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Models for Aero-Elastic Investigations

By

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Addendum

Models for Aero-Elastic Investigations

by

H. Templeton, B.Sc., F.R.Ae.S.

This Addendum provides a short note on two aspects omitted from the original paper, viz. gravitational effects and structural damping. A short list of references to earlier papers dealing with the subject is also added.

1 Gravitational Effects

The structural distortions produced in an aero-elastic model by gravitional forces may in some circumstances be important. Ideally, the gravitational-distortional effects should be identical for model and aircraft, but it is generally impossible to achieve this while satisfying the other similarity relationships. The most that can usually be done is to minimise as far as possible the gravitational effects on the model, which tend to be greater than on the aircraft.

Gravitational effects manifest themselves mainly in two ways. The first is that on vertically mounted aero-elastic model surfaces gravity effects modify the effective stiffness of the surface in a lateral displacement mode, particularly with a large tip mass in a fundamental type distortion mode. A method of minimising the effect associated with a tip mass is described in reference 7; the mass is hung away from the surface on long wires and is coupled to the surface horizontally, so that the mass partakes of the same horizontal motion as that of the surface to which it is coupled and only the inertia forces associated with this motion are transmitted to the surface.

The second important manifestation of gravity effects occurs on horizontally mounted model surfaces, where gravity effects associated with the mass of the surface, and particularly with any large masses carried by the surface, may distort the surface to a completely unrepresentative extent. The resulting aerodynamic forces may even be difficult to sustain. In reference 2, Scruton and Lambourne point out that the comparative gravitational effects are determined by the relation

$$\frac{\text{Angular deflection due to gravity for model}}{\text{Angular deflection due to gravity for aircraft}} = \frac{1}{\lambda}\left(\frac{V_A}{V_M}\right)^2$$

and they suggest that this ratio should be no higher than 3.

2 Structural Damping

The flutter characteristics of an aircraft are to some extent influenced by the structural damping present in the various modes. This influence can vary considerably; in main surface flutter it is fairly small for the amount of damping normally associated with typical structures; in control surface flutter, on the other hand, structural damping in either main surface or control surface modes may have a significant effect.

It may therefore be important, in some cases, to take account of the structural damping present in a model and of its influence on the model flutter characteristics. For a prediction model the damping should ideally be related to that of the aircraft; a logical relation would seem to be that the damping in any particular mode should be the same proportion of the critical damping in that mode as it is for the aircraft in the corresponding mode. If the structural damping in the model cannot be regulated but is significantly different from that of the aircraft, then some theoretical allowance for its effect on the flutter characteristics must be made.

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Models for Aero-elastic Investigations*

by

H. Templeton, B.Sc., F.R.Ae.S.

SUMMARY

An account is given of several types of aero-elastic model used for flutter investigations. The various purposes for which they are used are outlined, and the scale relationships for prediction models are derived. Different types of model construction are described and their main applications are defined.

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*Paper presented at a Conference on Model Techniques held in Venice, October 1955, by the Accademia Nazionale Dei Lincei of Italy.

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1 Introduction

Models have been used in the investigation of aero-elastic problems since these problems first arose. The subject is so complex that we have had to rely very much on experimental methods, either as a control on theory or to provide information in the absence of theory. In recent years the subject has become even more complicated, due to the advent of transonic and supersonic airspeeds and to the increasing complexity of aircraft structures, and models are being used more and more in this work.

Of the aero-elastic problems flutter is the most complex, and it is for flutter investigations that models are used to the greatest extent. In flutter a structural oscillation of the aircraft is maintained by the aerodynamic perturbations arising from the oscillation, which by the standard linear theory becomes divergent above a certain critical airspeed. A model test designed to reproduce this phenomenon must therefore adequately represent the aerodynamic, structural, and dynamic characteristics of the phenomenon. For other aero-elastic phenomena of a quasi-static nature - such as divergence and loss of control power - the dynamic characteristic is absent and the type of model required is correspondingly simplified. Similarly, vibration models involve no aerodynamic characteristic. In this paper attention is confined to the flutter model, as it embraces all the features that are involved in aero-elastic models.

Flutter models can be classified into two broad groups, according to the purpose for which they are used.

A. Research models, which do not represent any particular aircraft and are only broadly representative of full scale designs. They are used for the following purposes:-

(1) To assist in the understanding of a particular problem, for example to demonstrate what types of flutter may occur with a particular type of configuration.

(2) To provide an experimental comparison with theory.

(3) To provide general design information on the flutter trends that occur with variations in certain parameters, for example the effect of sweepback on wing flutter.

B. Prediction models, which are used to predict the flutter characteristics of particular full-scale designs. These models may be classified into two sub-groups, according to the basis of representation:-

(1) Models based on a theoretical representation of the full scale design, as used in the full scale flutter calculations. The model tests are then used primarily as a check on the results of the flutter calculations.

(2) Models based on the actual full scale design and intended to predict the flutter characteristics directly.

Models in class B are related to the full scale designs which they represent by certain scale relationships, and the full scale flutter characteristics are derived from the model characteristics by these same scale relationships.

In what follows, the scale relationships for the design of prediction models are first derived. Brief descriptions are then given of the various types of flutter model, according to their construction, with an indication of their main uses. The types of flutter model described are those known to the author.

2 Notation

a	matrix of non-dimensional inertia coefficients
a_{ii}	typical element of matrix a
b	matrix of non-dimensional aerodynamic damping coefficients
c	matrix of non-dimensional aerodynamic stiffness coefficients
e	matrix of non-dimensional structural stiffness coefficients
e_{ii}	typical element of matrix e
E	modulus of elasticity
(EI)	representative value of EI
F_i	mode function for the ith degree of freedom
I	moment of inertia of a transverse section
k	additional scale factor on transverse thickness
ℓ	representative length for aircraft
δm	element of mass
M	representative mass
q	column matrix of generalised non-dimensional co-ordinates
t	transverse thickness of skin, webs, etc.
V	airspeed for critical flutter condition
γ	material density
η	non-dimensional co-ordinate measured along wing, fuselage, etc.
λ	scale factor on overall dimension (aircraft length/model length)
μ	kinetic viscosity of fluid medium (coefficient of viscosity/density)
ν	frequency parameter ($= \omega\ell/V$)
ω	frequency (in angular measure)
ω_i	natural frequency of the ith mode
ρ	density of fluid medium

Subscripts

A	denotes value for aircraft
M	denotes value for model

3 Scale relationships for prediction models

The scale relationships for flutter models can be established very simply by the well known method of hypothetically defining the significant parameters involved and applying dimensional analysis. In this paper, however, they are derived on the basis of the flutter equations; although this derivation takes a little longer to present, certain features of the model representation are, in the author's view, more clearly brought out.

The flutter equations can be written in non-dimensional form as the matrix equation

$$(-\nu^2 a + i\nu b + c + e)q = 0 \tag{1}$$

where a, b, c, e are non-dimensional square matrices of inertia, aerodynamic damping, aerodynamic stiffness, and structural stiffness coefficients respectively. q is a column matrix of non-dimensional generalised co-ordinates and ν is the frequency parameter. The order of the matrices is equal to the number of degrees of freedom involved.

We consider a model which reproduces, on a non-dimensional basis, the flutter characteristics of a full scale design. Clearly, the flutter equations (1) must apply equally to both. The first requirements for the model are that it should be geometrically similar to the full scale design in external shape, and that its mass and stiffness distributions should be the same as those of the full scale design. The model should also be provided with the appropriate bodily freedoms, or at least as many of them as are considered to be important. As a consequence of these requirements, it follows that the normalised natural modes of vibration will be identical for model and full scale.

We consider the case where the flutter equations are based on the natural modes of vibration as the degrees of freedom, in which case the matrices a and e will be diagonal. The aerodynamic matrices b and c are functions of non-dimensional geometric parameters and of the normalised modal displacements, all of which are identical for model and full scale. They are also functions of non-dimensional aerodynamic derivatives or influence coefficients that in the general case are dependent on frequency parameter and Mach number, and to some extent on Reynolds number.

If the matrices a and e are identical for model and full scale, it follows that, under the same conditions of Reynolds number and Mach number, the flutter conditions of the model and full scale will be represented by identical solutions of equations (1), and that the frequency parameter will be the same for both.

A typical (diagonal) element of the matrix a is of the form

$$a_{ii} = \frac{1}{\rho \ell^3} \sum F_i^2 \, \delta m \, . \tag{2}$$

For the matrix e the corresponding element will in general be a function of both the flexural and torsional rigidities of the structure. Since these will be in the same ratio for the model as for the aircraft, it is sufficient to consider, for the present purpose, say a purely flexural mode, for which e_{ii} is of the form

$$e_{ii} = \frac{1}{\rho \ell^4 V^2} \int EI \left(\frac{d^2 F_i}{d\eta^2}\right)^2 d\eta \, . \tag{3}$$

Since F_i and η are invariant between model and aircraft, and since $\delta m \propto \gamma \ell^2 t$ and $I \propto \ell^3 t$, t being a representative transverse thickness of the structural material (skin, webs, etc.) then for the aircraft

$$(a_{ii})_A \propto \frac{\delta m}{\rho_A \ell^3} \propto \frac{\gamma_A}{\rho_A} \cdot \frac{t}{\ell} \tag{4}$$

$$(e_{ii})_A \propto \frac{E_A I_A}{\rho_A \ell^4 V_A{}^2} \propto \frac{E_A}{\rho_A V_A{}^2} \cdot \frac{t}{\ell} . \tag{5}$$

For the model, we consider first the case where the structural layout of the aircraft is reproduced exactly in the model. If the overall dimensions are scaled by the factor $1/\lambda$ (λ = ratio of aircraft length to model length) and transverse thickness by the factor k/λ, then from (4) and (5)

$$(a_{ii})_M \propto \frac{\gamma_M}{\rho_M} \cdot \frac{kt}{\ell} \tag{6}$$

$$(e_{ii})_M \propto \frac{E_M}{\rho_M V_M{}^2} \cdot \frac{kt}{\ell} . \tag{7}$$

For the a and e matrices to be identical for model and aircraft, therefore,

$$\frac{k\gamma_M}{\rho_M} = \frac{\gamma_A}{\rho_A} \tag{8}$$

$$\frac{kE_M}{\rho_M V_M{}^2} = \frac{E_A}{\rho_A V_A{}^2} . \tag{9}$$

Equality of Reynolds number $(V\ell/\mu)$ requires that

$$\frac{V_M \ell/\lambda}{\mu_M} = \frac{V_A \ell}{\mu_A}$$

or

$$\frac{V_M}{\mu_M} = \lambda \frac{V_A}{\mu_A} . \tag{10}$$

With $k = 1$ (model thickness to same scale as overall dimensions), relationships (8), (9) and (10) become the familiar basic relationships derived by dimensional analysis.

To summarise, the basic conditions for the model are

(1) The overall external and internal layout is geometrically similar to that of the aircraft (model dimensions $= {}^{1}/\lambda \times$ aircraft dimensions, model thicknesses $= {}^{k}/\lambda \times$ aircraft thicknesses).

(2) The model mass and stiffness distributions are the same as for the aircraft, and the appropriate bodily freedoms are present.

(3) The scale relationships (8), (9) and (10) are complied with.

As a consequence of these conditions, the frequency parameter $(\omega \ell/V)$ will be the same for model and aircraft, from which the frequency ratio will be

$$\frac{\omega_M}{\omega_A} = \lambda \frac{V_M}{V_A} . \tag{11}$$

It can easily be shown that the natural frequencies of aircraft and model in a corresponding mode are related by

$$\frac{(\omega_i)_M}{(\omega_i)_A} = \lambda \left(\frac{E_M}{\gamma_M} \middle/ \frac{E_A}{\gamma_A} \right)^{\frac{1}{2}} . \tag{12}$$

Using (8) and (9), relationship (12) becomes, with (11),

$$\frac{(\omega_i)_M}{(\omega_i)_A} = \lambda \frac{V_M}{V_A} = \frac{\omega_M}{\omega_A} \tag{13}$$

showing that the flutter frequencies are in the same ratio as the natural frequencies.

Some consideration is now given to the extent to which the basic conditions can be met. It will be assumed that the model is to be smaller than the aircraft ($\lambda > 1$). If the model speed is to be smaller than the aircraft speed ($V_M < V_A$), then relationship (10) requires a lower kinetic viscosity for the model than for the aircraft, which can be achieved in a compressed air tunnel. It is usual, however, to ignore condition (10) on the assumption that Reynolds number has a comparatively small effect on the flutter characteristics.

If the model is tested in air at the full scale density ($\rho_M = \rho_A$) relationship (8) becomes $k\gamma_M = \gamma_A$, which determines the value of k for a given model density. With $k = 1$ (model thickness reduced by same scale as the overall dimensions) relationship (8) could normally be satisfied only by testing at a different density.

The speed ratio can be obtained from (9); or, alternatively, by combining (8) and (9), it is obtained in terms of the structural elastic modulus-density ratios, and in this form is independent of k, thus

$$\frac{V_M}{V_A} = \left(\frac{E_M}{\gamma_M} \middle/ \frac{E_A}{\gamma_A} \right)^{\frac{1}{2}} . \tag{14}$$

At the same time, relationship (9) shows that, for given aircraft properties (ρ_A, E_A, V_A), the lowest achievable model dynamic pressure ($\rho_M V_M^2$) is directly proportional to the model stiffness.

To complete the aerodynamic similarity, the model test Mach number should be the same as the aircraft Mach number. For high Mach numbers the model may be tested in a high speed tunnel or on rockets, when a correspondingly high model stiffness will be required; or the model may be tested in a different medium, such as freon, in which high Mach numbers can be obtained at relatively lower dynamic pressures. Mach number similarity is not always obligatory, however. Low speed wind tunnel tests are the most convenient to perform and larger models can usually be used; it is therefore common practice to investigate the comparative flutter characteristics of the various structural and loading configurations of an aircraft by low speed model tests, and then to test the most unfavourable configuration on a high speed model at representative Mach numbers. Alternatively, in cases where high speed tests cannot be made, the low speed tests may be used to check theoretical calculations, and then the Mach number effect applied (as accurately as possible) through the calculations.

Relationships (8) and (9) apply to the case where the aircraft structural layout is reproduced in the model. In cases where the aircraft structure is simulated by a different type of structure in the model, the corresponding relationships derived from (2) and (3) are

$$\frac{M_M}{\rho_M} = \frac{1}{\lambda^3}\frac{M_A}{\rho_A} \tag{15}$$

$$\frac{(EI)_M}{\rho_M V_M^{\,2}} = \frac{1}{\lambda^4}\frac{(EI)_A}{\rho_A V_A^{\,2}} \tag{16}$$

where M is a representative mass in the sense that $\frac{\delta m}{M}$ is the same for model and aircraft, and similarly for the rigidity EI. Condition (2) of page 7 must of course still be met. The relationships corresponding to (14) and (15) become

$$\frac{V_M}{V_A} = \left[\lambda\,\frac{(EI)_M}{M_M}\Big/\frac{(EI)_A}{M_A}\right]^{\frac{1}{2}} \tag{17}$$

$$\frac{(\omega_i)_M}{(\omega_i)_A} = \lambda\left[\lambda\,\frac{(EI)_M}{M_M}\Big/\frac{(EI)_A}{M_A}\right]^{\frac{1}{2}} \tag{18}$$

from which relationship (13) is again derived.

4 Types of models

Various types of models will now be described, classified broadly according to their method of construction. There are many methods of constructing aero-elastic models, and any classification is bound to be somewhat arbitrary. The broad classifications adopted here are the following: flexible skin models, segmented aerofoil models, stressed skin models, solid models, and semi-rigid models.

4.1 Flexible skin models

In these models the external skin covering is very flexible compared with the internal structure and makes a negligible contribution to the total stiffness.

A simple form of the construction that has been used at the R.A.E. consists of a wooden framework covered with a skin of silk doped with a solution of vaseline in chloroform. The wooden framework is made up of one or two spars with uniformly spaced ribs. A diagram of such a model is shown in Fig.1, and a photograph of a model in a test rig is shown in Fig.2. Any desired mass distribution is obtained by fixing suitable lead weights to the wooden structure.

The construction of this type of model is similar to that of aircraft wings of twenty or more years ago, and these models were at one time used as prediction models. Examples of their use were the models used to predict the flutter characteristics of the Puss Moth and Gamecock aeroplanes. Nowadays, these models are used mainly for research tests. They are easily constructed and will survive a surprisingly large number of flutter tests. For instance, a model used at the R.A.E. to investigate the effect of large localised masses on wing flutter survived one thousand flutter tests.

The main disadvantage of these models for research tests is that structural stiffness changes cannot easily be made to them. To investigate such changes it is usually necessary to build a series of different models. Also, at airspeeds higher than about 200 ft per sec excessive ballooning of the skin is liable to occur, and this limits the use of these models to low speed tests.

4.2 Segmented aerofoil models

The essential structure of this type of model is a single wooden or metal spar, to which solid segments are attached to provide the external contour. The segments are made of a very low density material, either balsa wood or plastic, and are fixed to the spar by single point attachments so that the segments contribute no stiffness to the spar. The narrow gaps between the segments are then covered by strips of thin sheet rubber. A diagram of a segmented wing model recently constructed at the R.A.E. is shown in Fig.3.

This type of model appears to have a fairly wide application, though experience in its use is relatively small. Different mass and stiffness distributions are obtained by making different spars, but the same segments can be used with each spar. Structural parameter variations can thus be made fairly easily, and these models are therefore very suitable for research tests. At the same time they also have a good application as prediction models, since the spars can be made to represent the essential characteristics of an aircraft structure, based on theoretical design values (group B(1) of section 1); in particular, structural discontinuities such as cut-outs for undercarriage wheel bays can be represented in the model spar. These models do not suffer from skin ballooning and are therefore not limited to low speed tests. The main uncertainty with them is that concerned with the aerodynamic effect of the discontinuities or steps that occur between the segments as the model deforms. This effect would, of course, be lessened the greater the number of segments used.

In an alternative form of the construction the external contour is built up as a solid structure integral with the spar, and this structure is subsequently divided into segments by slots running to the spar. This enables models to be constructed more easily and quickly, but the segments contribute in some measure to the total stiffness, which becomes less controllable. Models of this type have been tested on rockets up to supersonic speeds.

4.3 Stressed skin models

As the name implies, the construction of these models is similar to that of modern aircraft in that the skin is a major stress carrier under load and contributes largely to the total stiffness. This type of model is mainly used for prediction tests where a close representation of the aircraft structure is required and the effect of varying structural parameters is to be investigated to a minor extent only, if at all. As these models are comparatively difficult to construct they are not generally used for tests where structural parameters are to be varied extensively.

The internal structure of the model may vary from a solid "filler" to the more conventional rib-spar structure. Models with a single spar combined with solid "filler" are probably the easiest to construct of those that can be used for prediction tests. There is a lower limit to the model skin thickness that can be used, because of buckling and manufacturing difficulties, and if the material used is the same as that of the aircraft (i.e. metal or wood) it is generally found that even with the lowest skin thickness possible the model stiffness is so high that the model is suitable only for high speed tests. This is no disadvantage if complete representation is required, but if it is desired to make low speed tests on a prediction model this type of model presents some difficulty.

One way out of the difficulty that has been tried is to use a plastic material for the model. In England some stressed skin models have been made in the plastic Xylonite, whose elastic and shear moduli are in approximately the same ratio as those of aluminium alloy but the absolute values are much lower. This enables Xylonite models to be made with reasonable skin thicknesses but with overall stiffnesses low enough for low speed tests. A notable example of this type of model was that of a delta winged aircraft made by Boulton Paul Aircraft Ltd. (A photograph of this model is shown in Fig.4.) In this case the model structure was a complete replica of the aircraft structure, even to small details. The model span was 5 ft, the overall scale factor ($^1/\lambda$) 0.186, the skin thickness scale factor ($^k/\lambda$) 0.391, and the speed ratio achieved was $V_M/V_A = 1/3.06$.

The disadvantages of Xylonite are that its stiffness is appreciably affected by temperature and humidity changes, and that creep of the material occurs under load. These properties are obviously undesirable for flutter work. Xylonite is also highly inflammable. Another plastic, Vinidur, was used for models in Germany during the last war; it is less susceptible to temperature, humidity, and creep effects, but is more brittle. It appears that both Xylonite and Vinidur models are liable to fail at comparatively low amplitudes of oscillation, and special precautions are particularly necessary with them.

Stressed skin research models with skins of aluminium alloy, plywood, and perspex, combined with a single spar and solid "filler", have been tested at the R.A.E. on rockets through the transonic speed range. Fig.5 shows the construction of these models, and Figs.6 and 7 show the assembly on the rocket.

4.4 Solid models

This class of models covers all those which have a solid internal structure but which do not possess a separate stress-carrying skin. Stressed skin models with a solid internal structure, already described in section 4.3, are thus excluded.

The simplest type of solid model is that which is made from a piece of homogeneous material, usually metal or wood. Such models are probably the easiest to manufacture, but are generally used only as research models since they cannot usually be made representative of aircraft structures. They are, however, eminently suitable as prediction models for the aerodynamic surfaces of guided missiles, which are often made in a similar way. The stiffnesses of these solid models are usually such as to restrict their use to high test speeds.

These models may be given a representative aerodynamic contour, or, in their simplest form, they may be made from flat metal plate with the leading and trailing edges rounded off. Flat plate models are particularly easy to construct, and they have been used extensively in America for general research tests at high speeds. In Britain they have been used very little, as it is considered that, even for research tests, they are too unrepresentative of aircraft constructions. In the author's opinion, however, they have a useful application in research tests where the main purpose is to obtain comparisons between experiment and theory. In other words, with reference to the model groups designated in section 1, flat plate models are unsuitable for groups A(1) and A(3), but may be usefully employed in group A(2).

Methods have been considered of making solid models more representative of aircraft structures. Two recent examples from America are interesting. The first is a simple development of the flat plate or machined metal solid model; the solid model is first made, and then a number of holes are drilled through the model. By varying the number, location, and size of the holes, different stiffness characteristics can be obtained, and stiffness characteristics that are fairly representative of aircraft structures can be achieved. The holes are subsequently filled in with a plastic "filler" to preserve the aerodynamic contour. Fig.8 illustrates a typical model of this type. It is doubtful whether such models could be employed as prediction models, but they enable solid models to be used for research tests in which structural parameters are varied with a given aerodynamic contour.

The second example is a fairly elaborate attempt to build a prediction model of a delta wing. A lattice structure of wooden spars (see Fig.9) forms the basic structure of the model, and the required stiffness characteristics of the model are presented in the form of influence coefficients for particular points of the lattice. An influence coefficient in this connection is defined as the deflection at one point of a structure due to unit load applied at another point, and the stiffness characteristics of a structure can be represented by the influence coefficients for an array of points presented in the form of a square symmetric matrix. The influence coefficients for the prediction model are derived from those for the aircraft by scale relationships similar to those presented in Section 2. In this particular example the required model influence coefficients are obtained by successive adjustment of the spar thicknesses, the influence coefficients being measured at each stage. Finally, the spaces between the spars are filled in with balsa wood to provide the aerodynamic contour. The process, though attractive in principle, is rather laborious in practice.

4.5 Semi-rigid models

These constitute a rather special class. A semi-rigid model is designed to deform in certain simple prescribed modes only, and it is almost entirely restricted to research tests where the main objective is a comparison between theory and experiment. The employment of a semi-rigid model serves to define the kinematic properties of the model precisely and thereby to reduce the uncertainties in the theory to that extent.

A common example of a semi-rigid model is that of a wing, constructed so that at the test speeds concerned it is virtually rigid in itself, but it is allowed freedoms in pitch about an axis along the wing and in roll about the root. The motions of the wing in pitch and in roll are separately restrained by appropriate springs. Such a model is illustrated in Fig.10 and, in terms of the wing mode terminology commonly used, it may be regarded as possessing only the two degrees of freedom of linear flexure and uniform twist. For the purpose of the tests the stiffnesses of the restraining springs may be and usually are varied, but it is important that in varying these spring stiffnesses the natural frequencies of the model in its prescribed modes should be kept well below the natural frequencies of the wing itself, which is intended to be effectively rigid. This sometimes presents a problem when semi-rigid models are used for high speed tests.

An interesting recent application of semi-rigid models at the R.A.E. has been to use them in flutter tests to obtain the aerodynamic forces operating on the fluttering model. The semi-rigid model, as already mentioned, defines the kinematic properties of the model, and in consequence the flutter equations for the model are likewise defined. Measurements are made of the airspeed and frequency, and of the amplitude and phase relationships between the degrees of freedom in a flutter condition. Repeat measurements are made for different flutter conditions, obtained by varying the spring stiffnesses, and the aerodynamic coefficients in the flutter equations are then obtained directly from these equations on substitution of the measured quantities. The method has so far been used for low speed tests only.

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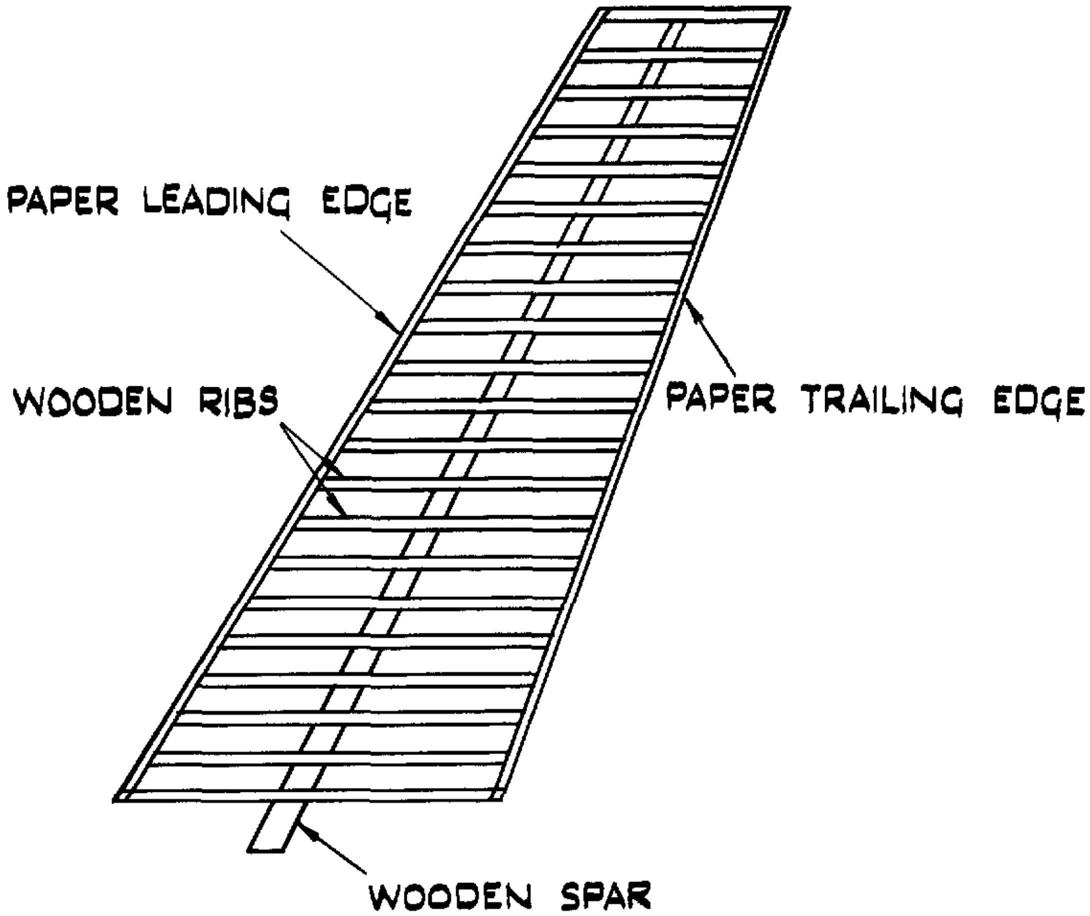


FIG. 1. WOOD AND SILK CONSTRUCTION

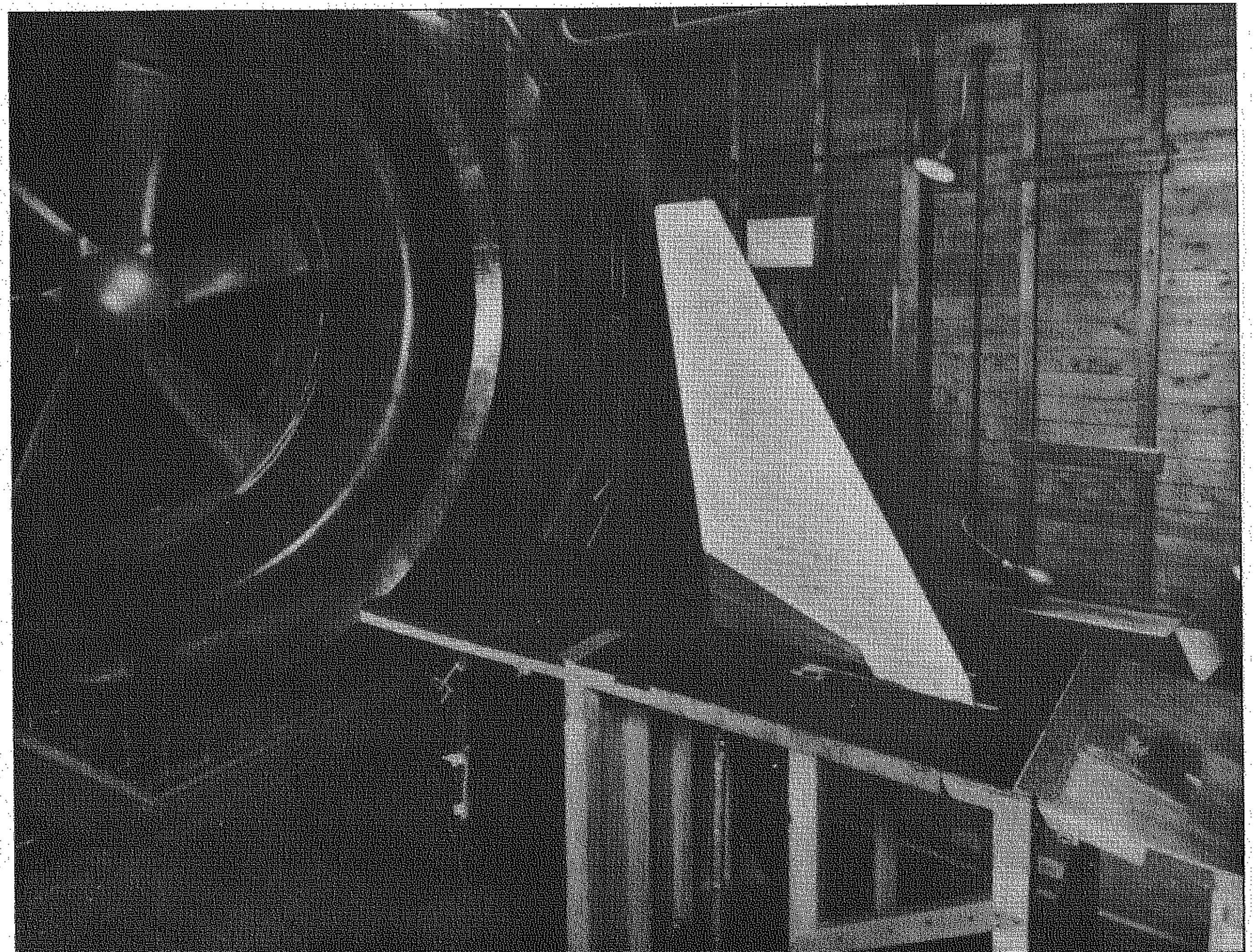


FIG.2. WOOD-SILK MODEL IN TEST RIG

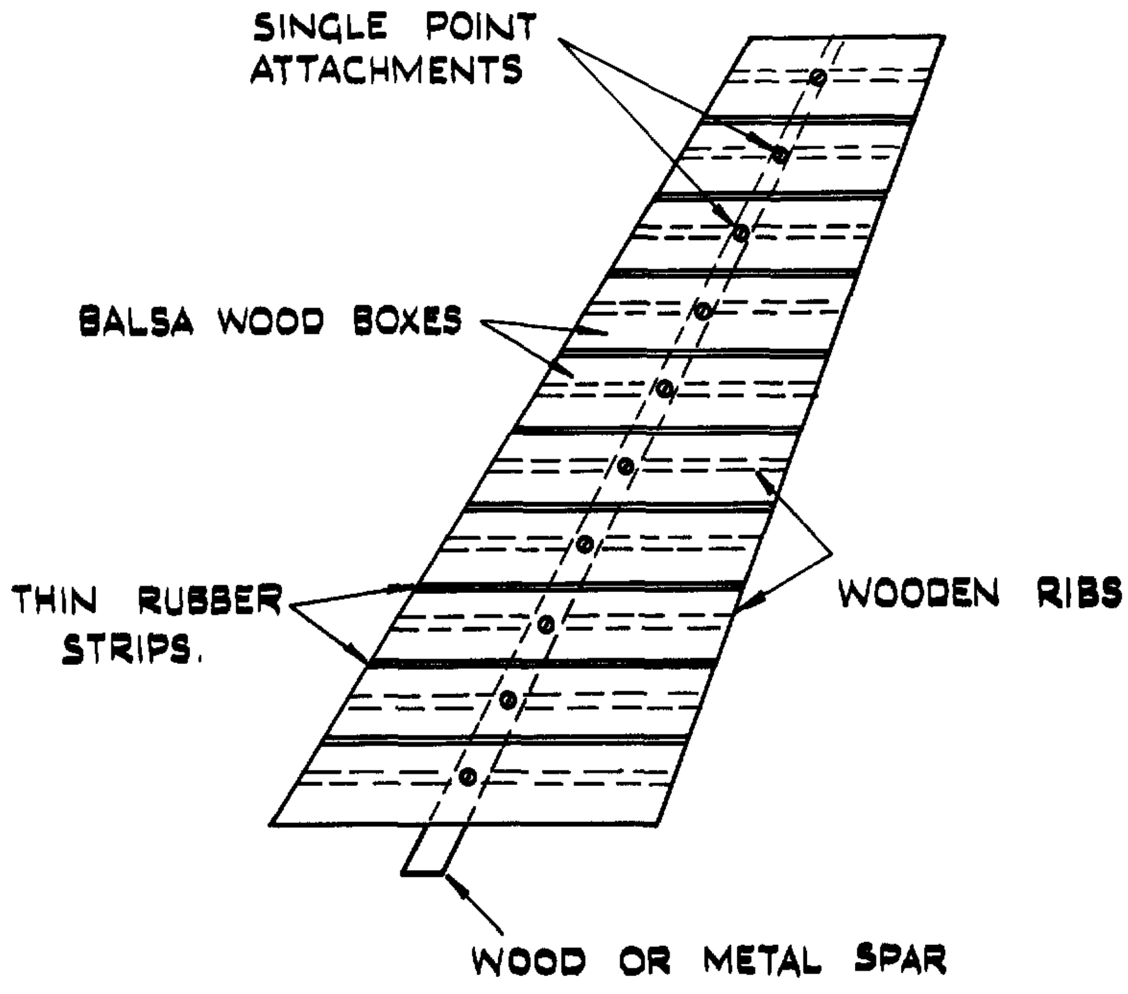


FIG. 3. SEGMENTED BOX CONSTRUCTION

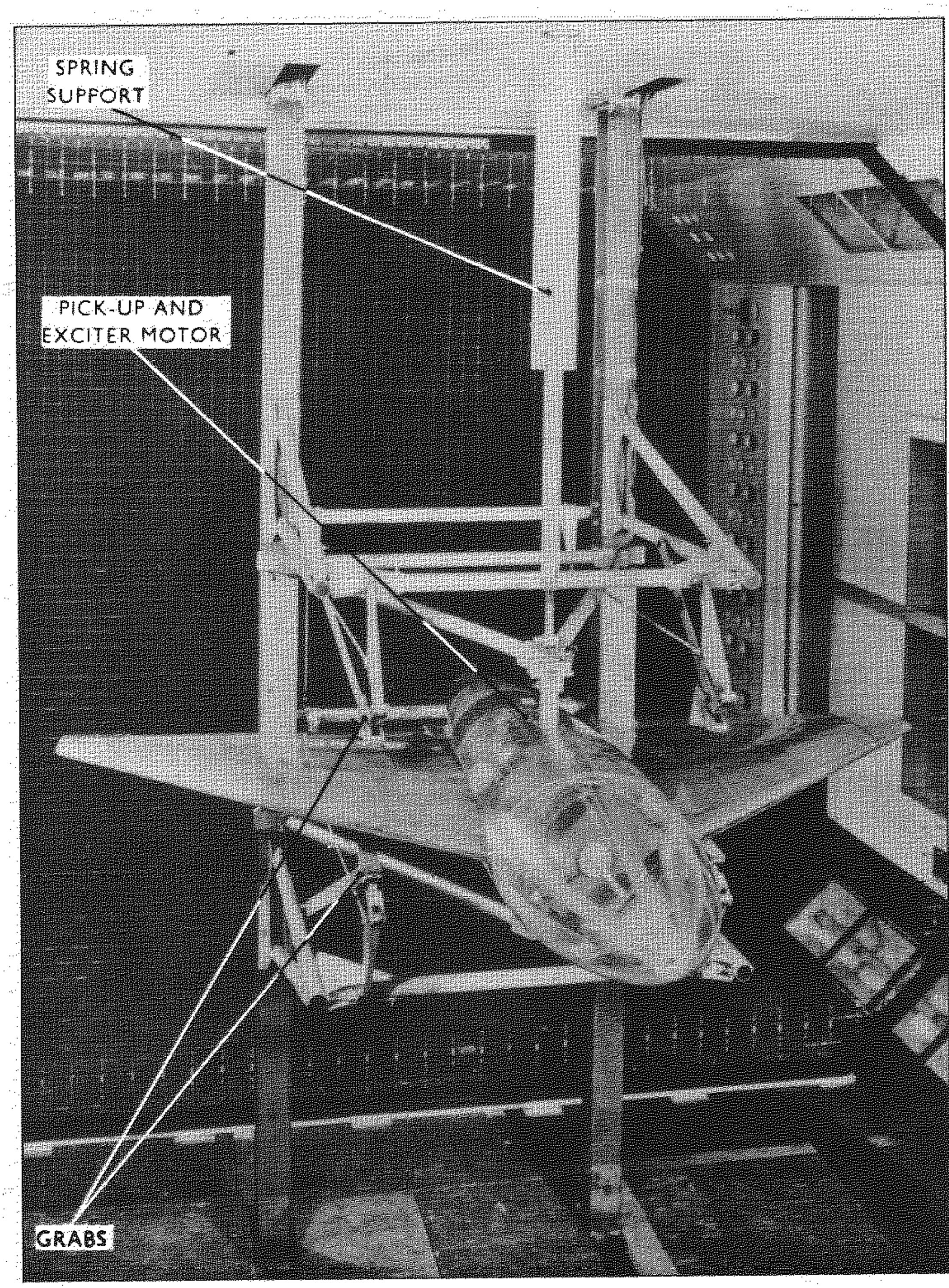
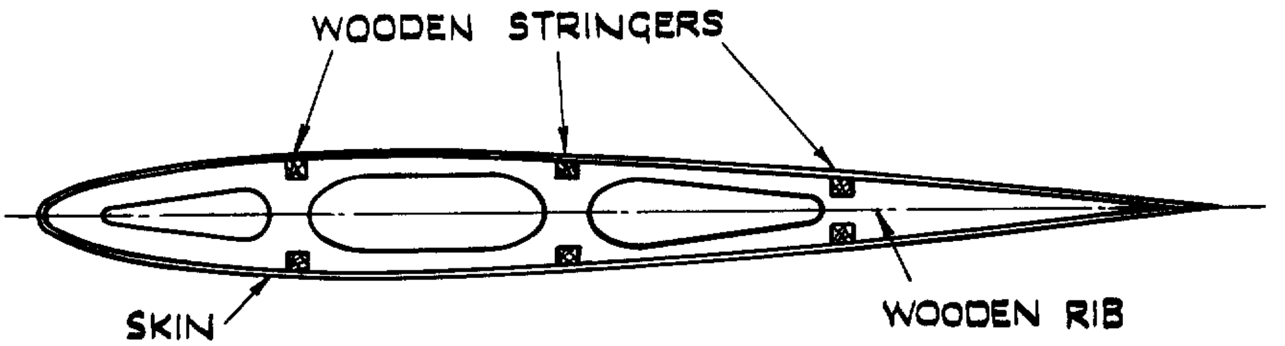


FIG.4. DELTA WING MODEL IN XYLONITE



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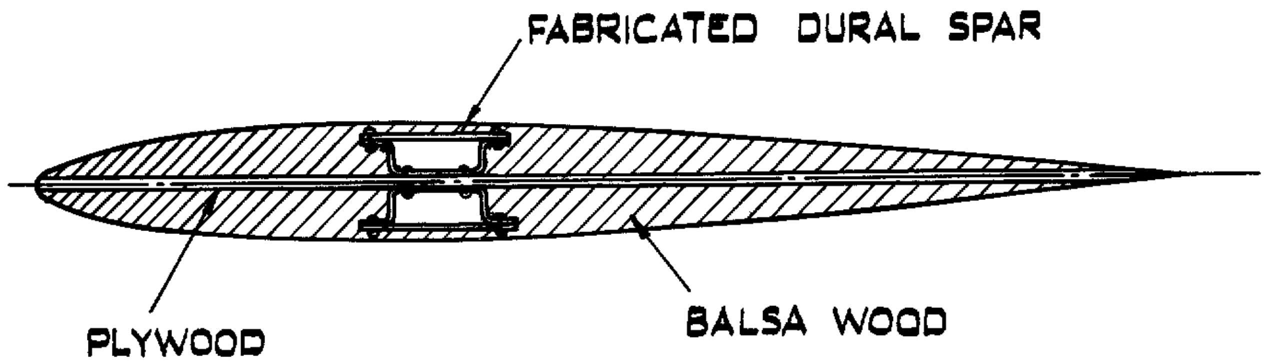
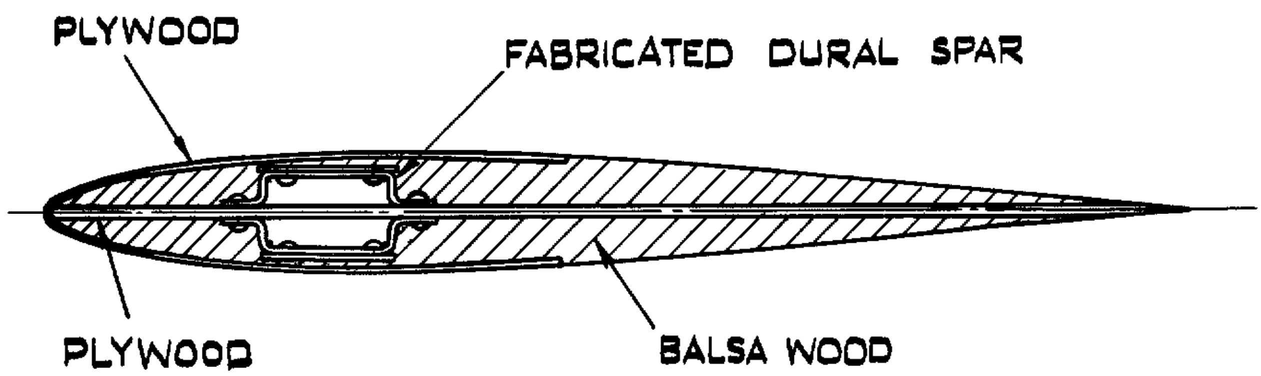


2. SOLID CONSTRUCTION



3. STRESSED SKIN WITH SOLID FILLER

FIG. 5. TYPES OF WING CONSTRUCTION USED FOR ROCKET MODELS.

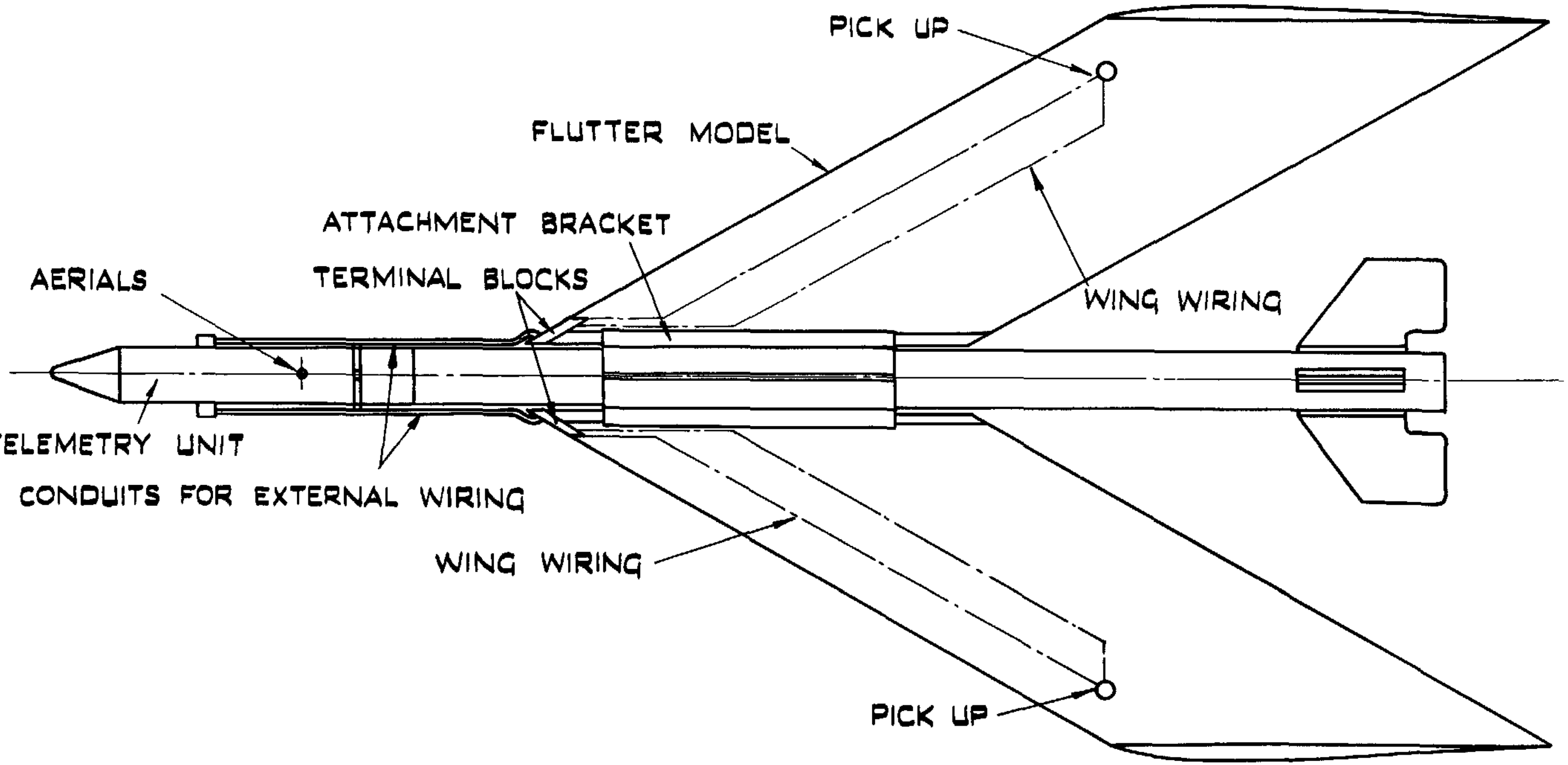
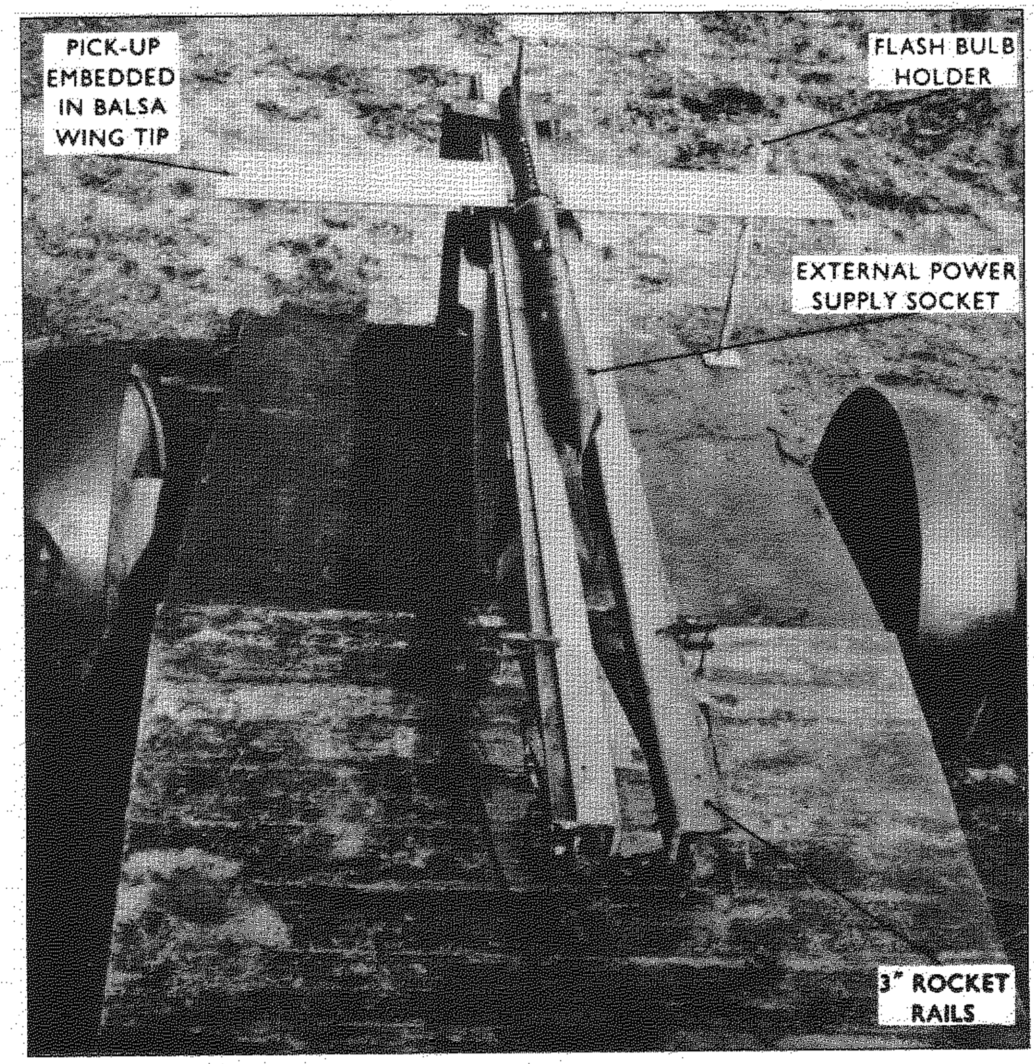
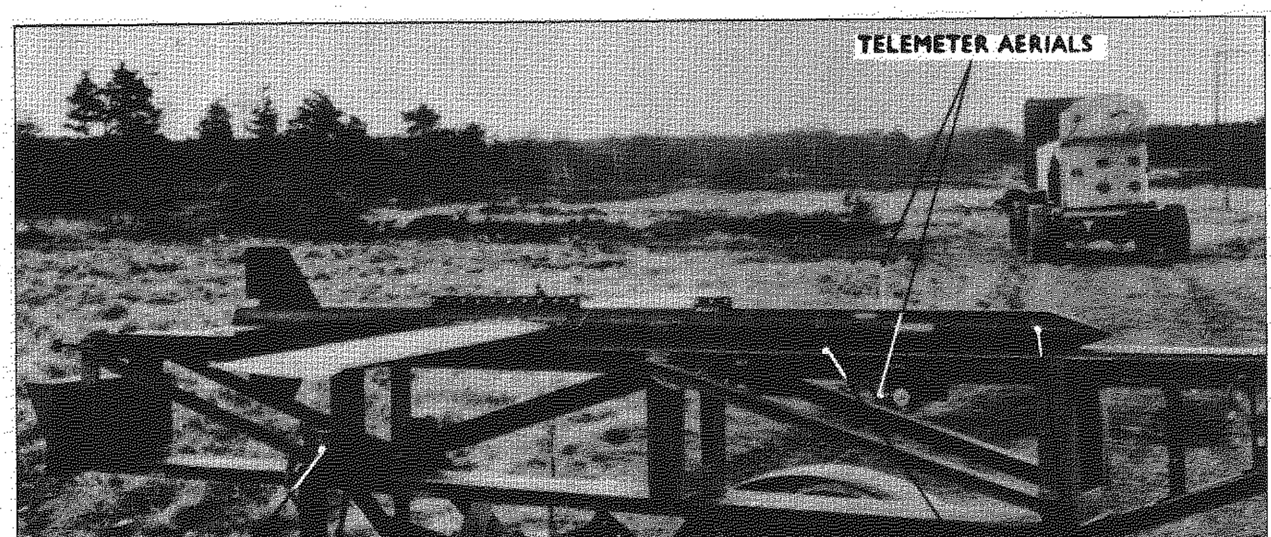


FIG. 6 ASSEMBLY OF WING MODEL ON ROCKET


PICK-UP
EMBEDDED
IN BALSA
WING TIP
FLASH BULB
HOLDER
EXTERNAL POWER
SUPPLY SOCKET
3" ROCKET
RAILS


TELEMETER AERIALS
HINGE
ELEVATION ADJUSTMENT
TELEMETER AND BALLAST
WEIGHT HOUSING

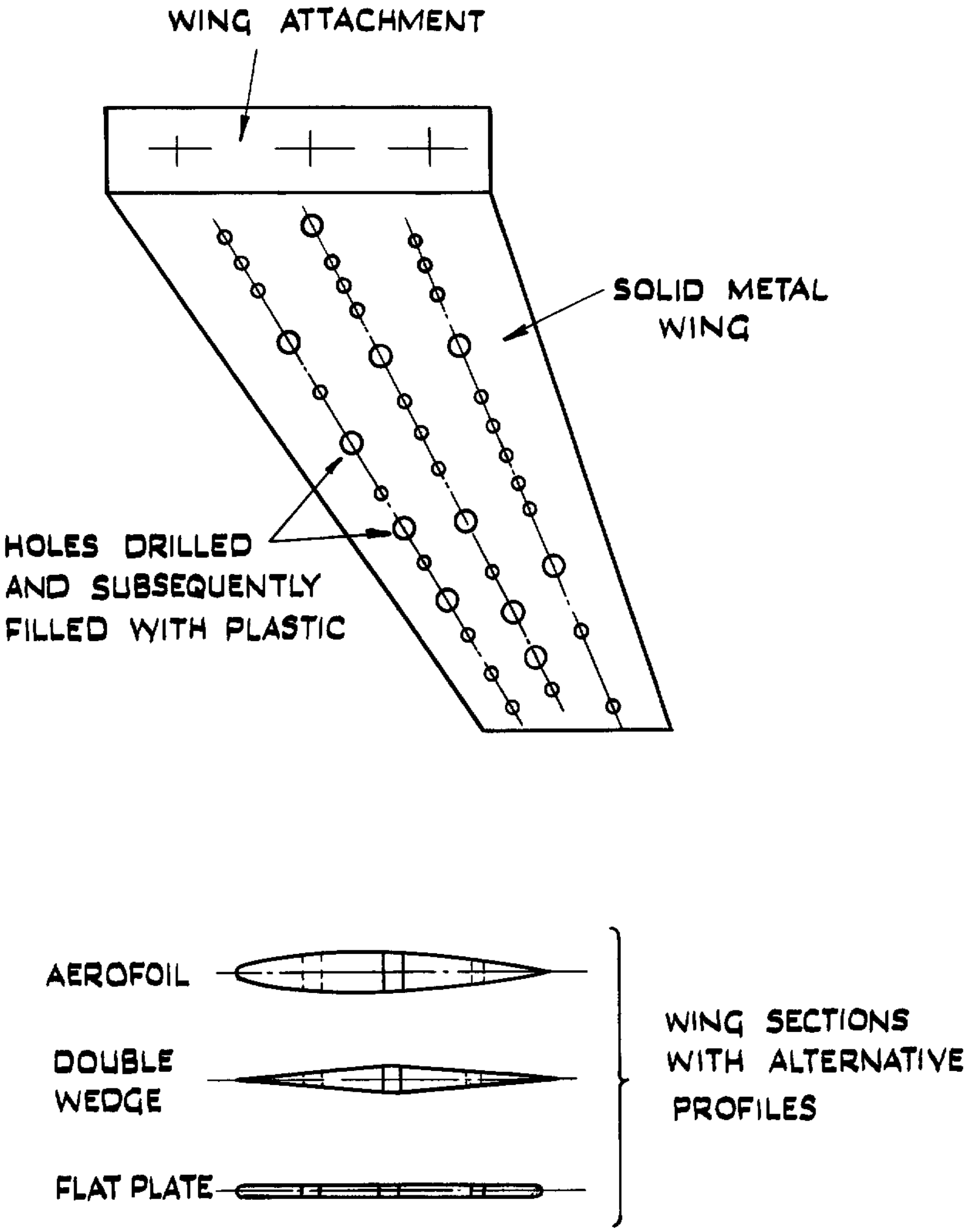


FIG. 8. THE SOLID "HOLED" MODEL.

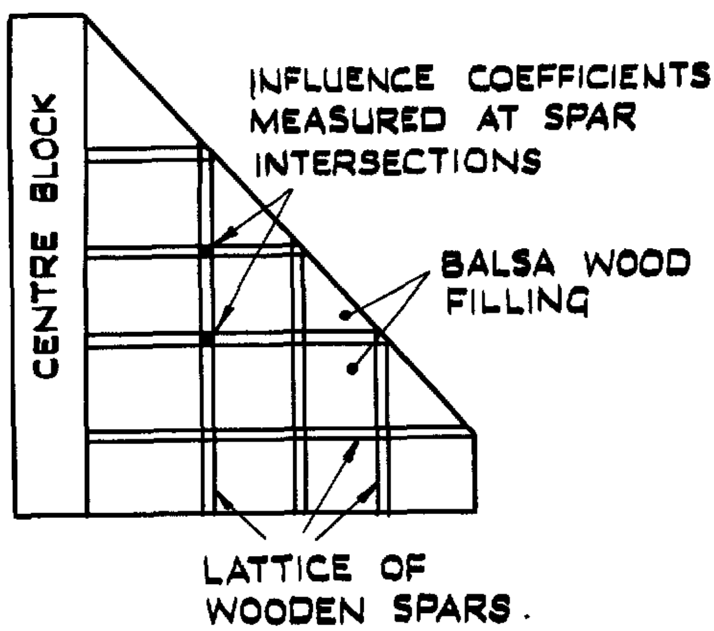


FIG. 9. LATTICE DELTA MODEL

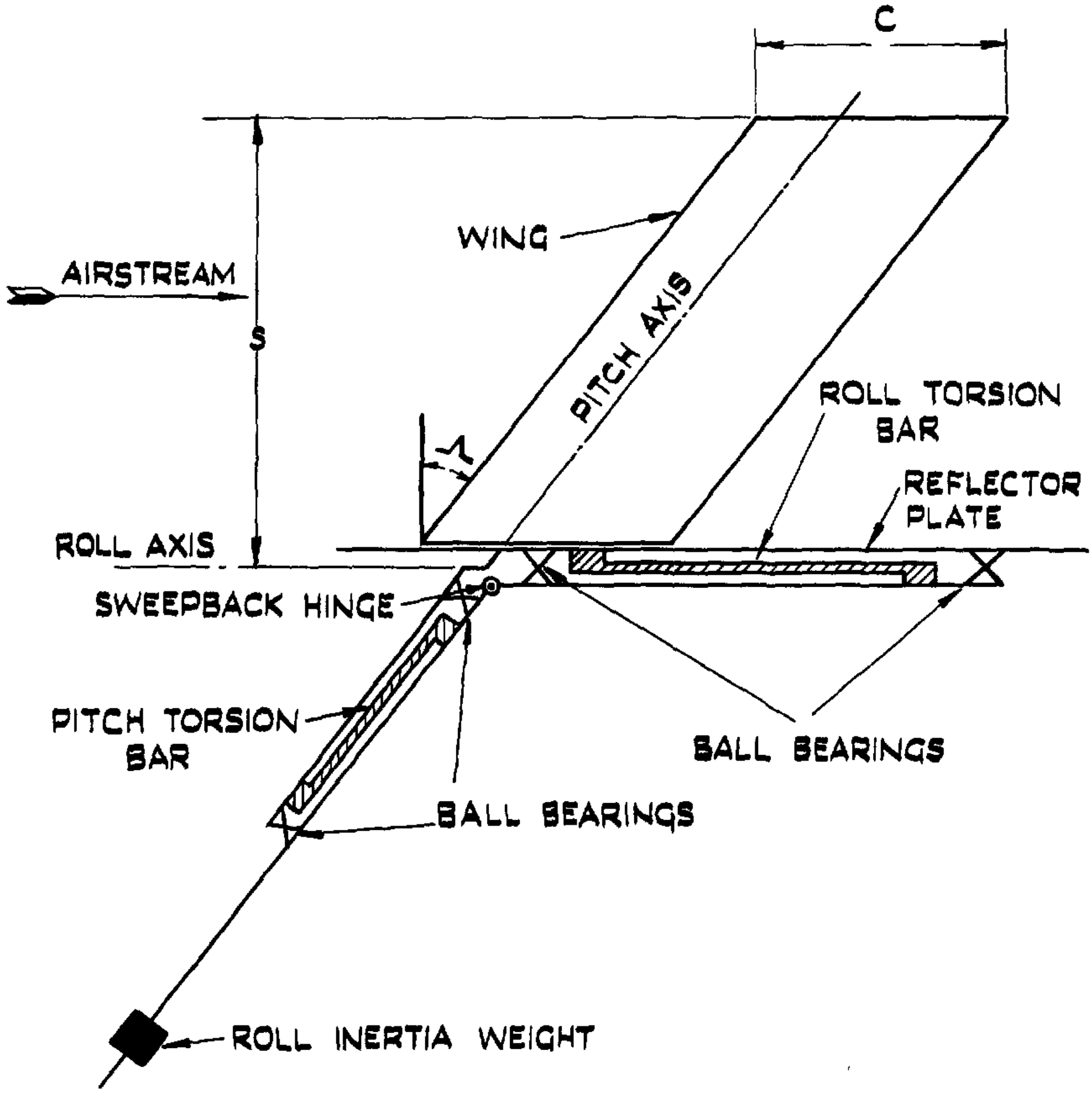


FIG. 10. SEMI - RIGID WING MODEL

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