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Improving Large-Scale Testing Capability by Modifying the 40- by 80-ft Wind Tunnel

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Interagency studies conducted during the last several years have indicated the need to improve full-scale testing capabilities. The studies showed that the most effective trade between test capability and facility cost was provided by repowering the existing Ames Research Center 40- by 80-ft Wind Tunnel to increase the maximum speed from about 100 m/s (200 knots) to about 150 m/s (300 knots) and by adding a new 24- by 37-m (80- by 120-ft) test section powered for about a 50-m/s (100-knot) maximum speed. This paper reviews the design of the facility, a few of its capabilities, and some of its unique features.

Introduction

THE experience and insight gained by the successful operation of the 40- by 80-ft wind tunnel over the past three decades have shown both the value of the existing facility and the requirement for even greater test capabilities. Current and planned development of V/STOL aircraft and advanced helicopters have increased the need for a facility with a larger test section and higher test speeds. The planned modifications to the 40- by 80-ft wind tunnel at Ames Research Center will consist of increasing the power of the drive motors and adding a new test section.

This paper discusses the background of and justification for the project, reviews the improved test capabilities for model size and test speed, discusses the options that have been considered as possible enhancements to the aerodynamic test capabilities, explains the improvement in the acoustic test capabilities, outlines some of the unique features of the design of the facility, and reviews the current status of the project.

Background Details

The value of full-scale subsonic testing has been convincingly demonstrated by the NASA 40- by 80-ft wind tunnel over the past 35 years. However, because of the increase in size of aircraft and the technological changes in aircraft, facility capabilities for performing this type of testing must be improved (see, for example, Refs. 1-6). To meet this need, NASA is planning two major modifications to the 40- by 80-ft wind tunnel. Figure 1 shows the modifications planned. The first modification consists of repowering the drive, which will increase the maximum speed in the 12- by 24-m (40- by 80-ft) test section from about 100 m/s (200 knots) to about 150 m/s (300 knots). The second modification is the addition of a new rectangular test section that will be about 24-m (80-ft) high by about 37-m (120-ft) wide. The maximum speed in the new test section will be about 50 m/s (100 knots).

Past experience with the existing 40- by 80-ft wind tunnel has demonstrated the value of adequate ground testing of advanced aircraft (or critical components of these aircraft) before making the large financial investment required for flight-test hardware. Experimental investigations in the 40- by 80-ft wind tunnel have prevented catastrophic in-flight failures of a number of advanced V/STOL research aircraft by exposing, during the wind-tunnel test, unanticipated deficiencies in critical components (rotor, propulsion, or control systems). As a result, substantial savings have accrued when tests in the 40- by 80-ft wind tunnel exposed deficiencies that were either fundamental to the concept or would have required a prohibitive increase in the program cost to correct. The overall savings accrued have more than offset the construction and operating costs of this facility for the last 35 years. In addition, the research contributions this facility has made to such advanced aircraft concepts as tilt rotor and lift fan VTOL aircraft, advanced helicopters, lifting-body aerodynamics, etc. (although difficult to quantify in dollars) are unquestionably of far greater value than the appreciable money saved by ground testing rather than flight testing the aircraft.

In 1967, the Aeronautics and Astronautics Coordinating Board (AACB) initiated studies of ground-based facilities in the U.S. The AACB's objective was to define those areas where the limitations of existing facilities could be expected to limit the performance or acceptability of future aircraft. The first step in this study was to review the degree to which existing facilities had met the test requirements of past aircraft development programs. Table 1 presents such a review and shows how the current speed and size limits of the 40- by 80-ft wind tunnel have influenced various aircraft test programs. As may be seen from the table, the size limitation has primarily constrained the fixed-wing aircraft investigations, while the speed limitation has primarily constrained the rotary-wing investigations. The test constraint due to size is caused by two basic factors: first, the long-term increase in aircraft size and, second, the continuing need to develop more lift from a wing of a given size. This latter

Table 1 Past programs affected by 40- by 80-ft wind tunnel limits

Program	Limit: Size	Limit: Speed
C-8 Augmentor Wing	X	
F-14	X	
F-15	X	
F-111	X	
Electra (prop. whirl)	X	X
US/FRG fighter	X	
AH-56A comp. helicopter	X	X
ABC rotor	X	X
Bell H.P. helicopter		X
XH-51A comp. helicopter		X
XC-142 tilt wing	X	
X-22 tilt duct	X	

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factor requires a larger test section (relative to the wing) to alleviate wind-tunnel wall-constraint effects on the complex flowfields that are typical of high-lift conditions. The test constraint due to speed is primarily caused by the need to improve the capability and efficiency of advanced rotorcraft.

Test Capability Improvement

Aerodynamic Testing

The increased capability in model size and speed which will result from the planned modification is shown in Fig. 2. Allowable model size is shown as a function of test-section speed. The size boundary (developed using Ref. 7) is shown as a band because the allowable size varies considerably, depending on the details of the model, the purpose of the tests, etc. At low speeds, where wake constraint effects caused by the wind-tunnel walls reduce the allowable model size, the addition of the new test section will cause a substantial increase in the size capability. This increase in size capability will substantially improve the capability for testing V/STOL and powered-lift aircraft, as well as rotorcraft, at low speeds. The increase in speed planned for the existing test section (also shown in Fig. 2) will allow more representative studies of high-performance rotorcraft than presently possible.

It is appropriate at this point to review the aircraft (listed on Table 1) for which the size and speed capabilities of the existing 40- by 80-ft wind tunnel are inadequate, and to assess the adequacy of the modified 40- by 80-ft wind tunnel to meet the requirements of these aircraft. The modified facility would eliminate all of the wind-tunnel speed and size limitations for testing these aircraft with the exception of the limitations associated with the Electra propeller whirl problem, which required a combination of test section speed and size that is not provided by the modified 40- by 80-ft wind tunnel. From this assessment, as well as consideration of long-term trends in aviation and the associated technical problems, it is believed that a good cost/benefit judgment has been achieved with the proposed modifications to the 40- by 80-ft wind tunnel.

Aerodynamic-Testing Enhancement Considered

Studies were made to examine the possibility of enhancing the test capability of the new test section. The goal was to eliminate or reduce the aerodynamic measurement errors and uncertainties caused by the test section walls so that larger models could be tested. "Self-correcting" arrangements, such as those of Refs. 8-13, and vented-wall configurations, such as those of Refs. 14-21, were considered. Figure 3 illustrates some results for a uniformly loaded wing with a ratio of wing-loading to aspect-ratio of 958 N/m^2 (20 lb/ft^2). The ratio of wingspan to test section width for a given correction is shown as a function of test-section speed. As shown, the greatest ratio or potential capability would result from using a self-correcting test section. A vented test section (passive venting) with a residual error of 0.5 deg in angle of attack results in approximately the same test capability as solid walls with an error in angle of attack of about 2 deg. Wall effects of this magnitude are correctable to within that tolerance, thus, little is gained by venting the test section. Despite the potential superiority of self-correcting test sections and vented test sections, it was decided not to implement either scheme.

Self-correcting test sections have not been developed for multienergy or powered-lift models. Experimental work to date has been on two-dimensional models (see, for example, Refs. 9-12). There have been limited three-dimensional theoretical studies on very simple model configurations (see, for example, Refs. 11 and 13). The judgment has been made, after considering these studies, that implementation of self-correcting techniques may ultimately be practical at small scale for three-dimensional powered-lift testing; however, implementation at full scale would require very complex and expensive systems and does not appear practical. In addition, flow-measuring instrumentation and computer capability would be required for full-scale implementation. The variety of model configurations, range of model sizes, and model support requirements required for full-scale testing would also substantially increase the complexity.

Test sections with passive venting for powered-lift testing were studied in Refs. 14-21. Large plenum chambers appear necessary (although Ref. 19 describes promising results with only small floor and ceiling plenums). Even though venting attenuates wall effects, there are residual errors. To date, techniques for correcting these errors have not been nearly as accurate or reliable as the application of corrections for solid-wall effects. As Fig. 3 shows, the solid wall with a 2-deg error (or correction) in angle of attack is essentially equivalent to vented walls with a 0.5-deg error in angle of attack, but the 2-deg error is correctable, while the 0.5-deg error is not. In addition, the venting requirements appear to depend on the model geometry and, for a given model, can depend on model attitude and lift. Such highly variable venting requirements demand a complex, automated venting system. An additional drawback, although less serious, is that venting increases the wind-tunnel drive power required; it is estimated that venting would increase the power for the new test section by about 7 to 8%. Because of these considerations, it was decided not to implement vented walls.

It is likely that, over the next few years, wall correction techniques will be improved so that larger models can be tested. The potential gain in size (using the techniques in Ref. 7) is illustrated in Fig. 4. As can be seen, if large corrections can be made reliably, the testing capability compares

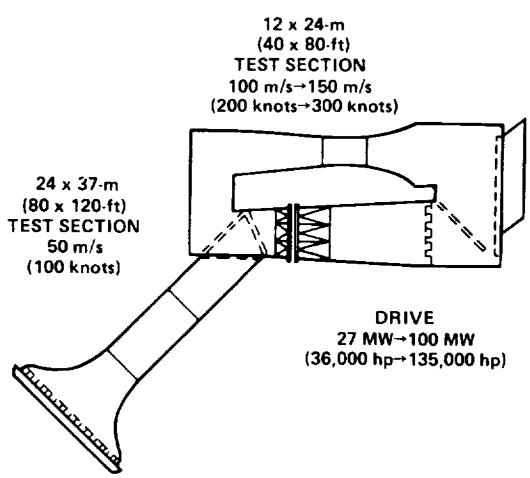

Fig. 1 40- by 80-ft wind tunnel modifications.

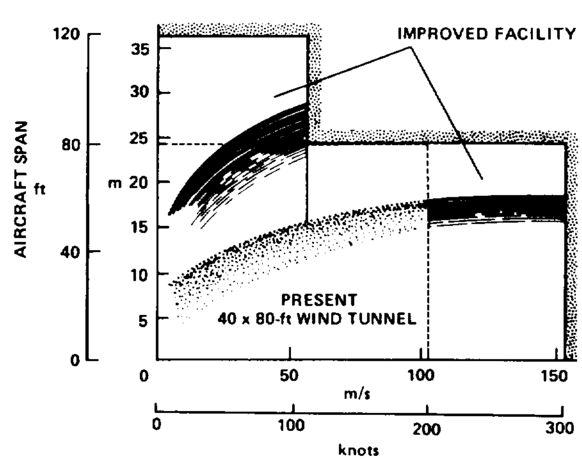

Fig. 2 Improvement in full-scale test capability.

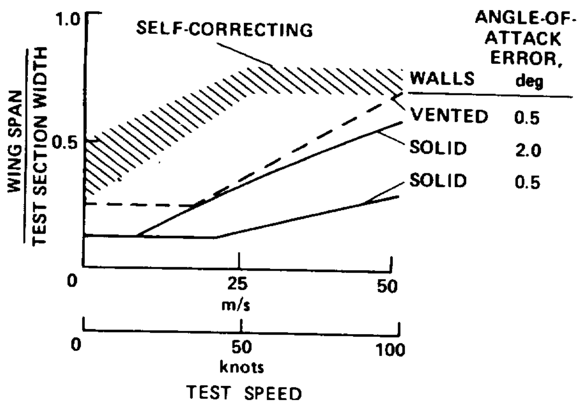

Fig. 3 Potential enhancement of test capability at a wing loading/aspect ratio of 958 N/m² (20 lb/ft²).

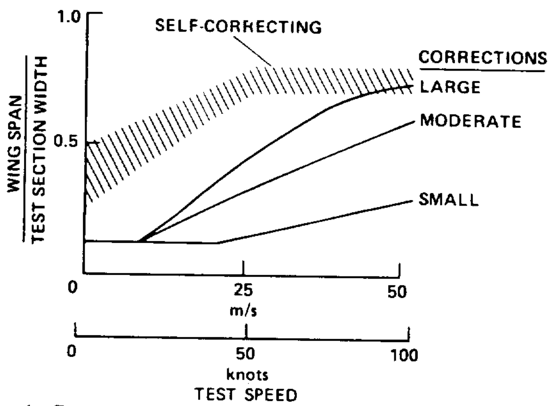

Fig. 4 Potential of improved wall corrections at a wing loading/aspect ratio of 958 N/m² (20 lb/ft²).

favorably with that for self-correcting concepts in the 30 to 50 m/s test-speed range, which is the range of interest for powered-lift or STOL configurations. (Test speeds below 30 m/s will probably require, for practicality and economy, approaches to error reduction other than analytically determined wall corrections, self-correcting test sections, or standard venting techniques.) The techniques for determining large corrections remain to be developed. However, it is expected that this will be done in the next few years. In addition, it appears likely that, if the instrumentation and computer techniques being developed for self-correcting test sections were employed for normal test sections, large corrections could be determined accurately by proper measurements. This means of determining wall corrections could be implemented in the new test section whenever the technology is developed.

Steady-State Ground-Effect Testing

For a number of years, NASA Ames has been sponsoring studies on the use of a blowing jet to energize the boundary layer on the floor of the test section for performing ground-effect testing (Refs. 22-26). Figure 5 illustrates the concept schematically. The jet is approximately two wing chords forward of the wing. The condition of the boundary layer is continuously monitored under the wing at the quarter-chord so that the jet may be properly set and adjusted as required. The capability for performing ground-effect testing is illustrated in Fig. 6, which is reproduced from Ref. 25. Lift coefficient is shown as a function of the ratio of flap trailing-edge height to wing chord. The suggested test ranges for fixed ground, blowing jet, and moving belt are shown. As can be seen from the figure, the blowing jet is substantially better than the fixed ground board, but not as good as the moving belt. However, the capability of the blowing jet is acceptable

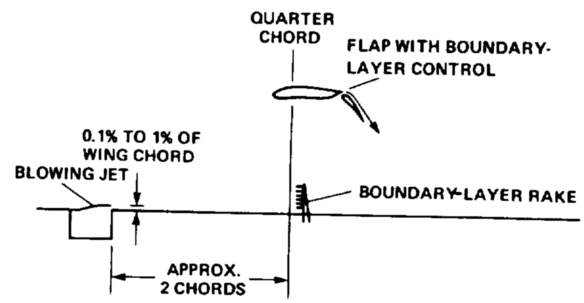

Fig. 5 Ground-effect testing using floor blowing.

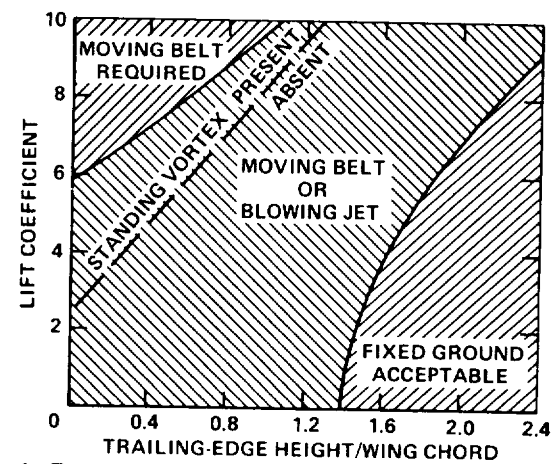

Fig. 6 Test ranges for fixed ground, blowing jet, and moving belt.

for powered-lift models and is substantially simpler to implement than a moving belt system. In view of this, studies on the blowing jet are continuing to be sponsored with the objective of eventual implementation in the new test section.

Acoustic Testing

In addition to the improvement in aerodynamic test capability to be achieved by the modification, the acoustic test capability will also be substantially improved. Over the past 5 to 10 years, aeroacoustic research has become increasingly important, and many facilities have been modified or constructed for this work (see Ref. 5). In the existing 40- by 80-ft wind tunnel many experimental investigations of aeroacoustic phenomena have been performed (see, for example, Ref. 27). The capability for performing acoustic studies in the modified 40- by 80-ft wind tunnel will be improved by reducing the test section background noise as well as by increasing the test speed and test section size.

The new drive system will be much quieter than the present drive system, even though the power will be increased to nearly four times that of the present system. In Fig. 7 the new drive background noise is compared with the present level. As shown, there will be a substantial reduction in background noise. The drive noise will be lowered by reducing the fan inflow distortion and by employing a fan with a much lower tip speed. The fan tip speed will be 115 m/s (337 ft/s) compared with 185 m/s (607 ft/s) for the present fan. The fan inflow will be improved by changing the fan arrangement as shown in Fig. 8. The fan will be located upstream of the support struts instead of downstream. The new drive requires a set of stators which will be located at least two rotor-blade chords downstream of the rotor to minimize interference and, hence, noise.

The drive system was developed with the aid of studies performed on 1.8-m- (6-ft) diam fan models. The model noise was scaled and increased to represent the noise of the six full-scale drive fans and then compared with the noise of the

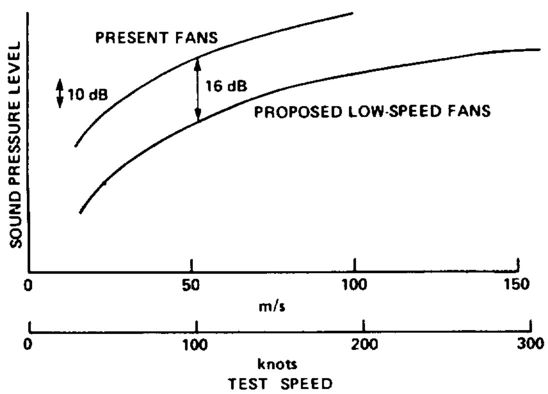

Fig. 7 Reduction in test-section background noise.

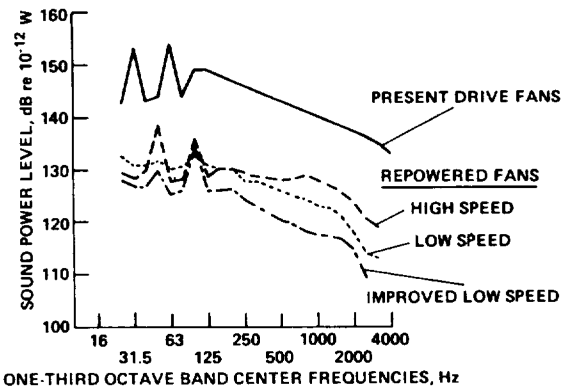

Fig. 9 Drive sound power level at 100 m/s in 12- by 24-m (40- by 80-ft) test section.

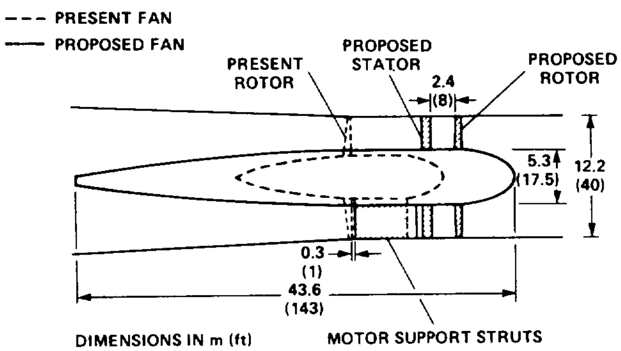

Fig. 8 Change in drive system geometry.

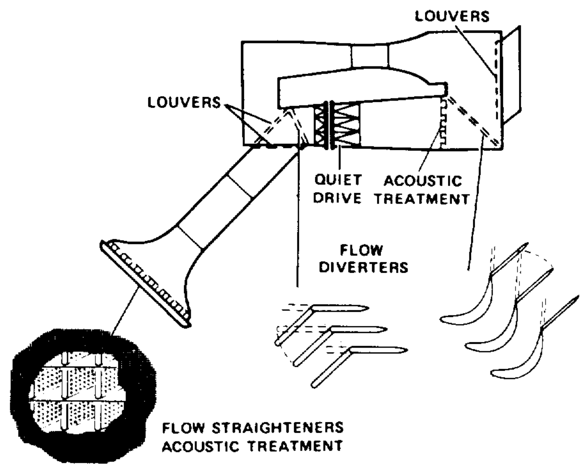

Fig. 10 Special features.

present drive fans. The results are shown in Fig. 9. Sound power level is shown in one-third octave bands for a test-section speed of 100 m/s (200 knots). The lower three curves were scaled from the model studies. Three fans were tested: a high-speed fan (tip speed 191 m/s, 627 ft/s) and two low-speed fans (tip speed 115 m/s, 377 ft/s). The two low-speed fans were quieter than the high-speed fan, and the improved low-speed fan was quietest. The improvements were made by improving the rotor and stator airfoil shapes and by improving the quality of the fan inflow.

The model development process was important to the optimization of the drive system. The resulting drive system will be significantly quieter than the present drive system. Since the existing facility is used extensively for acoustic studies, the reduction in background noise will be a very important improvement.

Special Features

Several special features of the modified facility are shown in Fig. 10. To control the airflow in either the closed return or the nonreturn circuit, there are various louvers and flow deflectors. The louvers at the locations indicated on the figure are relatively simple, two-position devices that either open or close the flow passage. However, the two sets of flow diverters shown are more complicated. The set at the intersection of the two circuits is the most complex and has been under extensive study. As shown, the forward portion of the device is in one of two positions, depending on the circuit being used. Not only is it important to minimize the power loss due to these deflectors, but it is important to minimize their wake so that its effect on fan noise is negligible. The set of diverters near the exit is less complex and consists essentially of straight-sided extensions of the present turning vanes supported by a pivot system.

As shown in Fig. 10, flow straighteners at the inlet reduce the effects of crosswinds on the flow quality in the test section. This minimal treatment appears to be acceptable because of the generally light wind conditions at the site. Critical low-speed testing will be scheduled for low-wind conditions which normally exist about 8 h each day. Many experimental investigations have been conducted to define the inlet treatment required to achieve satisfactory flow characteristics in the test section under all wind conditions (see, for example, Ref. 28). The present design does not incorporate all of the technology developed during these experiments, because, from a cost/benefit viewpoint, to specify that the 24- by 37-m (80- by 120-ft) test section must have excellent flow quality at low speeds under all conditions of external winds did not appear to be justified. If future use of the facility shows that test scheduling is being seriously curtailed by external wind conditions, the technology for additional inlet treatment is available.

The flow straighteners will be lined with acoustic treatment to lower the wind-tunnel noise in the surrounding community (see Ref. 29). The exhaust acoustic treatment will be in both the nonreturn and closed-return circuits (as shown in Fig. 10), and will reduce fan and model noise propagation out of the wind tunnel (in the nonreturn mode) and fan noise propagation into the present test section (in the closed-return mode).

Status

Various studies have been used to develop the design of the facility. Model tests were used to develop the flow diverter and louver systems, inlet and exit systems, and the drive system. The diverters and louvers were studied at about 1/10 scale, the inlet and exit systems at 1/50 scale, and the drive system at about 1/7 scale. Additional studies are being performed on test-section systems, on acoustics, and on the use of a blowing jet on the floor of the test section for ground-effect testing. Tests for optimization of the acoustic treatment are underway, as well as a study of inflow turbulence effects on fan noise. Final design on the modification began in 1974 and should be completed by mid-1979. Construction should be completed by mid-1981.

Concluding Remarks

A review of aircraft development trends, as well as extensive operational experience with the existing 40- by 80-ft wind tunnel, indicate the need for a major increase in the speed and size capability of this facility. The planned modifications will increase the maximum speed of the 12- by 24-m (40- by 80-ft) test section from 100 to 150 m/s (200 to 300 knots), and will provide a second test section 24 by 37 m (80 by 120 ft) with 50 m/s (100 knots) speed capability for low-speed, powered-lift, and rotorcraft testing. Design studies have shown that in spite of the large increase in wind-tunnel drive power, the use of a low tip speed fan will result in a drive that is quieter than the existing drive. These modifications will enhance the capability of the modified facility to perform propulsion and airframe noise research, as well as aerodynamic research.

The 40- by 80-ft wind tunnel has proved to be a valuable tool in aerospace research. The planned modifications will expand and enhance its already unique capabilities and utility. The improvements will be made by additions to an existing facility to minimize costs. This method of expansion of test capability should prove to be a useful and viable approach for other, smaller facilities as well.

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