The New National Wind Tunnel Complex

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Introduction

Research, development, and operational facilities are critical
to maintaining U.S. leadership in aerospace technologies.
Recognizing their importance, National Aeronautics and
Space Administration (NASA) Administrator Daniel Goldin
initiated development of a comprehensive long-term plan for
the nation's aerospace facilities. In early 1993, the National
Facilities Study Team was established as an interagency
group to study current U.S. aeronautical and space facilities
and formulate a national plan to improve American
aerospace competitiveness. Participants included NASA, the
Department of Commerce, the Department of Defense, the
Department of Energy, the Department of Transportation,
and representatives from industry. The aeronautics portion
of their report, the National Facility Study (NFS), was
completed in April, 1994. Its central recommendation was to
develop a new national wind tunnel complex (NWTC)
consisting of one transonic and one subsonic wind tunnel.

This facility would supplement the existing research-oriented
NASA wind tunnels in meeting the needs of the U.S.
aerospace industry to develop and design advanced,
efficient aircraft. In contrast to research tunnels, whose
design is driven by requirements associated with the
collection of scientific data from one-of-a-kind tests,
development tunnels are designed and built to minimize
cycle times and costs, so that industry can bring new aircraft
to market more quickly and at a lower cost than the
competition. Development tunnel design therefore
emphasizes not just aerodynamic capability (e.g., high
Reynolds number and flow quality) but also high productivity
and low operating cost. The proposed national wind tunnel
complex would meet these needs.

Funding of the NWTC may also be done differently than it
has been in the past. Although no firm proposal has yet
emerged, it is thought that the NWTC will be designed, built,
and financed by a joint government-industry consortium.
Significant barriers to this innovative approach, however,
would have to be overcome. The cost of the facility, for
example, has yet to be determined and will be strongly
affected by the highly charged political hurdle of site
selection. Another uncertainty is the size of the investment
government and industry can afford.

**Proposed National Wind Tunnel Complex**
**Technical Benefits**
The proposed NWTC can effect incremental increases in the economic competitiveness of commercial aircraft by enabling technological advances that increase lift and reduce drag and weight, and by improving our ability to estimate aircraft performance in advance of first flight. The value of the new complex lies in the capability to test models under simultaneous Reynolds number and Mach number conditions close to those experienced in flight. These two parameters permit predictions of full-scale flight vehicle performance through the use of simulated, subscale wind-tunnel models; that is, the closer the wind-tunnel Mach and Reynolds numbers are to those that will actually be encountered by the operational aircraft, the better the simulation of the aircraft's flight characteristics will be.

The flight Mach number is not hard to match, but it is technologically difficult and expensive to build facilities capable of testing large aircraft at--or close to--the full flight Reynolds number (a dimensionless parameter defined as the product of flight velocity, air density, and characteristic aircraft dimension, divided by the air's viscosity). Instead, most wind-tunnel testing is performed at lower Reynolds numbers, forcing engineers to extrapolate their data to the flight condition. The inherent uncertainty of this extrapolation requires aircraft design and performance estimates to be over conservative, precluding industry from utilizing the full value of their aircraft. It should be noted that manufacturers must guarantee performance prior to completing the aircraft design. High Reynolds number testing will reduce the uncertainty and thereby decrease design conservatism.

Transonic Wind Tunnel
The transonic wind tunnel (TSWT) would offer a maximum Reynolds number of 28.2 million[1] in an 11.5-ft by 15-ft test section, and would assist in the optimization of aircraft for cruise and other transonic flight conditions. The transonic tunnel will provide the largest overall benefit. Approximately 90% of the flight time for a subsonic transport is in transonic cruise (Mach number 0.75 to 0.9),[2] and reductions in cruise drag significantly decrease aircraft fuel consumption. This increases aircraft range and/or decreases fuel burn, reducing operational costs.

These benefits would be achieved by using the TSWT and its high Reynolds number capability in the high-speed design process. After an initial cruise wing design has been formulated using computational fluid dynamics (CFD), it is tested in a wind tunnel to verify that performance objectives have been met. The wind tunnel data may identify shortcomings in the design, so that engineers can redesign the wing for better performance using CFD techniques.[3] The pressure distribution and the location of the shock wave on the upper surface of the wing can be tailored to minimize flow separation and decrease drag. The high Reynolds number capability of the new TSWT will provide improvements in modeling accuracy, allowing designers to better optimize their designs.

The TSWT will also provide more accurate data on stability and control characteristics and aerodynamic loads for flight at both cruise and transonic off-design conditions. The stability and control data are used to size control surfaces[4] and the actuators which drive them, while loads data are utilized to design structural members. Improvements in the accuracy of flight simulation can reduce the size and weight
of these components by reducing the conservatism in their design. Reductions in drag can result, but the weight reduction is the most significant. Decreasing the empty weight of an aircraft increases its payload and range and/or reduces its fuel consumption and thrust requirements over its entire operational lifetime.

**Subsonic Wind Tunnel**

The subsonic wind tunnel (or Low-Speed Wind Tunnel, LSWT) complements the design process with the low-speed, high-lift testing capability needed to model take-off and landing. The advertised maximum full-span Reynolds number of 20.4 million[5] is a large improvement over existing test facilities and would address the present need to test near flight Reynolds number. Unlike that of the cruise condition, the fundamental physics of the highly complex flows associated with high-lift devices such as leading-edge slats and multipiece flaps are not as well understood. Furthermore, phenomena known as "reverse Reynolds number" effects makes the extrapolation of results from experimental data obtained in existing lower Reynolds number facilities to the full Reynolds number condition highly problematic. The LSWT will address both of these considerations by providing high Reynolds number testing capability for low-speed, high-lift configurations. Improvements in the accuracy of simulating high-lift flight conditions could enable engineers to design and build more productive and perhaps less complex high-lift systems, reducing aircraft size and weight, cutting engine size, decreasing aircraft cost, and reducing operations and maintenance costs.
Figure 1 illustrates the geometric complexities of a high-lift configuration with deployed slat and flaps as compared to a cruise configuration. Multiple lifting elements yield complex and interdependent viscous compressible flows which are not fully understood. For a three-dimensional wing with sweep, the problem is exacerbated. As a result, the CFD tools presently available cannot be relied upon for detailed design alone; the wind tunnel is a critical tool in the high-lift design process.

For example, until the development of the Boeing 767 in the late 1970s, it was believed that aerodynamic performance always improved with increasing Reynolds number. Wind tunnel tests, however, revealed an unexpected drop in high-lift performance at moderate Reynolds numbers, as shown in Figure 2. Although this so-called "reverse Reynolds number effect" itself is reasonably well understood, its onset, and therefore its effect on the complex flows associated with high-lift systems, is not predictable. It is believed that the "Reynolds number effects on high-lift [systems] are correlated with flow transition and the boundary layer characteristics."[6]

The present inability to wind-tunnel test at high Reynolds numbers necessitates large extrapolation of test data to the flight condition. Figure 2 illustrates how this extrapolation (the dashed line in the figure) fails to predict lift loss at high Reynolds numbers due to the reverse Reynolds number effect. If testing is done beyond the transition Reynolds number, however, the data can be extrapolated to flight conditions with less uncertainty. Nevertheless, our lack of understanding of this phenomenon suggests that tunnel data
should be obtained at the full flight Reynolds number to obtain a minimal level of uncertainty.

The LSWT will provide the testing capability necessary to test small aircraft at flight Reynolds numbers with full-span models and intermediate-sized aircraft like the Boeing 737 with semi-span models. Larger aircraft will also benefit from this increased capability, because their design risk can be reduced significantly if models can be tested beyond the transition Reynolds number. Unfortunately, the transition point is highly dependent on the specific geometry and boundary layer contamination characteristics of the configuration and can vary significantly. If transition occurs beyond 35 million[7], there will be considerable uncertainty in extrapolating LSWT data to flight conditions.

Performance Guarantees

In addition to their use in design, wind tunnel data are used to estimate aircraft performance.[8] Commercial airframers must contractually guarantee minimum performance levels to their customers long before the first aircraft is ever built, and aerodynamic measurements taken in the wind tunnel are used to determine the appropriate minimums. Overestimating performance, and the subsequent failure to meet guarantees, requires industry to make compensatory payments to the customer. Hence technical uncertainty in test data leads to conservative business guarantees. Underestimating performance, however, is equally undesirable, because customers bid on and purchase aircraft according to guaranteed performance levels. Thus over conservative guarantees penalize the aircraft by making it less attractive compared to its competitors and by
decreasing its value to the airline, thereby reducing the potential profitability of the design. The ability to make realistic, aggressive cruise performance guarantees is a compelling factor in the market-share equation.

Why Not Higher Reynolds Numbers?

The actual flight Reynolds number for a Boeing 747 in take-off and approach is about 40 million; during cruise it is about 60 million. Larger, future aircraft are likely to experience even greater flight Reynolds numbers. Why, then, build tunnels with maximum Reynolds numbers of only 30 million?

Admittedly, the difference between 30 million and 60 million at first appears quite substantial. The effect of Reynolds number on the aerodynamic properties of flight vehicles, however, is not a simple linear function. Considerable experimental experience suggests that the effects of Reynolds number scale according to its logarithm. The logarithms of 60 million and 30 million are 7.78 and 7.48 respectively, differing by less than 4%. Existing wind tunnels have Reynolds numbers near 10 million, so the difference in logarithms (from the desired 60 million) is about 11%. Hence in terms of the effects of Reynolds number, the new tunnels are much more accurate than existing tunnels. Also, it is not essential that the tunnels match the full flight Reynolds number for all aircraft. What is required is that the testing be done at a Reynolds number close enough to extrapolate the data to flight without significant uncertainties.

Transonic Wind Tunnel
Selection of the best wind-tunnel Reynolds number in the transonic regime is largely a matter of an educated opinion. The empirical data on this subject are not conclusive, and U.S. experts disagree on exactly how high the Reynolds number needs to be. The 30 million identified in the NFS emerged as an acceptable average of the opinions.

This value is not without empirical justification, however. Fundamental parameters such as skin friction drag and boundary layer displacement thickness tend not to vary very much between 30 million and 60 million. Thirty million is thought to correspond to the point at which the boundary layer flow is usually completely turbulent with transition located at the leading edge of the wing, so that extrapolation beyond that point is believed to entail minimal uncertainty.

**Subsonic Wind Tunnel**

As noted above, high-lift testing should ideally be done at the full flight Reynolds number because of the uncertainty associated with possible reverse Reynolds number effects. However, technological and economic constraints motivated the NFS to select 20.4 million (35 million for semi-span models) to provide a large benefit-to-cost ratio.

It was also noted earlier that a Reynolds number of 30 million is thought to be beyond the transition point for many aircraft and corresponds to the point where critical boundary layer characteristics appear to reach a plateau. It is therefore believed that the data collected at this Reynolds number can be extrapolated accurately to full scale.
The Reynolds number limit of the LSWT, however, introduces three concerns. The first relates to the flow over the smaller lifting elements in a high-lift system. The argument cited earlier for selecting Reynolds numbers around 30 million is that the flow will have stabilized enough to extrapolate the data to the flight condition. But for the flaps, slats, and other small surfaces this stable condition may not be reached even at full scale.

The size parameter generally used to compute the Reynolds number is the mean aerodynamic chord of the wing in the cruise configuration. Because the chords of high-lift devices are significantly smaller than that of the wing, the Reynolds number based on these chords is much lower, so the flow over these surfaces may not be as developed as that on the wing itself. Suppose, for example, that a flap's chord is 10% of the wing chord. If the flight Reynolds number (based on the wing chord) at Mach 0.3 is 60 million, the Reynolds number of the deployed flap would be 6 million, and a wind tunnel test performed at 30 million would yield a flap Reynolds number of only 3 million. But the boundary layer characteristics may not have stabilized between 3 million and 6 million, so the subsequent extrapolation could be inaccurate. This would mean that data from the LSWT may not be as valuable as predicted.

The second concern with the maximum LSWT Reynolds number (20.4 million; 35 million with semi-span models) is that it is based on a wind tunnel pressure of 5 atmospheres. Although the 12-ft NASA Ames tunnel operates at 5-6 atmospheres, the aerodynamic forces at these high pressures make it extremely difficult to build models for high-lift testing. The high-lift devices must be attached to the
model with brackets that are small enough not to disturb the airflow, yet large and strong enough to withstand the loads without bending or breaking. Beyond three or four atmospheres it is difficult to build brackets for high-lift models that can withstand the loads and are not too big. Although industry has built and tested models able to withstand 5 atmospheres, this ability has yet to be demonstrated for the as-yet undefined LSWT test section. Reduced pressure capability would reduce the LSWT's Reynolds number. Related issues are the as-yet unknown effects of wall interference and model sting stiffness; should either of these turn out to be a problem smaller models would have to be used, further reducing the effective Reynolds number.

The third and final concern is that should the Reynolds number goal selected for the LSWT prove insufficient for any reason, increasing its capability will incur high costs unless planned for in advance. The LSWT is believed to be near the practical operational limit for a conventional pressurized tunnel, as noted earlier. The NFS notes that increasing the size of the test section, cooling the flow, or using a heavy gas as the test medium[9] could conceivably increase the Reynolds number, but each of these "fixes" would significantly increase the cost of the facility, decrease its productivity, and increase operating costs.

What About Computational Fluid Dynamics (CFD)?

CFD has made considerable progress in recent years and is now able to predict some fluid flows accurately enough for its use as the basis for final design decisions. However, CFD has limitations both in its practical utilization and in its
capability that prevent its use as a replacement for wind tunnel testing. CFD simply cannot provide industry with the same type of data that the NWTC can generate.

Indeed, CFD and wind tunnel testing are complementary resources. CFD is usually able to generate data rapidly for a relatively small number of simulations at a cost much lower than that of a wind tunnel test. Tunnel tests are not only costly, but often require months of lead time. This investment of time and resources, however, is balanced by the large amount of data that can be obtained in the wind tunnel. Once a model is in the tunnel it is a simple matter to test it at numerous flight conditions. The tunnel Mach number, pressure, model orientation, and configuration (control surface deflections, for example) can be adjusted rapidly and cheaply to obtain a comprehensive aerodynamic characterization of the configuration over a wide spectrum of simulated velocities and altitudes. It is simply not feasible to utilize CFD to generate the same volume of data. CFD is best used strategically for analysis and design in limited but critical regions of the flight envelope, and in early advanced design to narrow the range of configurations that need to be tested in the wind tunnel.

Furthermore the capability of CFD to predict drag and highly complex flows accurately is still limited. The fundamental physics of complex flows with confluent boundary layer interactions, relaminari-zation, massive separation, and strong shocks are not completely understood. Additionally, the current turbulence models used in CFD are essentially mathematical correlations obtained from test data at lower Reynolds numbers. As a result, the complexities of high-lift systems, off-design transonic flight, and accurate drag
prediction cannot yet be adequately modeled with CFD. Wind tunnel tests (as well as flight tests) remain the sole source of usable data on such flows, and high Reynolds number testing can provide significant advances in their predictive accuracy. Note, however, that it is not necessary to conduct all testing at high Reynolds numbers, even with the new facilities. Configurations need to be evaluated for Reynolds-number sensitivity, because testing at lower Reynolds numbers (and thus lower pressure) is more productive.

Some argue that funds invested in wind tunnels could be better used to understand the fundamental fluid physics which underlie these complexities and thereby enable advances in CFD modeling. Clearly, investments in fundamental research are critical in continuing to advance our understanding of aerodynamics and improvements in CFD, and as such are important in their own right. But this is a long-term investment which does not address either the present need for capability or the complementary relationship of wind tunnels and CFD in the design process.

**Existing Wind Tunnels**

Existing tunnels, both in the U.S. and overseas, do not meet the performance goals of the NWTC. Although some transonic wind tunnels do meet or exceed the Reynolds number requirement of the proposed TSWT, none do so at comparable cost and productivity. Similarly, the productivity and operating cost of the LSWT are superior to those of existing tunnels and its Reynolds number capability is significantly greater.
The table on the next page shows the core facilities used for U.S. aircraft development, as compiled by government and industry experts. The proposed LSWT and TSWT are included for comparison. Facilities are listed according to Reynolds number.

Currently, the European DRA 5-m and ONERA F-1 wind tunnels are the subsonic tunnels-of-choice for industry, at least until the NASA Ames 12-foot tunnel comes back on line. Since the demolition and reconstruction of the NASA Ames 12-ft tunnel began in 1988, U.S. industry out of necessity has utilized these European facilities to do much of their low-speed testing. Whereas the Reynolds number capability of the 40x80-ft and 80x120-ft tunnels at NASA Ames may appear to make them likely candidates for development testing, their large size and low productivity, which translates to high cost per polar, make them unsuitable for use in commercial fixed-wing development.[10]

The NASA Ames 11-ft and AEDC 16T transonic tunnels are currently used by U.S. industry for high-speed testing, but the capability of the recently completed European Transonic Wind Tunnel (ETW) may force the companies to test their high-speed configurations abroad. Both the National Transonic Facility (NTF) at NASA Langley and the ETW are cryogenic tunnels, but the model handling and preparation facilities at the ETW enable it to achieve a much higher productivity than the NTF. The proposed TSWT, which achieves a moderately high Reynolds number through pressurization without cooling[12] and is designed to facilitate data acquisition, model handling, and model
preparation, can yield much higher tunnel productivity than any cryogenic wind tunnel.

It is possible to make improvements in the productivity of existing tunnels with refurbishment and upgrades.[13] The model handling difficulties associated with cryogenic testing, however, will continue to significantly limit productivity gains for the NTF.

Furthermore, increases in the Reynolds number capability of existing facilities are limited by their pressure shells and drive systems. As noted above, the use of heavy gases can increase the Reynolds number, but its effect on the data is not fully understood. Even with such modifications the Reynolds number capability of existing facilities would still be far from the goals of the NWTC.

In short, modifications to existing U.S. facilities will not yield the unique combination of capability, productivity, and cost that the proposed NWTC is designed to provide.

**Competitiveness**

It is important to note that U.S. industry is currently using European facilities to meet its wind-tunnel testing requirements. Boeing does significant low-speed testing in Britain's DRA 5-m tunnel, while Douglas utilizes the French ONERA F-1 tunnel. Completion of the rebuilt NASA Ames 12-ft tunnel in 1995 will reduce this practice, but the new European Transonic Wind Tunnel (ETW) may draw even more testing abroad.

**Access**
Timely access to these facilities, though currently available, could be threatened in the future by the emergence of national programs whose scheduling priority would supersede American commercial development. This would severely impact the ability of U.S. industry to compete on a timely basis.

**Government-Industry Relationships**

U.S. commercial aircraft manufacturers compete directly with the Airbus consortium, but the relationship between government and industry is significantly different in the U.S. than in Europe. Unlike their American competitors, European manufacturers of civil aircraft and engines often receive government-sponsored loans to subsidize product research and development. Repayment of this "launch aid" is contingent on a predetermined level of the developed product's commercial success. Only after a specified number of aircraft or engines are sold do the companies begin to pay back the loans with a percentage of their profit from additional sales. This dramatically reduces the company's financial risk in developing new aircraft. A recent General Accounting Office (GAO) report stated that as of 1990 the French, German, and British governments had invested $13.5 billion in direct support of Airbus products. By August of 1993 the amount repaid was only $3.5 billion.[14]

U.S. industry must compete head-to-head with its European counterparts and develop new products without having the government reduce its financial risk. The development costs for new aircraft must be completely underwritten by industry, often resulting in "peak negative cash flows that can exceed
the value of the company."15 The development costs for the 
new Boeing 777 are estimated by Aviation Week and Space 
Technology to be in the $4 billion to $5 billion range. The 
business risk of such investments, when combined with 
payback periods approaching 15 years, puts U.S. industry at 
a distinct disadvantage relative to its foreign competitors.

In addition to launch aid, European governments provide 
major ground test facilities for their industry, much like NASA 
provides to U.S. industry. The construction of the recently 
completed ETW, for example, was completely funded by the 
governments of Britain, France, Germany, and the 
Netherlands, and operating-cost shortfalls are being covered 
by these governments until 1997. During the past 15 years 
six new wind tunnel facilities have been constructed in 
Europe[16] which take full advantage of recent technological 
advances. In contrast, nearly all the major U.S. wind tunnels 
used in commercial aircraft development have been in 
operation for over thirty years, with the major NASA wind 
tunnels ranging in age from 30 to 60 years old (average age: 
38 years).[17] The demand for high Reynolds number, 
productive facilities did not exist when these U.S. facilities 
were built, and our present capability reflects this.

NASA's charter requires the agency to strive for 
preeminence in aviation. The proposed NWTC, if 
constructed, is an avenue by which the federal government 
could help the aerospace industry, as it has done in the past 
by building and operating the existing facilities, without 
providing a direct subsidy. The testing potential available 
with high Reynolds number facilities can reduce the financial 
risk inherent in the development of new designs and can 
assist the U.S. aerospace industry to maintain or improve its
economic competitiveness in the global market. The global commercial aviation market is projected at just under a trillion dollars over the next two decades, and it is estimated that every dollar invested in U.S. commercial aircraft generates $2.30 in gross domestic product. Halting the erosion of U.S. market share is therefore increasingly important. The NWTC is one possible means to help halt that erosion.

Foreign Use Of Tunnels

Whether or not Airbus and other foreign industries will have access to the NWTC has yet to be decided. As with American firms testing in foreign facilities, it is unlikely that foreign competitors will want to test in U.S. facilities unless forced to do so to remain competitive. U.S. industry today is forced to use European tunnels for testing that can't be accomplished in this country. The U.S. Department of Commerce plans not to deny Europeans access to U.S. wind tunnels, but it is possible that if foreign industry is allowed to capitalize on the capabilities of the NWTC, the competitive advantage of the wind tunnels to U.S. industry will be reduced.

Costs And Financing

The projected capital cost of the NWTC ranges from $3.2 billion to $2.5 billion or lower. The $3.2 billion estimate was based on the assumption that standard governmental acquisition procedures would be used to construct the facility. By using the best commercial practices this estimate was decreased to the current projection of $2.5 billion. These figures reflect the cost for the baseline facility,[18] but
the final tunnel complex may differ somewhat. NASA's Wind Tunnel Program Office in Cleveland, Ohio, is continuing trade studies and cost-benefit analyses aimed at decreasing capital costs to a target of $2.0 billion.

Although the capital costs of projects like the NWTC have been historically funded by government alone, the government's current position is that this time industry should contribute to the capital cost of the complex. Funding approaches for the NWTC are currently being debated and innovative business arrangements investigated. The current fiscal environments for both the federal government and the aircraft industry constrain the funding options, but industry[19] has agreed in principle to participate in a consortium whose objective is an affordable design.

Discussions with NASA have suggested that a 90%:10%/government:industry share might be acceptable.[20] Others in the Administration and Congress, however, prefer a greater contribution by industry to the shared cost, believing that a higher level of financial commitment would tangibly demonstrate industry's need for the facilities. They question how great the need is if industry is willing to share in only 10% of its cost. Industry, on the other hand, asserts that the majority of the long-term, low rate-of-return investment required to fund the capital cost of the NWTC should not and cannot be made by the private sector. In the competitive and lean international aerospace market, they say, U.S. industry simply cannot justify even a $2.0 billion short-term cost to gain such very long-term benefits. Also, the need to amortize the cost of the facility would inflate the price of U.S. aircraft, making them less
competitive in the marketplace and defeating the purpose of the NWTC.

User fees may be used to amortize some of the capital costs, depending on the operational costs and market price for wind tunnel testing. The estimated operational costs, however, are based on a series of assumptions including the national average for utility rates, wage rates, and a testing demand that equates to about two shifts of operation five days a week. The siting of the facility and other factors may change the current cost projections and make user fees an infeasible method of amortizing capital expenses, without sacrificing the fundamental NWTC motivation of providing low-cost development testing.

Financing options continue to be explored by joint industry-government teams, and their work will play a central role in deciding whether or not to construct the NWTC. One point of NASA-industry consensus that has already emerged is that funding for the wind tunnels should not come at the expense of the existing NASA aeronautics research and technology (R&T) base or High-Speed Research and Advanced Subsonic Technology aeronautics R&D programs. These programs are seen as critical to the future success of the national aeronautics enterprise and should not be sacrificed to build the facilities.

**Siting -- Schedule And Costs**

The siting process for the NWTC will have a significant impact on the schedule, the facility's cost, and operating costs. The selection must be made by November 1996 or the NWTC schedule will slip, and the facility will not be
operational by the 2002 target date. Roughly 70% of the design depends on site-specific considerations and cannot be completed until a siting decision has been made. Also, the site-specific Environmental Impact Statement required to construct the NWTC drives the program schedule and needs considerable lead time to perform.

The siting will also impact the operational cost of the facility. The local utility rates, for instance, can dramatically affect the facility's costs. The projection made in the NFS Report, based in part on experience with the NASA Ames 11-foot facility, assigns 35% to utilities, with 31% going to electricity alone.[21] This projection assumes the average national rates for electricity, water, and gas, but if the actual rates are higher at the selected site the operational cost projections could increase significantly. Labor, at 27%, is also a significant contributor to operational costs. Site selection also impacts capital costs; for example, in the size of cooling towers, weather protection, and seismic criteria.

The overall cost of the facility, however, will depend on the data presented when siting proposals are submitted. Utilities and labor rates will play a major role, but the combination package, which would include transportation costs, maintenance costs, constraints on critical subsystems, and state and local contributions, will determine the total facility cost at each candidate site.

**Positions**

The major parties involved in deciding whether or not to proceed with the construction of the NWTC approach the issue from different perspectives. Among the strongest
supporters are the commercial airframe manufacturers, who face competitiveness obstacles if the tunnels are not built. The NWTC would provide them with a competitive edge in the world market by granting them access to facilities having the unique combination of capability, productivity, location, and cost that they need. Although the engine and military-aircraft manufacturers would also benefit from these tunnels, their support for the initiative has been less vigorous than that of the civil airframers.

In the Congress, there is general support for the aeronautics industry as a whole, stemming largely from its role as a significant positive contributor to the U.S. economy and balance of trade. Several members of Congress have expressed the desire to put the first "A" back in NASA, emphasizing the importance of "A"eronautics to the nation. Similarly, there is support for the concept of new national wind tunnels in the relevant committees, but agreeing on the details surrounding the NWTC will probably prove difficult. The House Subcommittee on Technology, Environment and Aviation (TEA) is generally in favor of the tunnels, but the issue of siting the facility has already emerged as a political issue. California, Tennessee, and Virginia are mobilizing to compete in the siting process and vie for the multi-billion dollar project.[22]

There also appears to be support for the wind tunnels in the Senate, but language in the Senate's FY 1995 appropriation bill (see below) further reveals the importance of site selection when it states that site selection "must ultimately be based on principles of cost." It also calls for the formulation of a budget plan in which industry will share up to 20% of the capital cost. In March 1994, Senators
Rockefeller and Burns introduced S.1881, calling for a national aeronautical facilities strategy. Perhaps the most promising action was taken by the House and Senate Appropriations Committees in their August 1994 budget conference on the FY95 budget. They supported the Senate's insertion of $400 million in "new" FY95 funding toward NWTC construction, not requested by the Administration and, most important, not drawn from other NASA programs. The original Senate bill was characterized as a "use it or lose it pot" that could serve as a "down payment on the final completion of the project." The Senate intended that the appropriation elicit a "clear signal from the administration that they intend to proceed with [the wind tunnels]."

It is probable that the siting process will be subject to political pressures, especially with the 1996 national elections rapidly approaching.[23] Any decision which is not based on cost considerations, however, will inflate the price of the facility and its operating costs, and therefore will affect the financing options being investigated.

Aside from siting complications, the financing issue alone will be a difficult obstacle to overcome. The TEA subcommittee is "disappointed" with its perception of inadequate fiscal support from industry. The committee would like to see industry commit to more than the previously cited 10% of the capital costs of the program.

The Administration first became aware of the wind tunnel issue in the fall of 1993 during the budget preparation process for FY 1994. Because the information available at that time was insufficient to make a decision, it was deferred
until the National Facility Study was completed. The President's decision may be revealed when his FY 1996 budget is released.

Concluding Thoughts

It is likely that the Administration's leadership will ultimately determine the success or failure of the wind tunnel initiative. The decision will be largely influenced by the final cost of the tunnels, the joint industry-government financing arrangements, and the politics of site selection. In today's tight fiscal environment, the future of the NWTC is still not clear.

But although the investment cost of the NWTC is considerable, the costs of not developing the facility must also be kept in mind. There is a historical link between technological infrastructure such as wind tunnels and technological advances in aviation. Foregoing the opportunity to develop innovative facilities will put the U.S. aerospace enterprise at a competitive disadvantage, eroding a major source of U.S. strength in the global marketplace and the jobs that go with it.

References


**Footnotes**

1 The TSWT achieves a Reynolds number of 28.2 million at mach 1.0, a pressure of 5 atmospheres, and a temperature of 100 F. The reference chord used is 1.31 ft.

2 Transonic cruise ranges from Mach 0.75 to 0.90.

3 The current level of understanding of the physics of high-speed flows provides designers with the necessary tools to use in re-lofting the wing lines to optimize cruise performance. The TSWT will complement this by providing the experimental data necessary to guide the design modifications.

4 Flaps, slats, ailerons, elevator, rudder, etc.
5 The LSWT has a maximum full-span Reynolds number of 20.4 million at Mach 0.3, 5 atmospheres pressure, and 100 F in a 20-ft by 24-ft test section. The full-span reference chord used is 2.19 ft. Semi-span models can increase the Reynolds number to 35 million.

6 NFS, Volume 2, p. 4.

7 The maximum Reynolds number of the LSWT for semi-span models.

8 Performance includes passenger and cargo payload, range, fuel consumption, and cruise speed.

9 The effect on the test data resulting from using heavy gases, however, is not fully understood. The use of heavy gases as a test medium can increase the Reynolds number roughly by a factor of two because the heavy gas density-to-viscosity ratio is greater than that of air.

10 Full-scale rotorcraft, Short Takeoff and Vehicle Landing (STOVL) and acoustic tests are performed in these facilities.

11 Cryogenic wind tunnels super-cool the air (-300 F) by injecting cold nitrogen into the air flow. The low temperature increases the Reynolds number, thus enabling the high Reynolds number capability of tunnels like the NTF and ETW. The low temperatures, however, result in poor productivity largely due to the associated difficulties in handling the models at these temperatures.

12 The maximum pressure of the TSWT will be 5 atmospheres.

13 At the NASA Ames 12 ft tunnel the NFS projects productivity can be increased twofold "with aggressive pursuit of model handling, data acquisition, and control system modifications."

14 The Ames 12-ft tunnel has been demolished and reconstructed. The new tunnel will have a maximum pressure capability of 6 atmospheres which will yield a Reynolds number of 12 million /ft at Mach 0.3. Additionally, the new control system and test section design will assist in attaining a 4 polar / occupancy hour productivity goal for the new facility.


17 These tunnels are: ONERA F-1, DRA 5-m, DNW, ARA Bedford, KKK, and ETW.

18 NFS, Volume 2, Appendix 3, p. 10.

19 The National Facility Study explored several design concepts for the NWTC. The facility recommended and discussed here is Option D-5 of the report.


21 New Subsonic and Transonic Wind Tunnel Complex, p. 22.

22 NFS, Volume 2A, Attachment 2.

23 The probable sites in California, Tennessee, and Virginia are NASA Ames Research Center, the Air Force's Arnold Engineering Development Center (AEDC) in Tullahoma, and NASA Langley Research Center, respectively.