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Aspect-Ratio Effects on Compressor Cascade Blade Flutter

By

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Summary.—This report gives the results of cascade tests on blades of aspect ratio varying from 3·0 to 1·5, with particular reference to stalling flutter. It is concluded that the influence of aspect ratio on stalling flutter cannot be simply formulated but depends largely on the particular blade design. The effect on the magnitude of the flutter stresses is not critical although the curves do show a tendency to flattening at an aspect ratio about 2·0 (height/thickness ratio of 20), indicating that the advantages of further reduction in aspect ratio are relatively small. The ' critical flutter velocity ' is more complex. For the ' low ' to ' moderate ' stress levels the increase of critical flutter velocity, with decreasing aspect ratio, occurs quite gradually, while for the high stress levels the increase is very much greater, and is in fact itself quite critical.

1. *Introduction.*—An investigation of some of the basic characteristics of compressor cascade blade flutter has previously been made and reported in Refs. 1 and 2. Application of these characteristics along with other experimental data has also been made, for the case of stalling flutter, to the study of design methods for the avoidance of stalling flutter in axial-flow compressors (Ref. 3). Where flutter conditions cannot easily be avoided or the margin of safety is small (*i.e.*, ' borderline' cases), some means of reducing the resulting alternating stresses must usually be sought. One of the major factors involved is blade aspect ratio and this report describes tests carried out to study the effect of aspect ratio on the flutter characteristics of cascade blades.

2. *Description of Tests.*—2.1. *Equipment and Cascade Details.*—The tests were carried out in the National Gas Turbine Establishment No. 6 High-Speed Cascade Tunnel which had been modified so that cascades of blades of constant chord (0·75 in.) and aspect ratios of 2·5, 2·0 and 1·5 could be fitted (the normal build for this tunnel is for 0·75-in. chord blades and A.R. = 3·0). These modifications, as shown in Fig. 1, consisted of the provision of three sets of internal plates, one for each aspect ratio, which reduced the tunnel height to the necessary value, the blade tip clearance being nominally 0·050 in. The blades' section was of form 10C4/20C50 and they were mounted in cascade at a stagger of — 34·2 deg and a pitch/chord ratio of 1·0. The blades were cast in H.R. Crown Max with ' massive ' roots and were assembled into cascade by screwing onto a heavy base plate and soldering up the gaps, as described more fully in Ref. 2. By this means easy replacement of cracked blades could be made. The damping of the blades varied somewhat but an average value of the logarithmic decrement was 0·006.

Records of the blade tip movement, for subsequent analysis of the blade frequencies and stresses, were made by the optical method (involving reflection of light from a small mirror in the blade tip), which is fully described in Ref. 1.

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*N.G.T.E. Report R.197, received 18th October, 1956.

2.2. *Test Technique.*—Test runs were made over a wide range of air incidence and inlet Mach number, the procedure being to make simultaneous photographic recordings of the blade tip movements and of the relevant aerodynamic pressures at intervals over the range of air speed from near zero to choking conditions, at constant tunnel setting angle. This was repeated at small increments of setting angle, *viz.*, 2 deg. The cascade tests of Refs. 1 and 2 were done using tunnel-setting increments of 1 deg, but it was felt that in order to reduce the amount of analysis in these tests the bigger increment of 2 deg could be used, with little loss of detail in the results.

3. *Test Results.*—The evaluated stresses have been plotted in the form of contours, with air inlet angle as abscissae and inlet Mach number as ordinates. Fig. 2 has been adapted from Ref. 1 and shows the contours for a cascade of the same blade section, stagger, etc., but with an aspect ratio of 3·0. The stress contours for aspect ratio of 2·5, 2·0 and 1·5 are given in Figs. 3, 4 and 5 respectively. Also plotted with these contours are the critical and maximum Mach numbers. It should be noted that because of restriction of the aerodynamic measurements (on account of the short blade life under flutter conditions), the critical Mach number (M_{nc}) used in these results is defined as that Mach number at which the pressure rise through the cascade begins to fall, and the Maximum Mach number (M_{nm}) as that at which the pressure rise becomes zero again. As such, these values plotted cannot be obtained with as high an accuracy as that achieved by the more conventional measurements of cascade losses.

Fig. 6 shows some results of the measurements of the mean (' steady component of the ') blade tip movement, as extracted from the film records. The accuracy of this measurement is also low, as it involves measurement of small steady displacements superimposed upon large, random alternating displacements ; it also relies upon very accurate alignment of the optical ' elements ' at each tunnel setting. Nevertheless, by plotting these mean tip displacements against air inlet angle, curves can be drawn which give a reasonably good indication of the stalling angle.

4. *Discussion of Results.*—Examination of Figs. 2, 3, 4 and 5 shows that with decreasing aspect ratio, the higher stress stalling flutter zones decrease in size, their ' lower ' limits generally being displaced to higher incidences and Mach numbers. The ' greater than ± 10 tons/in.^{2} ' contours have disappeared entirely at A.R. = 2·0. It is interesting to note that the extent of the low-level flutter stresses, *viz.*, greater than ± 2 tons/in.^{2}, is very little changed over the aspect-ratio range covered.

The magnitude of choking and shock-stalling flutter, in the main, diminishes much more rapidly with decreasing aspect ratio. The choking flutter zone has virtually disappeared at A.R. = 2·0. The shock-stalling flutter zone, which for A.R. = 3·0 is a combination of flexural and torsional vibration (total stress between ± 10 and ± 20 tons/in.^{2}), is displaced to a higher Mach number for A.R. = 2·5, is of greater extent and consists of flexural vibration only. At A.R. = 2·0, however, this zone ceases to be an isolated one but joins with the stalling flutter zone at a much lower stress.

The following Table gives the fundamental cantilever and, where applicable, the second cantilever mode frequencies for the various cascades, measured under flutter conditions.

Aspect ratio	3·0	2·5	2·0	1·5
Fundamental cantilever mode c.p.s. ..	340	550	850	1400
Second cantilever mode c.p.s. ..	2110	2700		

By far the most frequently occurring type of flutter is stalling flutter and so a more detailed inspection of the results can be confined to this. In particular, only the initial part of the stalling flutter zone need perhaps be considered, say from stalling incidence (i_{stall}) to $i_{\text{stall}} + 6$ deg.

By comparing the relative stresses at comparable conditions for each aspect ratio the latter's influence on the stalling flutter stress can be more readily studied. Fig. 7 shows plotted the 'maximum' flutter stress, relative to that for A.R. $= 3 \cdot 0$, against aspect ratio for Mach numbers of $0 \cdot 5$, $0 \cdot 6$ and $0 \cdot 8$. Considerable scatter of the points does occur, as might be expected from the rather uneven shapes of the stress contours as shown in Figs. 2 to 5 ; curves drawn through the arithmetic means of the points for each M_n are, however, of quite 'smooth' form. The general inference to be drawn from Fig. 7 is that the maximum stress is reduced quite rapidly by decreasing the aspect ratio from $3 \cdot 0$ to $2 \cdot 0$, but that further decrease to $1 \cdot 5$ is not accompanied by much advantage in this respect. For the blade section tested the blade height/thickness ratio (h/t) is $10 \times$ A.R., so that the major stress reduction has been effected at about $h/t = 20$, below which the curves tend to flatten.

The shift in the boundary of the higher stress levels is perhaps of even more importance than the actual stress reduction due to decrease in aspect ratio, as it is by such means that the dangerous flutter regions could be removed outwith the compressor operating zone (*see* Ref. 3). The important concept here is that of critical flutter velocity (or Mach number), *viz.*, that inlet velocity at which the flutter stresses become 'significant'. Although the high stress regions are rapidly displaced to higher incidences (Figs. 2 and 3), the incidence limitation to the moderate stress levels is not greatly affected by aspect ratio. The problem of deciding at what level the stress becomes 'significant' is not easily dealt with in a general way ; it has to be considered in relation with the steady blade stresses and other conditions. Fig. 8 therefore shows the curves of critical-flutter Mach number against the aspect ratio for various arbitrary critical stress levels.

It will be noted from Fig. 8 that, for the lowest stress levels ($> \pm 2$ tons/in.^{2}) the effect of decreasing aspect ratio is to increase the critical-flutter Mach number only slightly. At moderate stress levels (up to about ± 10 tons/in.^{2}) a much more substantial increase occurs ; in the region of 50 per cent for a reduction in aspect ratio from $3 \cdot 0$ to $2 \cdot 0$. For the higher stress levels, however, over the stalled region under consideration at least, the effect of aspect ratio is much more critical, the flutter at these levels entirely disappearing between aspect ratios of $3 \cdot 0$ and $2 \cdot 5$. This is thus more in accordance with the simple theory of Ref. 3, from which it follows that the critical flutter velocity is inversely proportional to the square of the aspect ratio.

No simple general rule governing the effects of aspect ratio on stalling flutter can therefore be formulated. It would appear that much depends on the blade 'steady' stressing and how much margin of alternating stress can be allowed for safety.

5. *Conclusions.*—The influence of aspect ratio on stalling flutter cannot be simply formulated, but depends largely on the particular blade design. The effect on the magnitude of the flutter stresses is not critical although the curves do show a tendency to a flattening at an aspect ratio of about $2 \cdot 0$ (height/thickness ratio of 20), indicating that the advantages of further reduction in aspect ratio are relatively small. The 'critical flutter velocity' is more complex. For the 'low' to 'moderate' stress levels the increase of critical flutter velocity occurs quite gradually, while for the high stress levels the increase is very much greater, and is in fact itself quite critical.

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No.	*Author*	*Title*
1	D. A. Kilpatrick and J. Ritchie	Compressor cascade flutter tests. Part I.—20 deg camber blades, medium and high stagger cascades. C.P. 187. December, 1953.
2	D. A. Kilpatrick and J. Ritchie	Compressor cascade flutter tests. Part II.—40 deg camber blades, low and medium stagger cascades. C.P. 296. October, 1954.
3	A. D. S. Carter	A theoretical investigation of the factors affecting stalling flutter of compressor blades. C.P. 265. June, 1955.

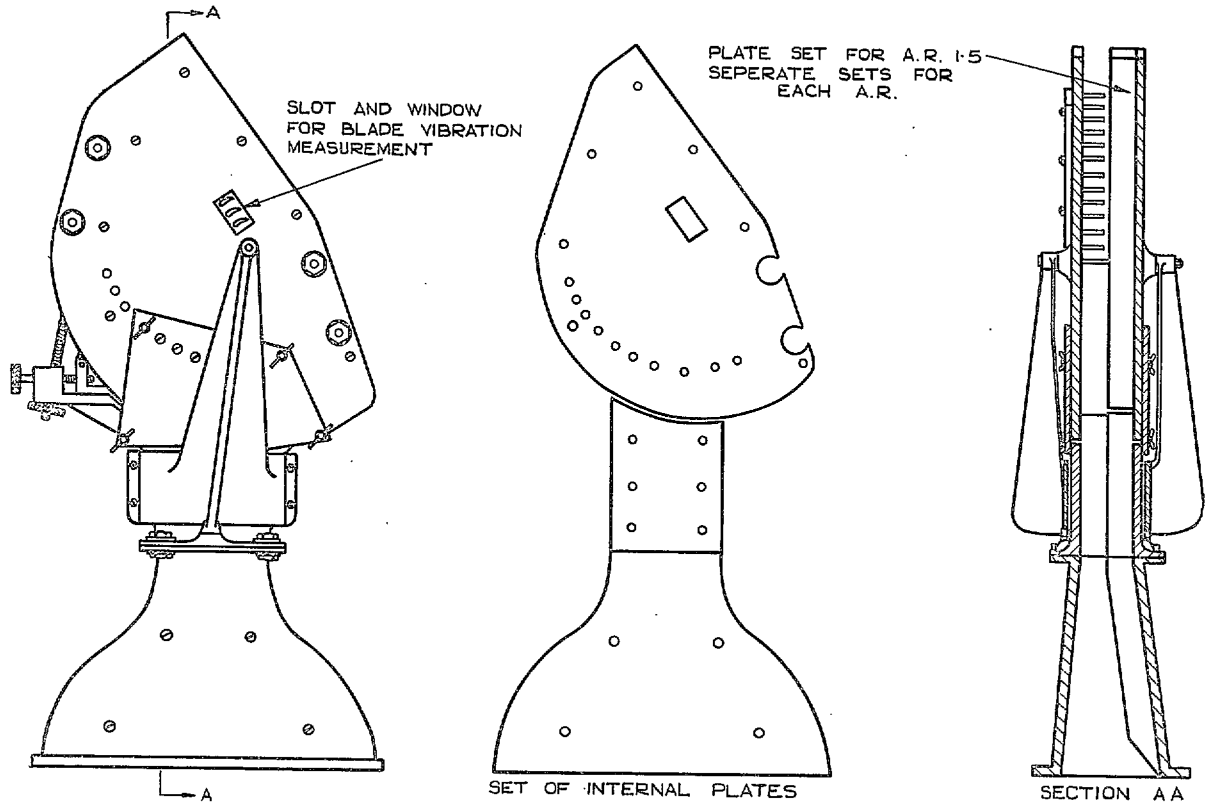
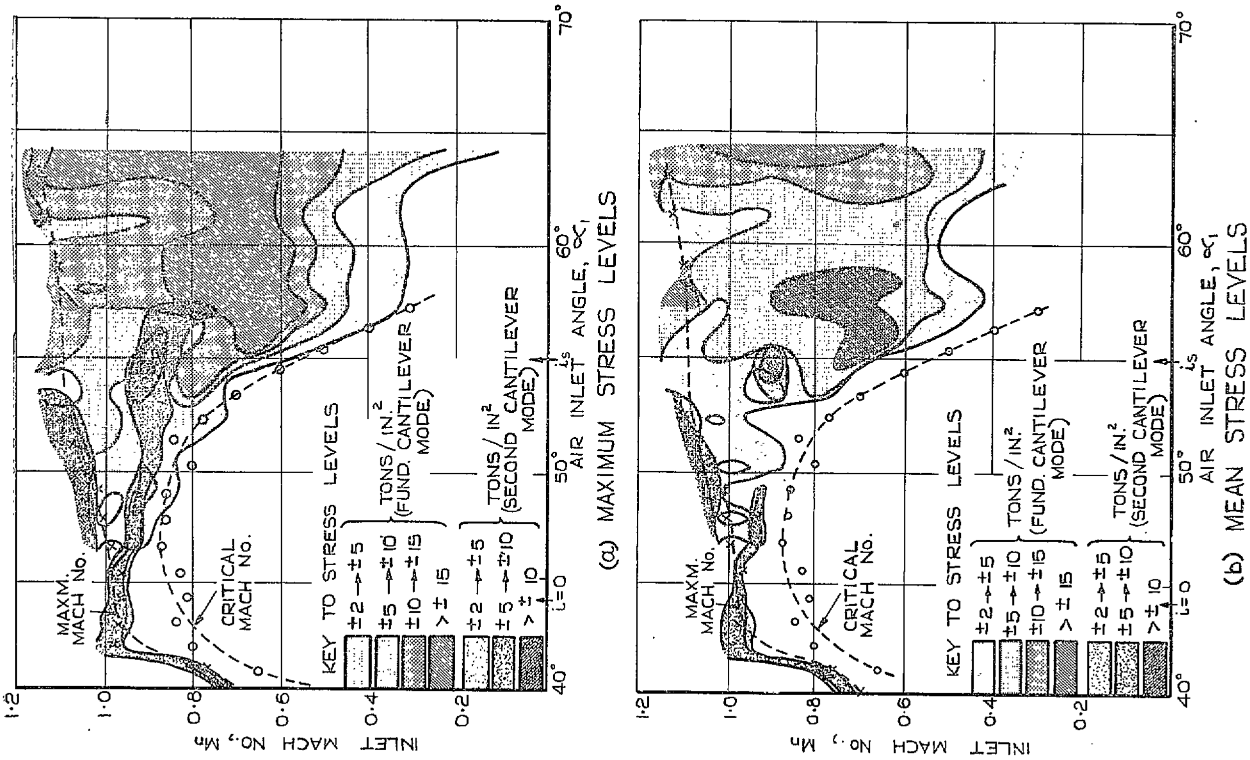


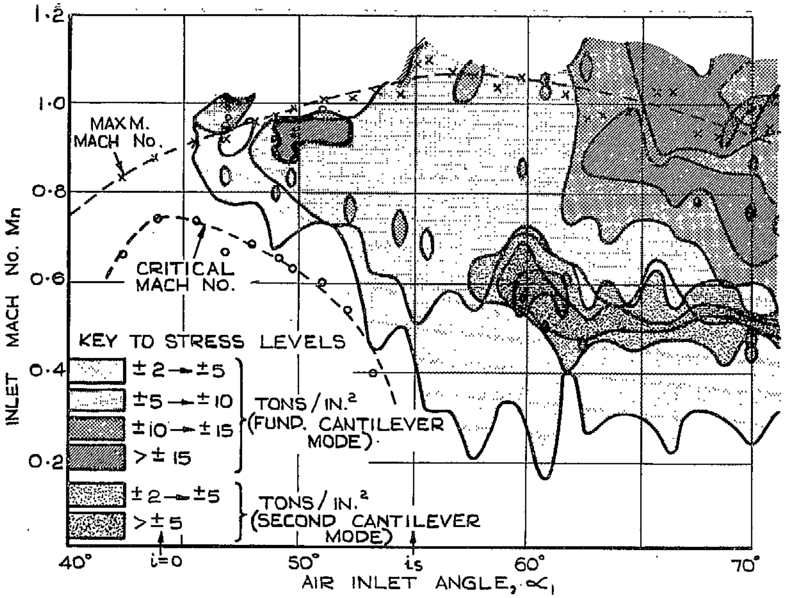
FIG. 1. Cascade tunnel modified for aspect-ratio tests.



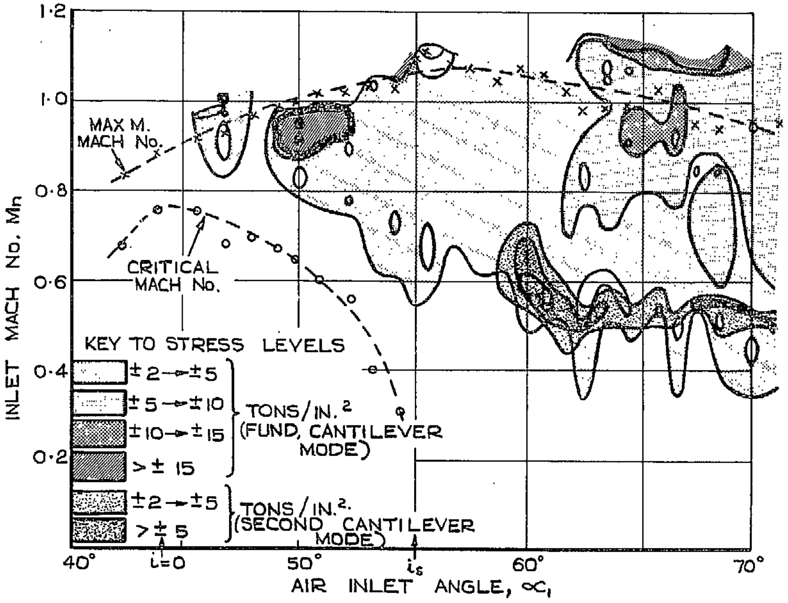
(a) MAXIMUM STRESS LEVELS

(b) MEAN STRESS LEVELS

FIGS. 2a and 2b. Cascade flutter stress contours (A.R. = 3·0).

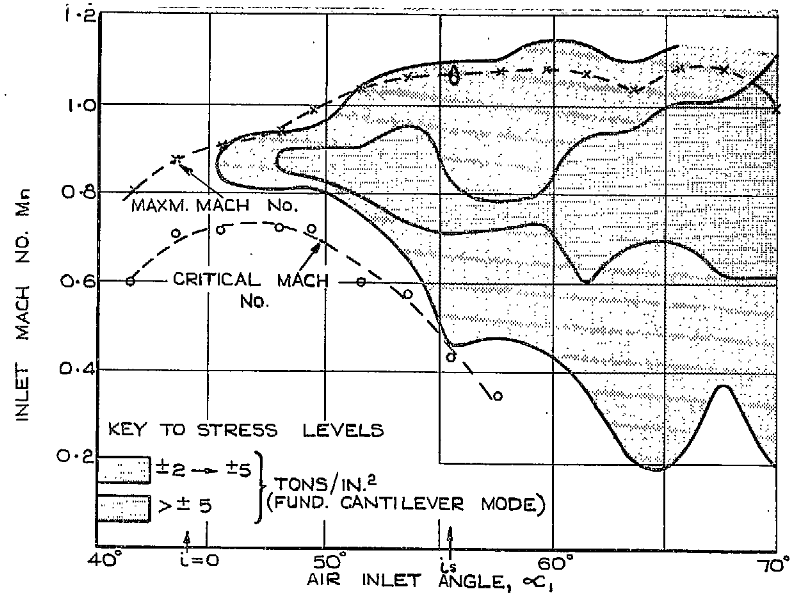


(a) MAXIMUM STRESS LEVELS

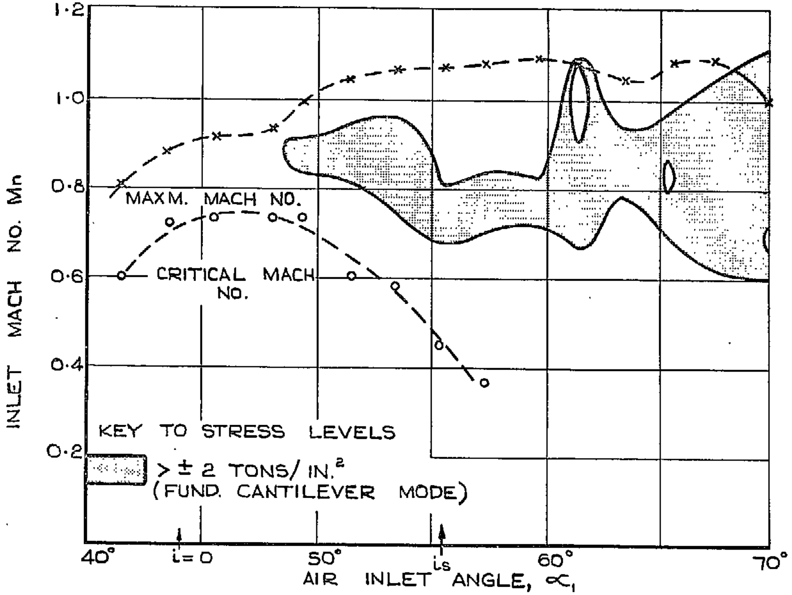


(b) MEAN STRESS LEVELS

FIGS. 3a and 3b. Cascade flutter stress contours (A.R. = 2·5).

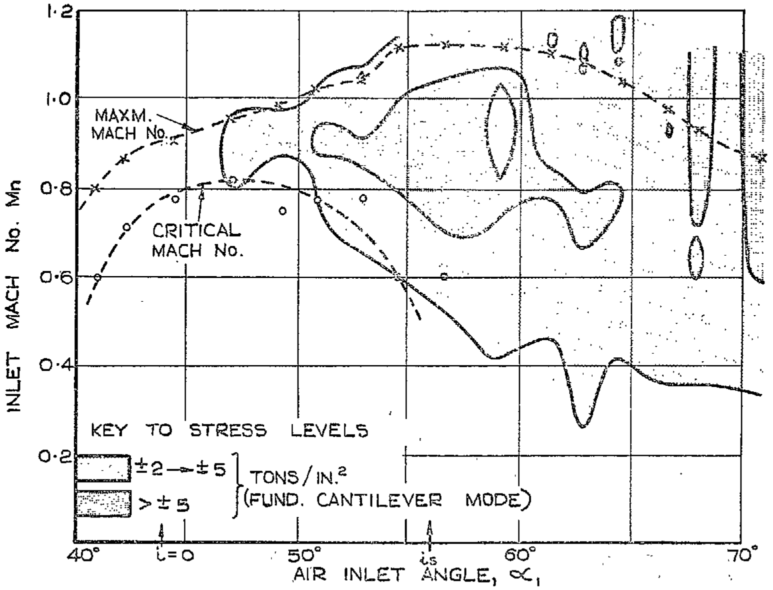


(a) MAXIMUM STRESS LEVELS

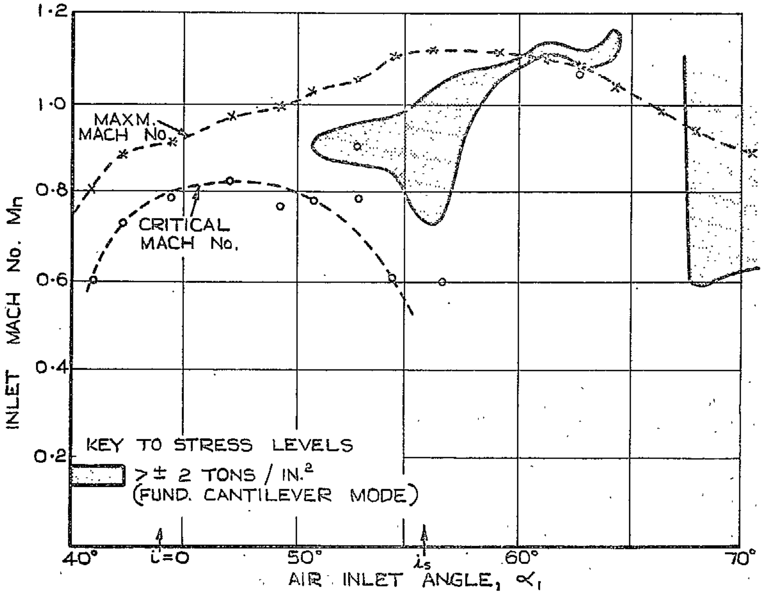


(b) MEAN STRESS LEVELS

FIGS. 4a and 4b. Cascade flutter stress contours (A.R. = 2·0).



(a) MAXIMUM STRESS LEVELS



(b) MEAN STRESS LEVELS

FIGS. 5a and 5b. Cascade flutter stress contours (A.R. = 1·5).

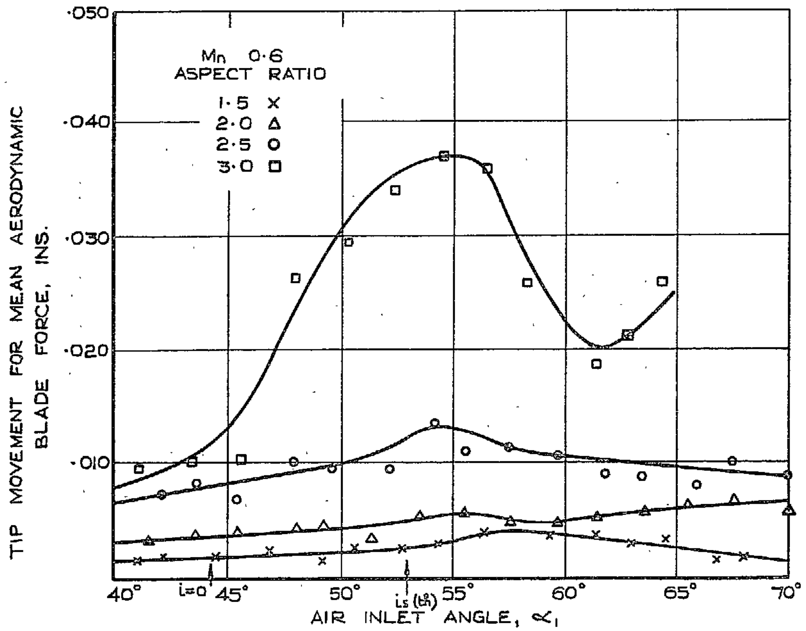


FIG. 6. Blade force characteristics.

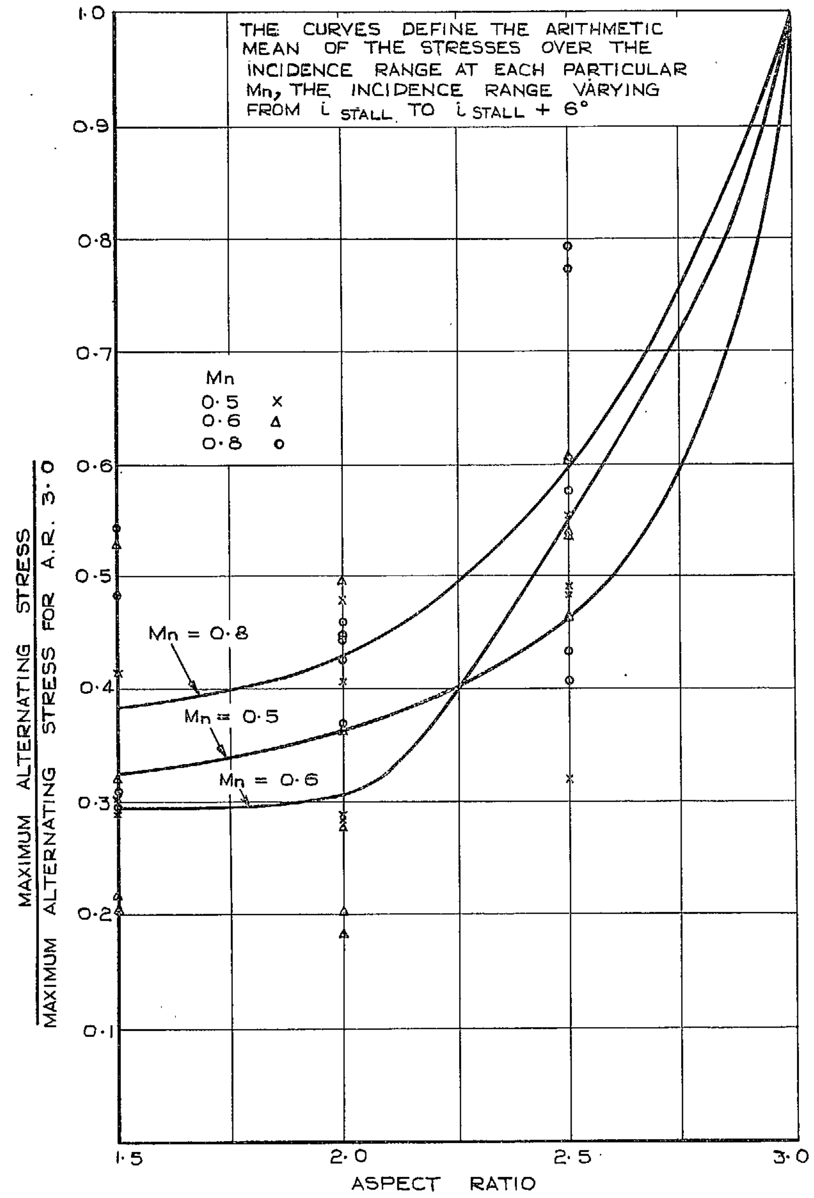


FIG. 7. Stalling flutter stress *vs*. aspect ratio.

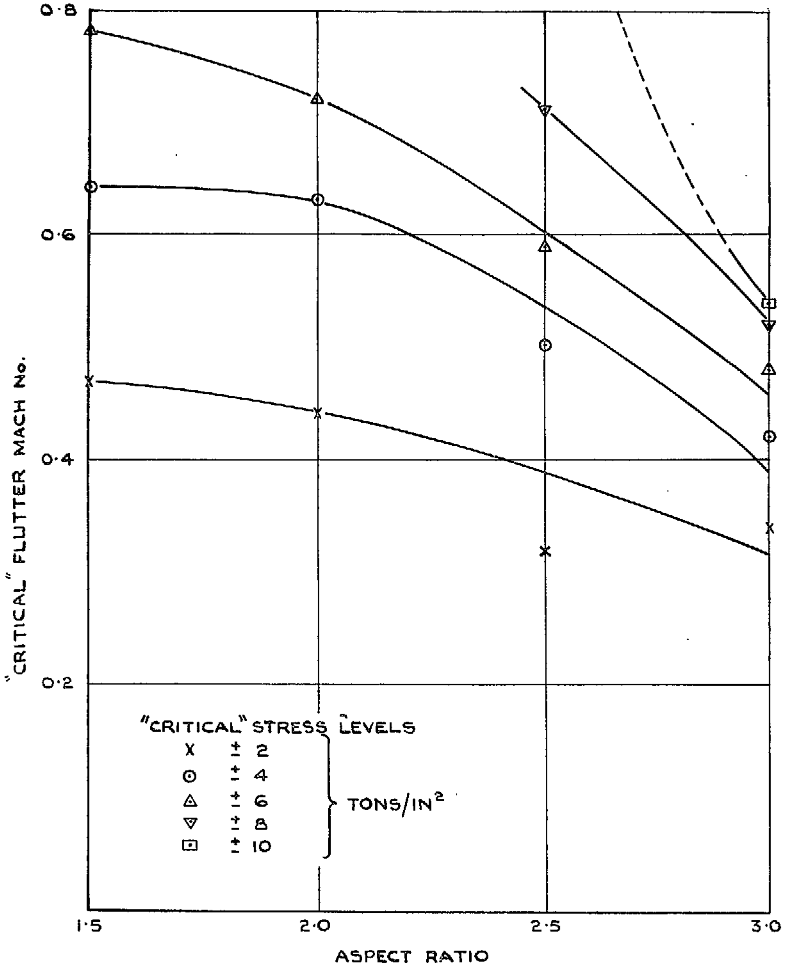


FIG. 8. Critical flutter Mach number *vs*. aspect ratio.

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