N88-21482

DEVELOPMENT OF DRIVE MECHANISM FOR AN OSCILLATING AIRFOIL

Clifford D. Sticht*

ABSTRACT

This paper describes the design and development of an in-draft wind tunnel test section which will be used to study the dynamic stall of airfoils oscillating in pitch. The hardware developed comprises a spanned airfoil between schleiren windows, a four bar linkage, flywheels, a drive system and a test section structure.

INTRODUCTION

The purpose of the experiment is to investigate dynamic stall which is a phenomenon associated with an airfoil moving beyond its static stall angle. Examples of where dynamic stall is present are in jet engine compressors, helicopter rotor blades and aeroelastic effects on aircraft wings where small amplitude and high frequency oscillations are present. When an airfoil is moved rapidly through an angle-of-attack range that includes the static stall angle, maximum lift can be greatly increased and becomes strongly dependent on the rate and amplitude of oscillation. There is a hysteresis loop developed in both lift and pitching moments with much larger magnitudes developed than in steady flow as shown in Figure 1. At the end of the cycle, where the vortex leaves the airfoil, there is an abrupt drop in lift and moment.

The test section, described in this paper, will be installed at the new Fluid Mechanics Laboratory at Ames Research Center, which has been developed to pursue basic research in aerodynamic science and technology. The Lab consists of four in-draft tunnel bays and a central experiment bay. These bays house a variety of small research wind tunnels, many of which will be driven by the Laboratory's 113 m^3/s (240,000 cfm) compressor. The wind tunnel, containing the test section being discussed in this paper consists of an intake with screens joined to a contraction section as shown in Figure 2. Downstream of this is the test section, followed by a variable throat to control the flow velocity. The flow then passes through a manifold and finally to the Lab's 6.0 MW (8000 hp) compressor.

* Research Engineer, NASA-Ames Research Center

DESIGN REQUIREMENTS

The oscillating spanned airfoil and test section were designed to meet the following specifications:

1. Variable angular displacement of oscillation with maximum adjustment of oscillation of 10 degrees, with specific indexing at 0, 2, 5, and 10 degrees, but with intermediate positioning capability

2. Mean angle-of-attack position of the airfoil to be adjustable from 0 to 15 degrees in 5 degree increments, with intermediate positioning capability

3. Angle-of-attack accuracy within 0.1 degrees

4. Motion of the airfoil to be simple harmonic within 10% and to have variable driving frequency up to 100 hertz

5. Viewing of the airflow around the airfoil to be unobstructed through windows near the wing

6. Maximum flow velocity of Mach 0.5

7. Airfoil NACA 0012, 7.62 cm (3in.)

8. Test section having a cross section of 25 by 35 cm

DESIGN

After studying several concepts, it was decided that a four-bar type mechanism was the optimum drive for the airfoil (Figure 3). This type of mechanism offered good load transfer, accurate positioning and produced simple harmonic motion within 3% of the ideal. It was necessary to have duplicate drives on both ends of the airfoil, since the wing has poor torsional stiffness and large relative masses at the ends.

The primary difficulty in design was to meet adequate structural integrity at 100 hertz and properly transfer loads to glass windows. Other difficulties were the geometric constraints imposed by the airfoil limiting the size of wing support.

The final wing design is of solid aluminum construction. It is simply supported at the ends to reduce the contact stress in the glass by transferring only concentrated loads to the center of glass plates. It is spanned between the tunnel walls as shown in Figure 4. The airfoil used is a NACA 0012 with the wing having a 7.62 cm (3 in.) cord and a span of 25 cm. When the window is driven at the maximum frequency of 100 hertz, peak angular velocity is 110 rad/s (1047 rpm) corresponding to a maximum angular acceleration of 68,800 rad/sec^2. The maximum aerodynamic loads on the NACA 0012 airfoil occur at an angle-of-attack of 25 degrees, driving frequency of 100 hertz and flow velocity of Mach 0.5. The load magnitude compared to a statically fixed wing is 2.5 times greater in lift and 5 times greater in pitching moment. For the load case where the tunnel is off, the amplitude of oscillating torque acting on wing is 10.9 Nm (96.7 in-lbs). Aerodynamic loading of the airfoil reaches a distributed lift of 681 N (13 lbs.), a drag of 307 N (69 lbs.), and a pitching moment of 10.2 Nm (91 in-lbs.) which tends to rotate the leading edge downward. This aerodynamic load combined with the inertia load of the airfoil is transferred through pinned supports at the ends of the wing. The ends of the wing are supported through tapered pins with spherical ends fabricated from 18% nickel maraging steel. The design of the pins is based upon the requirement to transfer concentrated loads to the center of the glass plate without bending. The pins are located at 30% and 70% of the cord and have maximum diameters of 5.89 mm and 4.24 mm, respectively. The loads are transfered to cylindrical inserts which slip fit into holes in the glass windows. The inserts are split along the diameter and held together by a band and a soft plastic tip (Fig. 5). At 100 Hertz and Mach 0.5, the peak dynamic loads are 356 N (80 lbs.) on the large pin and 160 N (36 lbs.) on the small pin.

The wing is supported at both ends by 15.2 cm (6 in.) diameter, 2.54 cm (1 in.) thick, optical scheliern windows that oscillate with the wing. This configuration was necessary to meet the requirement of unobstructed viewing of the airflow around the airfoil. Support of the windows is achieved through a circular magnesium frame mounted in the tunnel wall on radial contact and four-point contact bearings. The material used is borosilicate glass (BK-7), which has a breaking stress of about 34 MPa in tension and ultimate compressive strength of 593 MPa in contact with hardened steel. This design is based upon the relationships developed by Hertz, for cylindrical elastic bodies in contact, which predict that all principal stresses are compressive. In the cord direction, positioning of holes was chosen to minimize contact stresses. The hole size was restricted by the design requirement of using an airfoil NACA 0012 with a 7.62 cm. (3in.) cord. It was necessary to go to a D-shaped window to provide adequate edge distance at the driving pin locations. Transferring loads to the glass plate presented an interesting design problem because brittle materials do not behave as well under stress as do ductile materials. The strength of glass in compression is much greater than in tension. Consequently, the design was developed to take advantage of this property. Verification of the structural integrity and optical quality of the windows has been tested by applying the maximum dynamic loads statically.

A flywheel was incorporated in the design to store kinetic energy through each cycle and keep speed fluctuations to less than 1%. Mounted flush with the face of the flywheel is an eccentric disk for adjusting the amplitude of oscillation. The disk is clamped to the flywheel by a ring clamp to allow for infinite positioning of the wing amplitude from 0 to 10 degrees. Both eccentric disks are coupled by a smaller tubular shaft within the flywheel shaft as shown in Figure 6. This will produce equal amplitude adjustments on both sides of the tunnel. An axial hole in the shaft is symmetrically placed to balance the shaft for the eccentric disk coupling. From the inertia loads of the oscillating window and frame, peak dynamic loads of 6672 N (1500 lbs) act on the disk drive pin. The drive disk can be positioned for wing amplitudes with infinite adjustment between 0 to 10 degrees with indexed positions of 2, 5 and 10 degrees.

Adjustment of the airfoil mean angle-of-attack position prior to a test run is accomplished by rotation of the entire drive mechanism about the window bearing retainer (Figure 7). Side plates supporting the flywheel assembly on both sides of tunnel are capable of positioning the wing mean angle of attack continuously from 0 to 15 degrees, with specific angular indexing at 5 degree increments within this range. The side plate is centered through contact with the outer cylindrical surface of the window bearing retainer, which is fixed to the test section side wall. This will produce rotations about an axis which is coaxial with the window axis. The advantage of this method of changing the wing's mean position is that the movement is uncoupled with changes in amplitude of oscillation. Other design studies were conducted on a concept where mean angle-of-attack was achieved by translating the flywheel shaft vertically. This presented problems with changes occuring in amplitude of oscillation with a change in the mean over the range of 0 to 15 degrees.

The wing oscillation drive motion is provided by a DC servo motor with tach feedback which ensures minimum frequency drift. The support of the DC motor is centered at one end with the flywheel axis in order to maintain the same belt drive pulley centerline distance with a mean airfoil angle-of-attack adjustment. The opposite side of the support translates in elongated slotted brackets at the top of the test section.

INSTRUMENTATION

The tunnel is instrumented to provide airfoil amplitude of oscillation, mean angle-of-attack and driving frequency. Actual position of the airfoil is obtained through optical incremental encoders which are coupled through gears at the window frame and mean angle-of-attack indexing plate.

The mean angle-of-attack encoder is coupled through gears to the tunnel side plates. This encoder provides digital output of mean airfoil position and measures this statically during test setup. Measurement of amplitude of oscillation is achieved through another optical position encoder, gear-coupled to the window with a gear segment and pinion gear. With a coupling ratio of 10.8 to 1 and a resolution of 1024 counts per turn, a resolution of 31 counts per window degree is achieved. The encoder experiences a maximum angular acceleration of 743,000 rad/sec^2 when the driving frequency is 100 Hertz. Driving the encoder from one window frame produces unsymmetric loading of the mechanism. To minimize the loads transfered to the pinion, the gear diameter and tooth face width was kept small, using a steel with a high specific strength. This results in a peak tooth loading of 356 N (80 lbs.) at 100 Hertz.

Flow measurements will be made by a number of sophisticated optical techniques including laser velocimetry, strobic color schlieren and holographic interferometry.

PROJECT STATUS

The osillating wing drive mechanism and test section have been fabricated and will be integrated into the Fluid Mechanics Laboratory at Ames in early 1988. Testing is currently being conducted to verify the structural integrity and proper functioning of the drive. The development of this test section will benefit aerodynamic prediction for helicopters and aeroelastic response on wings by making important contributions to the study of dynamic stall.

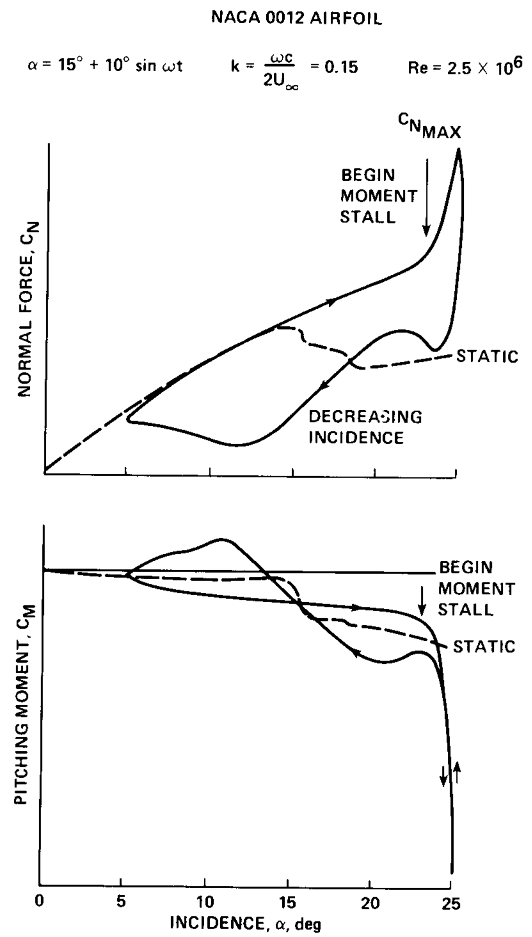

Fig. 1. Typical static and dynamic variation of normal force and pitching moment as function of angle-of-incidence.

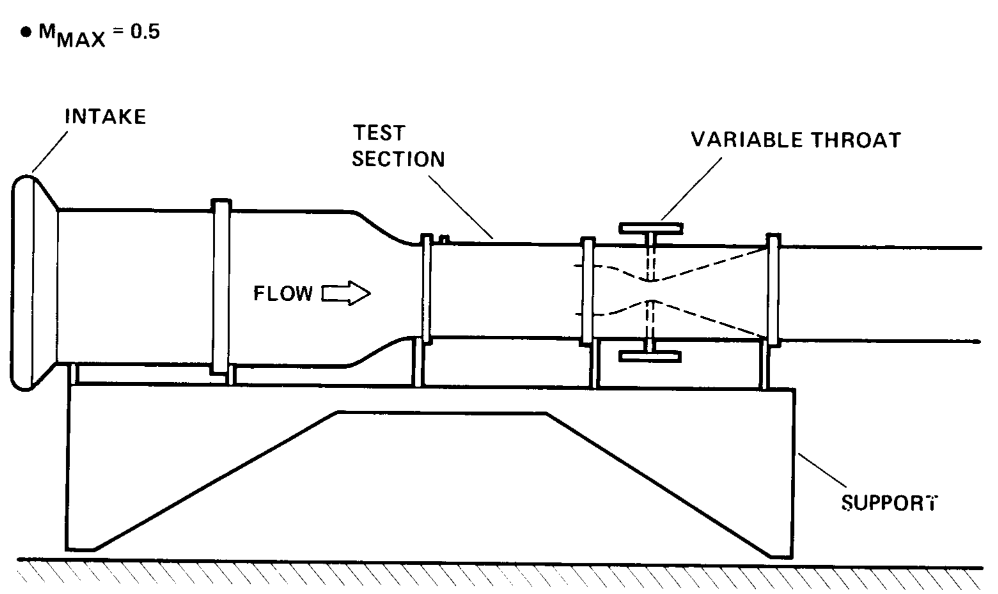

Fig. 2. Test section installation at fluid mechanics laboratory.

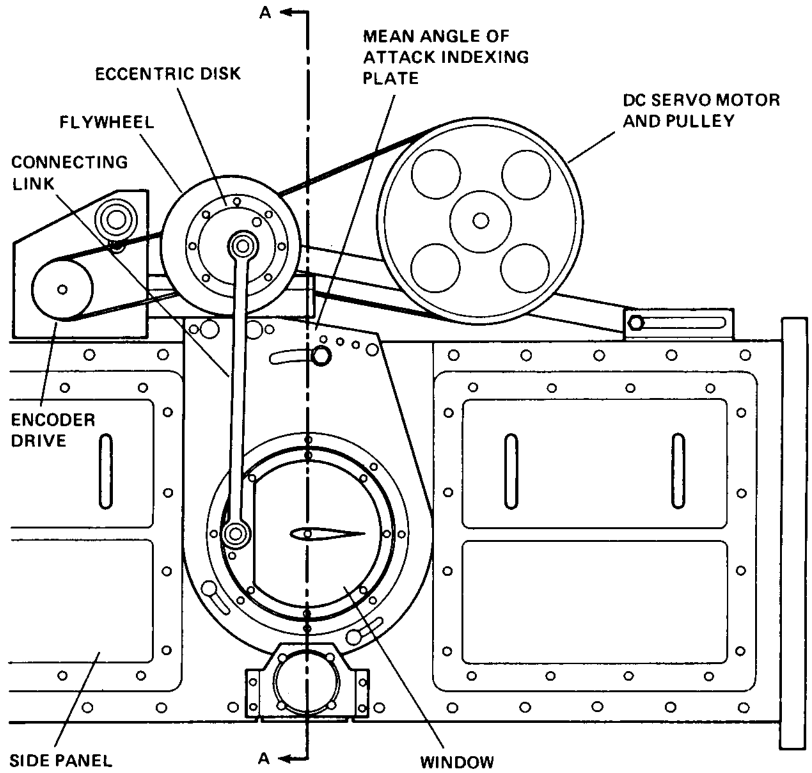

Fig. 3. Test section side view.

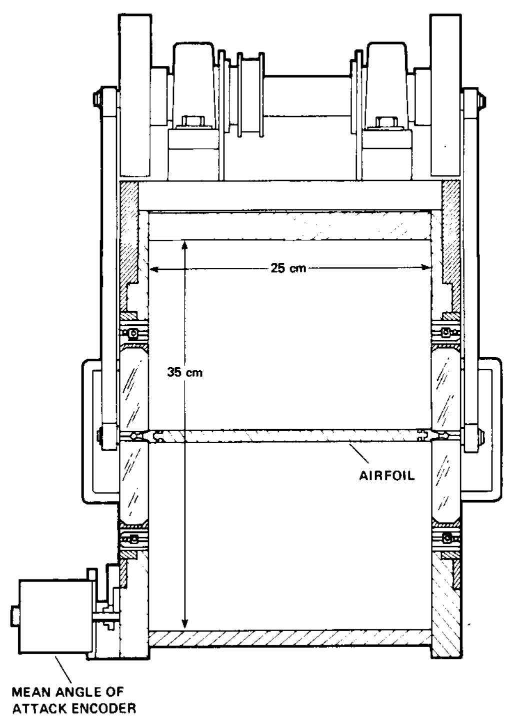

Fig. 4. Upstream view.

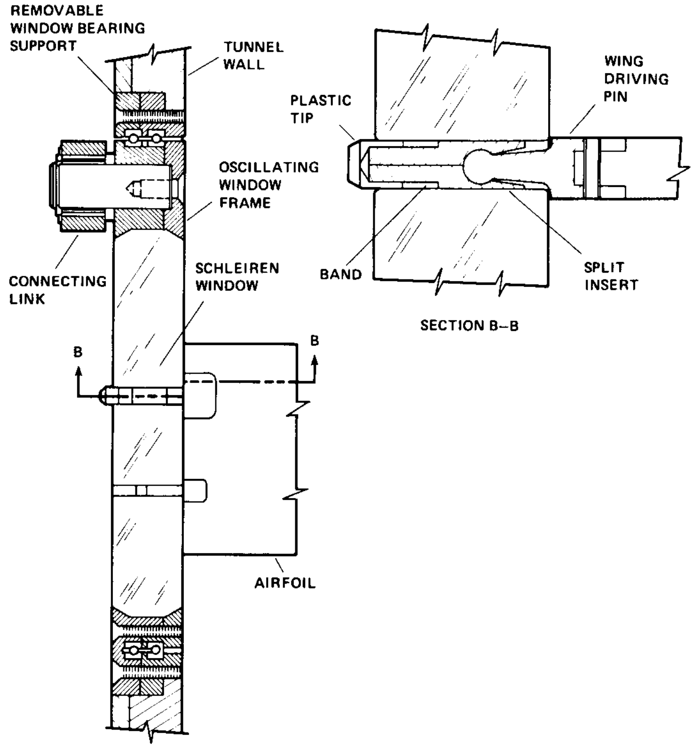

Fig. 5. Airfoil support at window.

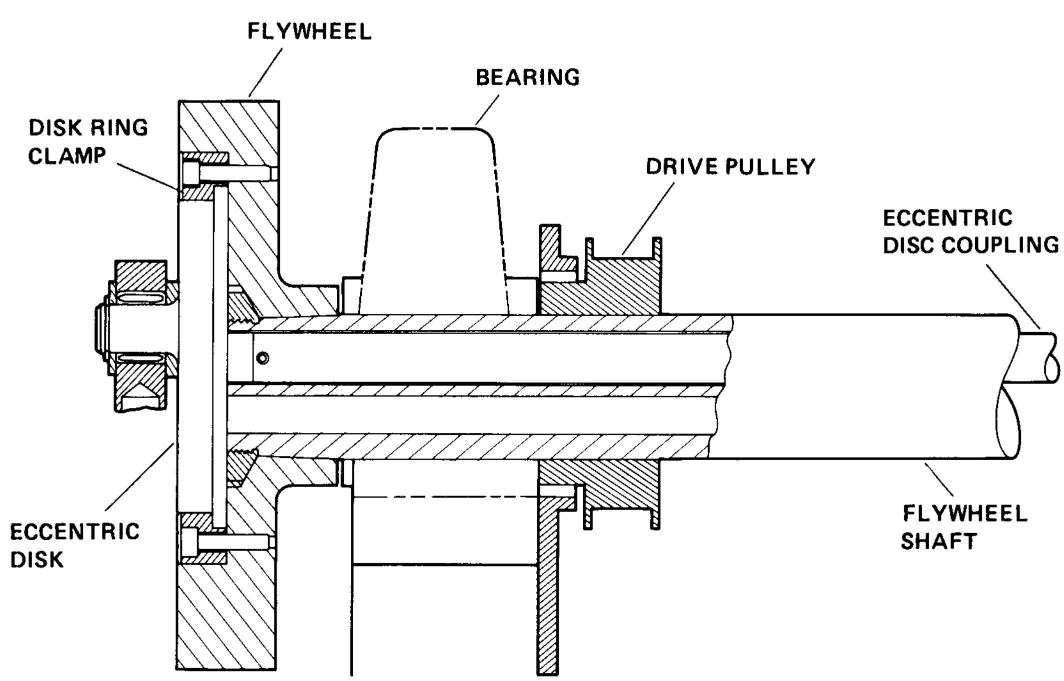

Fig. 6. Flywheel shaft assembly.

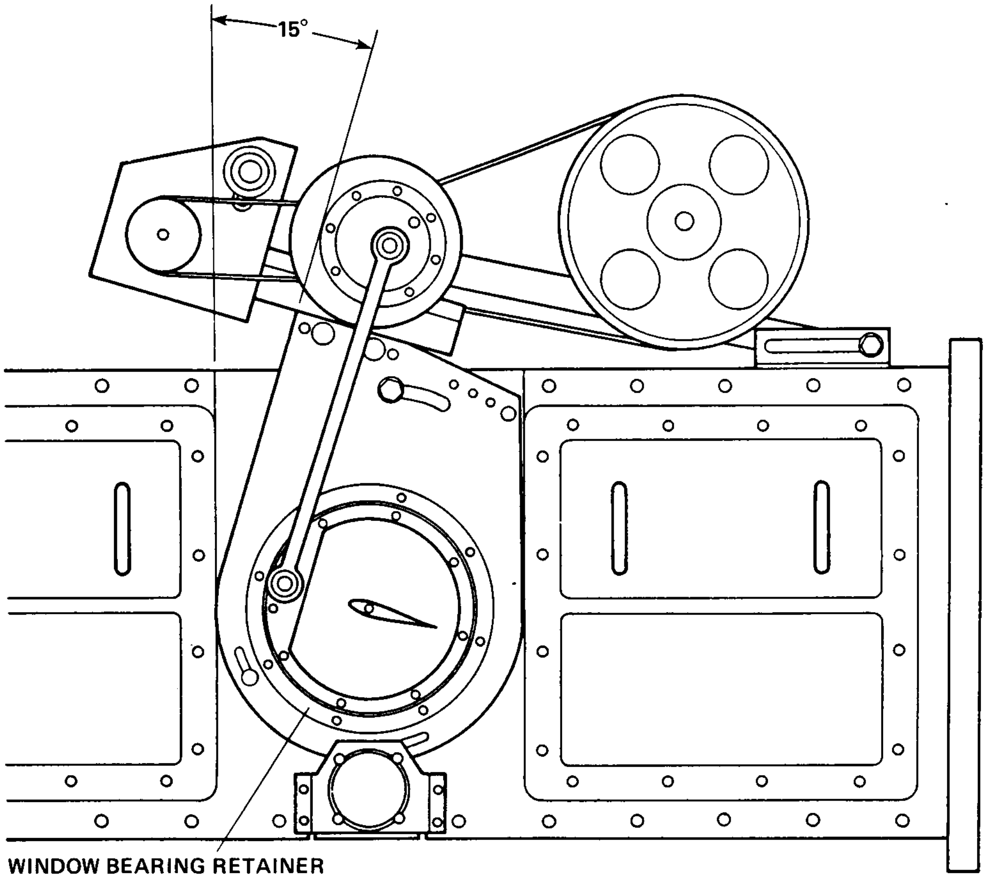

Fig. 7. 15 degree mean angle-of-attack position.