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Wind Tunnel Flutter Tests on an M-Planform Wing

by

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WIND TUNNEL FLUTTER TESTS ON AN M-PLANFORM WING

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SUMMARY

Tests were made in a low speed open jet wind tunnel to obtain the effects on the flutter of an M-wing of variation of inertia parameters of a nacelle at the wing kink. The effect of fuselage mobility was also investigated.

The results show that for the particular wing tested a nacelle mass up to about 0.8 of that of the wing can be tolerated at the kink without a significant adverse effect on flutter, and, in general, an aft position of nacelle c.g. is to be preferred. Lower flutter speeds are associated with symmetric fuselage freedoms than with antisymmetric ones.

The latter result is thought to apply to M-wings in general but the majority of the results obtained cannot be generalized.

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1 INTRODUCTION

Recent investigations of possible designs for a transonic transport aeroplane have been made by R.A.E.[1] which indicate that a wing of M-planform may have certain advantages aerodynamically. However, the aero-elastic properties of such wings also require consideration, and accordingly some theoretical investigations of aero-elastic effects have been made by Broadbent. In parallel with these investigations wind tunnel tests, described herein, have been made on a flexible M-wing having the basic planform of wing B (Fig.18) of Bagley's paper[1]. For this planform the wing kink is at 0.5 semi-span from the root, which Broadbent shows is a likely position from considerations of wing weight, strength and divergence speed.

A large nacelle is necessary at the wing kink for aerodynamic reasons[1], and the possible uses of this nacelle for fuel storage, engine installation, etc. imply wide variations in nacelle inertia properties that may affect the aero-elastic characteristics. The present wind tunnel tests are therefore largely concerned with the effects on wing flutter of variations in the nacelle parameters for different wing root constraints, i.e. with symmetric and anti-symmetric body freedoms.

2 DETAILS OF THE MODEL WING AND TEST RIG

A half wing model was used. The basic wing planform is shown in Fig.1, and the main details of construction are shown in Fig.2. The structure consists of a rectangular, solid dural spar at 0.4 chord aft of the leading edge with streamwise solid spruce ribs, 0.375" thick spaced at intervals of 1.0" along the span. Balance weights are provided on each rib to locate the wing inertia axis at 0.5 chord, and the wing is covered with silk doped with a solution of vaseline in chloroform. The inboard and outboard parts of the wing are connected by fork-ends on the spars that transmit bending and torsion loads whilst enabling the outer wing to be rotated relative to the inner wing through a sweep angle of $\pm 10^{\circ}$ from the basic position. A fairing encloses the structure at the kink, and consists of a light balsa shell of circular cross section. The fairing provides an adequate aerodynamic representation of the nacelle but its inertia properties are small enough to be neglected. This configuration is referred to as the 'bare wing'.

To obtain variations in the nacelle inertia parameters the remote loading rig developed by Gaukroger[2] was used (see Fig.3). With this arrangement the minimum inertia properties for the nacelle are obtained with the unloaded rig. Two basic configurations of the loading rig were used, one with a long loading platform (nacelle 'A') and the other with a short one (nacelle 'B'). Masses up to about 0.8 of the wing mass could be attached to the loading platforms.

The rig providing wing roll freedom[2] is shown in Fig.4, and that providing pitch and translation freedoms[2] in Fig.5. For the main series of tests the mass, roll interia and pitch inertia of the "fuselage" were fixed.

The mass and moment of inertia data for the wing, the "nacelles" and the "fuselage" are given in Table 1, together with some wing stiffness data*.

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*The fuselage is particularly massive by aircraft standards, but this was unavoidable since the test rigs were designed for conventional wings and could not adequately cater with the far forward aerodynamic centre of an M-wing. However, the results serve to indicate the trends to be expected with body freedom present, which was the main purpose of the tests.

3 TEST PROGRAMME

Resonance tests were made on the fixed root bare wing to obtain the resonance frequencies and nodal line positions for the first three modes, and the results are shown in Fig.7. In the subsequent flutter tests the first two resonance modes were dominant, and neither of these corresponds with a conventional mode of wing torsion, such as is usually found in wing flutter. However, the second mode contains a considerable amount of wing incidence as is evidenced by the nodal line crossing the nacelle. The third mode, which appeared to play little part in wing flutter, is primarily torsion of the inner wing about the spar axis and overtone bending of the outer wing.

For the flutter tests the wing was mounted vertically in the R.A.E. 5 ft open jet low speed tunnel. The main programme of tests was to determine the effects on flutter of mass value, moments of inertia and centre of gravity position for masses added to the basic nacelles. Investigations were made on the fixed root wing, on the wing with roll freedom for a particular fuselage rolling moment of inertia, and on the wing with pitch and translation freedom for a particular fuselage mass and pitching moment of inertia. For all tests the configuration was without a tailplane.

Some additional tests were made on the fixed root wing to investigate the effects of sweep variations for the inboard and outboard parts of the wing. The effect of variation of fuselage rolling moment of inertia was also investigated for the wing with "bare" nacelles, (i.e. no added masses).

4 RESULTS

The model wing as originally designed had a main spar of constant cross section for both the inboard and outboard parts. With this arrangement divergence of the bare wing occurred at about 70 ft/sec before the wing fluttered, though there were indications that removal of the balsa fairing at the kink raised the divergence speed to the point where a near flutter condition was obtained. The wing was modified by a 1/32" thick plywood insert on the upper and lower wing surfaces in neighbourhood of the spar, over the span of the inner wing (see Fig.6), which markedly increased the flexural stiffness (see Table 1) and raised the divergence speed far above the flutter speed. All the investigations of nacelle parameter variations were made on the modified wing.

The results are shown in Figs.8 to 12.

Fig.8 shows the effect of fuselage rolling moment of inertia for the wing with bare nacelles, and indicates that for values of fuselage rolling moment of inertia within the practical range there is a powerful stabilising effect of the roll freedom on flutter. The value of roll inertia chosen for the basic fuselage for subsequent tests is large by current standards, but ensures that the basic roll freedom flutter speed is low enough for trend investigations to be made within the limited speed range of the tunnel.

It is worth noting that in the course of the above investigations a near divergence condition for the wing was obtained at a tunnel speed of 210 ft/sec, when the fuselage roll inertia was small. In this condition the flutter speed is high, and divergence is opposed by the stabilizing springs of the roll rig.

Figs.9 and 10 show the effect of variation of a concentrated mass (i.e. a mass with negligibly small radius of gyration) at various chordwise positions with different wing root constraints. Similar trends are obtained with both nacelles and they may be summarised as follows:-

(a) The flutter speeds obtained with roll freedom are, in general, far higher than those for the wing with fixed root or with pitch and translation freedom.

(b) The flutter speeds obtained with pitch and translation freedom are somewhat higher than those for the fixed root wing for mass values up to about 0.5 of the wing mass. For greater mass values higher speeds are obtained for the fixed root condition provided the mass is in a forward position.

(c) If the mass is less than about 0.5 of the wing mass then higher flutter speeds are obtained with aft positions of the mass than with forward ones.

(d) For a mass of about 0.5 to 0.8 of the wing mass the flutter speed in the fixed root case rises very rapidly for forward positions and less rapidly for aft positions. When there is pitch and translation freedom the greatest increase in speed is obtained with aft positions of the mass.

Figs.11 and 12 show the results of a similar series of tests to those of Figs.9 and 10 for the effect of a localised mass (i.e. a mass having a appreciable radius of gyration) at various positions. The radius of gyration of the mass differs in the two cases and fewer c.g. positions can be investigated than for a concentrated mass because of the limited length of the loading platforms. Comparing Fig.11 with Fig.9 (nacelle A) and Fig.12 with Fig.10 (nacelle B) the trends obtained may be summarised as follows:-

(e) For nacelle B there is little effect of radius of gyration for the cases considered except that it has a stabilising influence on roll freedom flutter.

(f) For nacelle A the effect of radius of gyration is to improve the flutter properties for forward positions of the mass. For aft positions of the mass a reduction in flutter speed is obtained in the fixed root case, but when there are pitch and translation freedoms the effect is negligible.

Fig.13 shows the effect of sweep variations on the inboard and outboard parts of the fixed root wing for the bare wing and bare nacelle configurations. For the range of sweep investigated the effect on flutter is quite small.

5 CONCLUSIONS

The main conclusions to be drawn from this series of tests are as follows:-

(1) For an M-wing lower flutter speeds are likely to be associated with the symmetric body freedom case than with the antisymmetric case.

(2) Masses that are a considerable fraction of the wing mass (up to about 0.8 M_W) can be tolerated in aft positions at the kink without adversely affecting the flutter properties. In the majority of cases aft positions are to be preferred to forward ones.

(3) Small variations in sweep of the inboard and outboard parts of the wing are unlikely to have a significant effect on flutter.

It should be appreciated that these results are obtained from tests on one particular wing, and generalisation could be dangerous. Broadbent's theoretical investigations show that conclusions 1 and 3 may be general for M-wings with a kink at mid-semi-span, but conclusion 2 depends largely on the flexure:torsion stiffness ratio for the inner wing. For lower stiffness ratios (around five) it would appear that forward positions of nacelle c.g. are to be preferred.

LIST OF REFERENCES

No.	Author(s)	Title, etc.
1	Bagley, J.A.	An aerodynamic outline of a transonic transport aeroplane. A.R.C. 19,205, October, 1956.
2	Gaukroger, D.R. Chapple, E.W.	Wind tunnel tests on the effect of body freedoms on the flutter of a model wing carrying a localised mass. R. & M. 3081. May, 1956.

TABLE 1

Wing details

Wing section R.A.E. 101 t/c = 0.06
Sweep of $\frac{1}{4}$ chord line of inner wing = 55°
Sweep of trailing edge of outer wing = 55°
Wing span, root to tip (s) = 38 in.
Wing chord at the kink (c_k) = 12 in.
Wing aspect ratio (A) = 5
Wing weight, root to tip (M_W) = 4.6 lb
Wing c.g. position = 0.39s outboard from root, 1.60 c_k aft of leading edge of kink chord
Wing roll moment of inertia about root (I_R) = 2040 lb in.^{2}
Wing pitch moment of inertia about 0.5 c_k (I_p) = 1320 lb in.
Torsional stiffness of inner wing normal to spar = 11.3 lb ft/rad
Flexural stiffness of inner wing = 314 lb ft/rad
Spar length root to kink = 31.0 in.
Torsional stiffness of outer wing normal to spar = 6.8 lb ft/rad
Flexural stiffness of outer wing = 25.8 lb ft/rad
Spar length, kink to tip = 31.0 in.
Torsional stiffness in line of flight at 0.7s (m_θ) = 17.7 lb ft/rad
Flexural stiffness at 0.7s (ℓ_ϕ) = 56.6 lb ft/rad

Nacelle "A"

Weight of nacelle = 1.24 lb
c.g. position = 0.5 c_k
Pitch moment of inertia about c.g. = 134 lb in.^{2}

Nacelle "B"

Weight of nacelle = 0.79 lb
c.g. position = 0.5 c_k
Pitch moment of inertia about c.g. = 21 lb in.^{2}

Fuselage (values appropriate to the half wing)

Weight of fuselage = 12.7 lb
c.g. position = 1.5 c_k aft of the leading edge of the kink chord
Pitch moment of inertia about c.g. = 3100 lb in.^{2}
Roll moment of inertia = 810 lb in.^{2}

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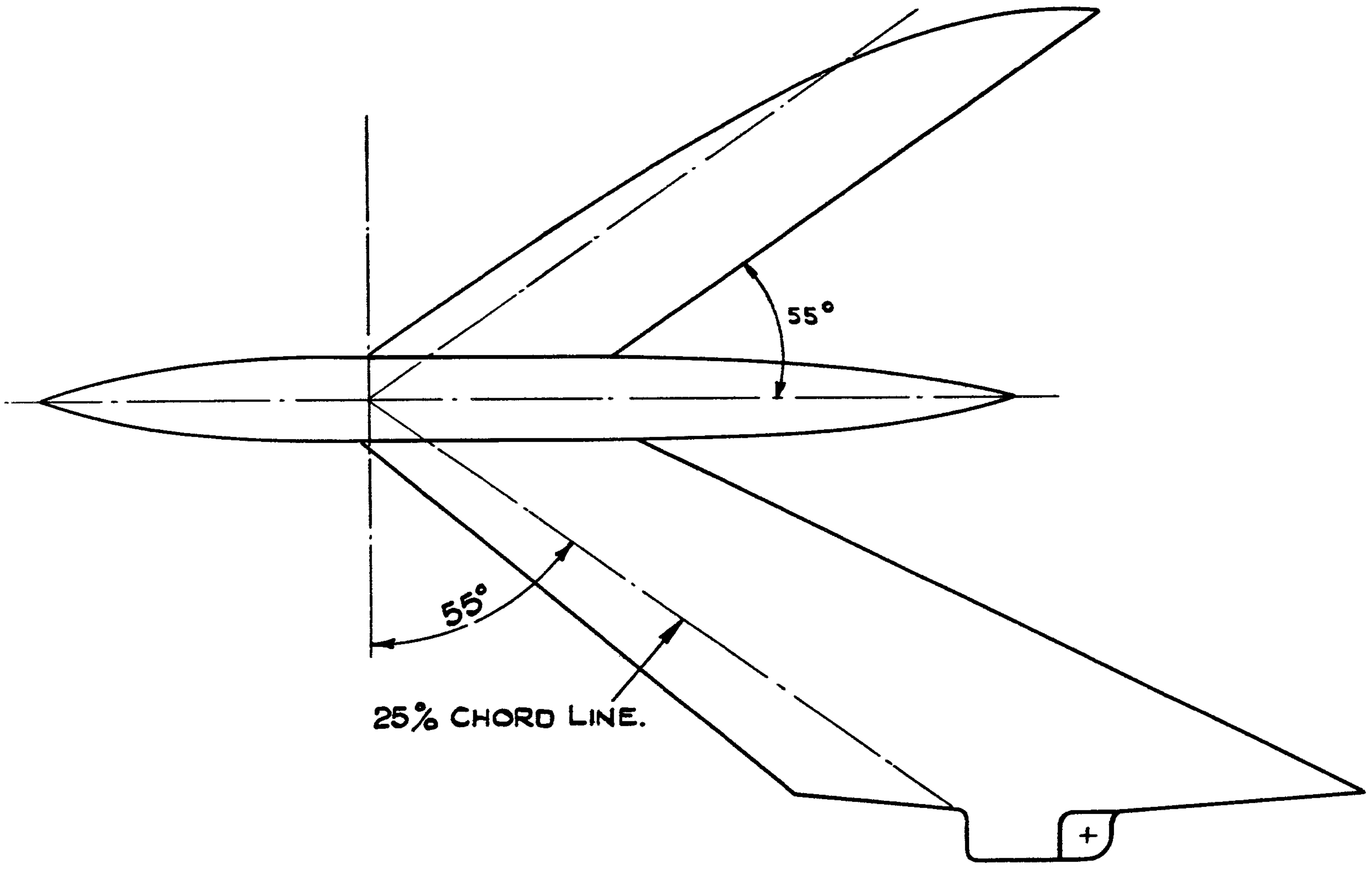
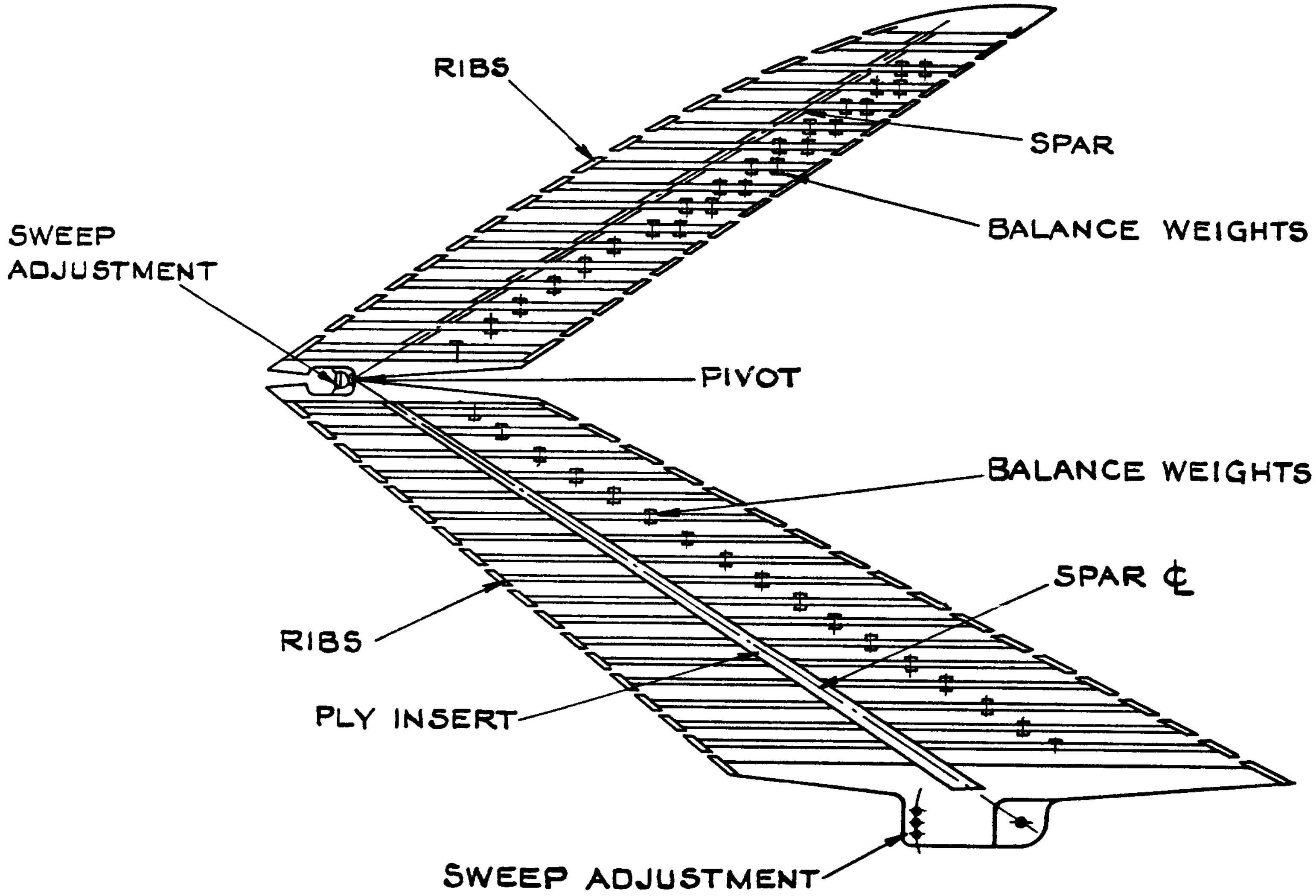


FIG.I. BASIC PLANFORM



WING COVERING :- SILK

FIG.2. WING DETAILS

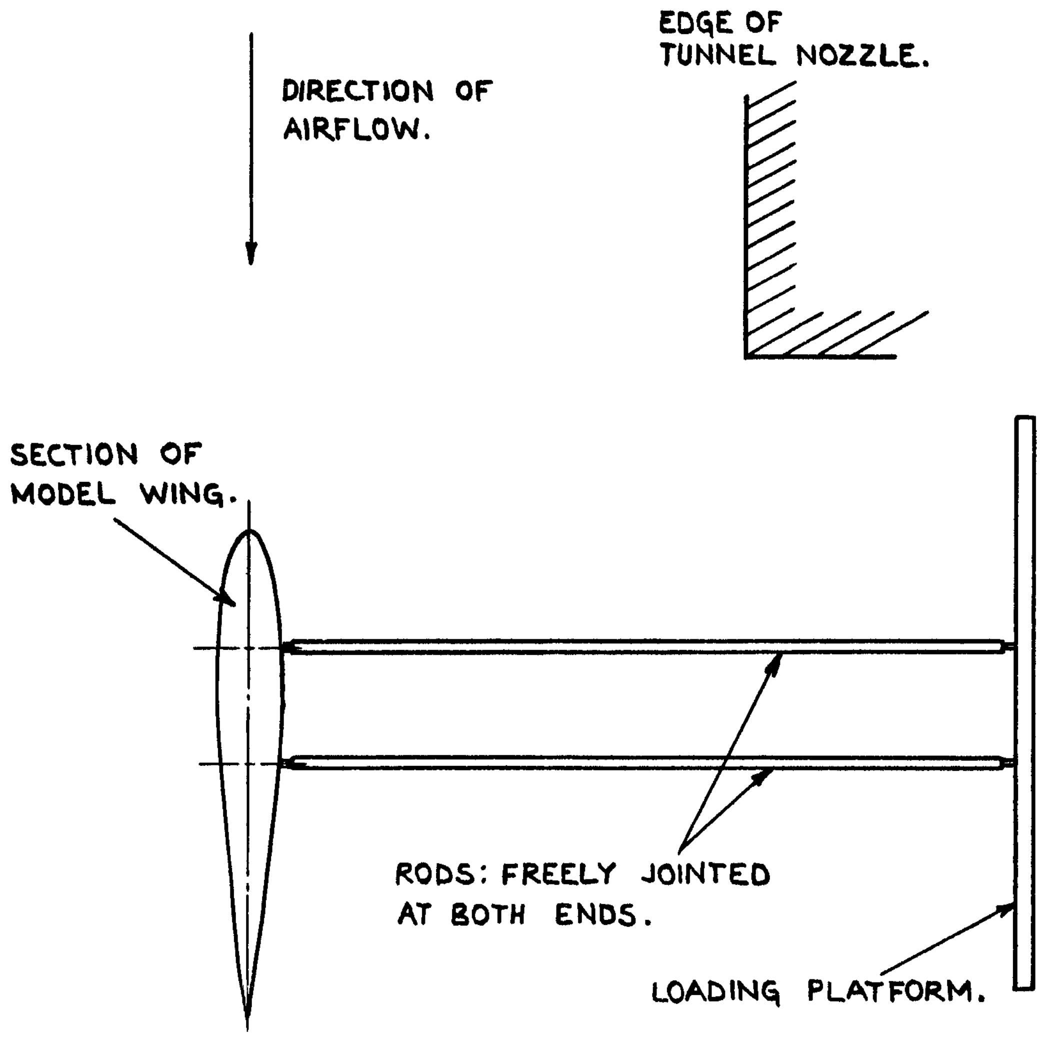


FIG. 3. METHOD OF APPLYING INERTIA LOADS.

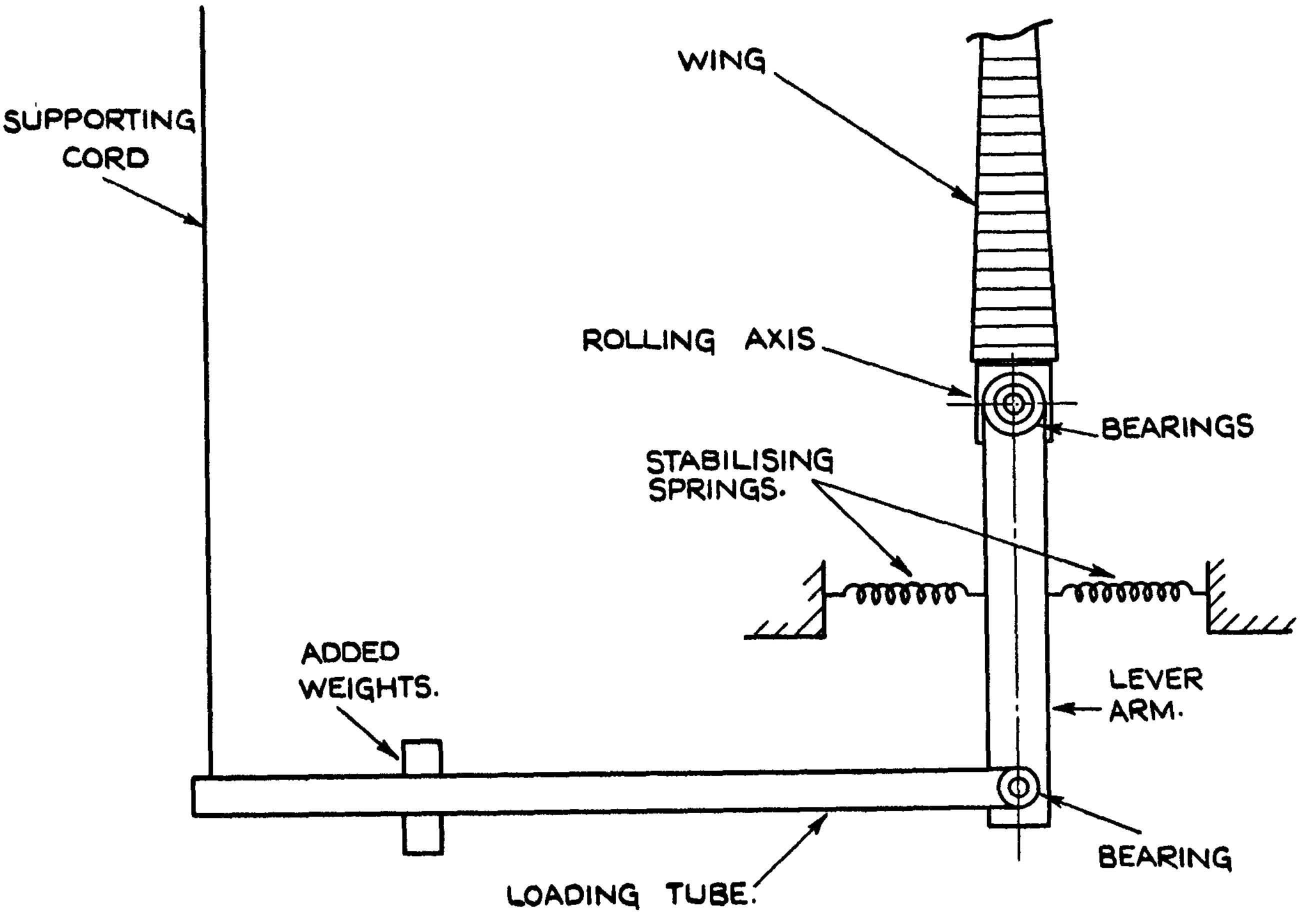


FIG. 4. ARRANGEMENT OF ROLLING FREEDOM.

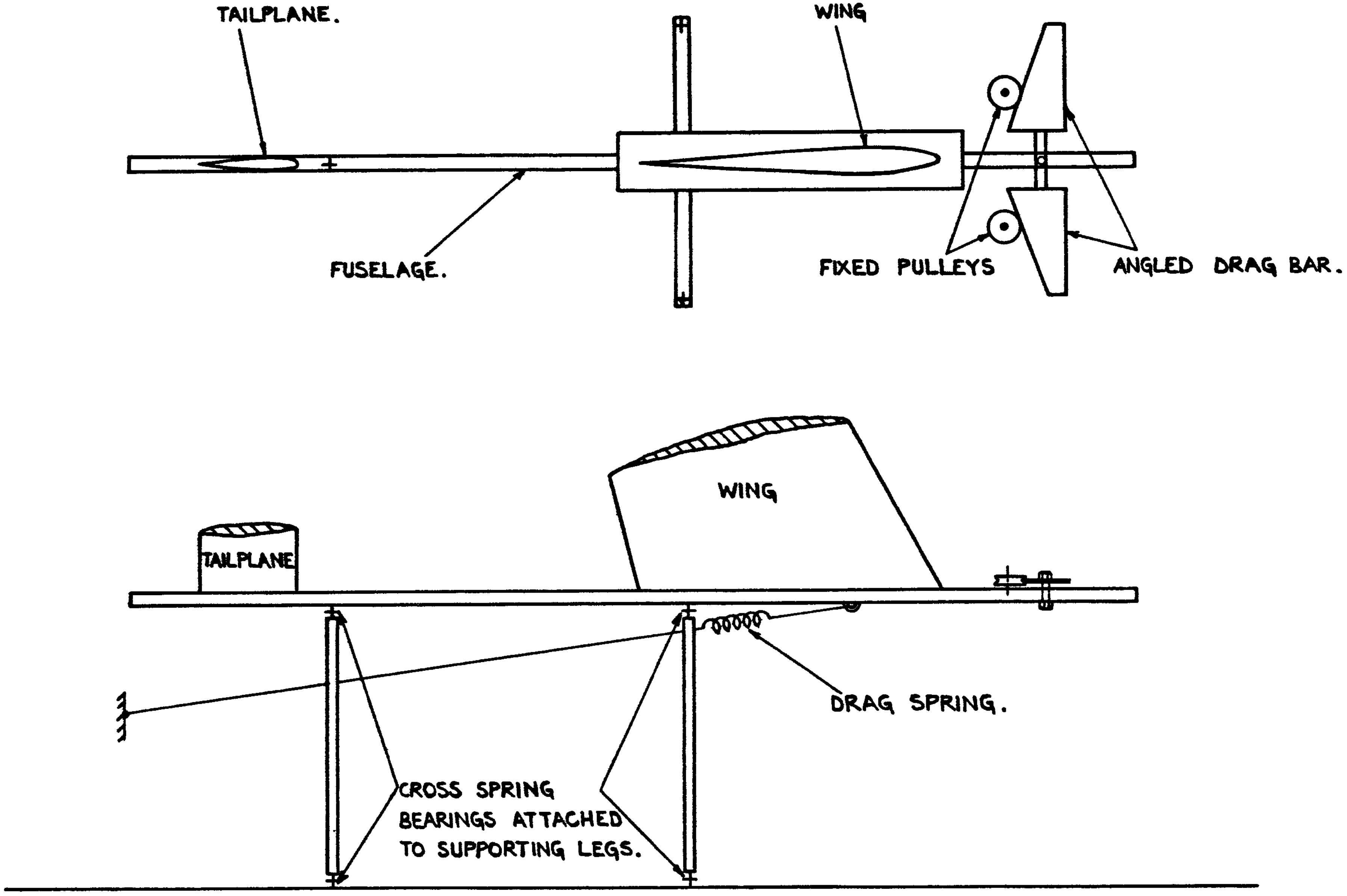


FIG. 5. ARRANGEMENT OF SYMMETRIC RIG.

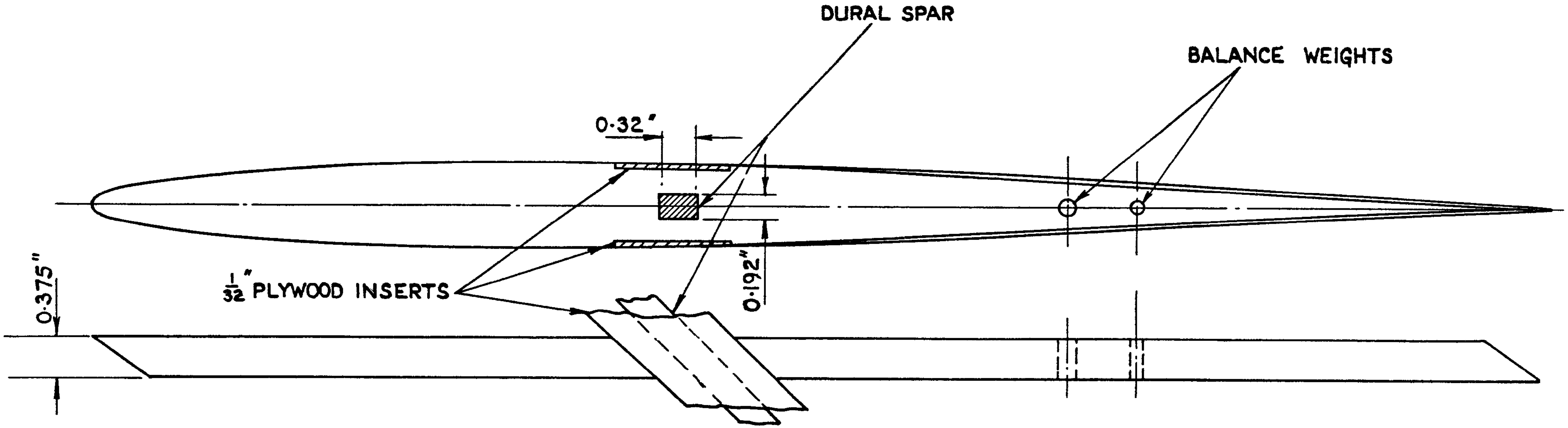


FIG.6. TYPICAL RIB.

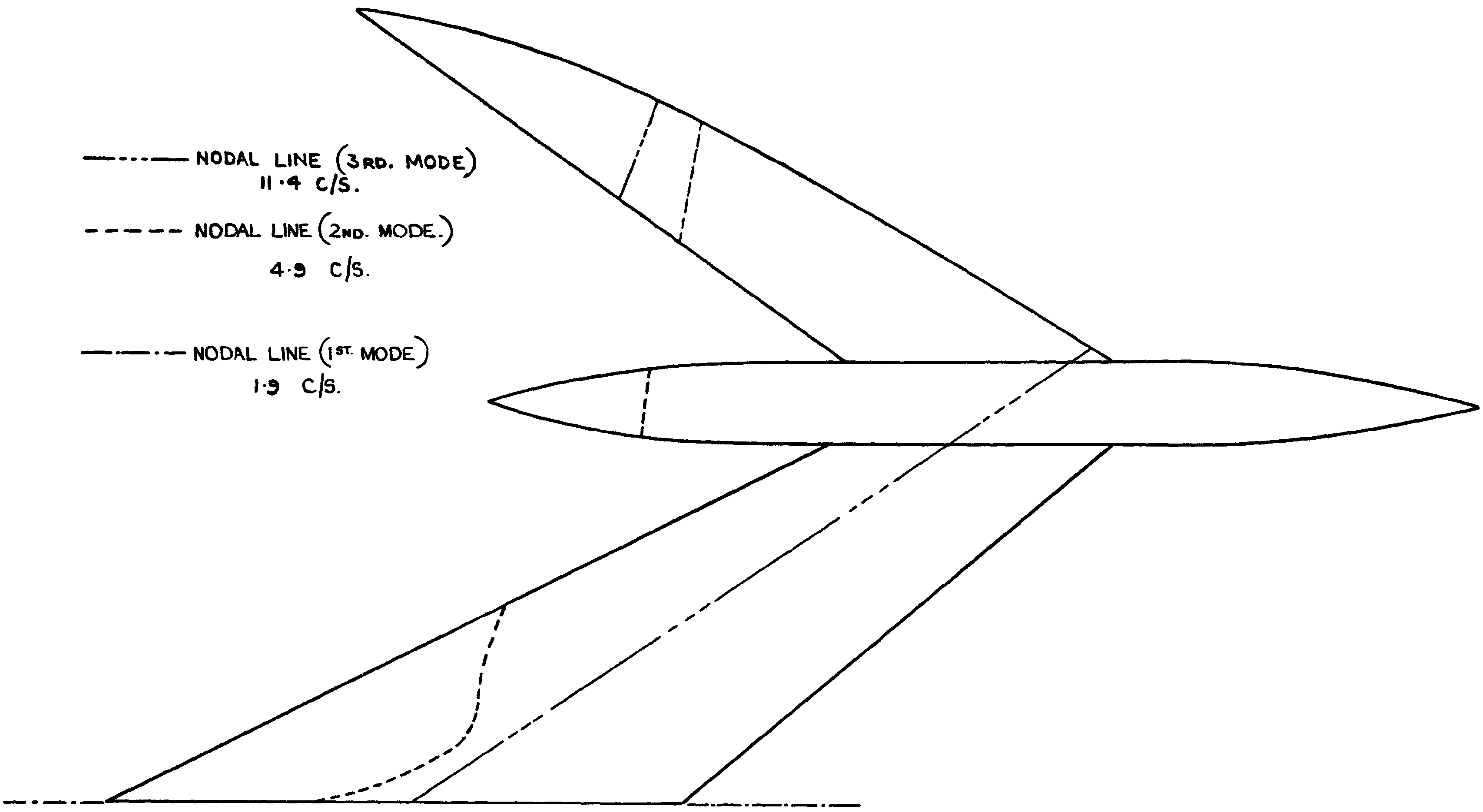
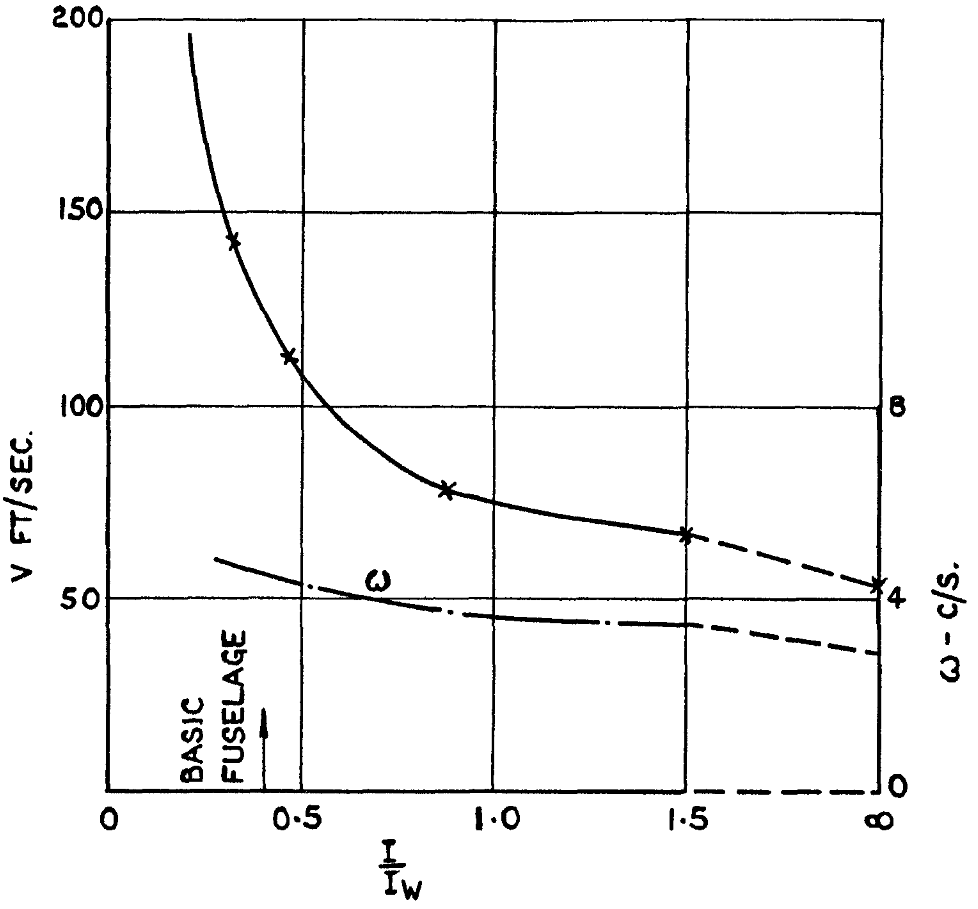
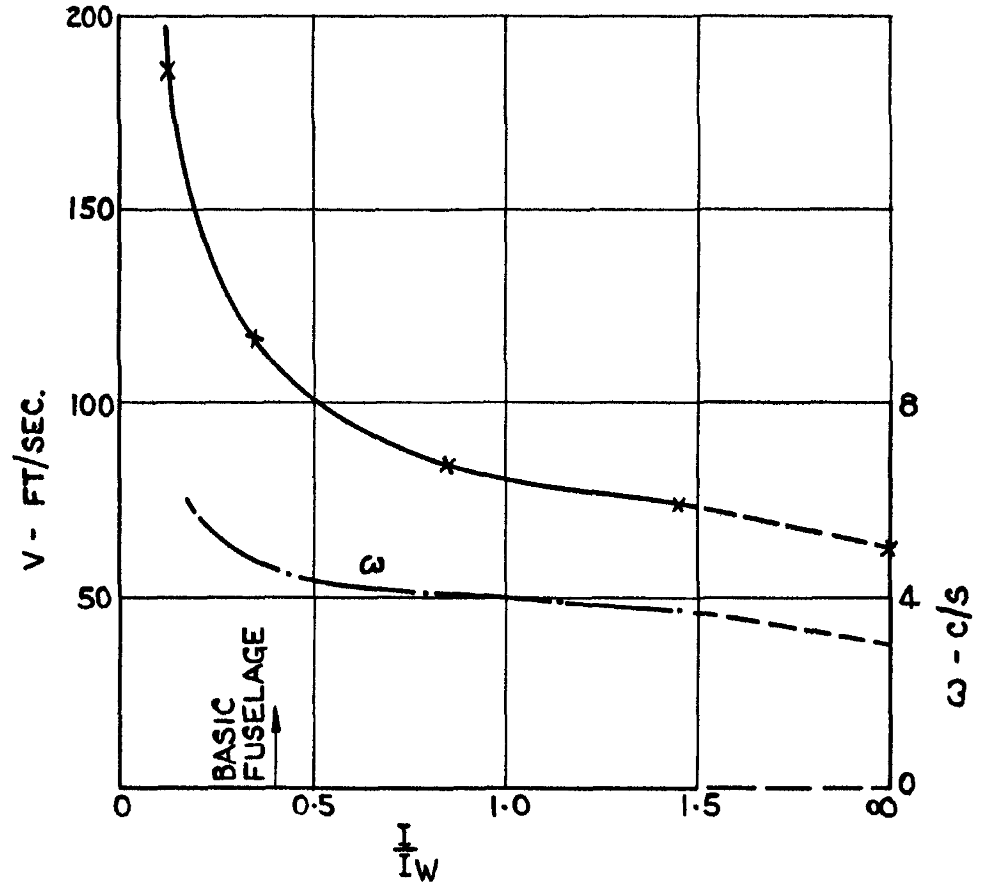


FIG. 7. POSITION OF NODAL LINES.



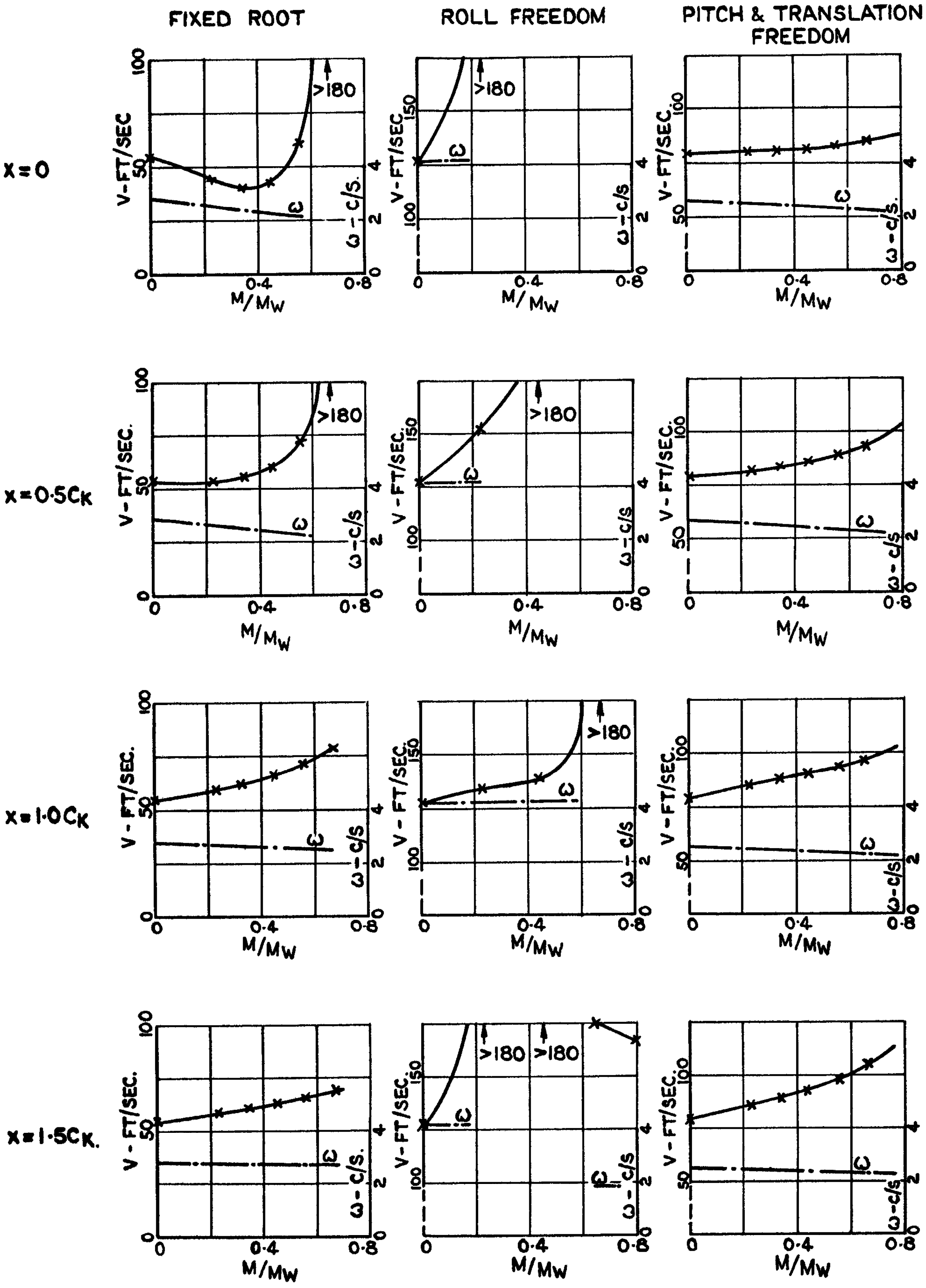
NACELLE 'A'



NACELLE 'B'

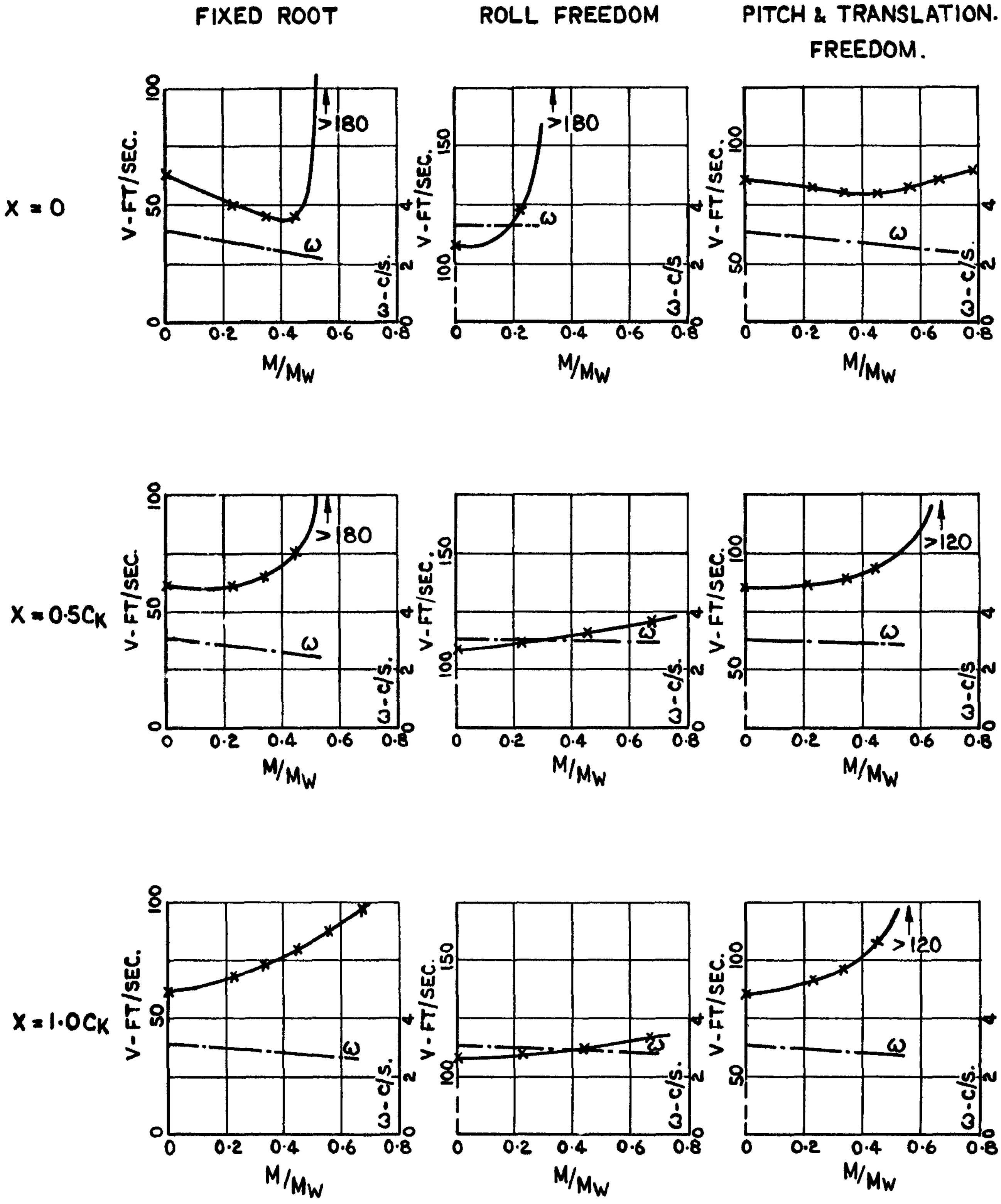
I = FUSELAGE ROLL INERTIA.
I_W = WING ROLL INERTIA.

FIG. 8. EFFECT OF FUSELAGE ROLL INERTIA ON FLUTTER.



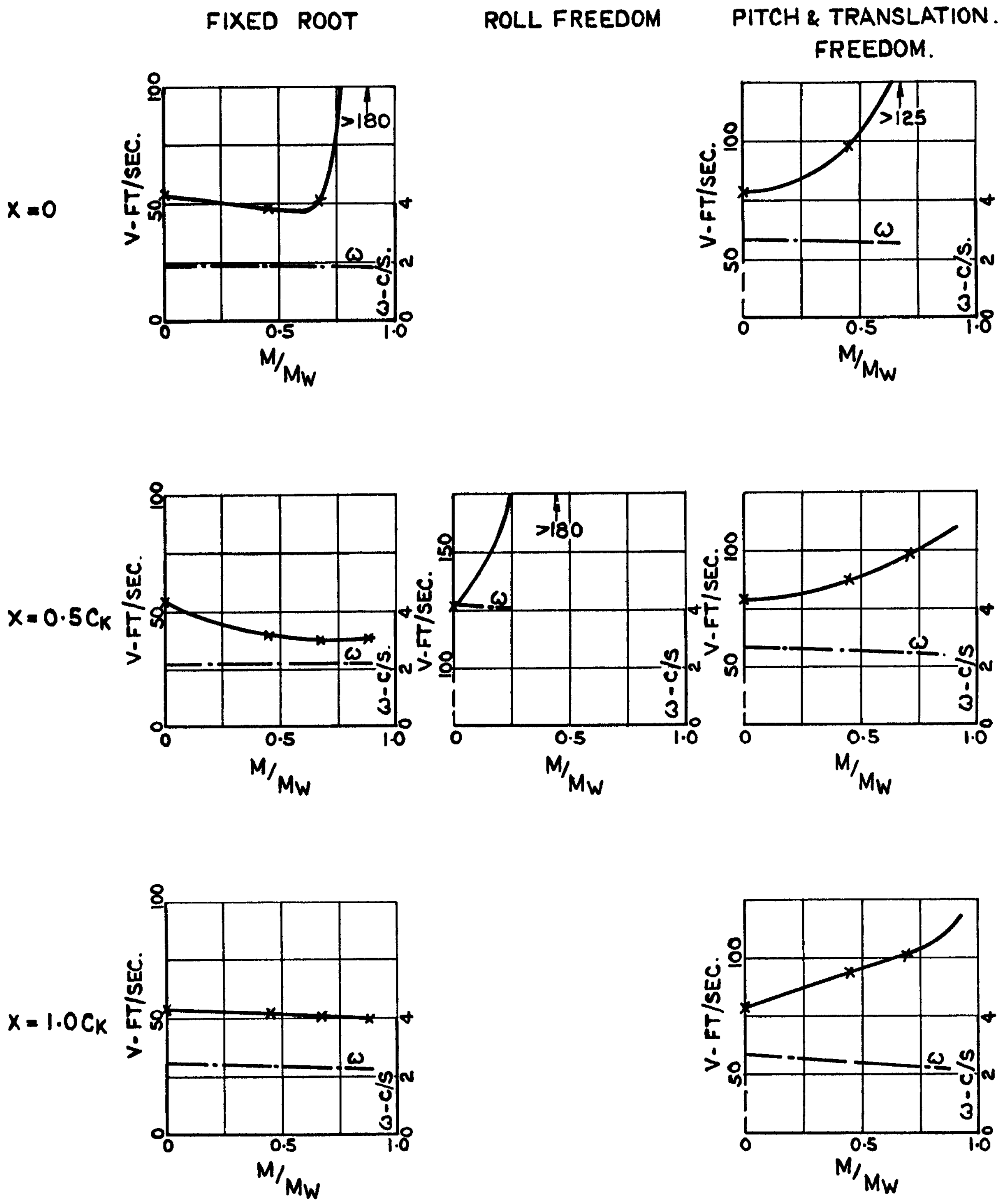
M = ADDED MASS (EXCLUDING NACELLE.)
MW = MASS OF BARE WING.
CK = CHORD AT THE KINK.
X = DISTANCE OF C.G. OF MASS AFT OF LEADING EDGE.

FIG. 9. EFFECT OF VARIATION OF A CONCENTRATED MASS ON FLUTTER.
NACELLE 'A'.



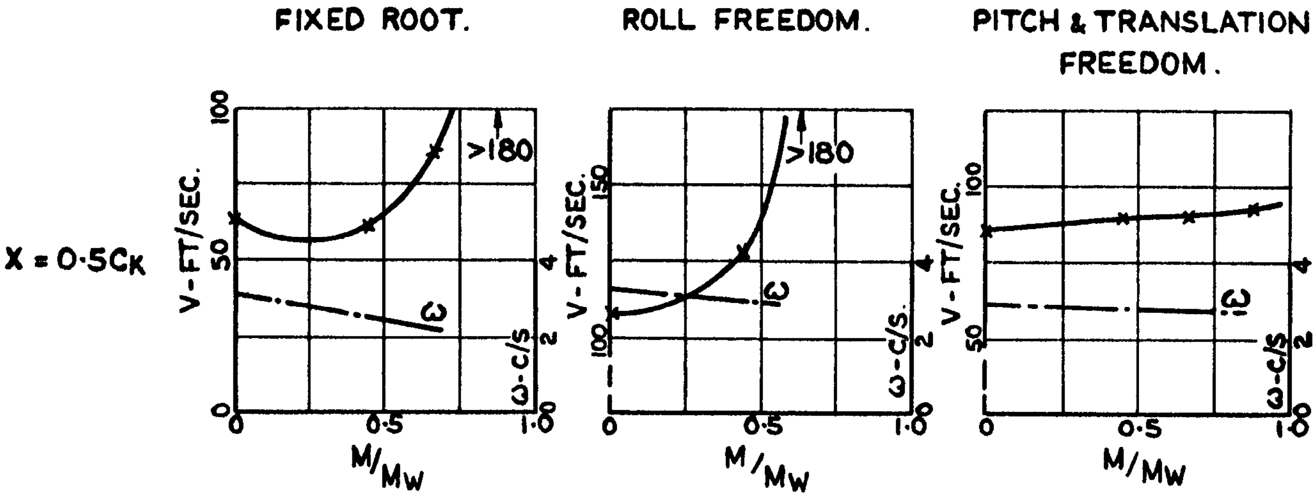
M = ADDED MASS (EXCLUDING NACELLE.)
M_W = MASS OF BARE WING.
C_K = CHORD AT THE KINK.
X = DISTANCE OF C.G. OF MASS AFT OF LEADING EDGE.

FIG. 10. EFFECT OF VARIATION OF A CONCENTRATED MASS ON FLUTTER. NACELLE 'B'.



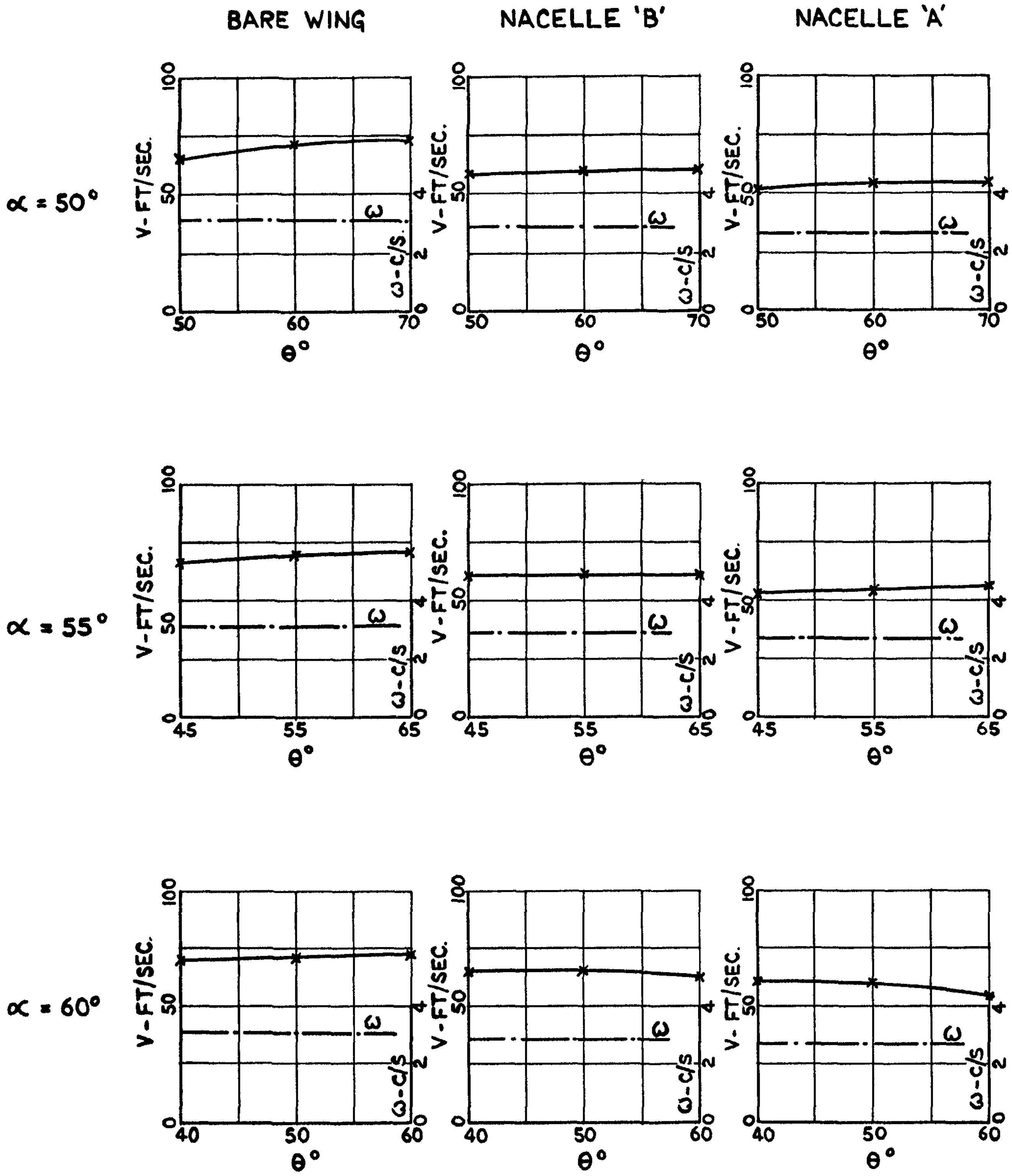
M = ADDED MASS (EXCLUDING NACELLE).
MW = MASS OF BARE WING.
CK = CHORD AT THE KINK.
X = DISTANCE OF C.G. OF MASS AFT OF LEADING EDGE.

FIG. 11. EFFECT OF VARIATION OF A LOCALISED MASS (RAD: OF GYRATION 0·92 CK) ON FLUTTER NACELLE 'A'.



M = ADDED MASS (EXCLUDING NACELLE).
M_W = MASS OF BARE WING.
C_K = CHORD AT THE KINK.
X = DISTANCE OF C.G. OF MASS AFT OF LEADING EDGE.

FIG. 12. EFFECT OF VARIATION OF A LOCALISED MASS (RAD: OF GYRATION $0{\cdot}5\,C_K$) ON FLUTTER.
NACELLE 'B.'



α = SWEEP OF $\frac{1}{4}$ CHORD OF INNER WING.
θ = SWEEP OF TRAILING EDGE OF OUTER WING.

FIG. 13. EFFECT OF VARIATION IN SWEEP OF OUTER WING ON FIXED ROOT FLUTTER.

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