NOTES ON FLUTTER INVESTIGATION OF REPUBLIC
F-105 TAIL SURFACES IN THE NACA 26-INCH
TRANSONIC BLOWDOWN TUNNEL

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Background

The late 1940's and early 1950's marked the entry of fighter-type aircraft into the realm of transonic/supersonic speeds. A bewildering array of new problems faced the designer of aircraft intended to penetrate this once forbidden range of flight. Among the problems posed was the necessity for the accurate analysis and prediction of the flutter speed of various components of the aircraft. State-of-the art flutter [redacted] prediction methods at that time usually made use of two-dimensional subsonic aerodynamic coefficients , perhaps with a high-subsonic-speed compressibility correction, in a strip type analysis. Unfortunately, the performance requirements of new fighter-type aircraft dictated the use of thin, low aspect ratio wings and tail surfaces. Two-dimensional aerodynamic coefficients were thus suspect even at low speeds, and in the transonic range, were assumed to be completely unreliable. No applicable transonic theory was available. Yet, the thin, flexable wing and tail surfaces operating at high speeds and dynamic pressures presented more of a flutter threat than had been encountered in previous aircraft design experience.

In an effort to provide some guidance to designers, a number of experimental studies of flutter at tansonic speeds were made with the use of the rocket propelled and free-fall model techneques. Although useful, these methods were too expensive and time-consuming to permit any systematic study of flutter at transonic speeds, or to permit the type of fine-tunning necessary in the study of a specific aircraft design. Further, the large new slotted-throat transonic tunnels, such as the Langley 8 ft and 16 ft tunnels, were not really suited for flutter studies.

The Langley 26-inch Transonic Blowdown Tunnel(TBT)

The Langley TBT, put into operation in about 1950, proved to be ideally suited for expermintal studies of flutter at transonic speeds. Designed especially for the investigation of the effects of variations in the Reynolds number on the aerodynamic characteristics of wings and bodies at transonic speeds, the airstream density could be rapidly varied at a number of fixed Mach numbers in the range from about 0.8 to 1.4. Test section Mach number was set by choking of an orfice plate located in the diffuser downstream of the test section; once the plate was choked, test section density could be varied independently of the Mach number by changing the setteling chamber stagnation pressure. High pressure air for operation of the TBT was stored in the Low Turbulence Pressure Tunnel and was supplied to the TBT through three very precise quick-acting valves. The TBT could be operated at stagnation pressures from about 25 to 90 psi. Maximum stagnation pressure in the Low Turbulence Pressure Tunnel was 150 psi; the difference between this pressure and the stagnation pressure in the TBT determined the maximum run time. Runs in the range from 10 t0 20 seconds were usual in flutter studies(destruction of the model frequently determined the end of the run). Orfice plates of different diameter were provided for different test section Mach numbers. An exterior view of the TBT is shown in figure 1, and one of the orfice plates is illustrated in figure 2.

Although designed for aerodynamic studies, the ability to fix the Mach number and independently vary the airstream density was precisely the desired formula for transonic flutter studies. Classical flutter theory shows the density and velocity to be independent variables, however, in most pratical cases, onset of flutter occurs at a constant value of dynamic pressure at low subsonic speeds. At transonic speeds, the value of the dynamic pressure corresponding to the beginning of flutter varies with the Mach number. A sketch showing the variation of dynamic pressure with Mach number for several different size orfice plates is given in figure 3 for the TBT. Also shown is a hypothetical flutter boundary for a particular aircraft, along with the maximum dynamic pressure flight profile for which the aircraft was designed. In the 1950's, the Air Force required a minimum margin of 30-percent in dynamic pressure between the flight path profile and the flutter boundary lines at all Mach numbers. For flutter studies of an aircraft at a particular Mach number, the tunnel stagnation pressure was increased until flutter occurred. If the corresponding dynamic pressure at that Mach number was not at least 30-percent higher than the maximum value for which the aircraft was designed, then design changes were required. Typically, the critical Mach number corresponding to the minimum flutter margin lay in the Mach number range between 0.85 and 1.05.

Model Mounting and Construction

In all wind tunnel testing, the accuracy of the data deteriorates as the size of the test model increases in relation to the size of the tunnel. The transonic wind tunnel poses a particularly restricting limitation in respect to the relationship between model and tunnel size. For a body, wing-body, or complete airplane model, the bow shock from the nose reflects back on the model for a Mach number range which extends from just above Mach one to a value at which the reflected shock wave passes behind the aft end of the model. Data obtained in the Mach number range in which the reflected shock strikes the model are considered to be invalid because of interference effects which cannot be readily evaluated. The smaller the test model in relation to the minimum tunnel crossectional dimension, the smaller will be the range of inadmissable Mach number. For adequate simulation of dynamic and elastic properties, however, flutter model size should be as large as possible with respect to tunnel size. Mounting the test model on a long sting whose nose extended into the subsonic flow region of the entrance cone eliminated the bow shock reflection problem for flutter tests in the TBT and allowed the use of test models of 15 to 18-inches in span.

A drawing of the flutter test set-up employed in the NACA TBT, taken from a report published in 1955, is shown in figure 4. Complete three-dimensional wing and tail models could be accomodated with the set-up shown in figure 4; vertical fin and rudder models could be mounted on one side of the long 3-inch diameter sting. Fuselage degrees of freedom such as rolling, pitching and vertical translation could be provided by suitable use of springs, pivots and flex-mounts contained within the sting(the mechanical details of these systems could get very complicated). Fuselage aerodynamics were, of course, not simulated but this deficiency was thought to be relatively unimportant in model flutter studies.

The output of the strain gages shown on the wing model in figure 4 was both recorded and visually monitored.

The beginning of flutter was indicated by the onset of sustained oscillations of a constant frequency. Tunnel parameters were simultaneously recorded along with the output of the strain gages. High-speed motion picture photography was used to record the behavior of the model; the model was also observed visually, and in an attempt to save it from destruction, the tunnel was quickly shut down at the first indication of flutter(sometimes successfully).

The validity of flutter data obtained in the TBT utilizing the mounting system shown in figure 4 was substantiated in 1951 by comparative tests . Studies were made in the tunnel with models, appropriately scaled, similar to those for which flutter data had been obtained beyond Mach 1.0 by the free-fall drop-model technique. Agreement between results obtained from the two different test techniques was gratifyingly close. Following these comparative investigations, systematic studies of the effect of such wing planform variables as aspect ratio and sweepback angle on flutter in the Mach number range between 0.8 and 1.4 were undertaken in the TBT. The results of these studies began to appear in 1953. Shortly thereafter, the TBT was in great demand for investigations of the flutter characteristics of various aircraft and missile configurations.

The validity of wind tunnel flutter model test results is critically dependent upon achieving a faithful representation in the model of the pertinent elastic and dynamic characeristics of the full-scale aircraft. Both art and science play a roll in the proper design and construction of flutter models. A skillfull selection of the pertinent characteristics to model requires an in-depth understanding of possible flutter modes to be encountered. For the F-105 studies in the TBT, as well as for flutter studies of several other aircraft, the firm of Dynamic Devices Inc. of Dayton, Ohio designed and constructed the models. The firm was headed by Lee S. Wasserman who was a highly knowledgeable engineer with a firmly established reputation in the flutter fraternity. For many years he was associated with the Air Force at Wright Field(as a civilian) but left in the early 1950's to form Dynamic devices. In addition to providing the models, Lee himself had a seemingly inexhaustable supply of suggestions and proved to be a valuable asset in any discussion of flutter froblems.

Flutter Investigation of F-105 Tail surfaces

Analytical studies at Republic Aviation indicated the possibility of flutter on both the horizontal and vertical tail surfaces of the F-105 airplane. Because of the previously noted limitations of theoretical flutter analysis at that time, the Air Force requested that these surfaces be investigated in the TBT(The Air Force representative during the various F-105 flutter studies was Walter J. Mykytow of the Wright Air Development Center). Discussions were first held between representatives of NACA, Republic and the Air Force either in the Fall of 1953 or the early part of 1954. Primary contacts at Republic were Sam Pines, head of the dynamics group and his assistant, Logan T. Waterman. Involved at Langley were Laurence K. Loftin, Jr., Frank T. Abbott, Norman S. Land, and later Robert W. Boswinkle. Many others at Langley participated in the flutter study of the F-105 tail surfaces, but to a lesser extent.

Two models of the all-moving horizontal tail of the

F-105A aorplane were delivered to Langley on October 18, 1954. On December 27 of that year, one of these models fluttered to destruction within the scaled operating range of the aircraft(see enclosure A). The second model was lost early in January 1955. Obviously, the horizontal tail of the F-105A had a serious flutter problem.

New and improved flutter models were constructed by Dynamic Devices and tests with these models were begun in the late spring of 1955. Frustrating can best be used to describe the series of tests which took place at that time. The tail design parameters controlling the onset of flutter could not be clearly identified, and thus many proposed fixes were tried without success. Status of the investigation is summarized in enclosure B which reports on a trip made by the author to Republic on July 5 and 6, 1955. Included in enclosure B is a description of the all-moving tail of the F-105 airplane. The test models of the horizontal tail employed in the TBT faithfully simulated the various degrees of freedon described in enclosure B

Paragraph 3 of B indicates a number of proposed changes for increasing the dynamic pressure corresponding to the onset of flutter on the horizontal tail. According to enclosure C, the proposed changes cleared the tail of all flutter problems within the flight boundary of the F-105A airplane. Clearance of the airplane was of course gratifying. Yet, the exact nature of the problem was never clearly identified, and the solution represented something of a brute-force approach. No information is available on the resolution of the questions raised in paragraph 2 of enclosure C. Apparantly, they raised no serious problems.

Although the F-105A horizontal tail flutter problem was solved, the F-105B raised some additional questions. First, the F-105B was designed to operate at somewhat higher dynamic pressures than those for the F-105A; second, whereas the yoke connecting the two sides of the horizontal tail was rectangular in crossection on the A model, a yoke of circular crossection was used on the F-105B to reduce manufacturing costs. Tests were made in 1956 and 1957 which cleared the horizontal tail of the F-105B airplane.

The vertical tail surfaces of the F-105 airplane were conventional and consisted of a fixed fin to which was attached the rudder. Control of the rudder was accomplished by neans of an actuator located at its root, that is, at the bottom of the rudder. Flutter tests were made in the TBT during the week of September 25, 1955 showed the presence of two modes of buzz within the flight envelop of the airplane. Enclosure D summarizes these tests and some of the suggestions offered for solution of the problem. The ensuing investigation identified the problem and eventually led to a satisfactory solution of the problem. Contrary to early thinking, the buzz mode was found not to involve oscillation of the entire rudder about its axis of rotation, but rather, torsional vibration of the rudder surface itself. Thus, increasing the stiffness of the rudder actuating system was found to be completely ineffective as a meanns of flutter supression. Large increases in rudder stiffness were apparantly not feasible on the full-scale aircraft. The use of a viscous damper(there may have been more than one) connecting the rudder to the fin was found to solve the problem. The damper(s) had to be located between the root and tip of the rudder at carefully selected positions for maximum effectiveness. A great deal of trouble was encountered with the small model dampers, particularly in determining the actual value of the damping. Unfortunately, no information appears to be available on the actual operation of these dampers.

Final Comments

It should be emphisized that the flutter investigation of the tail surfaces of the F-105 airplane in the TBT was a joint undertaking between NACA, Republic Aviation and Dynamic Devices, with financial support by the Air Force. Although NACA was in control of the project, the direct participation of the other groups was absolutely essential to the successful completion of the project.

Finally, Republic was so impressed with the capability of the TBT, that they built an exact copy of the facility(from NACA supplied drawings) at Farmingdale. Grumman acquired the facility from Republic(so I was told) early in the 1960's when the fortunes of Republic were at a low point.

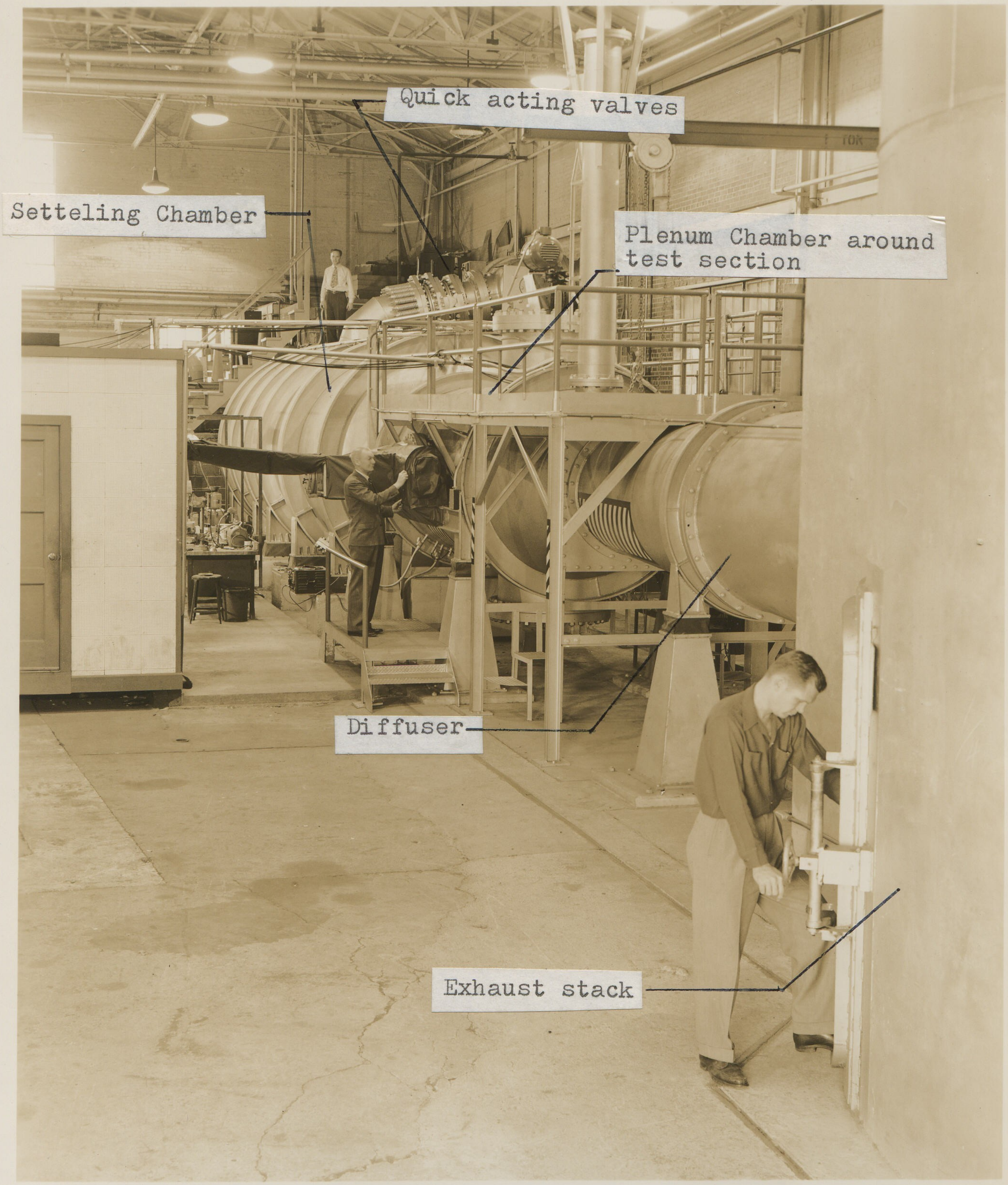

Figure 1.- Langley 26-Inch Transonic Blowdown Tunnel

NACA

LAL 73657

Figure 2.- Orfice plate used in Langley 26-Inch Transonic Blow-down tunnel.

NACA

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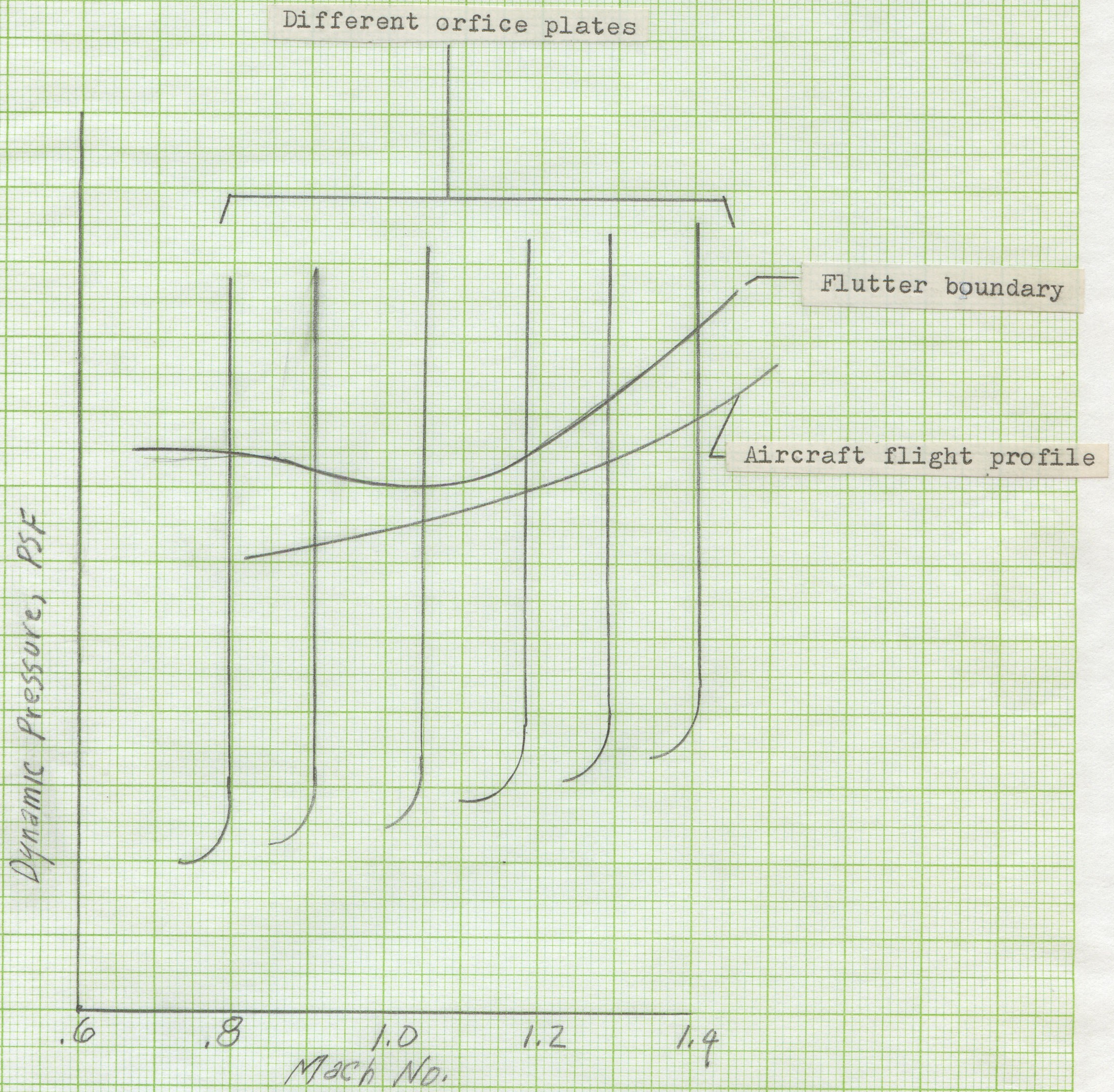

Figure 3.- Typical operating characteristics of Langley 26-inch Transonic Blowdown Tunnel.

Figure 4.- Node lines and frequencies in cycles per second. Model 14.

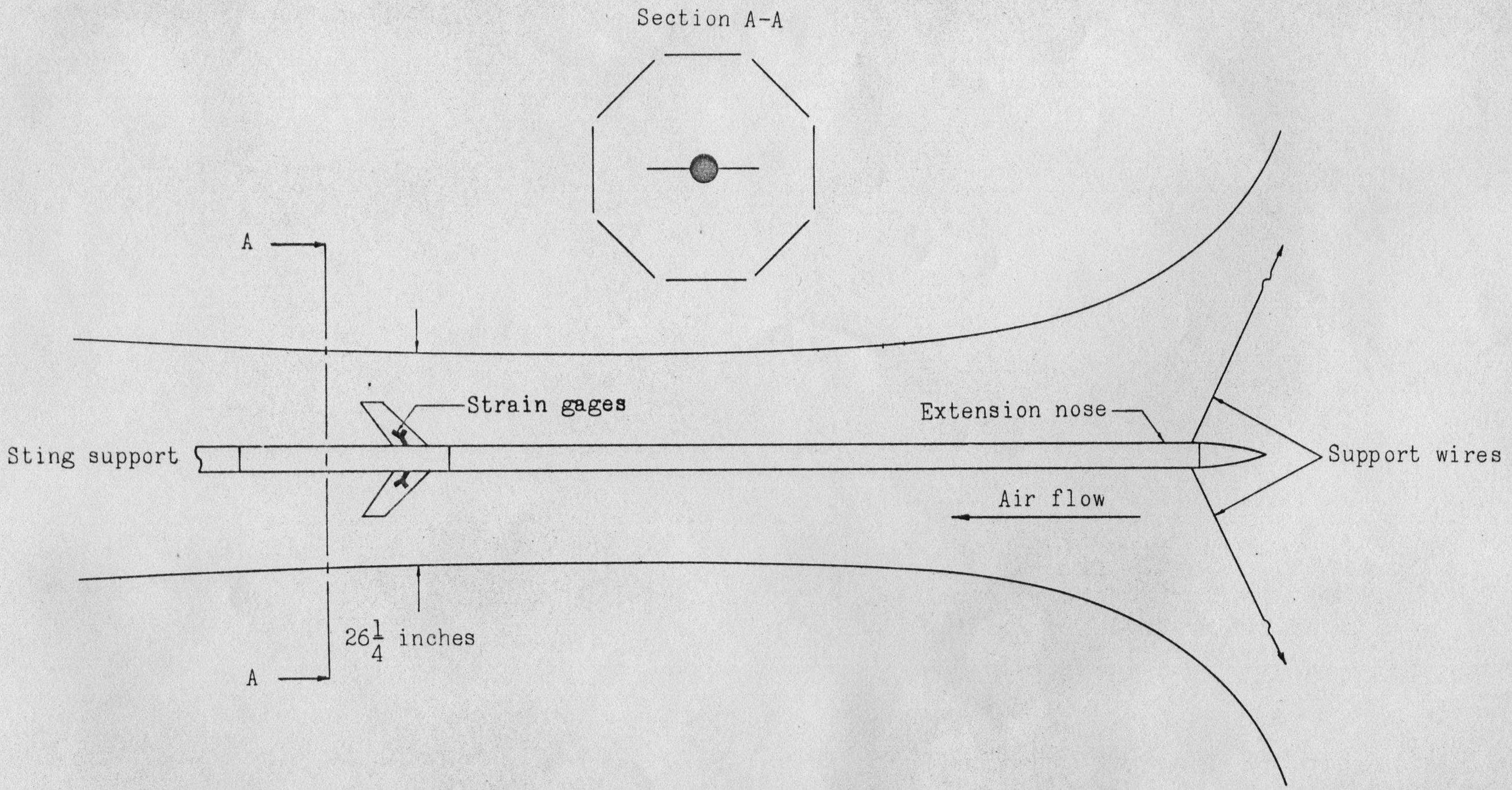

Figure 4 - Plan view of Langley transonic blowdown tunnel with flutter model installed.