DESIGN OF AN AEROELASTIC WIND TUNNEL MODEL FOR THE N-250 TRANSPORT AIRCRAFT

Harijono Djojodihardjo, Yan Mursal, Hone Suhartono, and Risdaya Fadil
Nusantara Aircraft Industries (PT IPTN), Bandung, Indonesia

and

Johannes Schweiger, Reiner Manser, and Mußmann
Deutshe Aerospace AG, Munich, Germany

Abstract

Flutter has been one of the most unpredictable and most dangerous risks to new airplanes. Although this potential risk for new designs has greatly been reduced by a better understanding of the physical interactions between aero-dynamic, elastic and mass forces acting on the airplane as well as by improved theoretical methods and the increased computational capacities, wind tunnel flutter models are still valuable design tools for the development of a new airplane.

PT. IPTN from Bandung, Indonesia is currently developing the N-250, a twin turboprop engine transport aircraft for up to 64 passangers. To support the development, a flutter wind tunnel model was designed and built in cooperation with the military airplane group of DASA in Munich, Germany. The model scales were optimized for tests in the 3 x 4 m test section of the low speed wind tunnel at the Indonesian research facilities (LAGG) in Serpong, Indonesia.

One of the main features of this flutter model is its high modularity which allows to test individual components like the T-tail and provides the possibility to replace all parts easily in order to integrate full scale design modifications or new versions of the airplane in the future.
The model is equipped with an internal flutter excitation system, which was especially designed for this model.

The stiffness properties of the model are represented by NC machined aluminium spars. The dimensions of these spars were calculated by a special computer program for flutter models. For complex attachments between component like the wing/fuselage interface, where simple beam elements can not be used to simulate the proper deformation characteristics, a structural optimization program was used to obtain a feasible design. At the same time, IPTN is also developing a half wing model of N-250, in cooperation with DLR Institute for aeroelasticity, for further design, modification and development studies.

Paralel to the model, a safety device for flutter tests at the Indonesian Low Speed Tunnel (ILST) Serpong was designed. It consists of hydraulically driven doors which can be deflected into the test section within less than half a second to reduced the dynamic pressure when a violent flutter case occured.

Introduction

The flutter characteristics are needed to determine optimum design of an aircraft structure. On the other hand, these characteristics are influenced by many parameters such as stiffness and mass distribution, location of control surfaces, wing and tail configuration. In the preliminary design most of the values of the parameters can not be obtained. Therefore, a study of this influence parameter is necessary. Such study can best be carried out by wind tunnel experimental method. These are the main reasons why IPTN decided to support the development N-250, depicted in Figure 1, by flutter model wind tunnel tests.

For the N-250 flutter model, a close cooperation between the IPTN and DASA specialists has been maintained. The cooperation covers the main project phases for the model: pre-design, design, manufacturing, instrumentation and calibration. The development of the flutter model has to incorporate latest development of the full scale design and has been provided by IPTN specialists. At the same time, IPTN is also developing a half-wing model of N-250, in cooperation with DLR Institute for Aeroelasticity, for further design, modification and development studies.

Flutter Model Concept

General Concept

In the case of a slender wing and fuselage configuration like the N-250 or other transport airplanes, the so called beams-and-panels concept is the best way to simulate the proper mass and stiffness data from the full scale design in the flutter model. This concept means that the individual components stiffnesses are concentrated in one spar whereas the exterior surface is represented by several individual segments attached to the spars without adding additional stiffness to the components when the model is deformed. This is achieved by gaps between these segments, the so-called panels. Figure 2 shows a typical fuselage section with the attachmwents between spar and panel, while Figure 3 depicts a typical wing section with the panel's foam core. The panel distribution of N-250 model for wing and fuselage is shown in Figure 4 and Tabel 1.

Tabel 1. N-250 Model Panelling

Part	Number of panel
Fuselage	6
Wings	34
Vertical Tail	6
Horizontal Tail	5

Modular Concept

From the beginning of the design it was intended to design the model in a way that possible design improvements in the future or other versions of the N-250 can be covered by additions to or replacements for the basic version model. Modified mass and stiffness distributions can be handled by replacing concentrated (lumped) masses or spars. In addition special connecting elements (springs) between the spars like in Figure 5 can be exchanged, similar to the control surface attachments. For external geometry modifications, only the individual panels have to be replaced.

For dedicated component tests like wing or empennage investigation of the model can be separated. This component can then be attached to an interface adapter which allows a clamped- type installation in the wind tunnel for dedicated component tests. An interface for the T-tail, including the rear fuselage, is already being manufactured at IPTN.

The advantages of component models are:

1. clear identification of the critical modes and read-across with a component model analysis,
2. Installation of the component model into a smaller test section like at the IPTN wind tunnel,
3. reduced efforts for test (equipment and manpower)

Similarities Concepts

The main requirement to build a model is the dynamical similarities between this model and the full scale aircraft. These dynamical similarities are :

a. similarity in aerodynamic shape
b. similarity in elastic axis location
c. similarity in stiffness and mass distribution
d. similarity in Mach and Reynolds Number
e. similarity in aerodynamic and inertia force ratio
f. similarity in reduced frquency
g. similarity in torsion and bending stifness ratio

The Reynolds similarity law, which is associated with viscosity of test fluid, is most essential for aerodynamics but it is very difficult to be considered during testing because the constraints of wind tunnel speed, fluid density, tunnel test section diameter, and model size. Fortunately, Reynolds similarities law is not mandatory in aeroelasticity and theoretical analysis is therefore limited to non viscous flow condition for practical approach. In this case Reynolds similarity is not important.

The most essential similarity for aeroelastic models is expressed by the reduced frequency, which is expressed by the eigenfrequency of the airplane, multiplied by chord, divided by the speed of the airplane. This parameter is formulated by :

$$k = \frac{\omega b}{V}$$

This value must be the same for the model in wind tunnel as for the full scale design and its flight envelope.

Dimensional Scale Factor

Tabel 2 shows dimensional scale factors which are used in flutter model design.

Tabel 2. Scale Factors For Aeroelastic Models

Scale Factor	Equation	N-250 Values
Length ratio	$R_L = \frac{L_m}{L_f}$	0.087
Velocity ratio	$R_V = \frac{V_m}{V_f}$	0.20
Structural density ratio	$R_\rho = \frac{\rho_m}{\rho_f}$	1.00
Mass ratio	$R_M = [R_\rho][R_L]^3$	6.585E-04
Mass moment inertia ratio	$R_I = [R_\rho][R_L]^5$	4.984E-06
Bending stiffness ratio	$R_B = [R_\rho][R_V]^2[R_L]^4$	2.294E-06
Torsion stiffness ratio	$R_{GJ} = R_B$	2.294E-06
Frequency ratio	$R_\omega = \frac{[R_V]}{[R_L]}$	2.3
Load factor ratio	$R_n = \frac{[R_V]^2}{[R_L]}$	0.46

In all these notations,:

L : length
V : velocity
M : mass
ω : frequency
ρ : structural density

whereas m and f indicate model and full scale values, respectively.

Model Design

The flutter model design is usually approached by simpliflication of the aircraft structures without neglecting its charäcteristics. This simplification is needed to obtain stiffnes, mass distribution, and external shape of the model.

To represent external shape of the airplane, several independent sections for each component are manufactured from foam material and covered by thin layers of composite material for their protection and to obtain a smooth surface. Individual lumped masses are integrated into these sections in order to represent the correct mass properties for each section. The fuselage of aeroelastic models is usually built from several shell-type panels, individually attached to the center spar. This will provide sufficient space for the integration of masses and for the model instrumentation and test equipment.

At the following section, the design aspects of flutter model will be discussed.

Stiffness Model

The flexible spar is used to simulate stiffness and a few parts of mass. In most cases a rectangular cross-section with an integrated rib, Figure 6, will allow the simulation of the stiffness.

To determine the spar properties of the the N-250 model, a DASA computer program was used. For preselected rib thickness, this computer program calvulates the required dimensions of the spar and the width of the rib.

Inertial Model Simulation

The total mass of the N-250 aircraft model, including spar, rib, and rib conecting mass, will be made less then total target mass. The added mass may be used to make the total mass of the model to be equal to total target mass.

Model Instrumentation

The tetsing of the aeroelastic model usually consist of :

a. flexibility coeficcient measurement
b. mass distribution measurement of each component
c. ground vibration testing to determine natural frequencies of the model

The equipments which are used in these testing are electrical components which can transform measured parameters to electrical signals.

The classical sensor for dynamic testing are the accelerometer which for N-250 testing are placed at the locations as showed by Figure 7. For pressure measurments, the same type of tranducers as for rigid aerodynamic models is used. The stain gauges are used for the recording of local or global forces of the models. Other intrumentation that will be used are signal conditioning, data aquisition, processing equipment, and Electro-magnetic motor which is used to give exitation. SDL HP 3565 and unix based 380 series 9000 are used to monitor the output signals from the accelerometers.

Wing/Fuselage Attachment Design

To optimize the N-250 performance, the full scale wing/fuselage attachment design was improved during the model design phase: the center wing section was immersed into the fuselage contour. This required a new approach to obtain the proper stiffness data and design the model's attachment interface properly.

Based on the detail NASTRAN finite element model from IPTN for the center wing and center fuselage section, the DASA structural optimazitation program LAGRANGE was used to calculate the required stiffness properties for the interface components in the model. By applying unit load cases, the resulting deformations were used as constraints in the coresponding model points. A similar approach was also used for the wing/engine attachment, where the full scale dynamic mode shapes and frquencies were used to calculate the required stiffness for the NC-machined spars.

Excitation System

A special excitation system was designed and built for the N-250 model: unlike for other flutter wind tunnel models, this excitation system is directly installed into the model. Usually, sufficient excitation is provided by the wind tunnel's turbulence or by special gust generator vanes installed in the test section. Because the LAGG wind tunnel has a rather low turbulence level and no gust exciter vanes are installed, the miniature exciter in Figure 8 was designed. It consists of a moving mass, installed into a box, which can be mounted in two different positions onto the rear fuselage to allow the excitation of symetric and antisymetric modes. The exciter mass is driven by a small electric motor which is controlled by a special frequency sweep generator.

Model Trim System

To trim the model at all speeds and for different weight conditions, the angle of attack of the horizontal tail can be varied by a trim motor installed in the rear fuselage, Figure 9. The motor drives a flexible shaft which is supported as stiff as possible at the top to provide sufficient pitch stiffness for the horizontal tail.

Design of the Double Hinge Rudder Attachment

It is known that the gear ratio between a primary control surface and a secondary surface can be very sensitive for flutter. Because the N-250 has a double-hinged rudder, where the rear rudder is deflected by the double angle compared to the forward rudder, the same mechanism was also installed into the model. While the forward rudder is supported by exchangable spring elements to simulate different actuator stiffness, the rear rudder is attached by the system depicted in Figure 10 to provide the correct ratios between the deflections of the two rudders.

Wind Tunnel Facilities

Model Suspensions Systems

Figure 11 illustrates the air support system which is used. This system include pneumatic cylinder and steel cable with 100 psi air pressure for model support and flying rod to keep the model in wind tunnel. The model is attached to the rod by the fitting shown in Figure 12. This concept allows the model to move up and down on the rod with minimum friction and it provides a free pitch motion.

Flutter Stoppers

The flutter stoppers are used to stop the test before damage happen when flutter occurs. A simple method to stop the flutter is afforded by reducing the dynamical pressure. That leads to the use of Q-doors. When the Q-doors are opened, the dynamical pressure will be reduced and the flutter can be stopped in about 0.5 second.

Preliminary Results For N-250 Half Wing Model

The preliminary flutter experiment of 1:11.5 scale of N-250 half wing flutter model which is illustrated by Figure 13, was executed at IPTN. The gust generator is used to excite the model. Figure 14 shows the experimental wind tunnel set up. The comparison of the values of the natural frequency between GVT and analytical result for each configuration is shown by Tabel 3. The experimental and the analytical result are illustrated in Figure 15.

Tabel 3 Normal mode calculation and GVT results comparison

Mode	Type of Mode	Calculation (Hz)	GVT (Hz)	Struct. Damp. (%)
1	1st bending	5.43	4.89	0.45
2	1st yawing	11.54	10.88	0.54
3	2nd bending	13.88	13.38	0.73
4	1st torsion	19.34	19.72	1.26
5	3rd bending	39.62	41.66	1.89
6	2nd yawing	44.26	46.37	2.00

Conclusions

A Flutter wind tunnel model for the N-250 transport aircraft was designed and built by IPTN in close cooperation with DASA. In spite of the geographical distance and the 5 hours difference in local time, the project was succesfully completed. Although the full scale design of the N-250 was still in progress with respect to size and external geometry of the configurations as well as for the structural design when the model design was initiated, less then 15 months were required to complete the model after go-ahead. The modular design concept of the model as well as efficient structural optimazitation and analysis methods allowed the incorporation of major design changes of the full-scale design into the model design as late at 6 months after go-ahead.

In combination with an already existing unsteady aerodynamic wind tunnel model, this flutter model will provide valuable information for the design optimization of the N-250, for the certification process, for design modification, and for derived configurations. In addition the incorporation of new technologies like active control methods for load alleviation, stability enhancement, or ride comfort improvements can be tested with this model.

At the same time, separate development of half wing model have been carried out to allow further flexibility in the design and development of the aircraft.

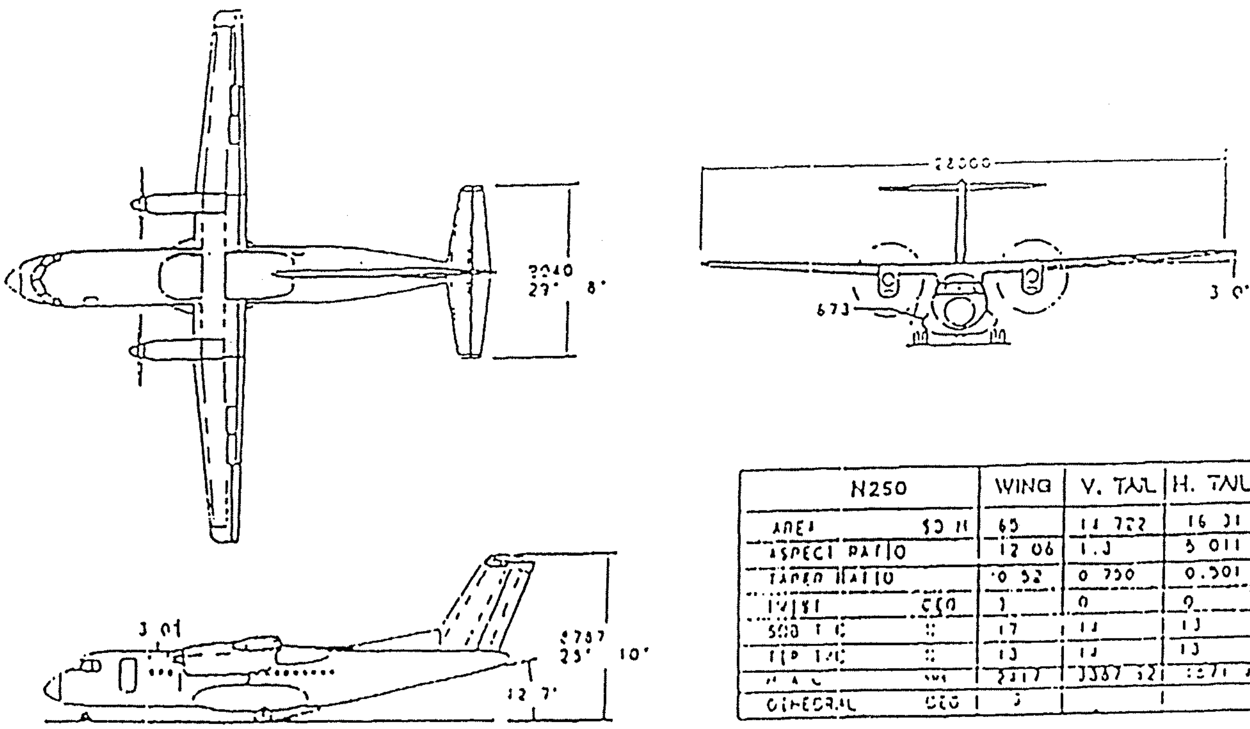
Acknowledgment

The authors would like to acknowledge the contribution and participation of many individuals at IPTN (PMTP, AEA-AD, WTT-FTC, AST-FTC), LAGG-BPPT, DASA and DLR who are involved in the flutter model project.

Bibliography

1. Bisplinghoff, R.L., Ashley, H., and Halfman, R.L., *Aeroelasticity*, Addison Wesley Publishing Company, Cambridge, Massachusetts, 1955
2. Djojodihardjo, H., Bonar, E.L., Asmara, P., Gunawan, S., *Analisis Karakteristik Flutter Struktur Ekor T Pesawat N-250*, Simposium Sistem Aeroelasto-mekanik, Bandung, 1990.
3. Djojodihardjo, H., Suhartono, H., Sekar, W.K., *Kaji Model Aeroelastik*,

Simposium Aero-elastomekanik, Bandung, 1990.
4. Djojodihardjo, H., *Penghitungan dan Pengujian Aeroelastik Guna Pengoptimuman Perancangan Pesawat Terbang, Metoda dan Kaji Kasus,* Simposium Sistem Aero-Elasto-Mekanik, Bandung, 7-8 Agustus, 1990.
5. Djojodihardjo, H., Suhartono, H., Indrawanto, Sudiro, *Uji Model Flutter N-250 di Terowongan Angin,* Proceedings SITRA 93, Simposium Nasional Ilmu Pengetahuan dan Teknologi Dalam Rekayasa Aeronotika, Bandung, 27-29 Juli, 1993.
6. Hoenlinger, H., *Studien Uber Rationelle Erstellung Eines Flatter Modells,* Enwicklungsring Sud GMBH, Munchen, 1968.
7. Schweiger, J., Manser, R., Hoenlinger, H., *Aeroelastic Wind Tunnel Models: Requirements, Design, Concepts, Instru-mentation, and Testing Techniques,* Proceedings SITRA 93, Simposium Nasional Ilmu Pengetahuan dan Teknologi Dalam Rekayasa Aeronotika, Bandung, 27-29 Juli, 1993.
8. IPTN Flutter Model Testing Group, *N-250 Half Wing Flutter Model Testing : Preliminary Report,* July, 1994.



N250		WING	V. TAIL	H. TAIL
AREA	SQ M	65	14.722	16.31
ASPECT RATIO		12.06	1.3	5.011
TAPER RATIO		0.52	0.750	0.501
TWIST	DEG	3	0	0
ROOT T/C	%	17	14	13
TIP T/C	%	13	14	13
M.A.C	MM	2317	3387.52	[illegible]
DIHEDRAL	DEG	3		

Fig. 1: N-250 Basic Geometry

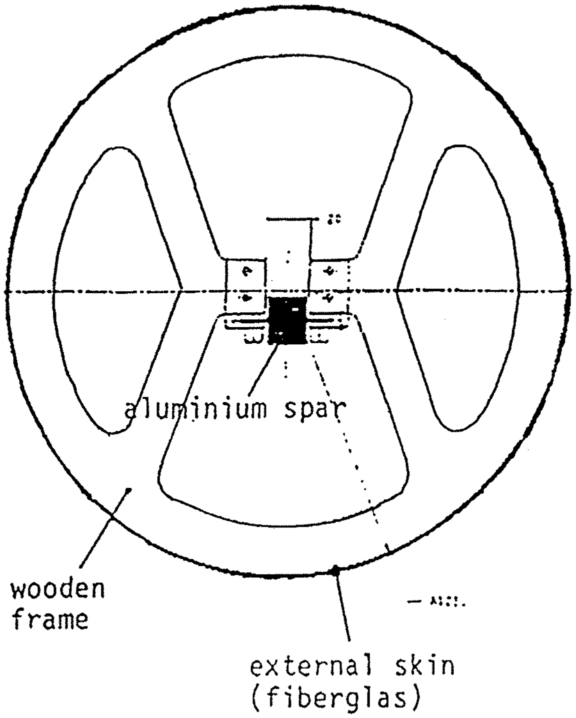


Fig. 2: Typical Model Fuselage Section

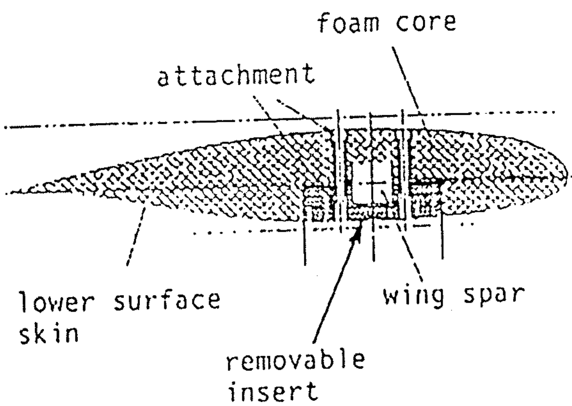


Fig. 3: Model Wing Section

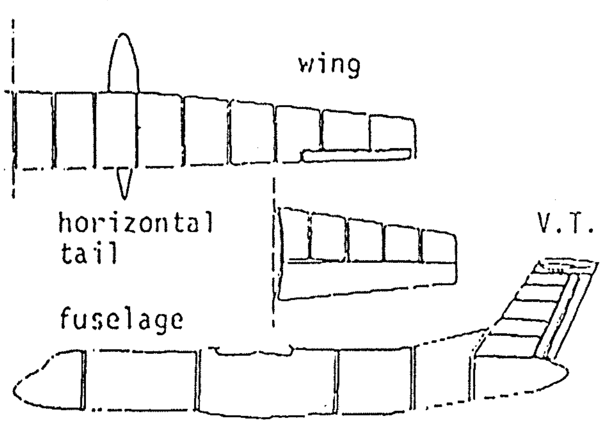


Fig. 4: Panel Distribution

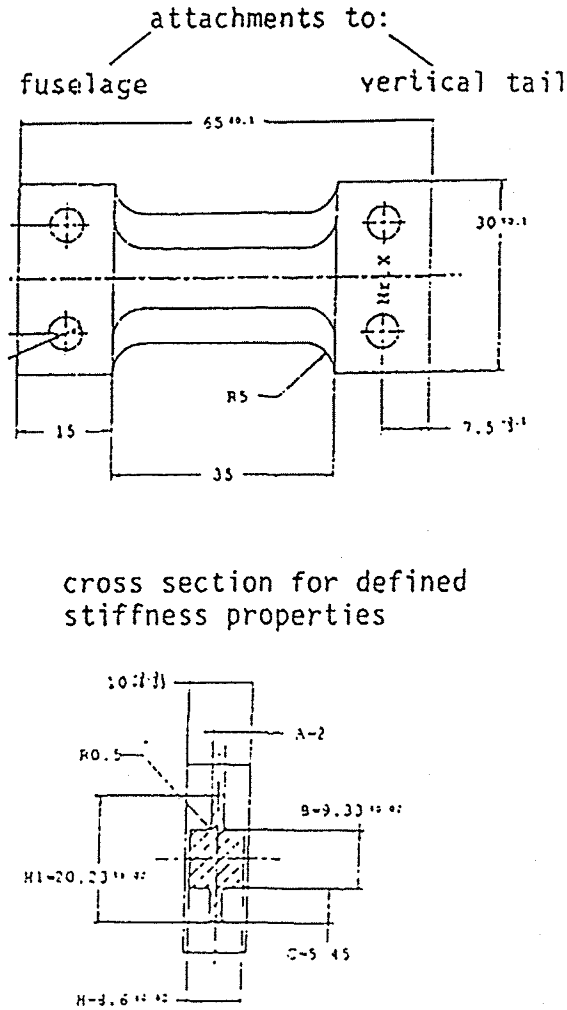


Fig. 5: Spring Element Between Fuselage and Tail

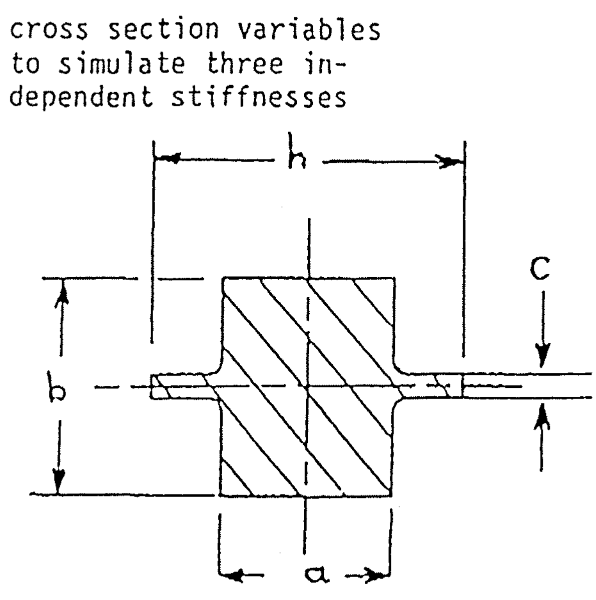


Fig. 6: Typical Spar Cross Section

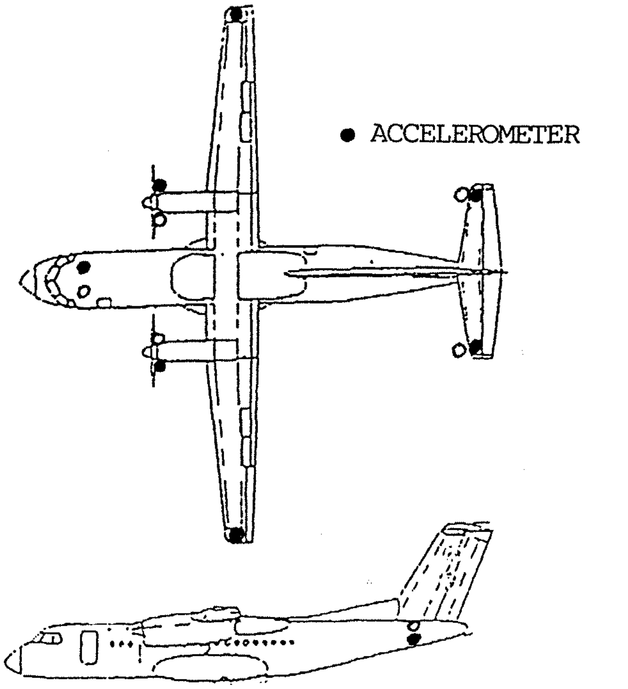


Fig. 7: Accelerometer locations at the N-250 model

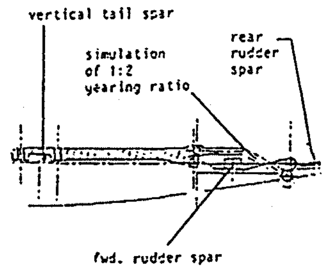


Fig. 10: Attachment Design for Rear Rudder

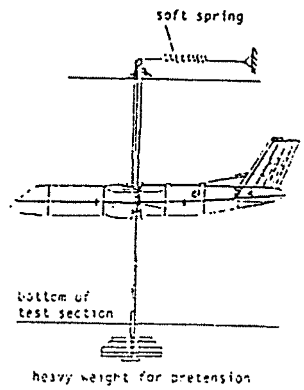


Fig. 11: Model Suspension System

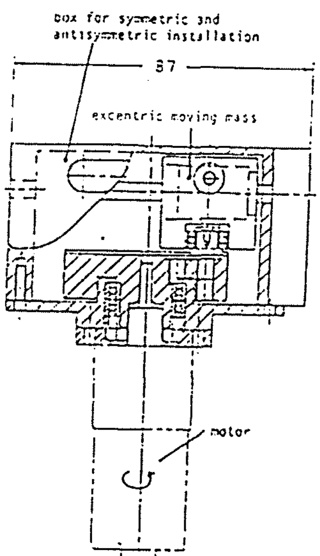


Fig. 8: Model Exciter

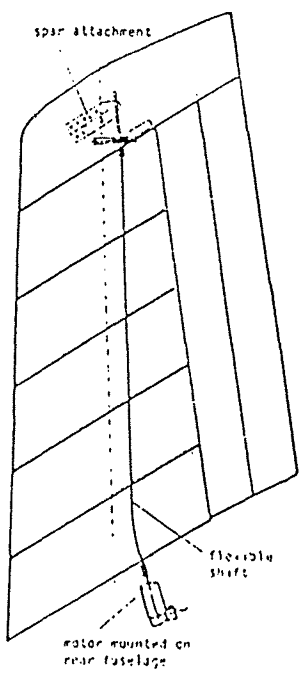


Fig. 9: Model Trim System for Horizontal Tail

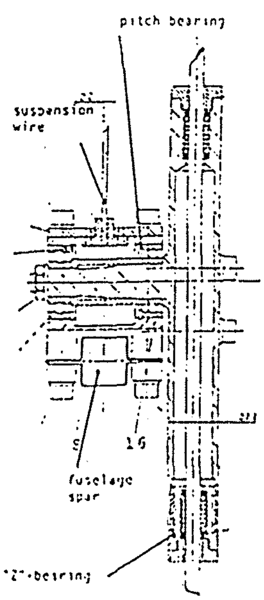


Fig. 12: Model Suspension Fitting

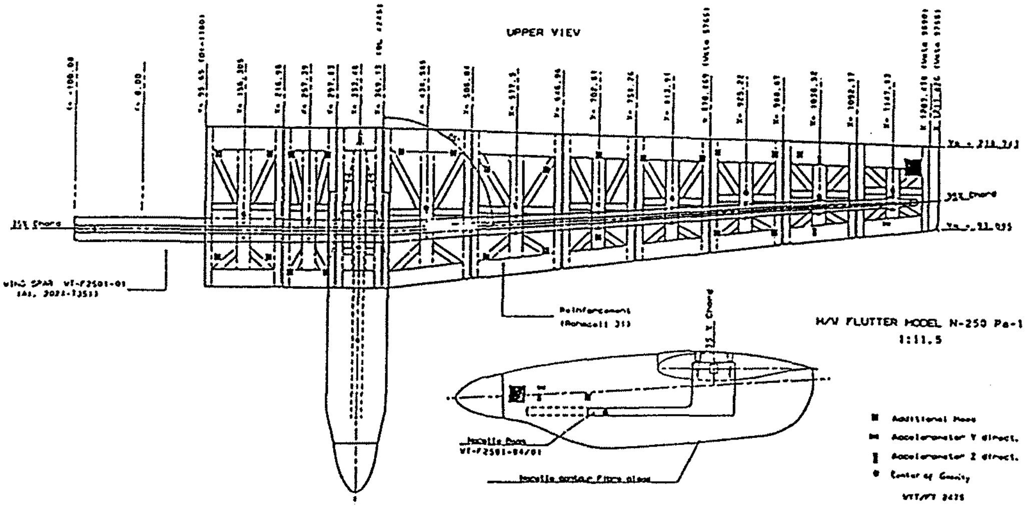


Fig. 13: N-250 Half Wing Flutter Model Geometry

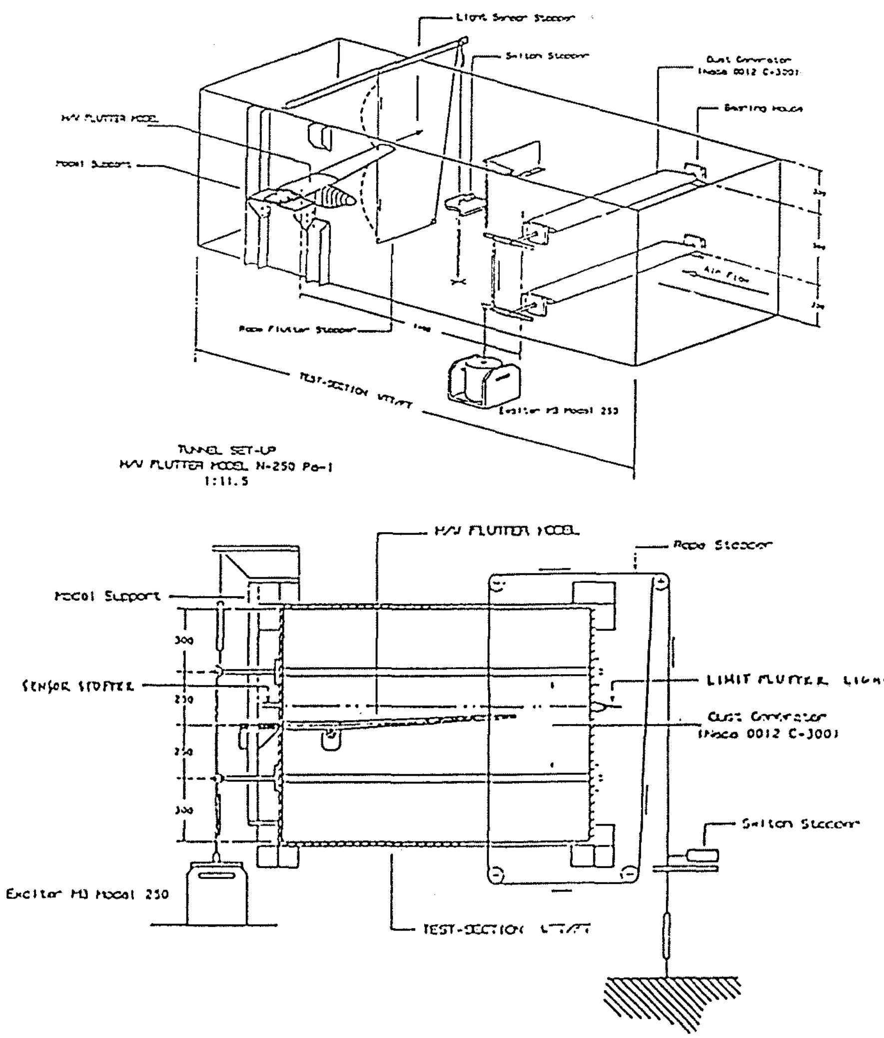
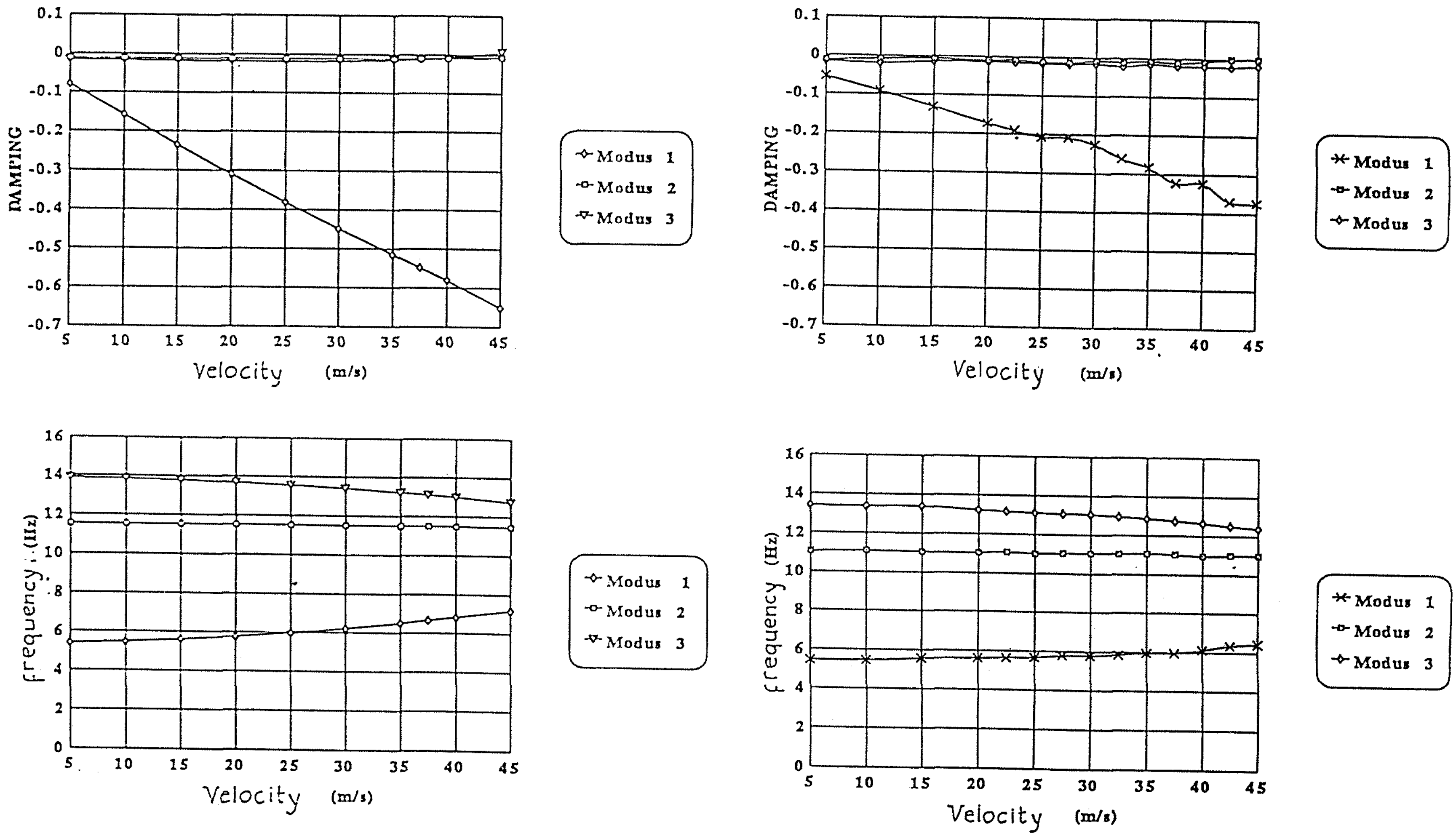


Fig. 14: Wind Tunnel Set Up



(a) (b)

Fig. 15: N-250 Half Wing Flutter Diagram
(a) analytical and (b) experimental result