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TWO-DIMENSIONAL OSCILLATING AIRFOIL TEST APPARATUS

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ABSTRACT

A Two-Dimensional Oscillating Airfoil Test Apparatus is presented as a method of measuring unsteady aerodynamic forces on an airfoil or rotor blade section. The oscillating airfoil test rig, which is being built for use in NASA Ames Research Center's 11x11-foot Transonic Wind Tunnel (speed range M = 0.4 - 1.4), will allow determination of unsteady loadings and detailed pressure distributions on representative airfoil sections undergoing simulated pitching and flapping motions. This paper will present the design details of the motion generating system and supporting structure. This apparatus is now in the construction phase.

INTRODUCTION

Experimental unsteady aerodynamic data are urgently needed to validate and guide computational aerodynamics research in process at Ames, Langley, and the Air Force Flight Dynamics Laboratory. Data obtained with this apparatus will be compared with theoretical work concerning boundary layer effects on aileron flutter. Boundary layer effects are a major reason for the large uncertainty and consequent weight penalty associated with current predictions of control surface or flap flutter at transonic speeds.

A helicopter blade in forward flight is subjected to wide variety of unsteady loads due to aerodynamic effects. The effects of cyclic pitch, flapping motions, and the asymmetry caused by advancing and retreating blades all contribute to unsteady aerodynamic loads. The unsteady flow is extremely complex because the speed regime may change from subsonic through transonic to supersonic in one revolution. The importance of predicting these forces becomes especially important at high forward speed where transonic effects on stability and flutter margins degrade performance. A rational theoretical study for unsteady aerodynamics is extremely complex; therefore, a concerted effort was directed by Ames Research Center into the design of a Two-Dimensional Oscillating Airfoil Test Apparatus. The test apparatus was especially designed to apply programmed pitching and heaving motions to the test airfoil so that different simulated blade systems could be included in the test program.

BASIC OPERATION

The Two-Dimensional Oscillating Airfoil Test Apparatus (see Figure 1) will oscillate a 20-inch (0.51 meter) chord, 54-inch (1.37 meter) span airfoil in

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Ames' 11x11-foot Transonic Wind Tunnel at frequencies from 0 to 60 HZ. The test objective will be to oscillate the airfoil at pitch angles to $\pm$ 2° of rotation about any point along the chord and also to vertically displace the airfoil up to $\pm$ 2-inches. The mean angle of attack of the airfoil will be variable over the range of -5° to +15°. Before each test, wedge blocks are manually installed between the top flexure and wing to obtain the desired angle of attack. See Figure 3.

The oscillating motions are produced by motion generators which are hydraulic actuators with push-pull rods connected to the airfoil. Two pairs of high performance servo-controlled linear-hydraulic actuators induce the motion. One pair of actuators is for driving the leading edge and the other pair for driving the trailing edge of the airfoil. Actuator cross-coupling is provided by the lightweight airfoil structure. The actuators contain two pistons on a common rod for the dynamic and static loads. Each actuator drives identical graphite-epoxy push rods and flexure bearings which attach to the four corners of the test airfoil.

TEST APPARATUS

Motion Generators

The servo-hydraulic actuator package was designed and built by M.T.S. System Corp. (Minneapolis, Minnesota) to Ames' specifications and will be driven by two 150 HP units rated at 65 GPM and 3000 PSI. Each actuator consists of two separate pistons on a single rod enclosed in a dual chamber cylinder as shown in Figure 2. The upper piston is used for generating dynamic forces. The lower section is for load biasing. The load bias system is used to support the constant aerodynamic load thereby reducing the size and power required for the dynamic cylinder. The load biasing circuit includes an accumulator to maintain a constant load bias force along with differential control. This load biasing section is controlled by a servo-valve system with a resonance frequency below 0.5 HZ. This system allows slow dynamic movement yet maintains static preload. As static bias requirements change, the servo-valve ports oil into the appropriate end of the cylinder. This essentially changes the accumulator (nitrogen precharge) and adjusts the static force output.

A velocity and position transducer are mounted in the center of the actuator. They combine into a single physical unit with coils and cores in line axially for placement within the hollow actuator rod.

The displacement or dynamic section is controlled by a high performance servo-valve coupled through a manifold into the cylinder. The valve spool lap is adjusted to achieve flow linearity of better than $\pm$ 2% to 35 GPM. The manifold houses adjustable cross-port relief valves. To keep the breakaway friction below 8 pounds force, controlled leakage clearance fits and labyrinth grooves are used on both piston and end caps.

A hydraulic service manifold between the power unit and servo-actuator provides hydraulic filtration and suppresses line pressure fluctuation in the high electrohydraulic actuator supply and return lines. This service manifold also houses safety features which include provisions for automatic low pressure shutdown and solenoid valves to relieve all system pressure.

The wing is mounted to push-pull rods through flexure bearings. The airfoil is a lightweight graphite-epoxy structure designed to withstand a 230 G acceleration and a 10,000 pound aerodynamic load. See Figure 3. Extensive development in the fields of engineering, fabrication techniques, and testing was performed at the Ames Research Center in order to obtain an acceptable graphite-epoxy structure of various configurations. The first natural bending frequency is above 100 HZ and the first torsional mode is above 60 HZ. Forty (40) dynamic pressure transducers and forty (40) static pressure taps are imbedded in the skin of the airfoil. Samples laminated like the final airfoil design had the following properties: an ultimate tensile stress of 130 KSI (8.96×10^8 N/M^2), a modulus of elasticity of 14×10^6 PSI (9.65×10^{10} N/M^2), and a density of 0.6 LBM/IN^3 (1.66×10^4 KG/M^3).

Support Structure

Included in the test apparatus are splitter plates with trailing edge flaps and side struts. The splitter plates are a practical method of supporting the two-dimensional model wing in the test section without extensive modification to the wind tunnel test section. All instrumentation in the model wing is funneled down through the central part of the splitter plate. Approximately 130 static pressure orifices are imbedded in the surface of the splitter chordwise and exit through the top of the splitter plate. Also, the splitter plate serves as a mount for the drag link and stabilizes the model wing in the lateral direction.

Trailing edge flaps were incorporated to adjust the pressure gradient in the channel between the splitters. Adjustments of the flaps are continuous, as opposed to discrete, and are remotely controlled. Angles between $\pm$ 5 degrees can be obtained about the center line of the flap.

The side strut is a supporting member to stabilize the splitter plates and to eliminate excessive deflection in the lateral direction due to aerodynamic loads imposed on the splitter plates (See Figure 1). The side struts are fastened to the splitter plates and protrude through the tunnel wall to the exterior tunnel structure.

PRETEST SETUP

A dynamic test will be conducted on the motion generators before installation into the 11-foot wind tunnel. All of these component designs are pushing the state-of-the-art and no previous test information is available to judge their worthiness when used in combination. Figure 4 illustrates the test setup. The test will determine what performance levels can be expected from the hydraulic system, the push-pull rods, the flexures, and the wing. The model will be preloaded by an underside airbag. The model wing will be oscillated vertically, causing a fluctuation in surface loading. In addition, the effect of the cyclic loading on the flexures and push-pull rods will be determined.

CONCLUDING REMARKS

The Two-Dimensional Test Apparatus was designed to apply programmed pitching and heaving motions to the test airfoil so that various applications to blade systems can be included in the test program. The results of these tests will be used as input parameters for the dynamic analysis of existing rotorcraft and for checking numerical and analytical schemes for advanced rotors. This paper has described an oscillating mechanism for wind tunnel studies which should provide the motions necessary for generating this aerodynamic data.

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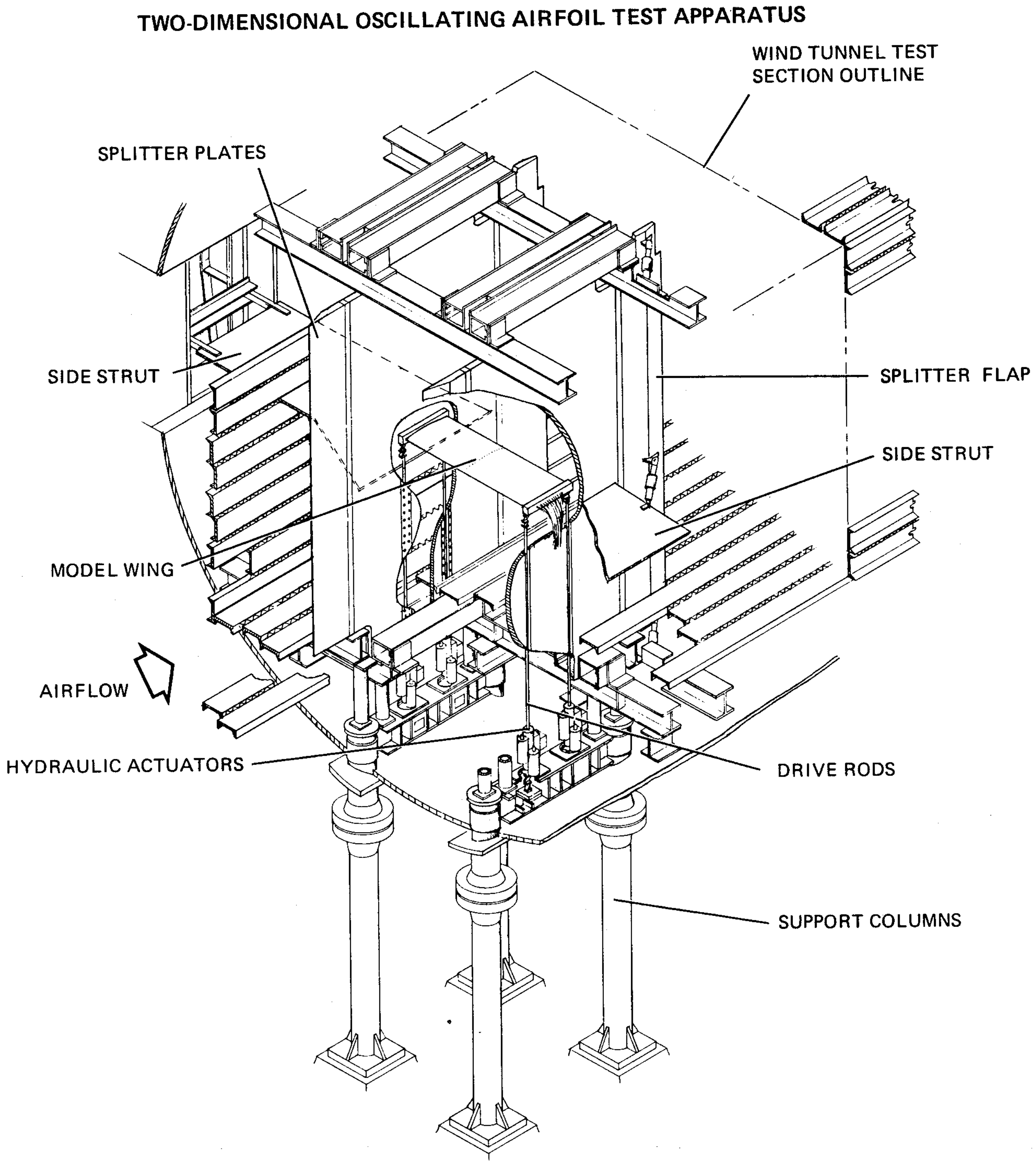

Figure 1 WIND TUNNEL INSTALLATION OF TWO DIMENSIONAL OSCILLATING WING TEST APPARATUS

TWO-DIMENSIONAL OSCILLATING AIRFOIL TEST APPARATUS

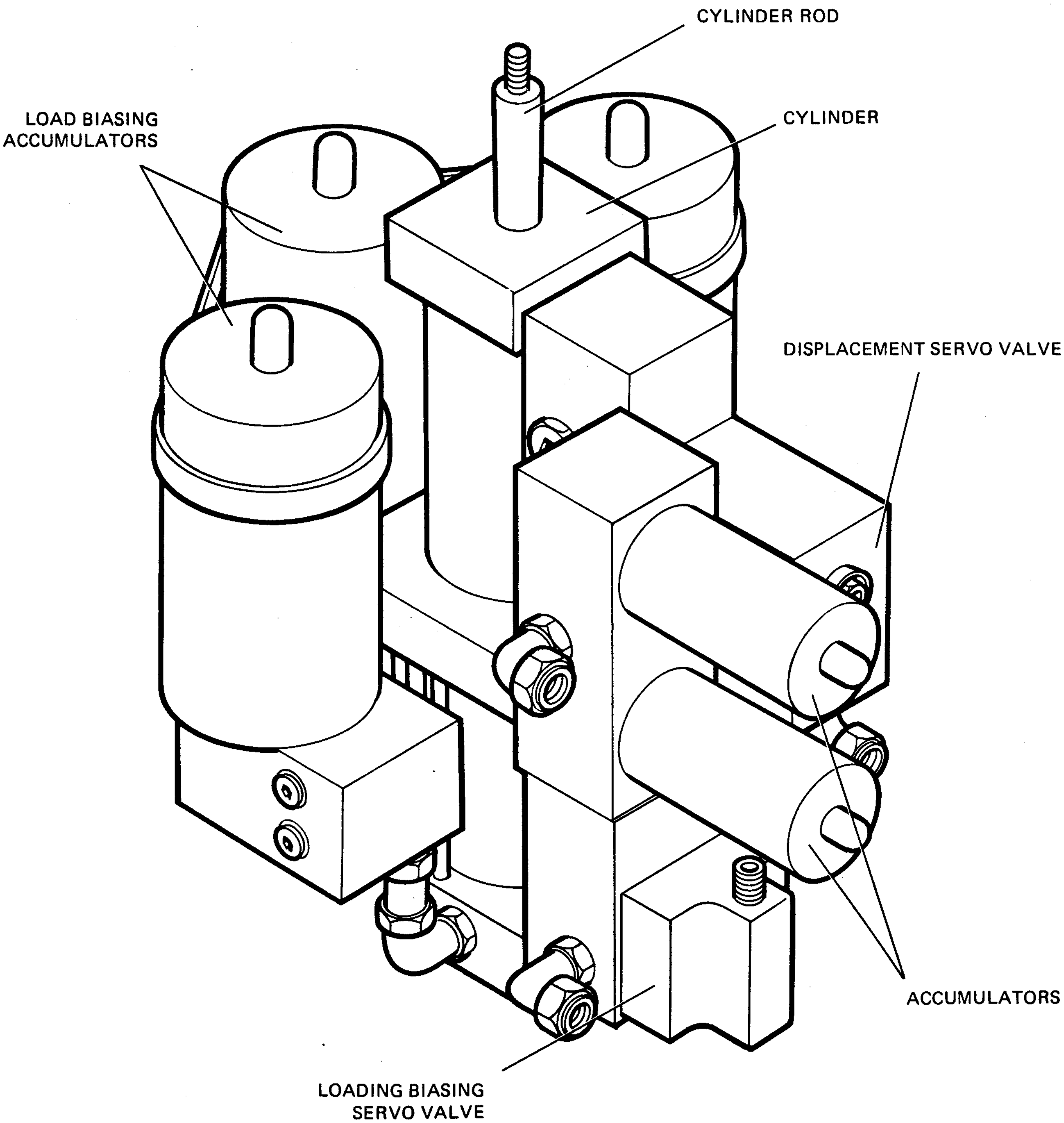

Figure 2 HYDRAULIC ACTUATOR

TWO-DIMENSIONAL OSCILLATING AIRFOIL TEST APPARATUS

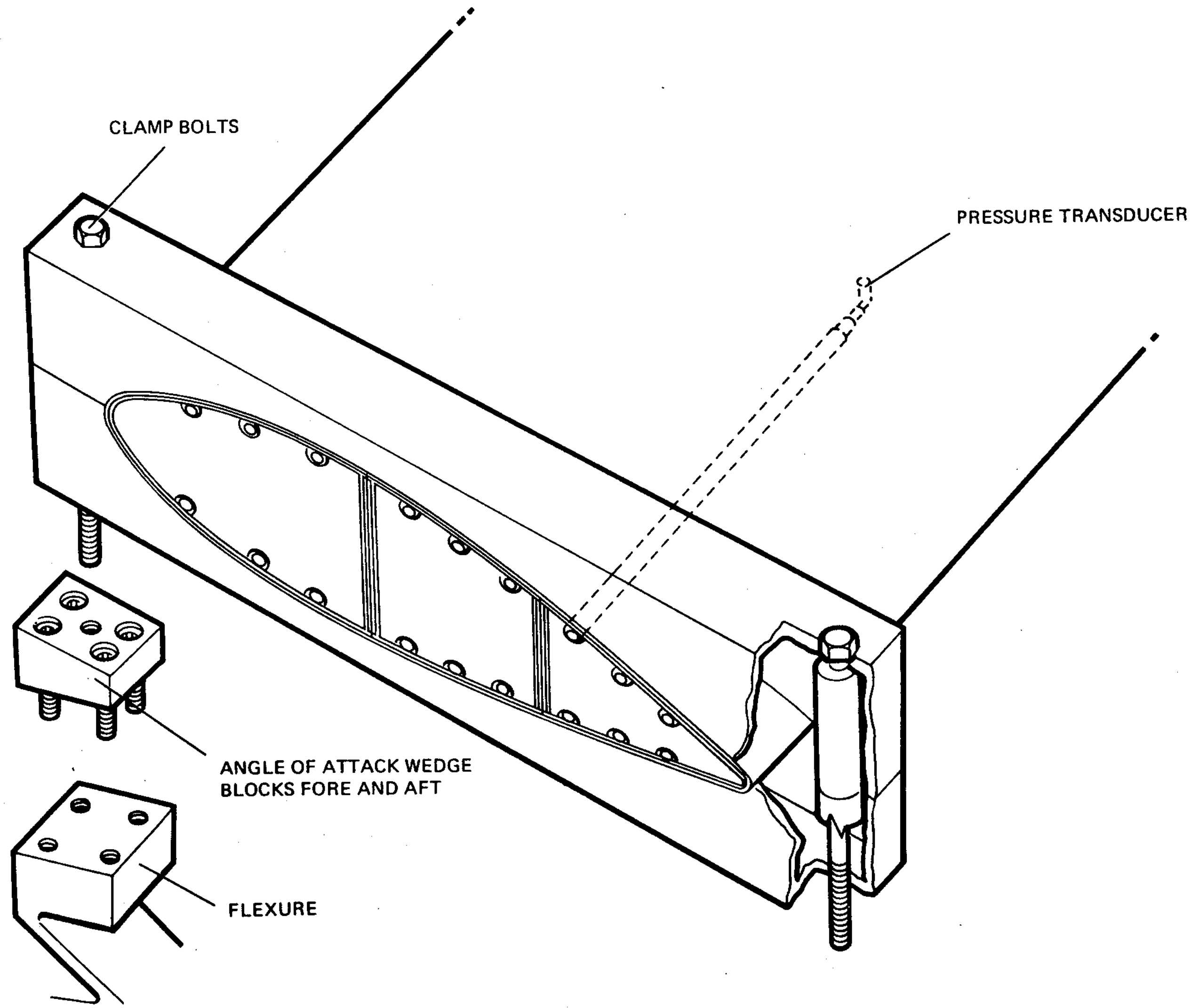

Figure 3 MODEL WING

TWO-DIMENSIONAL OSCILLATING AIRFOIL TEST APPARATUS

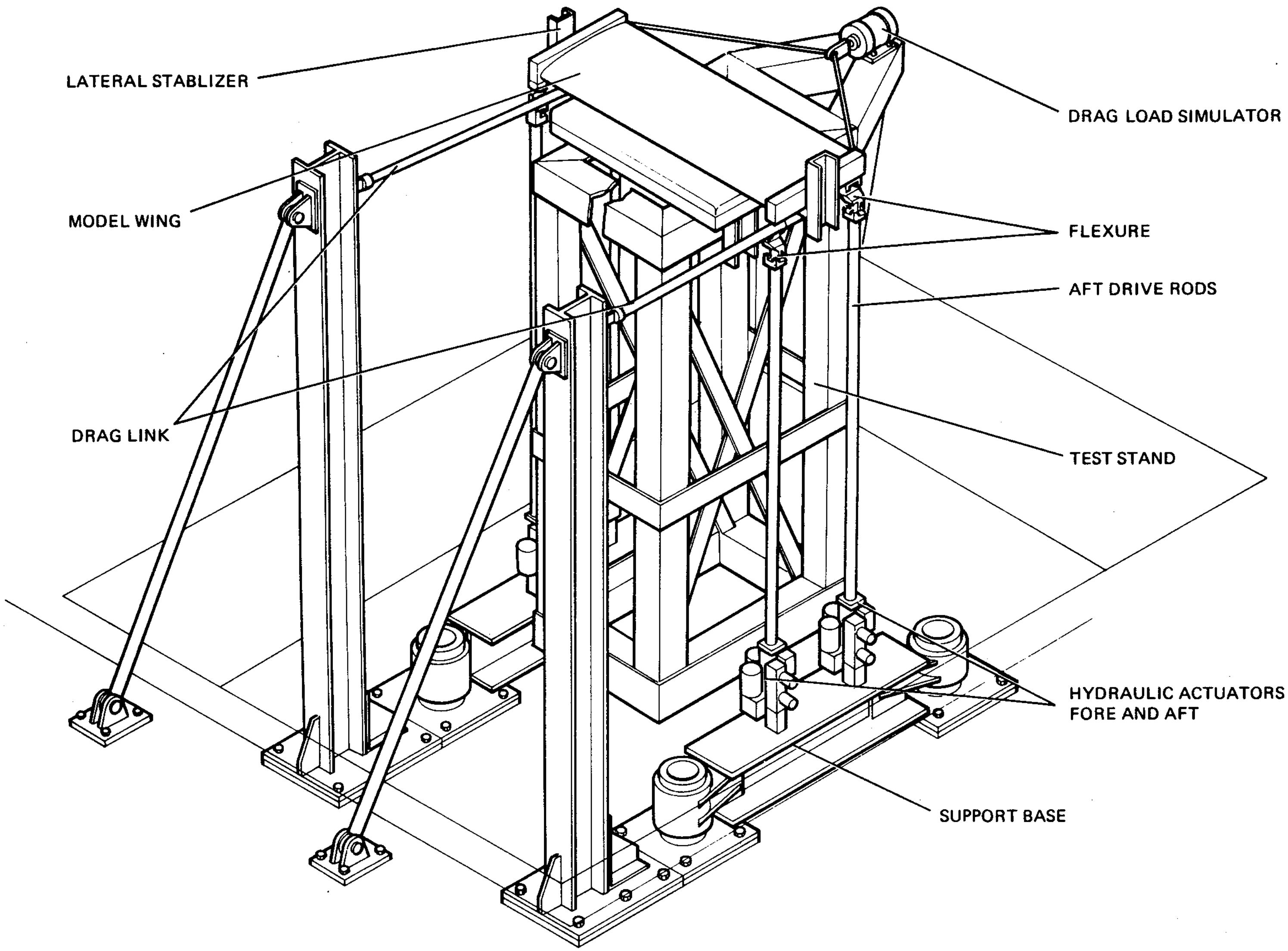

Figure 4 DYNAMIC TEST STAND