NASA Technical Memorandum 102827

Research at NASA's NFAC Wind Tunnels

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RESEARCH AT NASA'S NFAC WIND TUNNELS

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ABSTRACT

The National Full-Scale Aerodynamics Complex (NFAC) is a unique combination of wind tunnels that allow the testing of aerodynamic and dynamic models at full or large scale. It can even accommodate actual aircraft with their engines running. Maintaining full-scale Reynolds numbers and testing with surface irregularities, protuberances, and control surface gaps that either closely match the full-scale or indeed are those of the full-scale aircraft help produce test data that accurately predict what can be expected from future flight investigations. This complex has grown from the venerable 40- by 80-Foot Wind Tunnel that has served for over 40 years helping researchers obtain data to better understand the aerodynamics of a wide range of aircraft from helicopters to the Space Shuttle. A recent modification to the tunnel expanded its maximum speed capabilities, added a new 80- by 120-foot test section and provided extensive acoustic treatment. The modification is certain to make the NFAC an even more useful facility for NASA's ongoing research activities. This paper presents a brief background on the original facility and the kind of testing that has been accomplished using it through the years. A summary of the modification project and the measured capabilities of the two test sections is followed by a review of recent testing activities and of research projected for the future.

1. INTRODUCTION

The National Aerodynamics and Space Administration (NASA) has a wide assortment of wind tunnels. One of the most interesting and useful is the National Full-Scale Aerodynamics Complex (NFAC) located at NASA's Ames Research Center, Moffett Field, California. This tunnel, which is actually two tunnels in one, has received considerable attention in the last 2 years as it has completed an extensive modification, including repowering, and the addition of a new, large 80- by 120-foot test section. It compliments the original 40- by 80-foot section that has been in use since 1944. Figure 1 shows the tunnel as it now exists.

The original 40- by 80-foot test section maximum speed was 200 knots. That section can now be used for tests up to 300 knots. The increase in speed greatly expands the usefulness of the facility for high-speed STOVL aircraft research and for tilt-rotor and high-speed rotorcraft explorations. The 80- by 120-foot test section maximum speed is 100 knots and is large enough to permit full-scale Reynolds number testing on large models, or testing of actual aircraft of the Boeing 737 size.

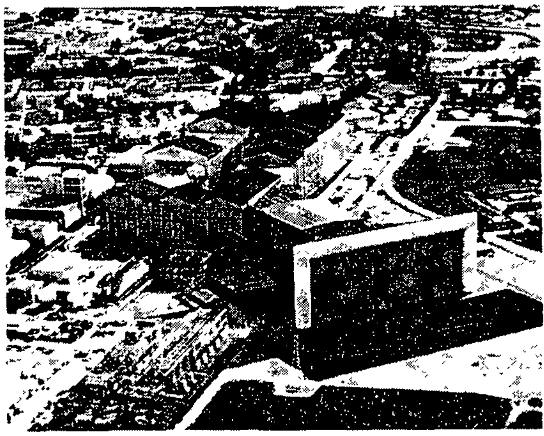

Figure 1. National Full-Scale Aerodynamics Complex

Acoustic considerations were given high priority in the new drive system design. Modern acoustics technology was incorporated to reduce drive-system-generated noise to extremely low levels. The test sections have also been acoustically treated, which allows detailed noise measurements to be made on the test vehicle during tests.

Before the start of research testing, integrated systems tests were conducted with the objective of checking operation of the NFAC and calibrating its performance. The wind tunnel meets or exceeds essentially all performance objectives. In the 40- by 80-foot section, the tunnel runs smoothly at its maximum test section speed of 300 knots (Mach 0.45). Throughout the operating envelope, the test-section dynamic pressure is uniform to within ±0.5%, the flow angularity is uniform to within ±0.5°, and the axial component of turbulence is generally less than 0.5%. The low-noise fans and acoustic treatment have resulted in background noise levels for this very large tunnel that are comparable to other (smaller) large-scale acoustic wind tunnels in the United States and abroad. In the 80- by 120-foot section, flow quality in this nonreturn leg is equally good and is not greatly affected by external wind conditions at the inlet.

Research testing has been under way in the 40- by 80-foot section since the summer of 1987 and in the 80- by 120-foot section since the summer of 1988. A wide scope of tests have been completed ranging from those involving the tilt-rotor and conventional helicopter rotors to test of a supersonic VSTOL fighter concept and a parafoil advanced recovery system for rocket-launch-system recovery purposes. The NFAC has a multiyear backlog of tests scheduled and promises to be

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a key element in many of the important research and development programs only now being envisioned.

2. BACKGROUND

The original 40- by 80-Foot Wind Tunnel was designed to accommodate all but the largest aircraft of the time. The facility covered 8 acres and had a circuit length of approximately 1/2 mile. Six 40-foot-diameter fans, each powered by a 6000-hp electric motor, generated airflow up to a maximum test section speed of 200 knots. The construction project was started in 1941 and the tunnel went into operation in June, 1944.

The early years were spent on a variety of projects, many of which led to increasing the speed of the aircraft being tested by means of drag reduction. Wing-flap systems were modified and tested so as to lower the landing speeds and give the pilots better control. This tunnel became the primary facility for investigating the low-speed characteristics of full-scale aircraft during takeoff and landing.

The 40- by 80-Foot Wind Tunnel contributed significantly to jet aircraft stability and control systems in the 1950s. Reducing the landing speed of jet aircraft greatly reduced the runway lengths required.

Testing of swept wings was also the subject of numerous tunnel entries. Even forward-swept wings were included. Tests of high-speed supersonic transport configurations such as that shown in Figure 2 added a great deal to the understanding of the aerodynamics of such configurations. During its design process the Space Shuttle (Figure 3) was tested in the tunnel at one-third scale. The landing phase of the Shuttle operation was of obvious interest to the designers and pilots. This work was built on the foundation of many lifting-body tests, some of which were also accomplished in this tunnel.

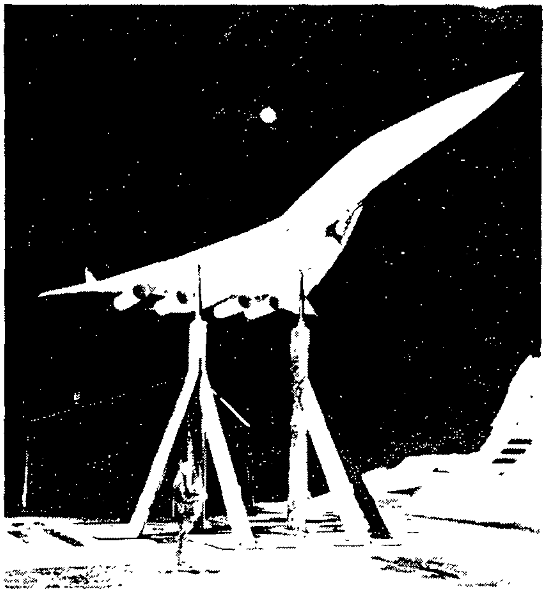

Figure 2. NASA SCAT-15F, Supersonic Transport, 1968

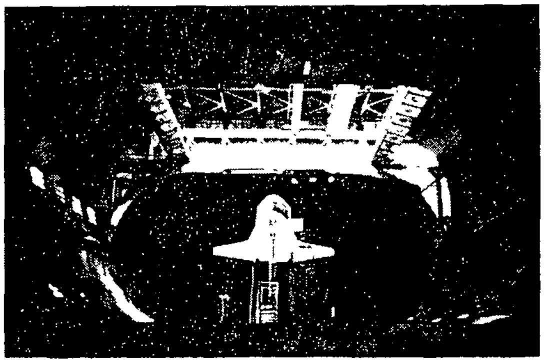

Figure 3. Space Shuttle One-Third-Scale Model, 1976

During the 1960s and 1970s the tunnel was used extensively for full-scale tests of helicopters and vertical and short takeoff and landing (V/STOL) aircraft. For V/STOL aircraft, special emphasis was placed on the transition from powered lift at low speeds to wing lift at high speeds. Examples of the types of configurations tested are shown in Figures 4 and 5. A model of the upper-surface-blowing concept as incorporated in the Quiet Short-Haul Research Aircraft (QSRA) is shown in Figure 4. The tilt-rotor was extensively tested during this period. Following earlier tests of the XV-3 and components of newer designs, the XV-15 shown in Figure 5 was tested in the tunnel prior to its highly successful flight-test program.

By 1980, the 40- by 80-Foot Tunnel had been used in over 550 tests involving several hundred aircraft and models. A wide range of configurations had been researched and much information had been added to aeronautical science as a result of investigations in this tunnel.

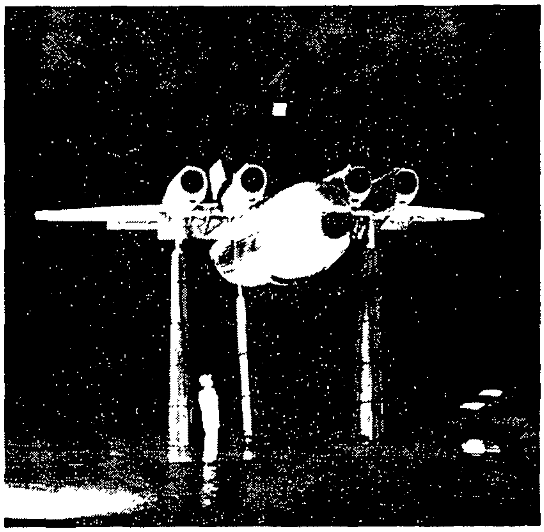

Figure 4. Quiet Short-Haul Research Aircraft, 1977

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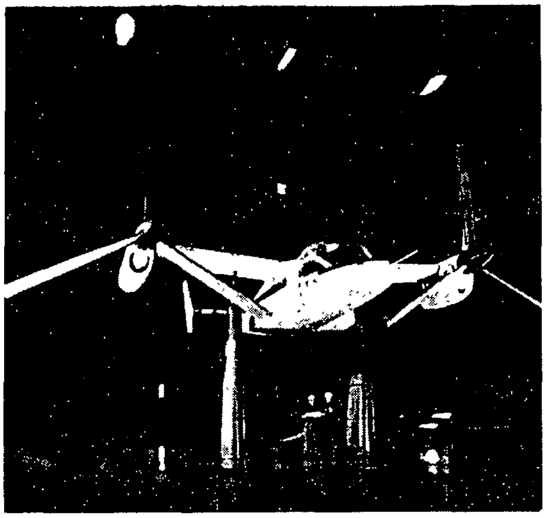


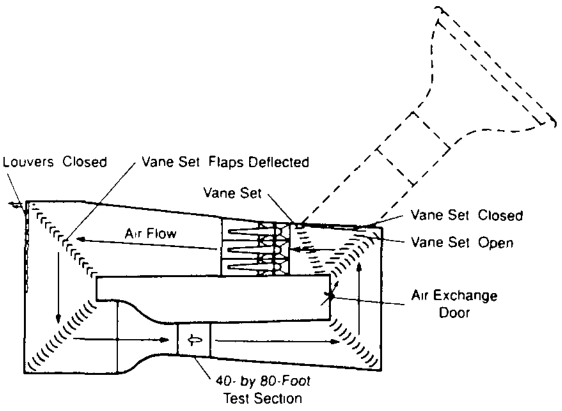
Figure 5. Tilt-Rotor Aircraft, XV-15, 1978

3. TUNNEL MODIFICATION

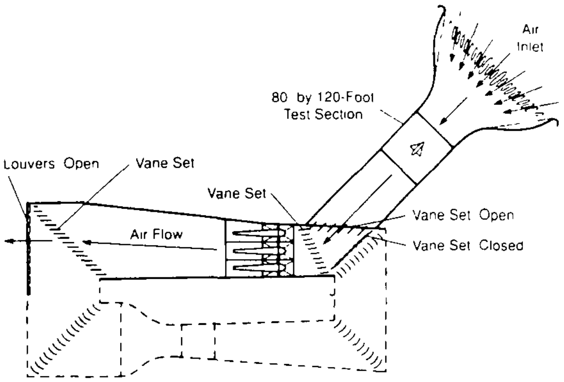
Even though the 40- by 80-Foot Wind Tunnel was one of the world's largest tunnels (a Soviet tunnel of approximately the same test section dimensions and a maximum speed of 135 knots had been built in 1938), the need for larger size and higher speeds had become obvious by the late 1960s. Emerging helicopter and V/STOL aircraft designs were targeted for larger size and higher speeds. To minimize tunnel-wall interference and to test at conditions typical of full-scale flight aircraft Reynolds and Mach numbers, more capability was required. In 1977 a decision was made to repower the tunnel and add a new, large, nonreturn test section to the facility. By increasing the total drive system power from 36,000 hp to 135,000 hp, 40- by 80-foot test-section speeds were projected to increase from 200 knots to 300 knots maximum. That same power level was expected to provide slightly more than 100 knots in the new 80- by 120-foot tunnel test section.

Figure 6 shows the facility in each of its two modes of operation. The old 40- by 80-Foot Wind Tunnel closed circuit remains essentially intact. A system of turning vanes and moveable louvers and a moveable set of exhaust louvers allows selection of operation with flow in either one or the other of the test sections at a time. By 1986 the modifications to the 40- by 80-Foot Wind Tunnel were completed. Integrated systems tests and flow calibrations were conducted, allowing the tunnel to become fully operational in mid-1987. The 80- by 120-foot section became operational in 1988, after similar systems tests and flow calibrations.

Testing for flow quality as a part of the integrated systems test was completed in both test sections. The calibration instrumentation boom is shown installed in each of the test sections in Figures 7 and 8.



(a) 40- by 80-Foot Wind Tunnel



(b) 80- by 120-Foot Wind Tunnel

Figure 6. NFAC Modes of Operations

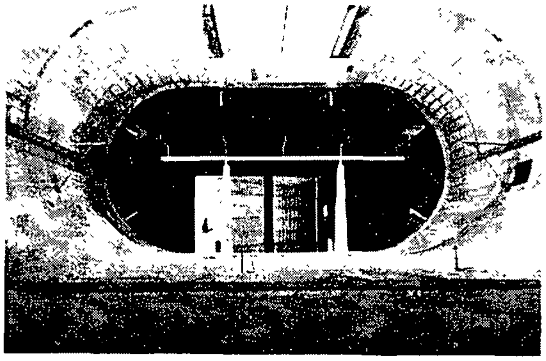


Figure 7. 40- by 80-Foot Test Section Calibration, 1987

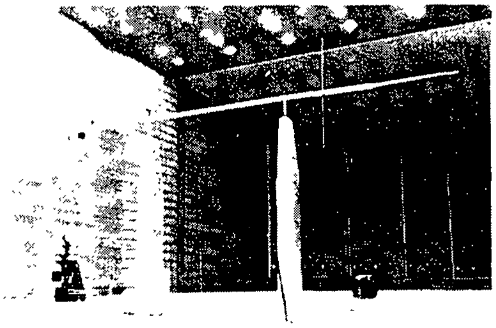


Figure 8. 80- by 120-Foot Test Section Calibration, 1988

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The test section flow characteristics for both sections can be summarized as follows:

- Speed uniform to within ±0.25%
- Flow direction uniform to within ±0.5°
- Axial turbulence intensity typically <0.5%

In addition to these characteristics, it was found that for the 80- by 120-foot test section, atmospheric winds do not have a significant effect on flow quality.

The careful attention that was given to acoustics in the design of the tunnel modification and test section treatment paid off. The test section noise is 5 to 10 dB lower, at equal airspeeds, than it was before the modification. The measured noise levels at a given tunnel speed are close to the background levels of other smaller tunnels used in the U.S. and abroad for acoustic research. These good characteristics are sure to make the NFAC a highly useful tunnel for acoustics research. Details of the measured flow quality and noise levels are included in references 1-3.

4. RECENT RESEARCH TESTING

As soon as possible after completion of the 40- by 80-Foot Tunnel flow calibration tests, research investigations were resumed. The first major test to be conducted was an investigation of tilt-rotor aerodynamics using a two-thirds-scale V-22 rotor and wing shown in Figure 9. The test had the dual purpose of measuring the wing download in the hover condition and of substantiating rotor performance in the presence of a wing at high forward speeds. The download work was an extension to full scale of the research reported in reference 4. By mounting the pressure-instrumented wing so that it was not connected to the rotor nacelle, and by having a sensitive rotor balance system, the rotor/wing interactions could be measured. This test yielded extensive data on download as effected by direction of rotor rotation and wing flap angle. The as-designed V-22 rotor direction was found to be optimal (reference 5). Forward flight data obtained up to 220 knots were found to match predictions well with little effect from the wing. Plans have been made for a Phase II test up to the full tunnel maximum of 300 knots following an upgrade in the rotor control system hardware.

Figure 9. V-22 Tilt-Rotor Tests in the 40- by 80-Foot Wind Tunnel, 1987

A second major test involved the E-7A supersonic STOVL configuration shown in Figure 10, mounted in the 40- by 80-Foot Wind Tunnel. This concept utilizes an ejector augmentor system and a variable-angle vectoring nozzle to provide lift and forward propulsion at low speeds. The ejector system doors are closed for high-speed forward flight and the concept uses conventional jet thrust and wing lift. These tests provided extensive data on ejector augmentation performance and combinations of direct jet thrust needed for transition to forward flight. Lift and draft polars for the high-speed mode were also obtained. The configuration appears to have considerable merit. Reference 6 provides details of these tests.

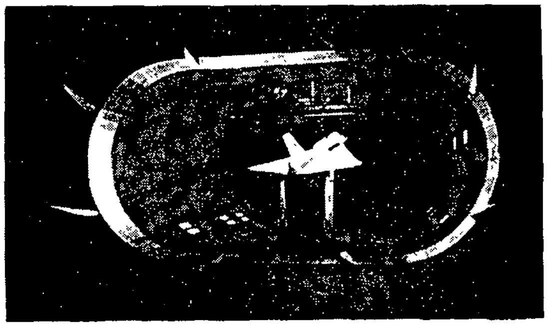

Figure 10. E-7A STOVL Configuration in the 40- by 80-Foot Wind Tunnel, 1988

The latest test in the 40- by 80-Foot Wind Tunnel was conducted to explore helicopter main rotor and fuselage aerodynamic interactions. This test installation is shown in Figure 11. The rotor, which is a Bell 412, was mounted on the NFAC's Model 576 test stand that incorporates a 1500-hp electric drive motor. This stand allows fuselage body loads to be measured

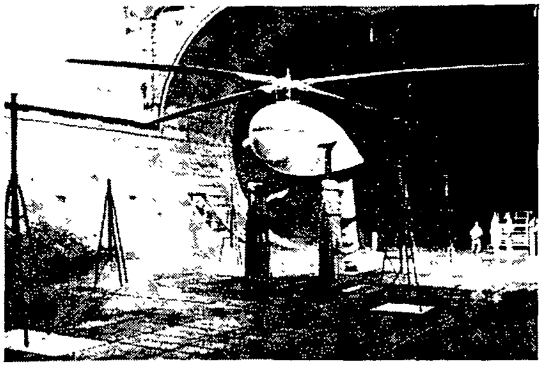

Figure 11. Helicopter Interactional Aerodynamics Test in the 40- by 80-Foot Wind Tunnel, 1989

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independently from rotor loads through the use of load cells supporting the fuselage shell. The fuselage is represented by a very simple, pressure-instrumented teardrop shape. Smaller-scale model data have already been obtained to aid in this full-scale effort. During the testing a full set of rotor and body performance and loads data as well as acoustics data were obtained up to 0.3 advance ratio at 0.68 tip Mach number for rotor shaft angles ranging from -4° to -12°. Future tests will explore higher advance ratios and will incorporate a separate tail rotor test stand to determine tail rotor interaction effects.

The first model test in the 80- by 120- Foot Wind Tunnel was conducted in the summer of 1988 and involved investigations of two large (30- and 60-foot span) controllable parafoils. This was part of an Air Force-sponsored study to explore the usefulness of such systems for recovery of spent booster rockets. Figure 12 shows the larger parafoil during testing. The primary objectives of the test were to determine the basic aerodynamics of the parafoils, their ability to flare for the final touchdown, and control mechanism behavior. Through the use of the tunnel balance and control line load cells, the basic aerodynamics were measured. The flare maneuvers were successfully accomplished and information on the parafoil's behavior was gathered. This testing, combined with drop-test data, has proved of great value to the project.

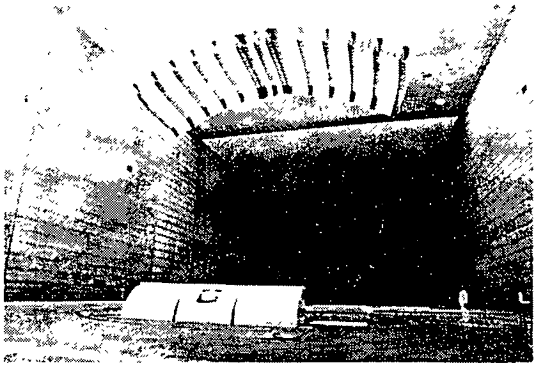

Figure 12. Parafoil Tests in the 80- by 120-Foot Wind Tunnel, 1988

The second test conducted in the 80- by 120-Foot Wind Tunnel during its startup phase was a cooperative effort between NASA, the National Science Foundation, and industry. It involved obtaining detailed pressure distribution measurements and flow-wake visualization behind a bluff body (in this case a truck trailer) and determining the effect of the boat-tail plates that can be seen in Figure 13. Although it is somewhat unusual for NASA to be involved with vehicle aerodynamics, the opportunity to gather base drag information for validation of CFD codes and to experiment with clever ways of reducing that drag has obvious value for potential aerospace applications. The pressure data obtained were very good, and excellent laser light sheet flow visualization was obtained of the wake flow. CFD comparisons are currently under way.

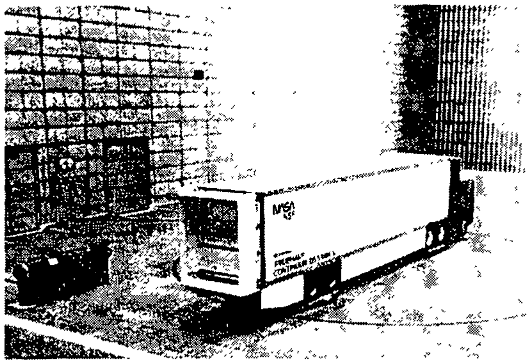

Figure 13. Base Drag Test in the 80- by 120-Foot Wind Tunnel, 1988

The drag reduction achieved by the boat-tail plates was measured both by use of the tunnel balance and by the use of load cells on the aft flat end of the truck trailer. A 10% reduction of overall drag was measured. This corresponds to 500-1000 gal/yr of fuel savings for a typical truck or up to 1 billion gal/yr for the entire U.S. fleet of tractor/trailers.

Currently, the E-7A is being tested in the 80- by 120-Foot Wind Tunnel. Figure 14 shows the test installation. These tests are expected to yield valuable data on the characteristics of such a configuration in the speed regime from 0-100 knots with reduced wall effects as compared to those of the 40- by 80-Foot Wind Tunnel. These data will also prove of great value in interpreting the aerodynamic characteristics as determined using the 40- by 80-Foot Wind Tunnel in that same speed range.

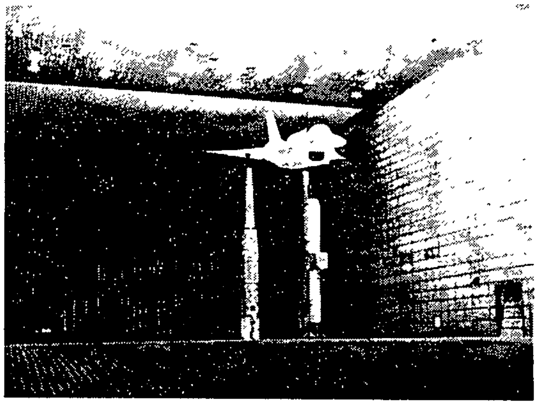

Figure 14. E-7A in the 80- by 120-Foot Wind Tunnel, 1989

5. FUTURE RESEARCH AREAS

The NFAC maintains an approximately 2-year projection of planned tests that is constantly evaluated to match test hardware and tunnel availability. Priority in the schedule sequence is based primarily on national need and is also subject to continuing review. Some of the planned future tests involve additional phases of the tests described earlier. For example, the V-22 Tilt-Rotor tests will be conducted up to tunnel maximum speed as mentioned. Future tilt-rotor exploration may involve a

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full-span model that is now in the conceptual stage. The interactional aerodynamics investigation is just the start of a series of tests designed to explore the multiple interactions of helicopter main and tail rotors and fuselage shapes. A rotor test stand is in fabrication that will facilitate the powered testing of large rotors (>45-foot diameter) in programs to determine their aerodynamic, dynamic, and acoustic characteristics at high speeds. Other rotor programs will involve such areas as active control and individual blade control.

An interesting test now in the planning stages involves the use of an F-18 aircraft to obtain flow-field measurements, aerodynamic forces, and structural response for the aircraft in conditions that are difficult or impossible to maintain in free flight. This is especially true in very high angle of attack conditions such as depicted in Figure 15. In the tunnel, these conditions can be established and the flow studied, whereas in flight the condition is transient and very difficult to study. For many of the effects of interest, such as forebody flow, and vortex trajectory and bursting, it is important to test at a Reynolds number well beyond critical. The use of an actual aircraft, rather than a subscale model, helps markedly in this regard. The use of long-range laser velocimeter equipment to obtain off-body flow-field information should aid in the continuing process of understanding complex flows and of improving CFD codes through the correlation of predictions with experimental data.

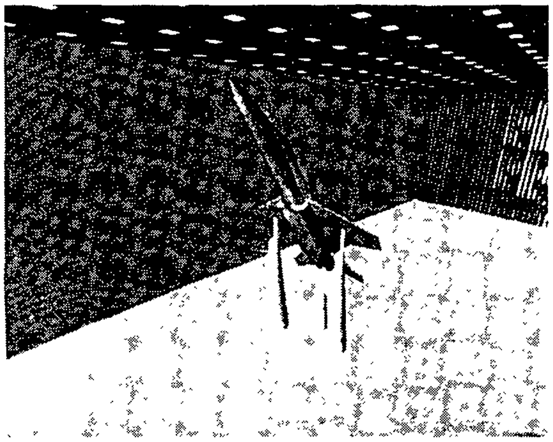

Figure 15. F-18 Testing in the 80- by 120-Foot Wind Tunnel

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Acoustics-related testing is expected to become an increasingly important component of the NFAC's activities in the future. With the excellent acoustic characteristics already built into the facility and with a major acoustic treatment modification on the drawing boards to further improve the 40- by 80-Foot Wind Tunnel test section, the NFAC's unique position as a prime large-scale acoustics facility is assured.

As evidenced by the research that has been accomplished since the tunnel modification, and as can be seen from the plans already in place for future projects, the NASA Ames NFAC wind tunnels are a key element in the U.S. aeronautics capability.

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16. Abstract

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