# DESIGN CONSIDERATIONS OF THE NATIONAL TRANSONIC FACILITY

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## SUMMARY

The current inability of existing wind tunnels to provide aerodynamic test data at transonic speeds and flight Reynolds numbers is an area of great technical concern. The proposed National Transonic Facility (NTF) is a high Reynolds number transonic wind tunnel designed to meet the research and development needs of NASA, DOD, industry, and the scientific community. The proposed facility will employ the cryogenic approach to achieve high transonic Reynolds numbers at acceptable model loads and tunnel power. By using temperature as a test variable, there is provided a unique capability to separate scale effects from model aeroelastic effects. The performance envelope of NTF is shown to provide a ten-fold increase in transonic Reynolds number capability ($R \approx 500 \times 10^6$/meter at M=1 in a 2.5 meter test section) compared to currently available facilities.

## SYMBOLS

Values are given in both SI and U. S. Customary Units (latter in parentheses).

| | |
|---|---|
| A | Cross-sectional area |
| $\bar{c}$ | Wing mean chord |
| °F | Degrees Farenheit |
| hp | Horsepower |
| K | Kelvin |
| kW | Kilowatt |
| $\ell$ | Length |
| M | Mach number |
| p | Pressure |

| | |
|---|---|
| q | Dynamic pressure, $1/2\ \rho V^2$ |
| R | Reynolds number = $\frac{\rho V \ell}{\mu}$ |
| T | Temperature |
| V | Velocity |
| $\rho$ | Density |
| $\mu$ | Viscosity |

Notations and Subscripts:

| | |
|---|---|
| bar | $10^5$ Newtons/m$^2$ (0.987 atmospheres) |
| L | Local |
| psf | Pounds per square foot |
| psia | Pounds per square inch absolute |
| t | Total |
| TS | Test section |
| $\infty$ | Free stream |

## INTRODUCTION

The historical aeronautical leadership of the United States in the development of high-speed aircraft - commercial as well as military - has been largely due to the excellent facilities used in the conduct of aeronautical research and development. In spite of this hallmark, during the last ten years it has become clearly apparent that better facilities are needed to simulate the complex aerodynamic phenomena occurring at speeds near the speed of sound. This urgent need for a new research and development facility has been recognized at all levels of NASA and DOD, by the U. S. aerospace industry, and by the scientific community. The sense of urgency has been increased by the current national thrust toward energy conservative aircraft and the importance of maintaining military preparedness in a world of turmoil.

## HIGH REYNOLDS NUMBER FACILITY NEED

Transonic flows are found to embrace almost every aspect of flight — for aircraft (fig. 1) as well as space vehicles. The performance of the slowest of aircraft — the helicopter — is constrained by rotor "compressibility effects" on efficiency and noise, while commercial transports cruise at the "drag-rise" Mach number where shock waves first form on the wing. Modern military aircraft fight at altitude and penetrate on-the-deck at transonic speeds. The supersonic transport experiences its minimum thrust margin for acceleration near Mach 1. For space vehicles, the maximum dynamic pressure and buffeting occur during acceleration through the transonic speed regime, while critical transonic stability and control problems are encountered during reentry.

The area of great technical concern is the inability of existing wind tunnels to provide accurate design information for civil and military aircraft which must operate in the transonic flight regime near the speed of sound. The major transonic test deficiency has been Reynolds number simulation of full-scale flight. This deficiency has been dramatized during the past decade by unexpected problems in flight which have often required expensive redesign.

The wing is the most critical element. An appreciation of the complex nature of transonic flows can be gained from figure 2 where low Reynolds number flow over an airfoil is made visible by special methods (Schlieren system). Flow is from left to right. The subsonic flow ahead of the airfoil accelerates to supersonic speeds over the upper surface. At the base of the shock, the thin"boundary layer" of air adjacent to the surface thickens and separates from the airfoil creating a broad wake of fluctuating flow. These flow characteristics result in changes in lift and pitching moment, and increased drag and buffeting compared to the high Reynolds number flows characteristic of flight.

The shock wave pattern in the main field of flow is governed by the test Mach number — defined as the ratio of free-stream velocity to the speed of sound. The boundary-layer flow adjacent to the surface, however, is governed by a different parameter — "Reynolds number." If one tests a model at "full-scale" Reynolds number, the boundary layer characteristics will be similar, and the skin-friction drag will be the same as in flight. There are many wind tunnels in use that can test models at flight Mach numbers, however, there are none which can provide the transonic Reynolds number simulation of full-scale flight. In fact, the capability of present aircraft to fly near the speed of sound at low altitudes and the increased size of transport aircraft are such that the best transonic test facilities only provide about one-tenth of the required Reynolds number. The complex nature of the flow in the transonic region makes it impossible to analyze the performance or to extrapolate accurately from scale model tests obtained with current Reynolds number capability.

The transonic Reynolds number phenomenon of concern was first evidenced in flight tests of the USAF C-141 cargo aircraft about a decade ago (fig. 3). Correlation of the wing pressure coefficient measurements between wind tunnel and flight at high subsonic speeds demonstrated a significant difference in the chordwise location of the wing shock. Subsequent research at Langley (ref. 1) showed these results to be a Reynolds number phenomenon associated with the small scale of the wind-tunnel tests. At low test Reynolds numbers, the shock position is forward on the airfoil with a resultant increase in the separated region behind the shock and attendant increase in drag. As the test Reynolds number is increased, however, the shock wave moves rearward and the region of separated flow and attendant drag is reduced. Modifications to the C-141 were required to accommodate the air loads associated with flight conditions, and to this day all C-141 aircraft carry approximately a one-percent payload penalty in added structural weight for the fix.

As transonic aircraft continue to grow in size, they place even greater demands on the wind tunnel. The problems that have been evidenced in today's transport development programs will become even more critical as the gap between wind tunnel and flight Reynolds number continues to widen as shown in figure 4. Current wind tunnels provide full-scale test capability for "DC-3" type aircraft only. As the speed and size of aircraft have increased, currently available facilities provide only about one-tenth full-scale cruise conditions for projected aircraft.

The lack of high Reynolds number experimental facilities has greatly slowed the progress of basic transonic research. Since basic research is the cornerstone upon which future advances are founded, a critical facility lack can seriously jeopardize aeronautical progress. The future of aeronautics will be based on the knowledge of the researcher and the quality of his facilities. Progress may come one small step at a time. But a one-percent improvement in ten different areas results in a 10-percent gain — which is significant by any standard. And occasionally these step advances in the hands of an enlightened scientist will coalesce into a technical breakthrough which can revolutionize the whole field of aeronautics. The "area-rule" concept for the design of transonic/supersonic aircraft and the "supercritical airfoil" developed within the U. S. merit such a classification. It is toward future advances such as these that a new high Reynolds number transonic facility is aimed.

## EVOLUTION OF THE NATIONAL TRANSONIC FACILITY

During the past several years, there has emerged a clear national and international consensus of the priority need for a large, high Reynolds number transonic wind tunnel (ref. 2-4). It was recognized early that because of the projected very large construction costs, this must necessarily become a government sponsored facility. Many approaches to high Reynolds number have been explored and developed both in the United States and in Europe (ref. 5). A chronology of activities in the field of development of high Reynolds number ground-test facilities in the United States is presented in figure 5.

An important influence on the facility development program was the significant technology advance in a wind-tunnel concept employing cryogenic nitrogen to provide increased Reynolds numbers with modest drive horsepower and reduced model loads (ref. 6 and 7). The potential of low temperature operation to achieve high Reynolds numbers had been considered previously by Smelt of the Royal Aircraft Establishment in 1945 (ref. 8), but the concept was not pursued until an effort was initiated at the Langley Research Center in 1971.

From the Langley experimental efforts, details were worked out for a high Reynolds number transonic tunnel using extremely cold nitrogen to cool the flow and provide increased Reynolds numbers with reasonable drive power requirements and model loads. Figure 6 illustrates the effects of decreasing tunnel temperature on the tunnel test conditions. It will be noted that as the temperature is decreased from a nominal value of 322 K (120°F) characteristic of conventional water-cooled tunnels, the Reynolds number of the flow increases approximately five-fold as the temperature approaches 89 K (-300°F). Further, this is accomplished with approximately a 50-percent reduction in drive power. This represents a ten-fold decrease in installed drive power compared to a conventional wind tunnel (322 K; 120°F) of the same size operating at the same Mach number and pressurized to provide the same test Reynolds number. This major reduction in installed drive power requirements makes possible the location of a continuous flow, high Reynolds number transonic tunnel at an existing research center having modest power resources.

Also noted in figure 6 is the fact that the increase in Reynolds number through a reduction in test temperature is accomplished without an increase in dynamic pressure which influences model loads. This is a significant benefit of cryogenic operation, for the range of high Reynolds number testing can be greatly expanded before encountering limiting structural loads on the model or excessive model distortion. The cryogenic tunnel concept provides the unique experimental capability of changing test Reynolds number without an attendant change in model loads (and therefore model shape). This is considered by many experimenters as a technical breakthrough in its own right.

Langley accelerated its cryogenic tunnel effort and extended the theoretical studies of "real gas" effects, developed a practical means for obtaining low temperatures, and constructed and operated two pilot cryogenic tunnels. The pilot facilities in a series of critical experiments validated the cryogenic concept for aerodynamic testing, demonstrated the attainment of uniform temperatures in the settling chamber, and provided useful experience relative to the operating problems of liquid nitrogen injection, research instrumentation, and cryogenic shell design (ref. 9 to 11).

NASA and USAF both developed firm plans for transonic facilities during 1973 and 1974. The Air Force had obtained Congressional approval in the FY 75 budget for an intermittent operation High Reynolds Number Tunnel (HIRT), and NASA had planned for a fan-driven cryogenic transonic research tunnel (TRT) to be included in the FY 76 budget. Both the NASA and USAF tunnel projects encountered the abrupt escalation of construction costs in 1974, causing the USAF to defer construction of HIRT and NASA to withhold TRT from its FY 76 budget request. DOD and NASA officials then agreed to undertake an additional joint study under cognizance of the Aeronautics and Astronautics Coordinating Board (AACB) to seek a common solution to transonic wind-tunnel needs. Accordingly, a special AACB Aeronautical Facilities Subpanel of NASA/DOD representatives was organized in November of 1974 to initiate this study.

The Subpanel in May of 1975 recommended that a single, continuous-flow facility employing the cryogenic concept should be built at the earliest possible date to serve the combined needs of both NASA and DOD (ref. 12). Recommendations for NTF performance characteristics were agreed upon (fig. 7). The Subpanel further recommended that the facility be located at the NASA Langley Research Center and be known as the National Transonic Facility (NTF). A memorandum of agreement accepting the AACB Subpanel recommendations was signed by NASA and DOD (June 2, 1975). It was emphasized in the Subpanel report that the NTF was to be a <u>national</u> facility with approximately 40 percent of the occupancy projected for DOD work, 40 percent for NASA, 15 percent for proprietary aerospace industry work, and 5 percent for other government agencies and the scientific community. The Aeronautics Panel of the AACB would be charged with oversight responsibility.

The basic performance characteristics of the NTF follow the specific recommendations of the AACB Aeronautical Facilities Subpanel as summarized previously in figure 7.

## DESCRIPTION OF THE NATIONAL TRANSONIC FACILITY

### General Arrangement

The National Transonic Facility will be a conventional wind tunnel in appearance (fig. 8) and is described in detail in reference 13. The NTF will be a closed-circuit, fan-driven pressure tunnel capable of operating at pressures up to 9 bars (130 psia). It will have a slotted test section of 2.5 by 2.5 meters in cross section. The existing 4-Foot Supersonic Pressure Tunnel (4' SPT) drive motors and their drive control system will be utilized. The 4' SPT will be deactivated and the NTF constructed on its site. In addition to the existing drive motors which are rated at 52,220 kW (70,000 hp) for 10 minutes, an additional 44,760 kW (60,000 hp) motor will be added in line to provide the power required to drive the tunnel at maximum pressure and a test Mach number of 1.0.

The most unconventional feature of the NTF will be at its cryogenic operation. The tunnel will operate at temperatures from 353 K (175°F) down to 89 K (-300°F). Liquid nitrogen will be expanded into the circuit for the initial cool down and to absorb the heat rise associated with the gas compression by the fan. Pressure control will be provided through the controlled venting of the gaseous nitrogen through a large vent stack to assure mixing with air and eliminate any hazards which might result if cold gaseous nitrogen were allowed to accumulate at ground level. The current baseline design of the tunnel incorporates an internal insulation system which will be discussed in more detail subsequently.

### Aerodynamic Circuit

As mentioned previously, the NTF will have a slotted test section 2.5 meters (8.2 ft.) square (fig. 9). To assure high-quality flow, a contraction from the stilling chamber to the test section of 15 to 1 in area is employed. Three anti-turbulence screens are located at the beginning of the contraction. A "quick" diffuser accommodates the large channel area increase to the stilling chamber and screens. This diffuser requires a flow resistance with accompanying pressure loss to assure the absence of flow separation. This loss was accepted as a trade-off against a large increase in cost of the pressure shell for a more efficient diffuser.

## Test Section

The test section for the NTF (fig. 10) is designed similar to that of the existing Langley 8-Foot Transonic Pressure Tunnel which is known to be efficient and have good quality flow. The length of the slotted region is three test-section heights. The top and bottom walls, which are adjustable in divergence angle to compensate for boundary-layer growth, have six longitudinal slots in each wall. The side walls are fixed with two longitudinal slots in each wall. The design will allow the slot open width and edge shape to be easily modified. Adjustable and remotely controlled reentry flaps are provided at the downstream end of each slot. The position of these flaps during tunnel operation will be adjusted to control Mach number gradients through the test section and to minimize power consumption.

Complete models will be sting supported from a circular arc strut affording a total model pitch angle range of 24°. The sting will have a roll mechanism capable of rolling the model through 270°. Model pitch rate is controllable in either a continuous or pitch/pause mode at rates from 0° to 4° per second. Provisions for accommodating wall-mounted half-span models will be made for cases where larger model sizes are required.

## Test Section Isolation System

Although the cryogenic approach using $LN_2$ has been shown to require the least capital investment and to be the most energy conservative approach to high Reynolds number testing, the cost per data point for high Reynolds number tests will be considerably higher than for current low Reynolds number data. Consequently, every step possible is being taken to conserve nitrogen, which is the largest single contributor to operating costs. One of the provisions made to conserve nitrogen is test-section isolation doors (fig. 11) which will be capable of isolating the test section such that the pressure can be reduced to atmospheric without venting the entire circuit. The test-section side walls can be lowered to insert work access tunnels from both sides which capture the test model and seal around the model sting to provide a "shirt-sleeve" environment for model change.

## Drive System

The cryogenic concept requires that the drive system be capable of producing a constant compression ratio over a large temperature range. This requirement has a major impact on the design of the drive system in view of the direct relationship between fan performance and the stagnation temperature of the gas entering the fan. The desired performance in the NTF is obtained by using a single-stage fan with variable inlet guide vanes and fixed outlet stators in combination with a main drive system incorporating a two-speed gear box.

The electric motors in the drive are coupled through the gear box in a unique arrangement. The two existing motors are wound rotor induction motors and have a Kramer drive control system which accurately controls their rpm to within 1/4%. These motors are capable of 52,220 kW (70,000 hp) for 10 minutes at 840 rpm (fig. 12). A reduction gear reduces the maximum fan speed to 600 rpm. To maximize the horsepower available, liquid rheostats are added to provide constant torque at rpm values down to 60% of the maximum speed. A low-speed gear is available which will permit a shift in rpm and allow full Kramer horsepower also to be available at 360 rpm. This rpm will be used largely for the cryogenic operation and the maximum pressure which are combined to produce the maximum Reynolds number. The horsepower required to drive the tunnel at M=1.0 for the maximum Reynolds number condition is more than is available from the existing motors, therefore an in-line 44,760 kW (60,000 hp) synchronous motor has been added to meet this need. The existing motors will be used to bring the synchronous motor up to speed. A maximum fan shaft power of 93,250 kW (125,000 hp) is available at a fan speed of 360 rpm. Under this condition, Mach number control is achieved by moving the position of the inlet guide vanes. The guide vanes are capable of controlling Mach numbers over a range between M=0.4 and M=1.2 with an acceptable level of efficiency.

### Internal Insulation

The NTF will employ in its design an internal insulation to minimize the temperature excursions of the large pressure shell. In doing so, it (1) greatly reduces the liquid nitrogen required to approach steady-state operating conditions, (2) it minimizes the thermal stress in the pressure shell, thereby alleviating thermal fatigue and enhancing the service life of the pressure shell, and (3) it affords the opportunity to combine thermal insulation and acoustic attenuation functions into a system which could reduce the noise in the tunnel circuit. The baseline design of the insulation system (fig. 13) employs about 6 inches of fiberous insulation contained with close-woven glass cloth and covered with a corrugated flow liner which is supported by "tee" rings welded to the pressure shell and insulated from the liner. The "tee" rings are about 1.22m (4 ft.) apart. The liner is corrugated to absorb the circumferential thermal strain. Slip joints are provided for the longitudinal movement. Filler blocks are used under the corrugation to block flow from one insulation segment to the next. Considerations of insulation flammability, service life, and thermal performance under a high pressure and flowing cryogenic environment are the subject of an extensive verification test program.

## NTF PERFORMANCE

### Reynolds Number Test Capability

With the drive system described previously, the NTF performance at a selected Mach number can be presented as shown in figure 14. The operating map for Mach 1 shows the variation of chord Reynolds number as a function of stagnation pressure for various values of constant temperature. Similar plots can be made for other Mach numbers. The boundaries of the operating envelope are defined on the left by the maximum tunnel operating temperature (353°K; 175°F) and the compression ratio limit of the fan-drive system; on the upper left corner by the available drive power limit (93,250 kW; 125,000 hp); across the top by the maximum operating pressure (9 bar; 130 psia); and on the right by the nitrogen condensation boundary (heavy dashed line). The latter boundary represents a limiting value of pressure and temperature where condensation of gaseous nitrogen will occur at a local Mach number of 1.4. Within the lower dark shaded region, the NTF can be operated with the variable-speed induction motors only in the high gear ratio. For pressures above the shaded region, the low gear ratio is required and the drive is operated at synchronous speed (360 rpm).

Inspection of figure 14 illustrates the unique test capability of a cryogenic tunnel. The dynamic pressure ($1/2\rho V^2$) is independent of temperature and is a function only of stagnation pressure and Mach number. Thus for a given test Mach number, the dynamic pressure can be held constant while the temperature is varied to provide a controlled variation in Reynolds number. Such a test capability permits isolation of pure Reynolds number effects from aerodynamic loading changes which arise from unwanted model distortion under changing dynamic pressure. Conventional wind tunnels, which tend to operate at essentially constant temperature, follow along a single temperature line requiring a change in pressure to produce a change in Reynolds number. This unique capability of cryogenic tunnels opens a new dimension in wind-tunnel testing and may well become the single most important capability of this facility concept. It should also be noted that pure model aeroelastic effects can be evaluated by holding Reynolds number constant while the pressure is varied (moving vertically on the plot).

## Maximum Performance Envelope

The maximum test Reynolds number usually occurs where the nitrogen condensation boundary intersects the shell pressure limit. The maximum Reynolds number is plotted as a function of Mach number in figure 15. This overall maximum tunnel Reynolds number capability is bounded by the shell operating pressure limit for Mach numbers up to 1.0. Between M=1.0 and 1.2, the performance is limited by the maximum horsepower available. Above M=1.2 the fan maximum compression ratio limits the performance. Note that the goal of a Reynolds number of $120 \times 10^6$ for M=1.0 is achieved. At the bottom of figure 15 is an overall envelope of the Reynolds number capability of wind tunnels in the United States. The NTF will be capable of increasing ground-test Reynolds number by about one order of magnitude over currently existing facilities.

## Model Loads

A critical design problem of NTF is associated with the large model loads encountered in the operation of the facility at maximum performance conditions. The model stress is related to the level of test dynamic pressure ($1/2\rho V^2$), which is a function of stagnation pressure and Mach number but independent of temperature. In figure 15, lines of constant dynamic pressure are superimposed on the overall performance map of the tunnel. Most current large transonic wind tunnels operate at dynamic pressure levels up to about 0.5 bar (approx. 1000 psf). There are a few tunnels which have dynamic pressure capability up to about 1 bar (approx. 2000 psf). The NTF will have a maximum dynamic pressure capability of 3.3 bar (approx. 7000 psf). Although the NTF, by virtue of employing the cryogenic approach, will have a much lower ratio of dynamic pressure to Reynolds number as compared to the other approaches to high Reynolds number testing, it can still produce model loads up to three times those experienced in existing wind tunnels. Technology appears to be in hand to accommodate these loads. However, force measuring balances, sting deflections, and model deformation will tend to take on more importance as the NTF is utilized to its maximum Reynolds number capability.

## Productivity

The NTF is being designed to satisfy a national need for high Reynolds number test capability at transonic speeds. Moreover, as a national facility it must accommodate the projected workload of NASA, the DOD, the aero industry and the scientific community. As a consequence of this, as well as the need to conserve energy, the NTF is being designed to produce data at a relatively high rate. Typical existing wind tunnels produce data at about 26,000 specific sets of test conditions in a year, where a set of test conditions is defined by a combination of Mach number, Reynolds number, angle of attack, angle of yaw, and so forth. The NTF is targeted to produce measurements at the rate of 104,000 sets of test conditions per year, or four times the conventional rate. To achieve this goal, the tunnel control and data acquisition system is highly automated. Computer control is used extensively to insure optimum procedures and safety in the tunnel operation. A modern data acquisition system will be provided with "quick look" data capability to minimize retesting due to improper measurements.

## Full-Scale Flight Simulation

The test Reynolds number capability of NTF in meeting projected requirements of advanced aircraft is summarized in figure 16 for civil aircraft. It will be noted that for large subsonic transports of the B-747 category, the NTF will attain full-scale test conditions for the cruise point (solid circle) as well as for the high-speed, "max. q" load condition. The high Reynolds number peak at M=0.5 cannot be met by the design NTF performance envelope. This is not considered a significant deficiency, however, for the Reynolds number effects for fully subsonic flows at low angles of attack are usually small and predictable at high Reynolds number levels. For the advanced "span loader" transport ($\bar{c}$=16.8m; 55 ft.) in the one million kg (2.2 million lbs.) category, the NTF can attain full-scale test conditions for the cruise point. The high-speed "max. q" load condition, however, can only be met by use of a side-wall mounted, semispan model. This is an accepted test procedure for high aspect-ratio configurations.

For the large supersonic transport (341,000 kg; 750,000 lbs.), full-scale test conditions can be attained for the subsonic cruise point (M=0.95) and for the major portion of the transonic climb and let-down corridor. The high Reynolds number peaks in the M=0.5 range can largely be met in NTF by the use of larger-size models permitted for purely subsonic testing. For the space shuttle type configurations, the NTF will attain full-scale test conditions for all subsonic/transonic flight conditions.

## NTF OPERATING PLAN AND SCHEDULE

Although the NTF is being designed and constructed by NASA and is envisioned to be operated by NASA, it is, in fact, a national aeronautical resource. As such, it will be managed in a manner which will effectively serve the aeronautical research and aircraft development needs of the government, industry, and scientific organizations. The facility will be staffed to the level required to support the needs of the varied users. Current organizational plans provide for NTF oversight responsibility to be assigned to the NASA-DOD Aeronautics and Astronautics Coordinating Board (AACB).

The final design of the NTF is underway. Funding is programmed for initial appropriation in the FY 1977 budget. Construction is scheduled to begin in October 1976 and to be complete at the end of 1980. Checkout and calibration is to be completed in July 1981, at which point the facility should be ready for use as a research and development tool. The total project budget is 65 million dollars including contingency and escalation.

## CONCLUDING REMARKS

Plans are underway to provide this nation with a new high Reynolds number transonic wind tunnel designated the National Transonic Facility. This facility is designed to satisfy the combined testing requirements of NASA, DOD, the aeronautical industry, and the scientific community. Gaseous nitrogen at cryogenic temperatures will be used as the test medium to provide high Reynolds numbers at transonic speeds. The NTF will provide a ten-fold increase in transonic Reynolds number test capability as compared to existing U. S. facilities and will permit testing current and projected aircraft at or very near full-scale flight conditions. A unique research capability inherent in the cryogenic approach provides for valid separation of the effects of model aeroelasticity, Reynolds number, and Mach number on aircraft configuration performance. The NTF will be located at the NASA Langley Research Center and is projected to be operational in 1981.

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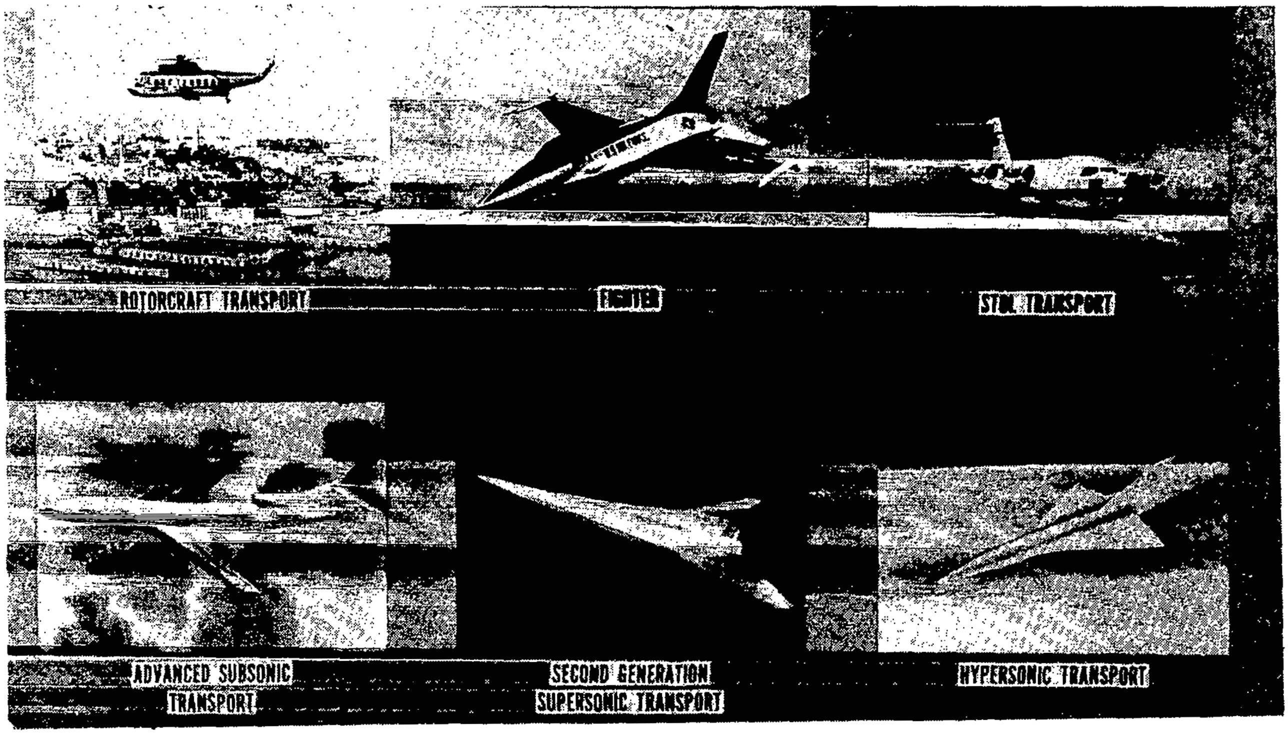



Figure 1.- Transonic flows affect all aircraft.

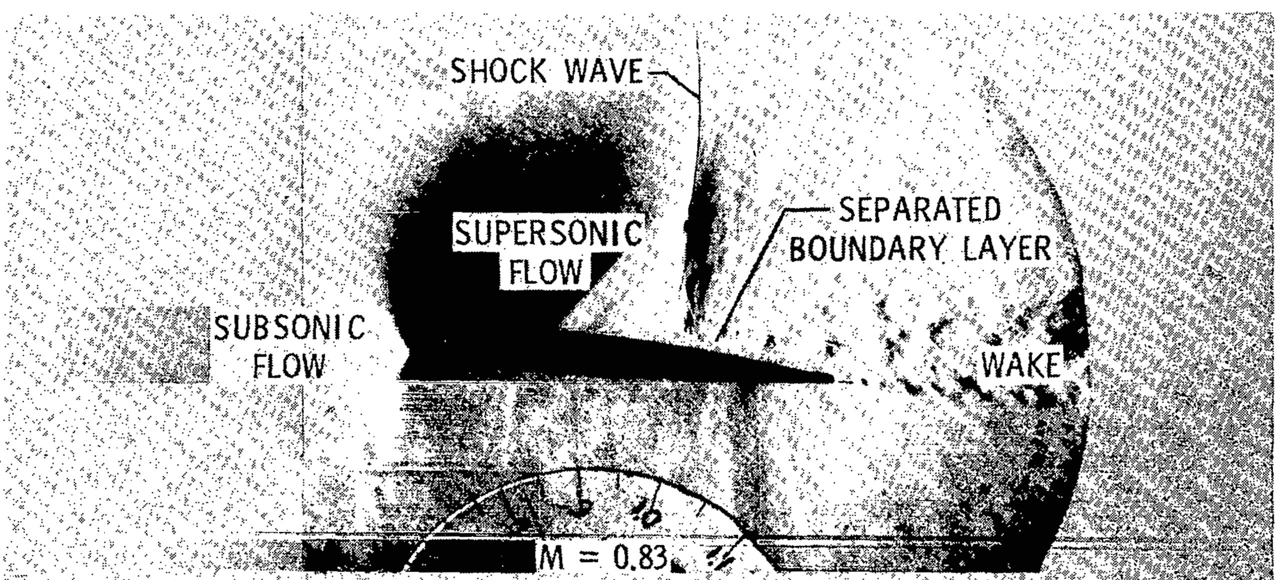



Figure 2.- Schlieren photograph of complex transonic flow over 2-D airfoil. M = 0.83.

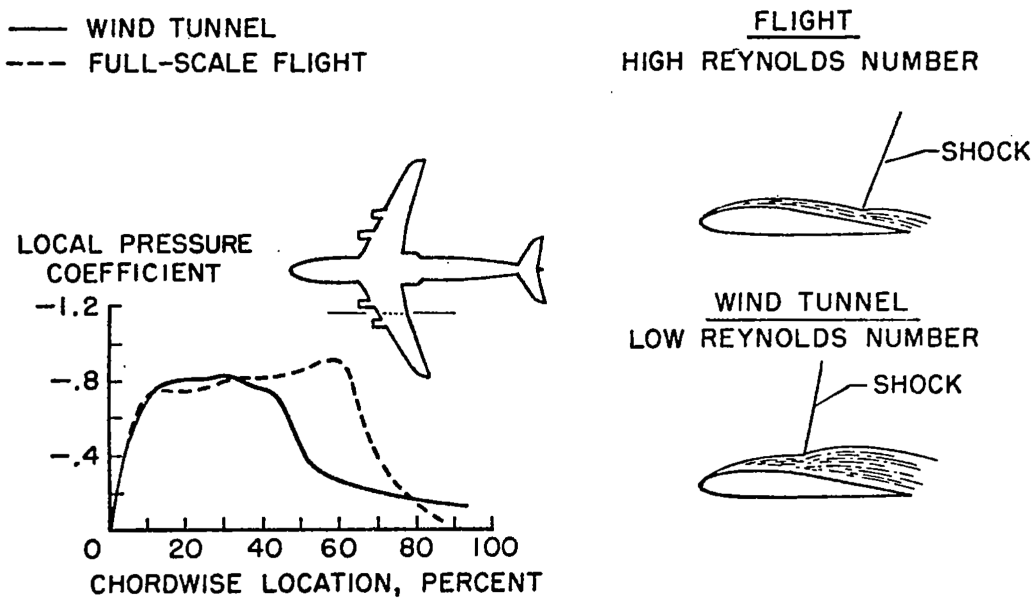



Figure 3.- Effects of shock induced flow separation over wing of transport aircraft. M = 0.85.

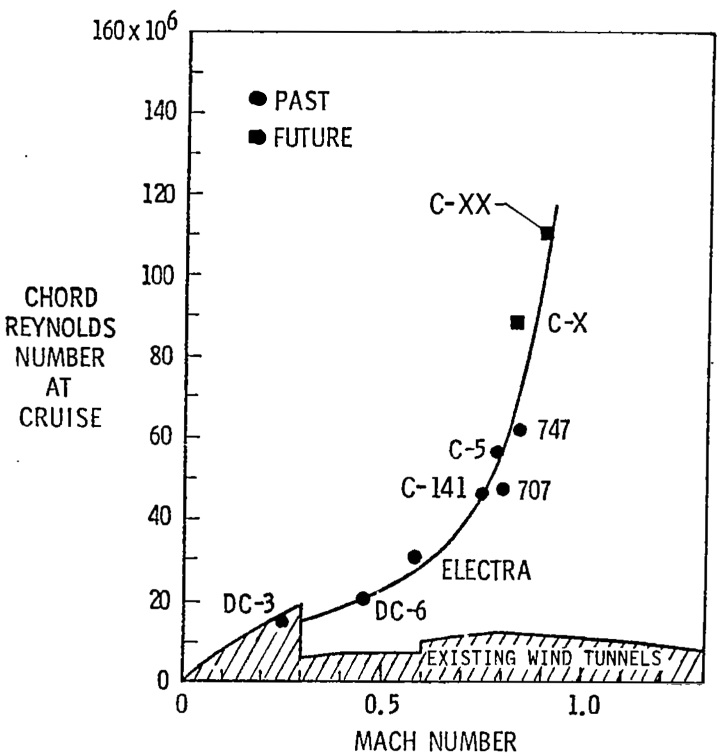



Figure 4.- Illustration of the growing facility gap in test Reynolds number capability.

| DATE | FACILITY | STATUS |
|---|---|---|
| 1967 | 8 X 10 FT. LUDWIEG TUBE (HIRT) | PROPOSAL |
| 1969 | .078 SCALE HIRT | PILOT MODEL |
| 1969 | 32-INCH LUDWIEG TUBE | OPERATIONAL AT MSFC (32" DIA.) |
| 1970 | HYDRAULIC DRIVE TUNNEL | A/E STUDY (6 X 6 METER) |
| 1971 | BLOWDOWN TUNNEL | 600 & 3000 PSI TANK FARM |
| 1972 | INJECTOR TUNNEL | 600 & 3000 PSI PILOT TUNNEL |
| 1972/73 | CRYOGENIC TUNNEL | LOW SPEED MODEL<br>PILOT TRANSONIC MODEL |
| 1974 | HIRT | PRELIMINARY ENGINEERING REPORT |
| 1974 | TRANSONIC RESEARCH TUNNEL | PRELIMINARY ENGINEERING REPORT |

Figure 5.- Chronology of high Reynolds number facility concepts and pilot tunnel development within the United States.

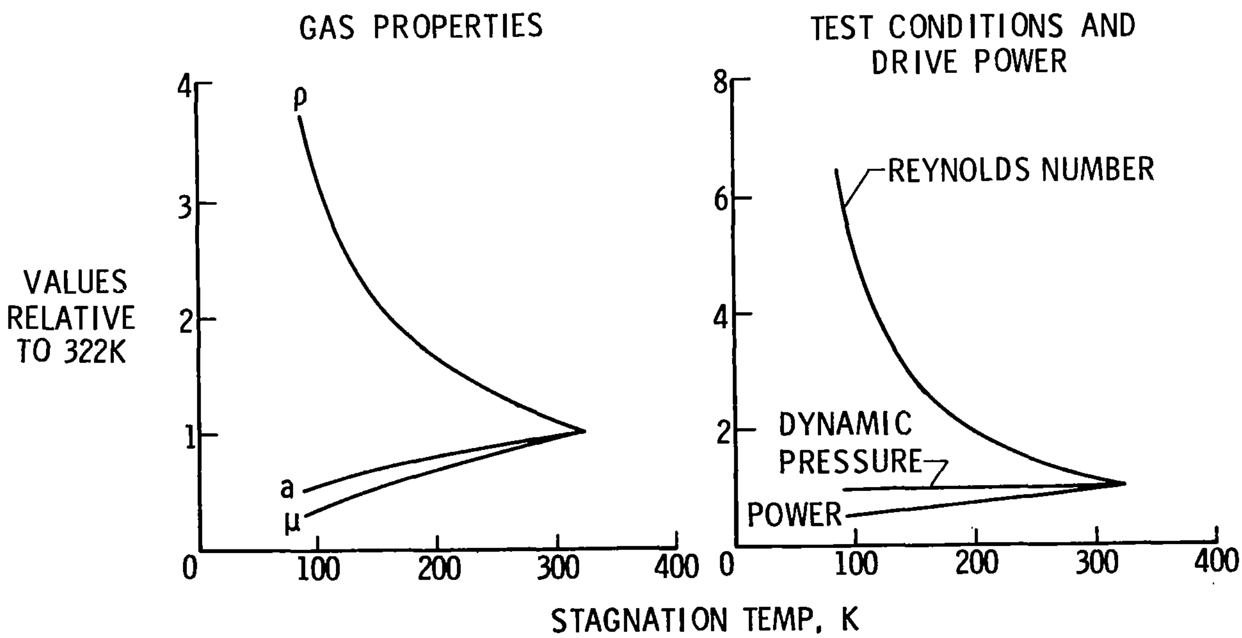



Figure 6.- Effect of temperature reduction on test conditions and drive power. $M_{\infty} = 1$; constant stagnation pressure.

- A SINGLE TRANSONIC TEST FACILITY IDENTIFIED AS THE NATIONAL TRANSONIC FACILITY (NTF)

- CRYOGENIC CONCEPT

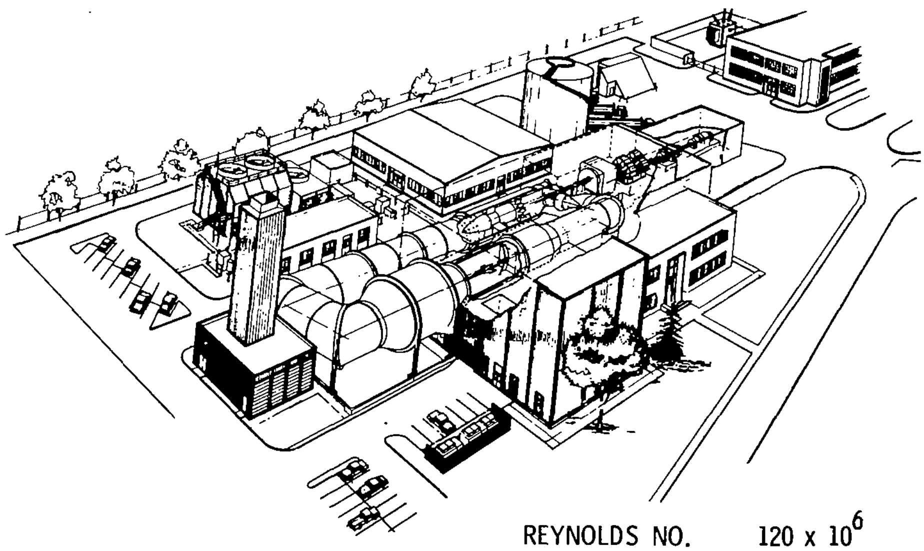
- NTF HAVE THE FOLLOWING LEADING CHARACTERISTICS:

| | |
|---|---|
| TEST SECTION SIZE | 2.5 METERS SQUARE |
| DESIGN PRESSURE | 130 PSIA OR ≈ 9 BAR |
| DESIGN MACH NUMBER RANGE | 0.2 - 1.2 |
| STREAM FLUID | NITROGEN |
| PRODUCTIVITY/EFFICIENCY | 8,000 POLARS/YR |
| REYNOLDS NUMBER(1) | $120X10^6$ (M = 1) |

- NTF BE LOCATED AT LANGLEY RESEARCH CENTER

(1)BASED ON $\bar{c}$ = 0.25 METER (0.82 FEET)

Figure 7.- Summary of AACB Subpanel recommendations relative to NTF.



| | |
|---|---|
| REYNOLDS NO. | $120 \times 10^6$ |
| TEST SECTION | 2.5 x 2.5 meter |
| RUN DURATION | CONTINUOUS |
| COST | $65 Mil |

Figure 8.- The planned National Transonic Facility.

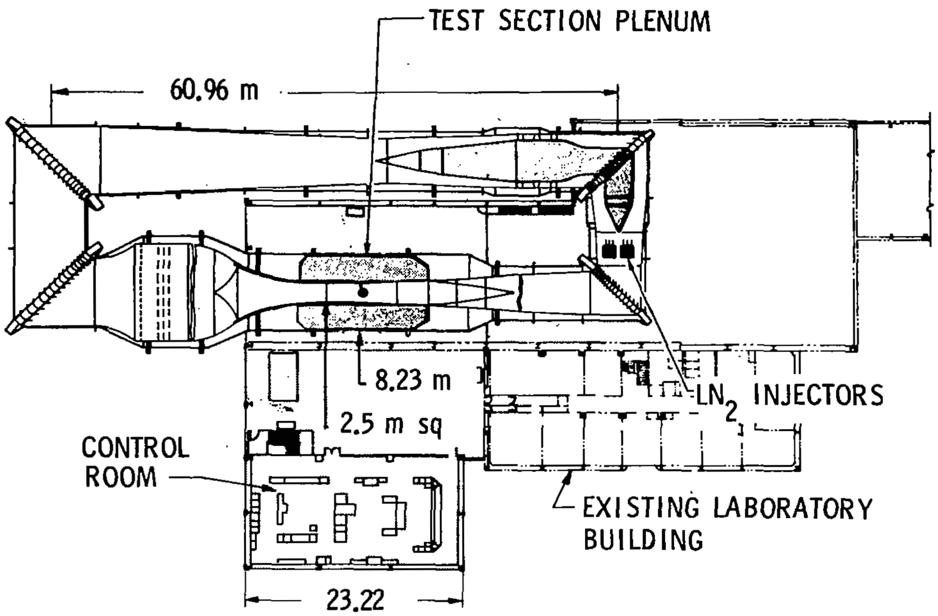



Figure 9.- Plan view of the facility.

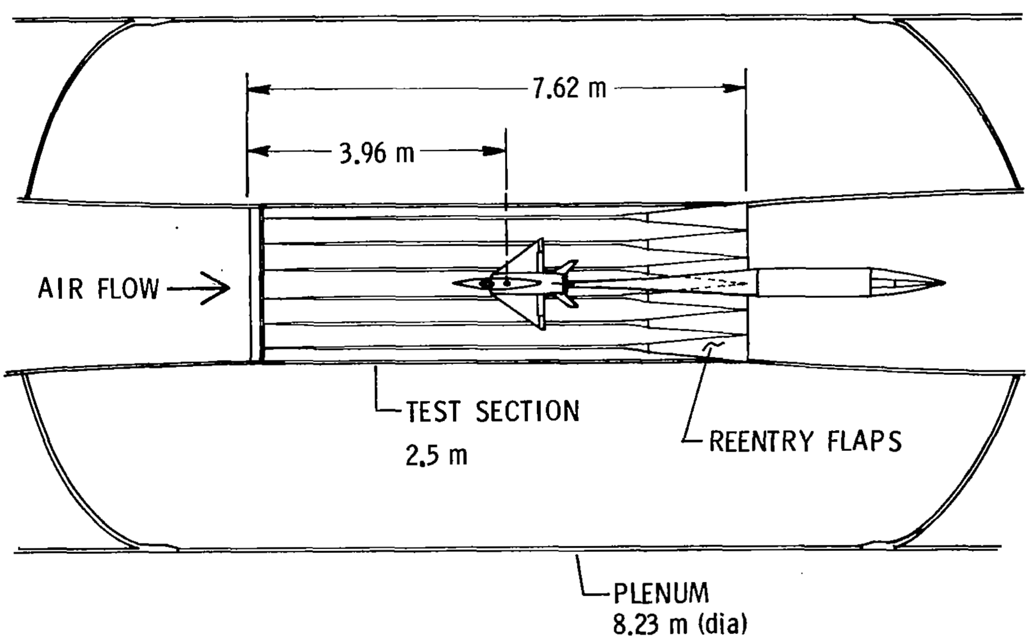



Figure 10.- Baseline slotted wall and model support system.

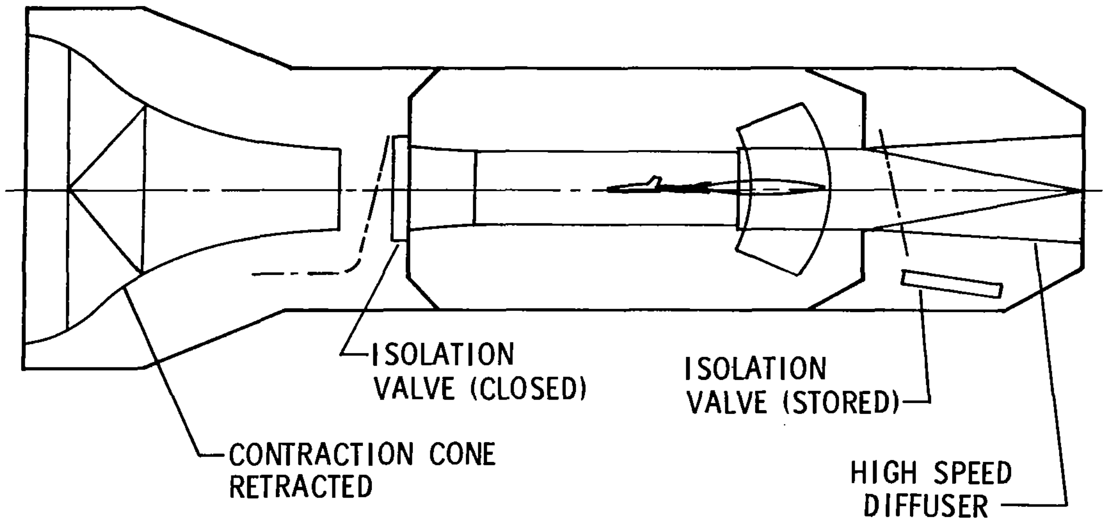



Figure 11.- Test section isolation system.

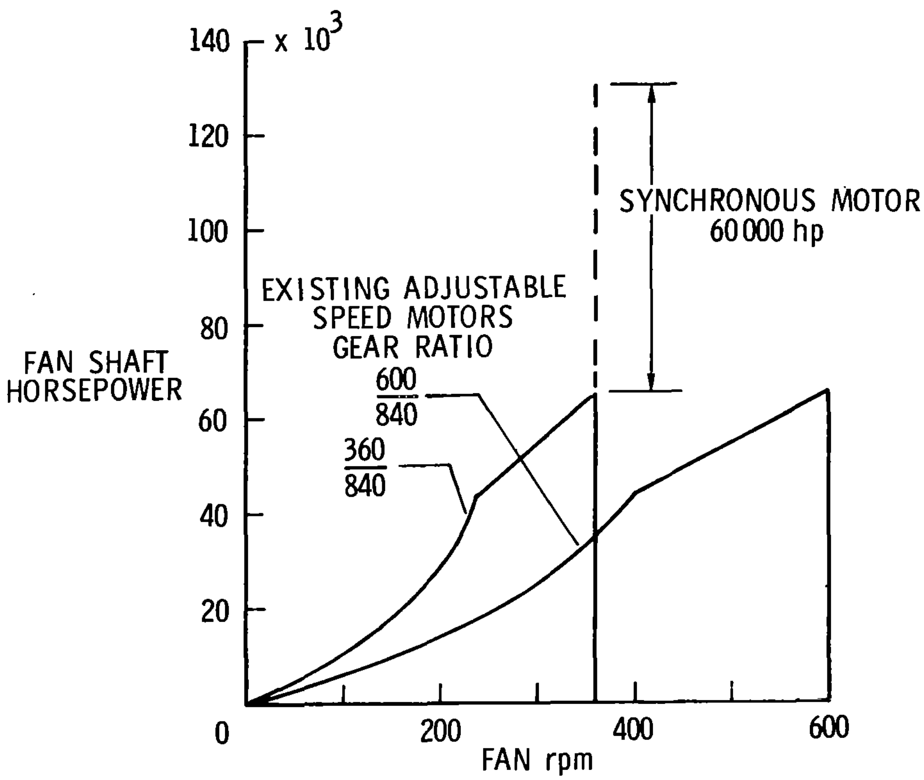



Figure 12.- Available fan drive power (10-minute rating).

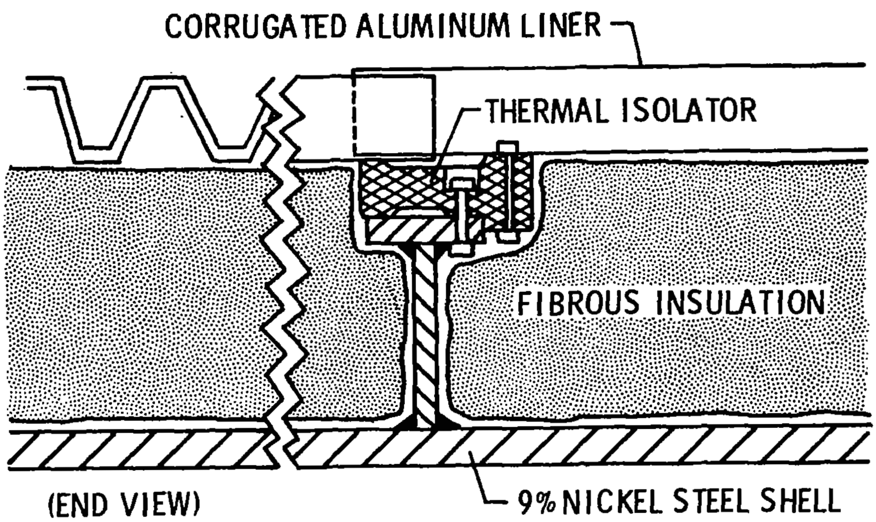



Figure 13.- Internal insulation and liner concept.

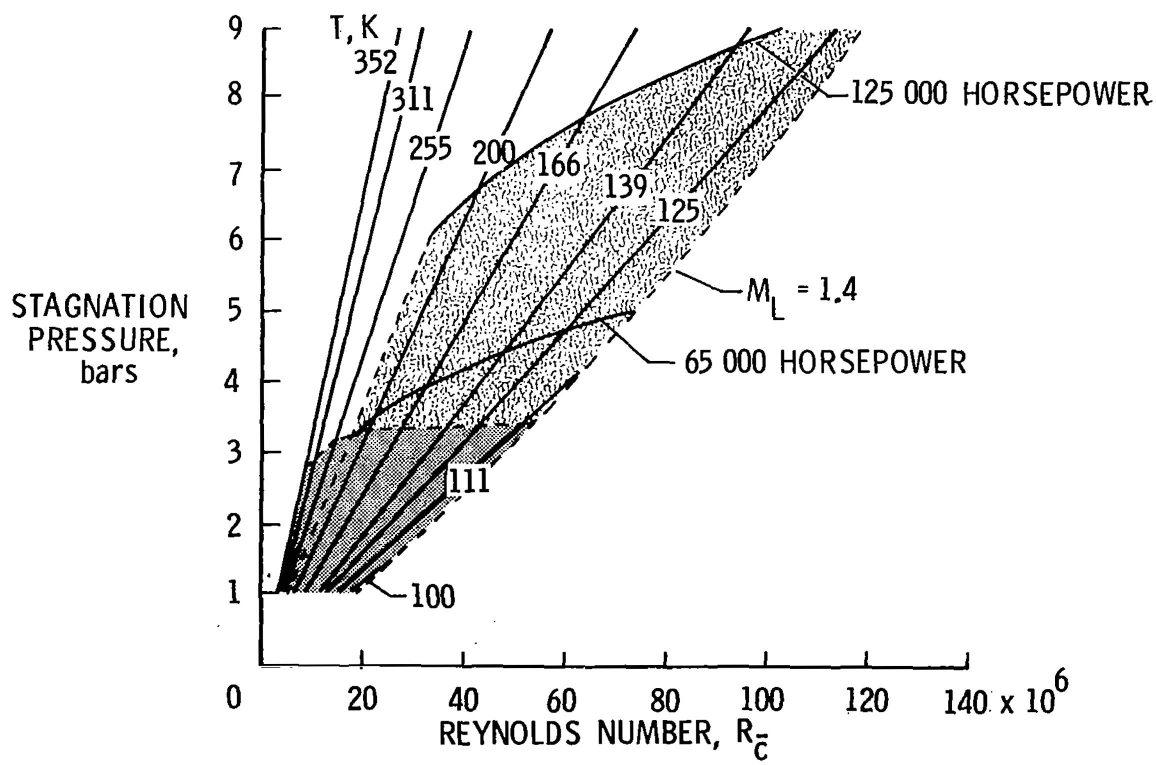



Figure 14.- NTF operating envelope at $M_\infty$ = 1. ($\bar{c}$ = 0.25 m).

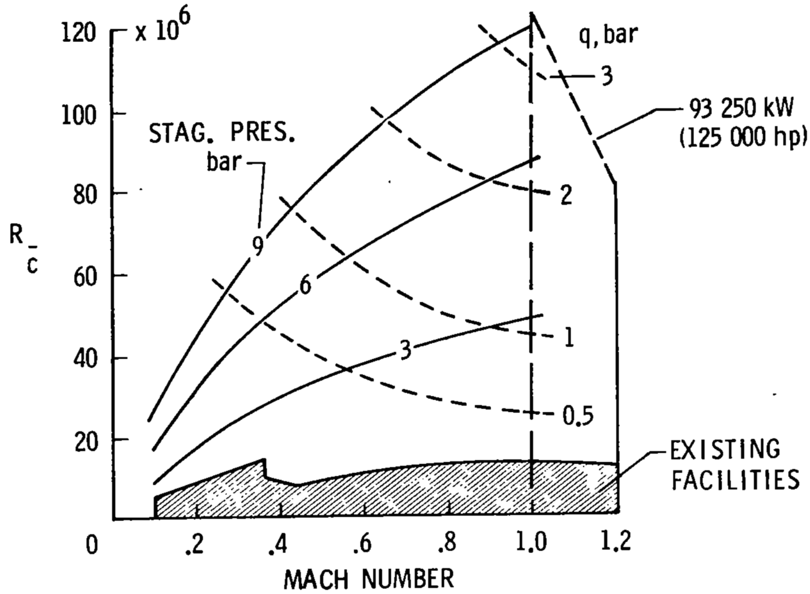



Figure 15.- Maximum Reynolds number operating envelope. ($\bar{c}$ = 0.25 m).

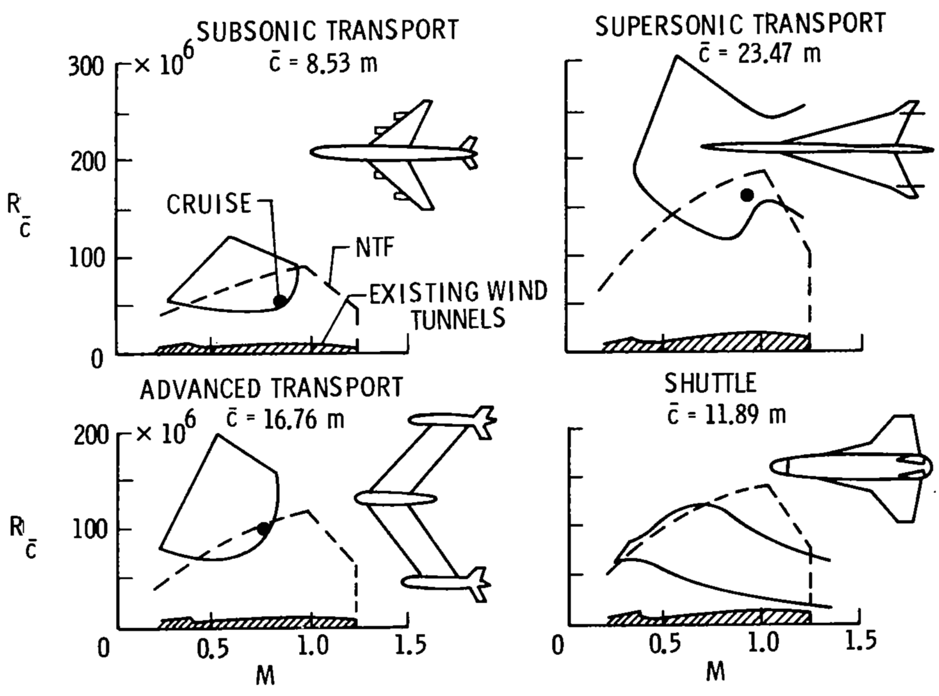



Figure 16.- Comparison of typical flight Reynolds number requirements with NTF capability for various civil aircraft.