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DYNAMIC CHARACTERISTICS OF A BENCHMARK MODELS PROGRAM SUPERCRITICAL WING

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Abstract

This paper presents the dynamic characteristics of the Benchmark Supercritical Wing. The Benchmark Supercritical Wing is a rigid semi-span model with a rectangular planform and a supercritical airfoil shape. This model will be tested on a flexible mount system, called the Pitch and Plunge Apparatus, that provides a well defined, two-degree-of-freedom dynamic system. This model/mount system is scheduled to be flutter tested in Langley Research Center's Transonic Dynamics Tunnel. The objective of the wind-tunnel test is to simultaneously gather flutter data and wing surface pressure data (both steady and unsteady) at two spanwise stations for use in analytical code development. This model is part of the Benchmark Models Program of the Structural Dynamics Division of NASA Langley Reasearch Center, which was initiated to facilitate the development and evaluation of aeroelastic CFD codes. The Benchmark Supercritical Wing is the second of a series of three similar models which will provide simultaneous flutter and pressure data for use in code evaluation. This paper defines the dynamic characteristics of the model/mount system as determined in a preliminary ground vibration test. A general description of the model, flexible mount system, and instrumentation are included as well as a summary of the data set which the testing of this model is intended to produce.

Nomenclature

c	length of model chord, in.
x	distance in model chordwise direction, in.
x/c	fractional chord length
y	distance in model spanwise direction, in.
z	distance perpendicular to model mean chord plane, in.

Introduction

A significant number of aircraft aeroelastic problems occur in the transonic speed range. Non-classical instabilities such as buffet, control surface buzz, limit cycle oscillations, and shock induced oscillations are encountered in the transonic regime. Classical flutter is of greatest concern at transonic Mach numbers as well. Aeroelastic analysis using computational fluid dynamics (CFD) codes holds promise for rational analysis of all these phenomena.[1] Currently, however, the assessment of CFD codes in the transonic region is far from complete, even for the classical flutter problem.

One handicap in the evaluation of CFD codes is the lack of well documented experimental data sets. Some of the investigations give only the flutter boundary defined in terms of the test conditions such as dynamic pressure and Mach number at flutter, sometimes even omitting the flutter frequency. Few of the flutter investigations provide quantitative details of the flow field at the flutter condition. Data sets such as these are useful as a guide for CFD code evaluation, but when analytical results do not correlate well there is often not enough information available to determine the source of the error.

Recognizing the difficulty of evaluating CFD codes in comparison with available experimental data sets, the Structural Dynamics Division of the NASA Langley Research Center has initiated the Benchmark Models Program (BMP). This wind-tunnel test program is tasked with investigating unsteady flow phenomena to facilitate the development and evaluation of computational aeroelastic codes.[2-5] One way in which

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the BMP is assisting in CFD code evaluation is by performing tests which produce combined flutter and unsteady pressures data sets. In order to provide this kind of data, the BMP is conducting flutter tests on a series of rigid, instrumented half-span models with a flexible mount. This flexible mounting system, called PAPA for Pitch And Plunge Apparatus, allows the rigid models to achieve classical flutter within a well-defined dynamic system. The Benchmark Supercritical Wing, described in this report, is the second in a series of three similar models which the BMP is testing in the Langley Transonic Dynamics Tunnel using the PAPA mount. All three models are rigid, rectangular wings with the same planform characteristics and with as close to identical wind-off dynamic characteristics as possible; but each will have a different airfoil shape. The first model tested in this series, the Benchmark NACA 0012 model, is described in reference 4. The third model, the Benchmark 64A010, is scheduled to be tested in 1993.

The purpose of this report is to provide a complete description of the model/PAPA mount system. Structural dynamic properties determined in a preliminary wind-off ground vibrations test are included. Emphasis will be on providing enough model characteristics to permit interested parties to begin generation of an analytical model in anticipation of the experimental aerodynamic and aeroelastic data base to follow.

Description of Model and Test Apparatus

Model

The Benchmark Supercritical Wing has a simple rectangular planform and an SC(2)0414 airfoil section. The model has a chord of 16 inches and a span of 32 inches giving it a panel aspect ratio of two. Beginning at the 32 inch span-station, the model terminates in a tip-of-revolution where the radius is equal to half the airfoil thickness at each position along the chord. Figure 1 presents a top-view sketch of the model.

Figure 2 shows an outline of the SC(2)0414 supercritical airfoil section. This section was selected from several airfoils described in reference 6. The "SC(2)" designation indicates it is part of the family of second generation supercritical airfoils, while the "0414" indicates that the airfoil section has a design lift coefficient of 0.4 and a maximum thickness of 14 percent of the chord. The lift coefficient and airfoil thickness characteristics of the airfoil section were selected from several possible variations based on the flexible PAPA mount load limits and the internal volume required for pressure measurement instrumentation. Design coordinates for this airfoil can be **found** in reference 6.

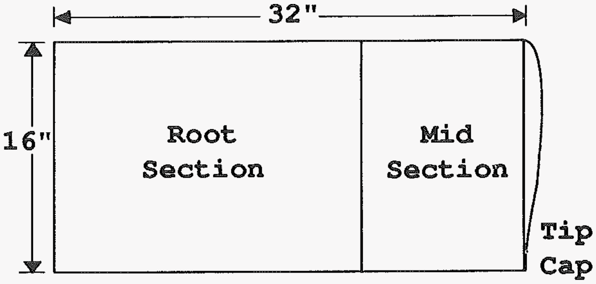


Figure 1. Planform Sketch of Model.

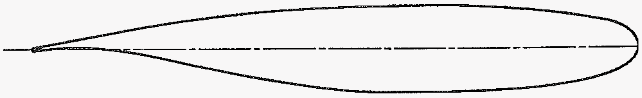


Figure 2. SC(2) 0414 Airfoil Section.

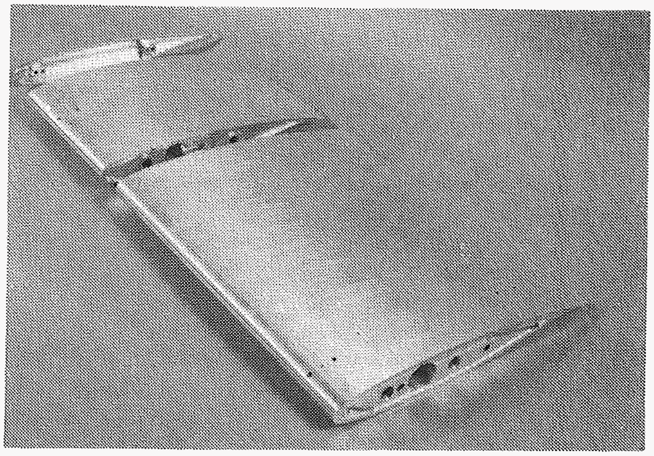


Figure 3. Photograph of Model Disassembled.

Figure 1 shows that the Benchmark Supercritical Wing is composed of three sections. A photograph of the model with the sections detached is presented in figure **3.** These sections, called the root section, mid section, and tip cap, were machined out of solid aluminum. The separation points of the model sections were selected to allow access for easy installation, repair, and removal of the in-situ pressure measurement instrumentation. To further facilitate access to instrumentation, the mid-section and tip cap unbolt from the tip end so that the instrumentation can be accessed with a minimum of delay and without removing the model from the PAPA mount system.

The tip cap is a hollowed out section 0.1 inches thick. It is attached to the mid-section with two small bolts each with an accompanying shear pin. The seam between the tip cap and mid-section is at the 31.8 inch span station, which is 0.2 inches inboard of the tip-of-revolution. When the tip cap is attached, the two small bolts are recessed below the surface of the tip-of-revolution and covered over with dental plaster to provide a smooth surface.

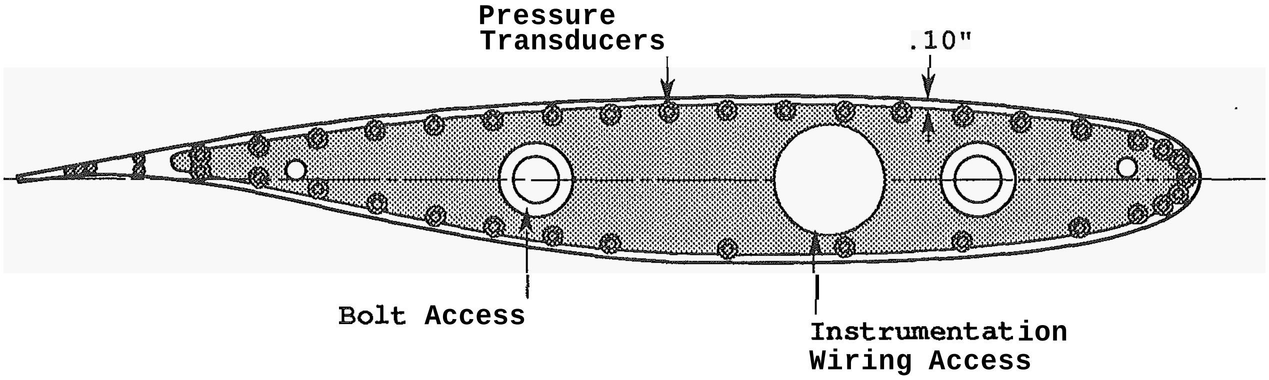


Figure 4. Sketch of Mid Section End-View.

The mid section and root section are solid aluminum with several access holes drilled into and through them. The inboard and outboard edges of these sections are recessed 0.15 inches, leaving a rim 0.1 inches thick. When the root and mid-sections are attached, a cavity is created to allow room for instrumentation wiring and reference pressure tubing. Figure 4 is a sketch representing the end-view of both the root and mid sections. The shaded area is the recessed instrumentation cavity.

Figure 4 also shows where the major access holes for both sections are located. The large diameter hole at the 30 percent chord, for example, provides egress for instrumentation wiring and reference pressure tubing. The series of 40 small holes around the perimeter and near the surface, are drilled horizontally 1.25 inches into the sections and are for installation of the differential pressure transducers. The mid-section attaches to the root section with two bolts which are accessed through the two medium sized holes shown in the figure as well.

Model Instrumentation

The Benchmark Supercritical Wing contains 80 pressure transducers. The mid section houses the 40 pressure transducers which provide the surface pressure distribution at the 95 percent span station while the root section houses the same number of transducers which provide the surface pressure distribution at the 60 percent span station. Figure 5 shows graphically the locations of these two rows of pressure measurements. The chordwise distribution of the pressure transducers can be seen in figure 4. This distribution is identical for both spanwise stations.

Table 1 provides the measured x/c locations for all 80 pressure orifices. At each spanwise station there are 23 pressure orifices on the upper surface (including one each at the leading and trailing edges) and 17 on the lower surface. All but two of the pressure transducers are installed approximately 0.1 inches from the measurement point on the model surface. The two exceptions are the trailing edge transducers at both span stations. The distance between the trailing edge orifices and the corresponding pressure transducers is approximately 0.7 inches.

Four low frequency accelerometers are installed in the Benchmark Supercritical Wing. These accelerometers are used to verify flutter frequency and rigid body motion during testing. Figure 5 shows the locations of the 4 accelerometers on the model. Also, type "T", copper-constantin thermocouples were installed on the outboard edge of both the root and mid-sections of the model. They are positioned near the pressure transducers at each span-station so that a temperature history can be recorded.

PAPA Mount

The flexible mount system called the Pitch and Plunge Apparatus (PAPA)[7-8] is used by the Benchmark Models Program to provide a well defined, two-degree-of-freedom dynamic system on which rigid, instrumented models can undergo classical flutter

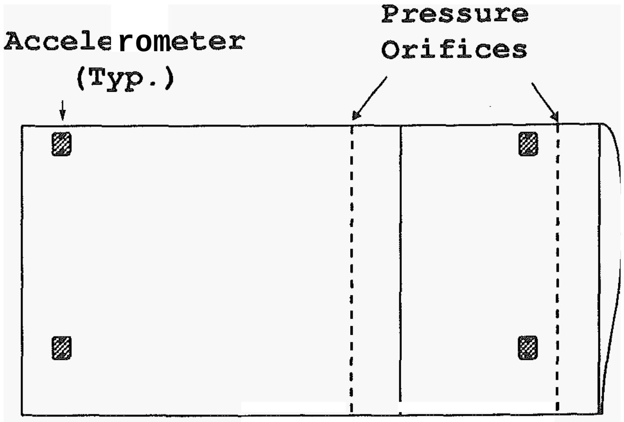
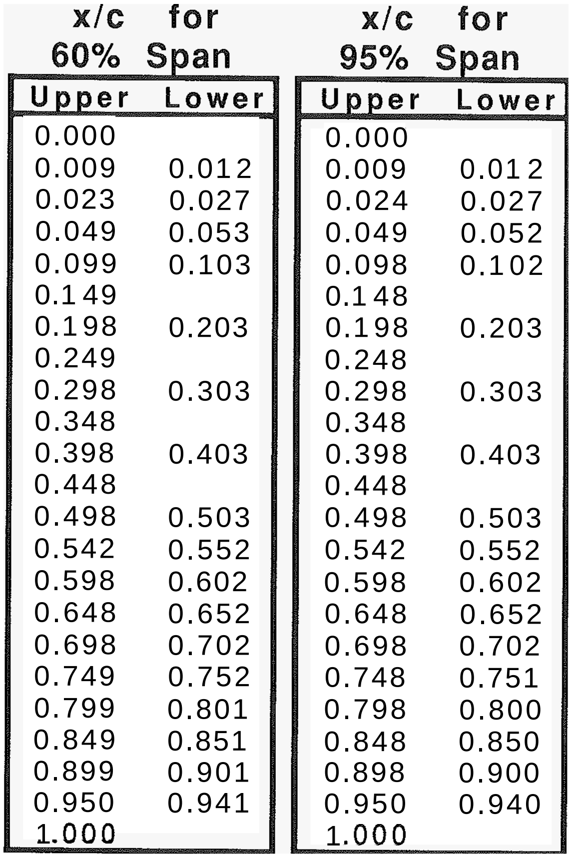


Figure 5. Model Instrumentation.

Table 1. Measured Distribution of Surface Pressure Orifices.



x/c for 60% Span		x/c for 95% Span	
Upper	Lower	Upper	Lower
0.000		0.000	
0.009	0.012	0.009	0.012
0.023	0.027	0.024	0.027
0.049	0.053	0.049	0.052
0.099	0.103	0.098	0.102
0.149		0.148	
0.198	0.203	0.198	0.203
0.249		0.248	
0.298	0.303	0.298	0.303
0.348		0.348	
0.398	0.403	0.398	0.403
0.448		0.448	
0.498	0.503	0.498	0.503
0.542	0.552	0.542	0.552
0.598	0.602	0.598	0.602
0.648	0.652	0.648	0.652
0.698	0.702	0.698	0.702
0.749	0.752	0.748	0.751
0.799	0.801	0.798	0.800
0.849	0.851	0.848	0.850
0.899	0.901	0.898	0.900
0.950	0.941	0.950	0.940
1.000		1.000	

when subjected to wind-on testing in the TDT. A photograph of the PAPA mount is presented in figure **6.** The PAPA consists of a moving plate supported out from the tunnel wall by a system of four rods of circular cross-section and a centerline flat-plate drag strut; all having fixed-fixed end conditions. The moving plate is made of steel with a thickness of one inch and can be considered rigid for the purposes of generating an analytical model. The rods and flat plate drag strut provide linear elastic constraints so that the moving plate and attached model will oscillate in pitch and in plunge. The wind-off characteristics of the rigid-body pitch and plunge modes are largely determined by the length and cross-section of the rods as well as the mass of the moving plate and model. The main purpose of the drag strut is to increase stiffness in the x-y (chordwise) plane.

A top view sketch of the PAPA mount is presented in figure 7. Ballast weights can be added to the inboard fore and aft portions of the moving plate. These weights are used to uncouple the pitch and plunge modes by moving the center of gravity forward or aft as necessary to locate it on the system elastic axis. The ballast weights also allow tuning of total system mass and inertia so that airfoil models of slightly different mass can all be tested at the same frequencies for more meaningful correlation of results between models.

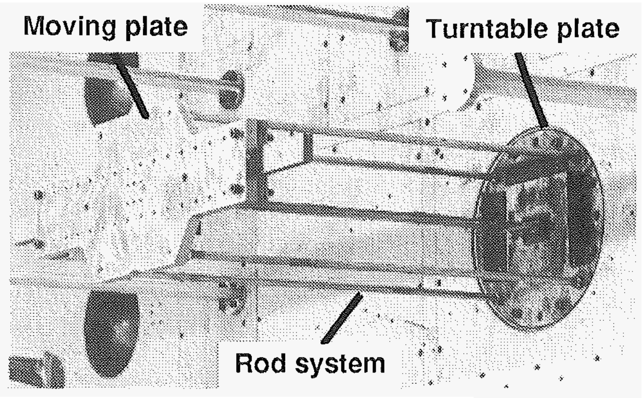


Figure 6. Photograph of PAPA Mount.

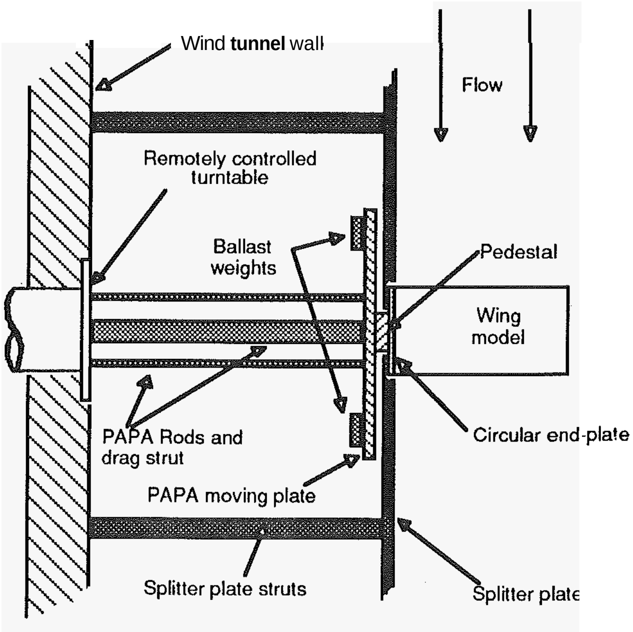


Figure 7. Top-View Sketch of PAPA Mount.

In the tunnel test section the PAPA mount is located behind a splitter-plate which will be described in a subsequent section. The model attaches to the PAPA moving plate by means of a short pedestal block which protrudes through an opening in this splitter-plate. All loads are transferred from the model to the PAPA mount through the pedestal. The pedestal, much shorter than the model in the chordwise direction, sits in **a** small hole in the splitter-plate which is large enough to allow the PAPA/model assembly to translate several inches in the vertical direction without contacting the splitter-plate.

Flow through the splitter-plate is prevented by **a** thin end-plate at the base of the model which covers the opening in the splitter-plate. The end-plate is circular in shape with a diameter equal to one chord length and mounts between the pedestal and model. The end-plate is recessed into the splitter-plate such that it's outer surface coincides with the surface of the splitter-plate to preserve smooth aerodynamic flow. The inner surface of the end-plate is less than 1/10 inch from the recessed portion of the splitter-plate, but is not allowed to rub against this surface. Figure **8** shows the model and end-plate mounted in front of the splitter-plate in the test section.

Instrumentation on the PAPA includes strain gage bridges that are calibrated to measure vertical loading and vertical displacement, as well as torsional moment and pitch angle. Mounted on the moving plate are two accelerometers to record pitch and plunge motion and an angle-of-attack accelerometer which is used to measure the static pitch angle of the moving plate.

OTHER TEST HARDWARE

During testing a splitter plate serves to separate the model from the test-section-wall boundary layer as well as from the PAPA hardware. A picture of the model and splitter-plate mounted in the tunnel test section as viewed from upstream is shown in figure 9. The centerline of the model/PAPA system is seven feet from the leading edge of the splitter plate, which is 12 feet in length and 10 feet in height and is suspended out from the test-section wall by struts 40 inches in length.

Instrumentation on the splitter plate includes 20 pressure transducers. These splitter-plate surface pressure measurements provide data on the aerodynamic conditions at the model root plane which could be used to check boundary conditions for CFD analysis. A boundary layer rake, with 10 measurement locations extends out 5 inches from the splitter-plate surface to determine the boundary layer thickness at a position corresponding to one chord behind and one chord above the model trailing edge.

During wind-tunnel testing forced excitation of the model at subcritical conditions is accomplished using a jet thruster. The thruster is attached to the aft end of the moving plate of the PAPA mount. The excitation can be in the form of a one or two cycle burst, allowing data to be recorded as the model response decays, or at a constant input, allowing data to be recorded for a constant amplitude response. The force input by this jet thruster into the PAPA/model system is recorded in the data set.

Behind the splitter plate, the PAPA rods, drag strut, and moving plate are enclosed in an aerodynamic fairing. This aerodynamic fairing can be seen in figure 9. The only parts of the apparatus exposed to aerodynamic forces during testing are the Benchmark Supercritical Wing and the end-plate (to a much lesser degree).

At the tunnel wall, the PAPA mount is attached to a remotely controlled turntable so that the model angle of attack can be varied. The model/PAPA system can be rotated to 5 degrees in either the positive or negative direction; the model, however, can attain angles-of-attack slightly greater in magnitude than this due to twisting of the PAPA mount.

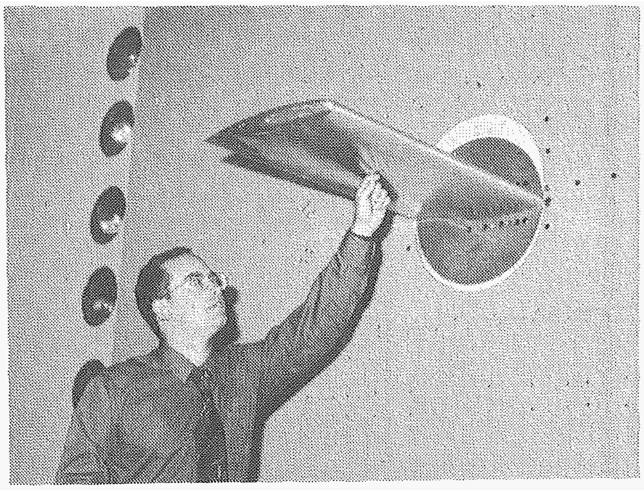


Figure 8. Model Mounted in Test Section.

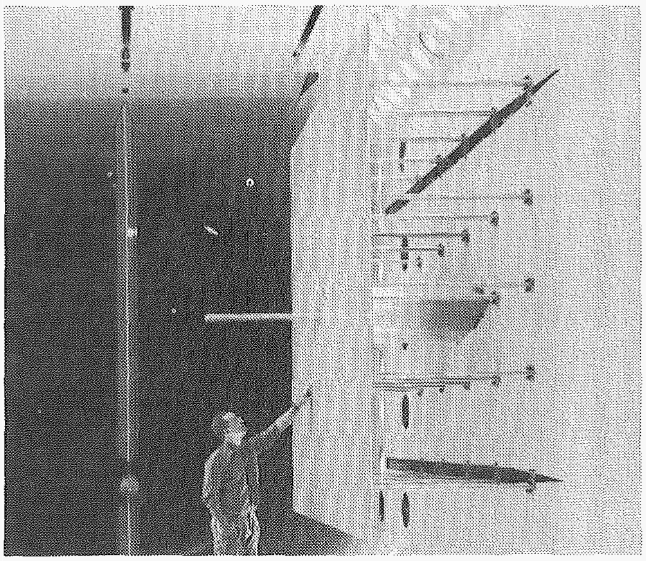


Figure 9. Photograph of Test Apparatus.

Preliminary GVT Results

A preliminary ground vibration test (GVT) has been performed to define the wind-off natural frequencies of the PAPA/model system. Qualitative mode shapes corresponding to these frequencies have also been determined. What follows is a summary of those results. A final set of GVT measurements will be performed just prior to testing of the model and will be published in a later report. These values, however, are not expected to change significantly.

Figure 10 shows a stick figure representing the Benchmark Supercritical Wing, the moving plate, the four rods, and the drag strut. A roving accelerometer referenced to a load cell at the shaker attachment was used to measure transfer functions at **44** locations on the model and the PAPA mount. These locations are

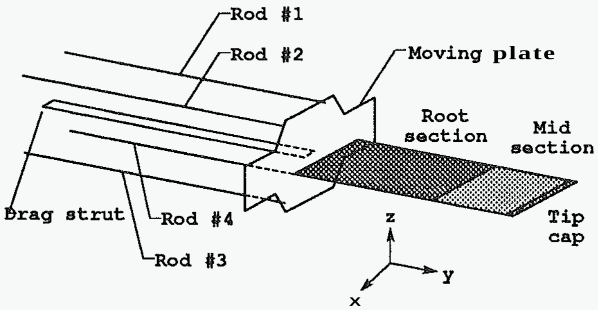


Figure 10. Representation of PAPA/Model System.

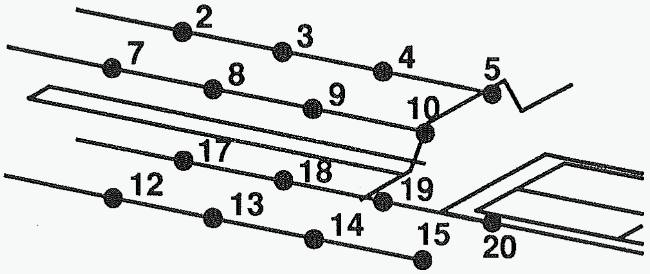


Figure 11. Rod Measurement Locations.

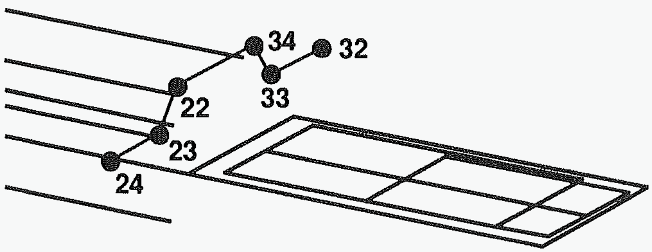


Figure 12. Moving Plate Measurement Locations.

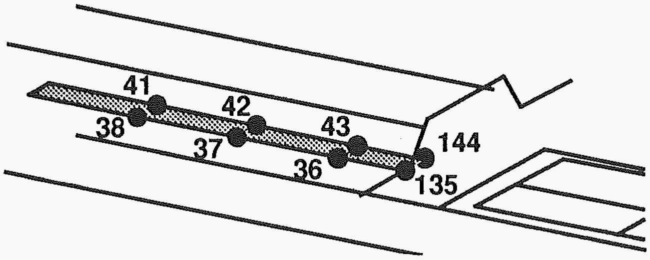


Figure 13. Drag Strut Measurement Locations.

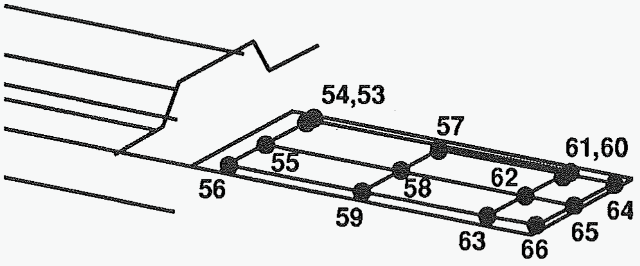


Figure 14. Model Measurement Locations.

labeled and shown in figures 11-14. Table 2 lists the x, y, and z coordinates of each of the GVT measurement points. The origin for this set of coordinates is located at the model mid-chord in the x-direction, at the model root in the y direction, and at the center line of the model in the z direction. All measurements on the model were taken on the upper surface.

Table 2. GVT Measurement Locations.

Pt.	x, in.	y, in.	z, in.	Component
2	- 5.25	-31.	5.25	Rod #1
3	- 5.25	-22.	5.25	Rod #1
4	- 5.25	-13.	5.25	Rod #1
5	- 5.25	- 3.	5.25	Rod #1
7	5.25	-31.	5.25	Rod #2
8	5.25	-22.	5.25	Rod #2
9	5.25	-13.	5.25	Rod #2
10	5.25	- 3.	5.25	Rod #2
12	5.25	-31.	- 5.25	Rod #3
13	5.25	-22.	- 5.25	Rod #3
14	5.25	-13.	- 5.25	Rod #3
15	5.25	- 3.	- 5.25	Rod #3
17	- 5.25	-31.	- 5.25	Rod #4
18	- 5.25	-22.	- 5.25	Rod #4
19	- 5.25	-13.	- 5.25	Rod #4
20	- 5.25	- 3.	- 5.25	Rod #4
22	6.	- 2.25	6.25	Moving Plate
23	8.4	- 2.25	3.	Moving Plate
24	16.	- 2.25	3.	Moving Plate
32	-16.	- 2.25	3.	Moving Plate
33	- 8.4	- 2.25	3.	Moving Plate
34	- 6.	- 2.25	6.25	Moving Plate
135	1.5	- 7.	0.	Drag Strut
36	1.5	-13.	0.	Drag Strut
37	1.5	-22.	0.	Drag Strut
38	1.5	-31.	0.	Drag Strut
41	- 1.5	-31.	0.	Drag Strut
42	- 1.5	-22.	0.	Drag Strut
43	- 1.5	-13.	0.	Drag Strut
144	- 1.5	- 7.	0.	Drag Strut
53	- 7.	2.5	0.	Wing Model
54	- 6.4	2.5	0.	Wing Model
55	0.	2.5	0.	Wing Model
56	6.4	2.5	0.	Wing Model
57	- 6.4	15.	0.	Wing Model
58	0.	15.	0.	Wing Model
59	6.4	15.	0.	Wing Model
60	- 7.	27.	0.	Wing Model
61	- 6.4	27.	0.	Wing Model
62	0.	27.	0.	Wing Model
63	6.4	27.	0.	Wing Model
64	- 6.4	32.	0.	Wing Model
65	0.	32.	0.	Wing Model
66	6.4	32.	0.	Wing Model

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