas a high Reynolds number tunnel would have obtained the same results at a fraction of that cost.

Another alternative is to use test results from existing wind tunnels with about 10 to 12 million Reynolds number capability. The results are then extrapolated to the higher Reynolds number levels which aircraft would be expected to attain in flight. However, as aircraft have grown in size and increased in speed, it has been necessary to extrapolate over a ten-fold magnitude of Reynolds numbers. NASA views this approach as no longer being an acceptable alternative.

The absence of a high Reynolds number tunnel, however, has not prevented developing aircraft such as the C-5A, the F-14, the F-15, and the B-1, but it could reduce development cost. The stated objective of a high Reynolds number tunnel is to identify aerodynamic design discrepancies before development and/or production of an aircraft. Without such a tunnel, deviations from desired design characteristics may not be discovered until flight tests are performed at which time the cost of correcting a discrepancy is incredibly high. A high Reynolds number would not replace flight testing as this is the final step in the evaluation of an aeronautical vehicle. However, its use for testing may minimize the amount of flight testing that needs to be performed and thereby reduce cost.

MATTERS FOR CONSIDERATION BY THE COMMITTEE

We believe the Committee, in deciding whether to fund NTF, should:

- --Require NASA and the Air Force to identify research and development programs for future aircraft that will require NTF's capability.

- --Obtain independent expert opinion on whether the capability planned for TRT would have been adequate in event there are no prospects for future development of large supersonic aircraft.

- --Seek expert opinions as to whether test results from NTF can be extrapolated to higher levels in event there are prospects for future development of large supersonic aircraft.

- --Obtain independent expert opinion as to whether the cryogenic concept is sufficiently tested to insure that major construction and operational problems will not be encountered and that reasonable reliance can be placed on the present forecasts of cost, completion, and operational results.

CHAPTER 6

SCOPE OF REVIEW

Our review was designed to develop information that would be helpful to the House Committee on Appropriations in its consideration of appropriation requests for HIRT and ASTF or similar facilities. It included examination of records and documents related to HIRT and ASTF; interviews with officials of the Air Force, the Navy, and NASA who were involved in planning and justifying the facilities; research of laws, regulations, and policies having an impact on fund requests for the facilities.

Our review was made principally at Air Force Headquarters in Washington, D.C. We initially programed our work into two phases so that the House Committee on Appropriations could be provided with information for use in its hearings on the Air Force's appropriation request for fiscal year 1975.

In the first phase, we developed information on the areas of interest specified in the Chairman's request of February 27, 1974. The information was provided to staff members of the House Subcommittee on Military Construction Appropriations. The information was used as a basis for questioning Air Force witnesses about plans for HIRT and ASTF. As a result, considerable information is available in the record of hearings before the Subcommittee for fiscal year 1975--Part 2--on the areas in which the Chairman's letter expressed an interest.

After the hearings, we made the second phase of our review which was devoted principally to studying the methods to develop the program and obtaining information on program changes since the 1975 appropriation hearings. This report discusses the results of our work during the second phase.

APPENDIX I

Congress of the United States
House of Representatives
Committee on Appropriations
Washington, D.C. 20515

dms

February 27, 1974

B-180766

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

Dear Mr. Staats:

The Air Force plans to spend about $300 million on the construction of two new test facilities--a High Reynolds Number Transonic Tunnel (HIRT) and an Aeropropulsion System Test Facility (ASTF). I would like for your office to assist in evaluating the appropriation request for both those facilities.

The Air Force plans to build the test facilities at Arnold Engineering Development Center, Tennessee. This year's appropriation request includes around $44 million for construction of the HIRT and an unspecified amount for design of the ASTF. The Air Force currently estimates the construction cost for the latter facility at over $250 million and these funds may be included in next year's appropriation request.

The Committee desires information on the need and planned use for the new test facilities. It also needs to know their exact construction and annual operating cost; the adequacy of utilities, particularly power, at Arnold to operate the facilities; and the action taken to solicit financing and interest by private enterprise.

As your study progresses, I suggest meetings between your representatives and the Committee's staff to work out the nature and timing of reporting.

The Committee has no objections to the Department of Defense being informed of this request.

Sincerely,

George Mahon

Chairman

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