C.P. No. 32
(12738)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Air Bags as Flexible Supports in Ground Resonance Testing of Aircraft

By

R.L.Moffat and D.R.Gaukroger, M.A.

LONDON: HIS MAJESTY'S STATIONERY OFFICE
1950

Price 1s. 3d. net

C.P.32.

Technical Note No. Structures 47

September, 1949

ROYAL AIRCRAFT ESTABLISHMENT.

Air Bags as Flexible Supports in Ground Resonance Testing of Aircraft

by

R.L. Moffat
and
D.R. Gaukroger, M.A.

SUMMARY

Stiffness and natural frequency tests have been made on an air bag designed for the ground resonance testing of a medium size aircraft. Results are compared with those obtained from an existing theory and from a new theory put forward in this report. Agreement between the experimental results and the theory of this report is very good. The results show that the present design of air bags does not provide the low frequency anticipated.

LIST OF CONTENTS

LIST OF ILLUSTRATIONS

1 Introduction

A consideration[1] of various types of flexible support for aircraft during ground resonance tests indicated that one of the most promising methods of providing the desirable low support frequency was by the use of air bags. No detailed investigation of the behaviour of air bags under various conditions of loading has been made up to the present and the method of support has not been widely used in the resonance testing of aircraft. Recently, however, air bags were specially designed for use with a large aircraft and the results obtained indicated that the support frequency was higher than the frequency predicted theoretically.[1] A detailed investigation was therefore made of the characteristics of an air bag of similar design to those used in the above tests, and the original theoretical treatment[1] was examined in detail.

This report gives the results of stiffness and frequency tests made on the air bag, and shows that the formula for the bag frequency of Ref.1 is incorrect. A new formula is established and shown to agree well with the test results. It is concluded that the present design of air bags does not provide the required low frequency support for vertical motion of the aircraft for ground resonance testing and that further development is necessary.

2 Type of air bag tested

The air bag on which the tests were made was constructed of three ply dinghy fabric and the main dimensions are given in Fig.1. The sides of the bag consist of five lobes, the junctions of which are held in position by 30 cwt. cable. During design experiments the bag was found to be unstable in both shear and roll. To overcome this instability, vertical diaphragms were provided internally, and a surrounding apron attached to the lobes was fitted externally. The diaphragms allow free expansion of the bag up to a height of thirty inches; this height is subsequently referred to as the 'design height' and bag heights are expressed as percentages of it. A pressure of 2 pounds per square inch above atmospheric is regarded as 'design pressure' and this gives a 'design load' of 8150 pounds, other loads being expressed as percentages of design load.

3 Method of test

3.1 The test rig shown in Fig.2 was used in both stiffness and frequency measurements. A 6' x 6' x $\frac{1}{2}$" steel plate "A" formed a loading platform to which additional weight could be directly added, while the beam "B" hinged vertically to a fixed point at one end and to the loading plate at its centre point acted as a stabilizer. For the stiffness tests increments of load were added and the variation in bag height measured. Three sets of initial conditions were examined - heights of 30", 30.5" and 31" under a load of 24.6% of design load (i.e. 2000 lb). The difficulty of loading above 73.7% of design load (6000 lb) by means of dead weight prevented a direct loading up to the full design load. For a fourth stiffness test therefore a lever system was used and the starting conditions were:- bag height 31" and load 61.4% (5000 lbs). The load was increased incrementally to 110.4% (9000 lbs). Considerable friction was apparent in the lever system, and for this reason direct loading was used in all other tests.

The variation of pressure with bag height under constant load was measured in order to determine the effect of the internal diaphragms, and the decrease of supporting area with height.

3.2 To obtain the bag frequency under load the beam "B" was excited vertically at its free end; it was convenient to excite by hand since damping was so low that only at the resonant frequency was it possible to obtain any appreciable amplitude. The frequency was measured by timing a number of cycles.

4 Test results

4.1 Stiffness tests

Curves of bag height against air pressure for various loads are shown in Fig.3. Two points are noteworthy:-

(i) that the stiffening effect of the internal diaphragms becomes apparent between 100 and 103% of the design height,

(ii) that below the design height there is a slight variation of pressure with height, indicating that the bag supporting area decreases with increase of height; this is due to the rounded edges of the top and bottom of the bag.

The stiffness test curves are shown in Figs.4 and 5; these indicate a diaphragm effect between 102 and 103% of design height, but owing to the risk of damage to the air bag, heights above 103.3% (31 inches) were not investigated, and the critical height for diaphragm effect is not accurately established from the static test results.

4.2 Frequency tests

The bag frequency variation with load and height is shown by the set of curves in Fig.6. A cross plot of these results is shown in Fig.7 which gives variation of frequency against load (a) as measured, (b) as calculated from the stiffness measurements, and (c) as calculated from the formula given in para.5.1 of this report. The frequencies obtained from stiffness measurements have been corrected assuming isothermal conditions for stiffness and adiabatic conditions for frequency measurements. Due to diaphragm effect a critical height is apparent in Fig.6. This is at 101% of design height and indicates the upper limit of bag height permissible for effective operation.

5 The comparison of experimental and theoretical results

From the consideration of a simple air column of height S, unit cross-sectional area, internal pressure p_o and applied loading W_o, Molyneux[1] establishes that the stiffness of such a column is given by:-

$$K = \frac{\gamma\, p_o}{S}$$

where γ is the adiabatic constant for air, he concludes therefore that the frequency of the applied load on the column is:-

$$f_v = \frac{1}{2\pi}\sqrt{\frac{\gamma\, p_o\, g}{S\, W_o}} \qquad \text{..... (1)}$$

Using the relationship $W_o = p_o$ ..... (2)

he then derives

$$f_v = \frac{1}{2\pi}\sqrt{\frac{\gamma g}{S}} \qquad \text{..... (3)}$$

Relationship (2) is, however, inconsistent with the use of W_o in (1), where it represents the applied structural loading (inertia of the ambient air being ignored). On this interpretation, (2) should be replaced by

$$W_o = p_o - p_A \qquad \ldots\ldots (4)$$

p_A being the atmospheric pressure, and expression (3) is then replaced by

$$f_v = \frac{1}{2\pi}\sqrt{\frac{\gamma\, p_o\, g}{S(p_o - p_A)}}$$

or

$$f_v = \frac{1}{2\pi}\sqrt{\frac{\gamma g}{S}\left(1 + \frac{p_A}{\Delta p}\right)} \qquad \ldots\ldots (5)$$

where Δp = excess bag pressure above atmospheric.

Using formula (5) a theoretical curve is shown in Fig.7 and shows good agreement with the measured frequencies. There will inevitably be some difference due to the bag expanding laterally under load; this should reduce measured frequencies compared with theoretical and Fig.7 confirms that this is so. Fig.7 also shows the error which arises from the use of the frequency formula

$$f_v = \frac{1}{2\pi}\sqrt{\frac{\gamma g}{S}} \ .$$

The linearity of the stiffness curves (Figs.4 and 5) seems at first sight to be erroneous; the curves should follow the pV curve for the mass of air in the bag. But, as is shown in Fig.8, the section of the pV curve in which the pressure and volume are varied is small by comparison with the rest of the curve, and the stiffness curves are assumed to be linear within the limits of experimental error. Similarly, with differing initial condition in the stiffness tests, different stiffnesses would be expected, since the mass of air, and hence the isothermal constant is varied. But the pV curves for the small air mass variation which occurs in the bag are nearly parallel, and again the stiffness variation cannot be measured within the limits of experimental error.

6 Discussion of results

In designing a flexible support for ground resonance tests it is shown that a sufficiently close estimate of air bag frequency can be obtained from the formula:-

$$f_v = \frac{1}{2\pi}\sqrt{\frac{\gamma g}{S}\left(1 + \frac{p_A}{\Delta p}\right)}$$

where f_v = vertical frequency in c.p.s.

p_A = atmospheric pressure

Δp = excess air pressure in bag above atmospheric

S = bag height.

For all but very large aircraft the lower limit of the lowest fundamental symmetric frequency can be taken as 3 c.p.s.[1] and the corresponding desirable support frequency as $\frac{1}{3}$ of this value[1]: viz. 1 c.p.s. For the latter value and taking an air bag 30 ins. in height the internal pressure necessary is 12.4 lbs/sq.in. At this pressure a bag diameter of only 14.5 inches would be required to support the design load of the bag already tested.

Generally, it would be impractical to use air bags more than six feet in height, and if the bags are in direct contact with the under surface of an aircraft a loading in excess of 2 pounds per square inch is prohibitive. A bag of this height and at this pressure would have a frequency of 1.3 c.p.s. (approx.). This value is in excess of the desirable frequency of 1 c.p.s. but might be reduced if special means were used to distribute the load of the aircraft.

7 Conclusions

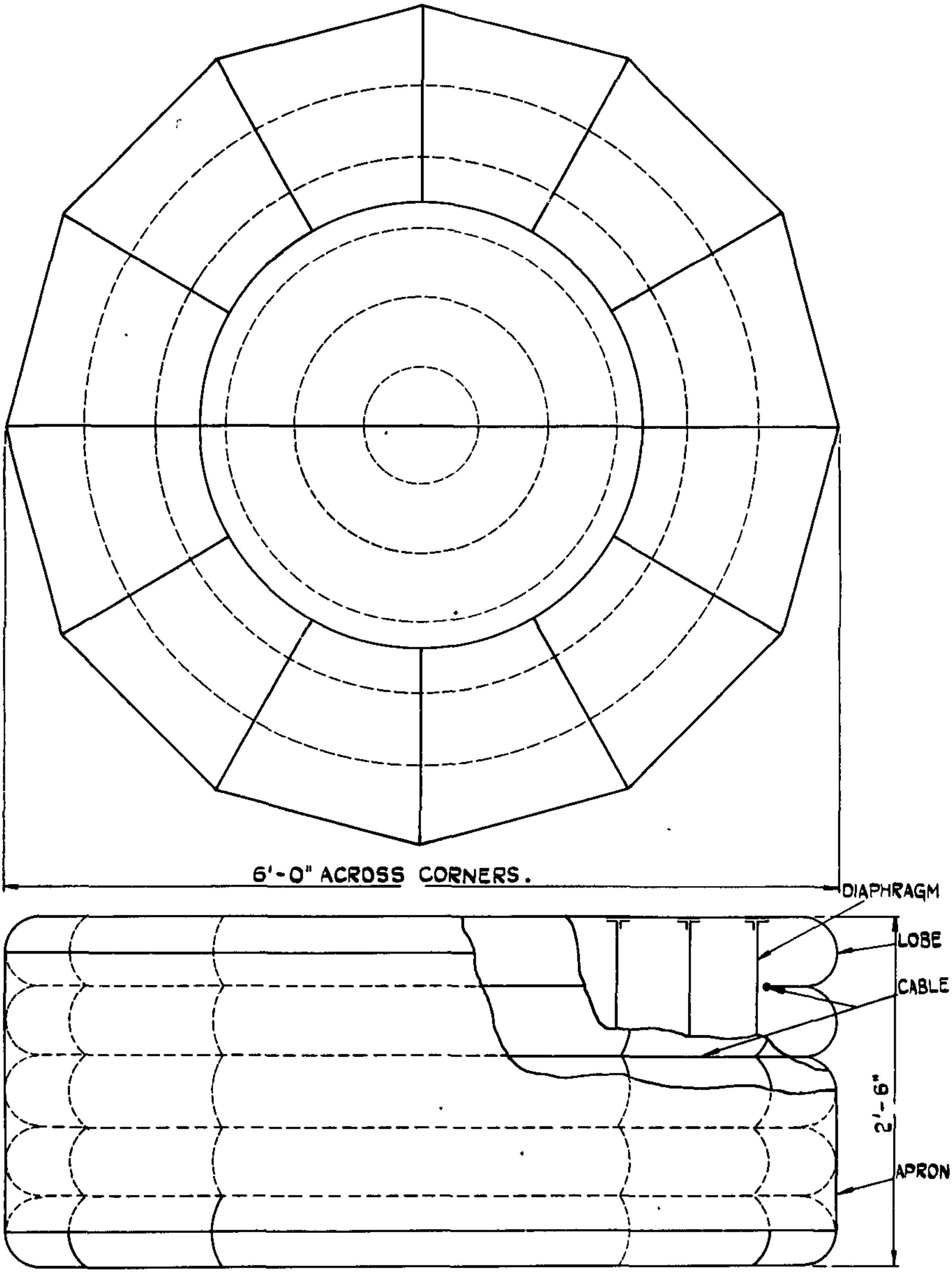
The experiments and theory of this report show that the present design and application of air bags do not provide the desirable low frequency support required in the ground resonance testing of medium and large size aircraft and that further development is necessary.

LIST OF REFERENCES

No.	Author	Title, etc.
1	W.G. Molyneux	Flexible supports for the ground resonance testing of aircraft. R.A.E. Report No. Structures 32. September, 1948. ARC. 11.964.

Wt. 2078.CP32.K3. Printed in Great Britain.

FIG. 1.



SCALE :- $\frac{1}{12}$ FULL SIZE. MATERIAL :- 3 PLY DINGHY FABRIC.

FIG. 1. TYPE OF AIR BAG TESTED (6FT. DIAMETER)

FIG. 2.

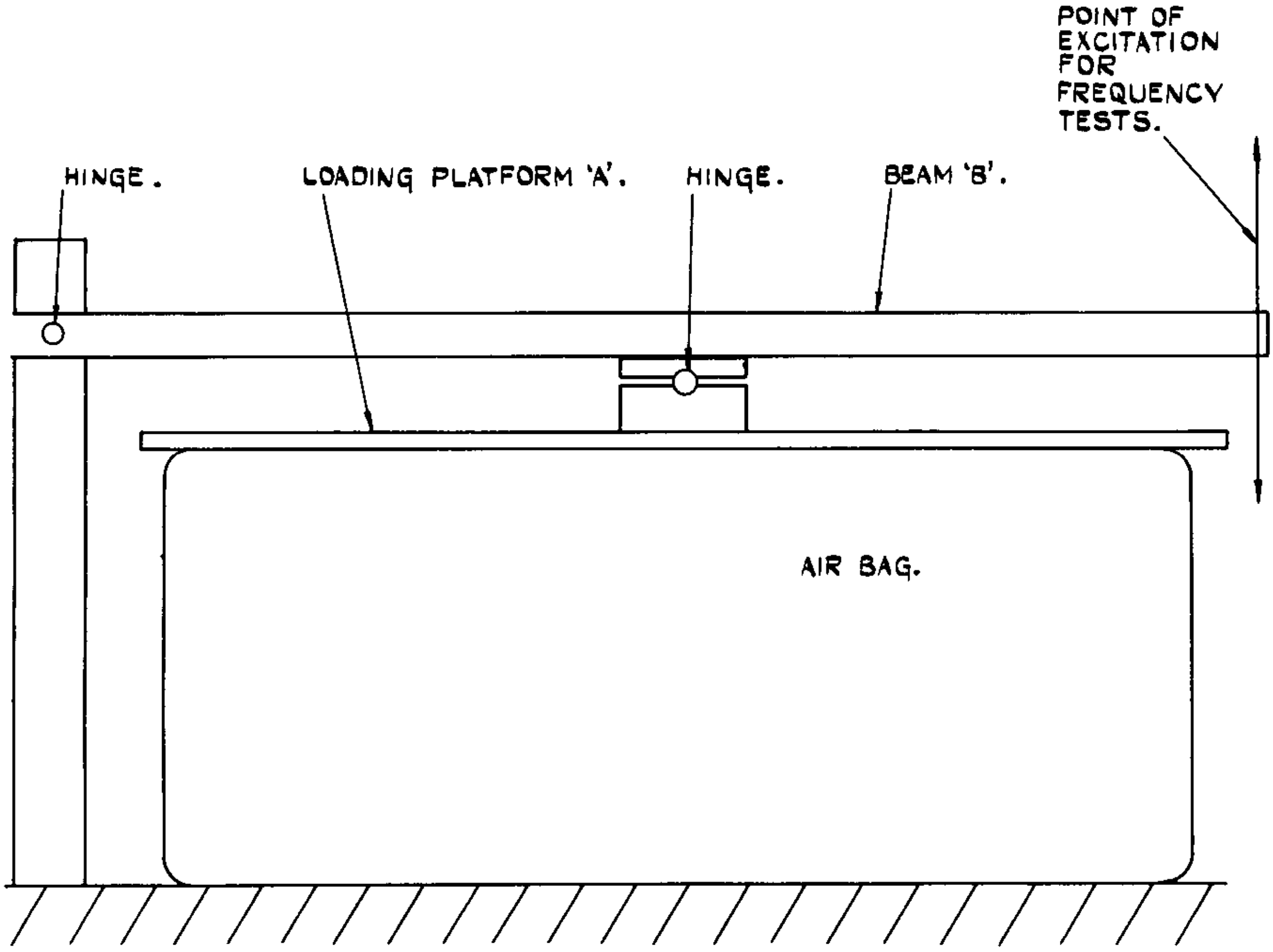


FIG. 2. TEST RIG FOR AIR BAG.

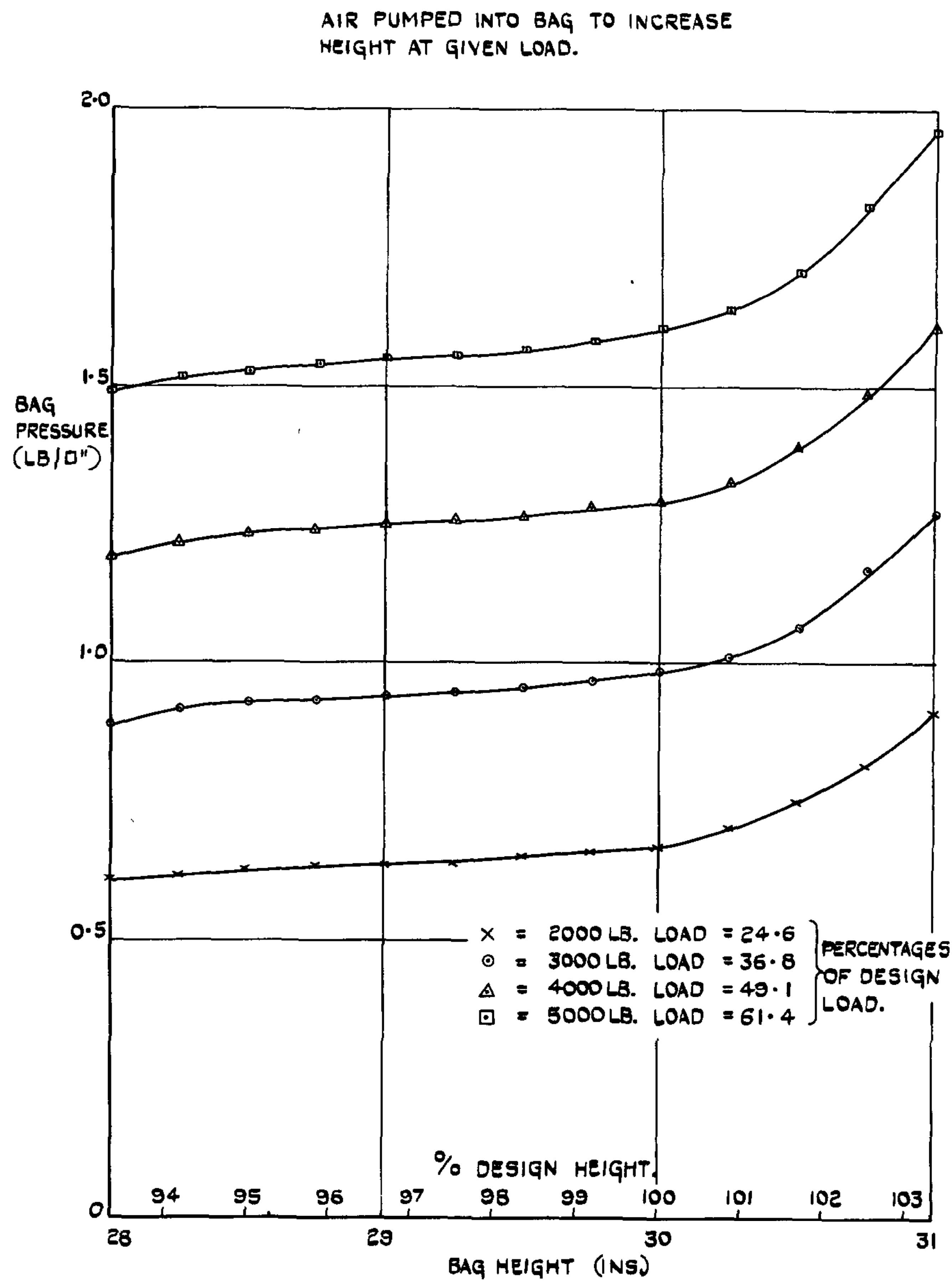


FIG. 3. BAG HEIGHT — PRESSURE CURVES FOR DIFFERENT LOADS EXPERIMENTAL.

FIG. 4.

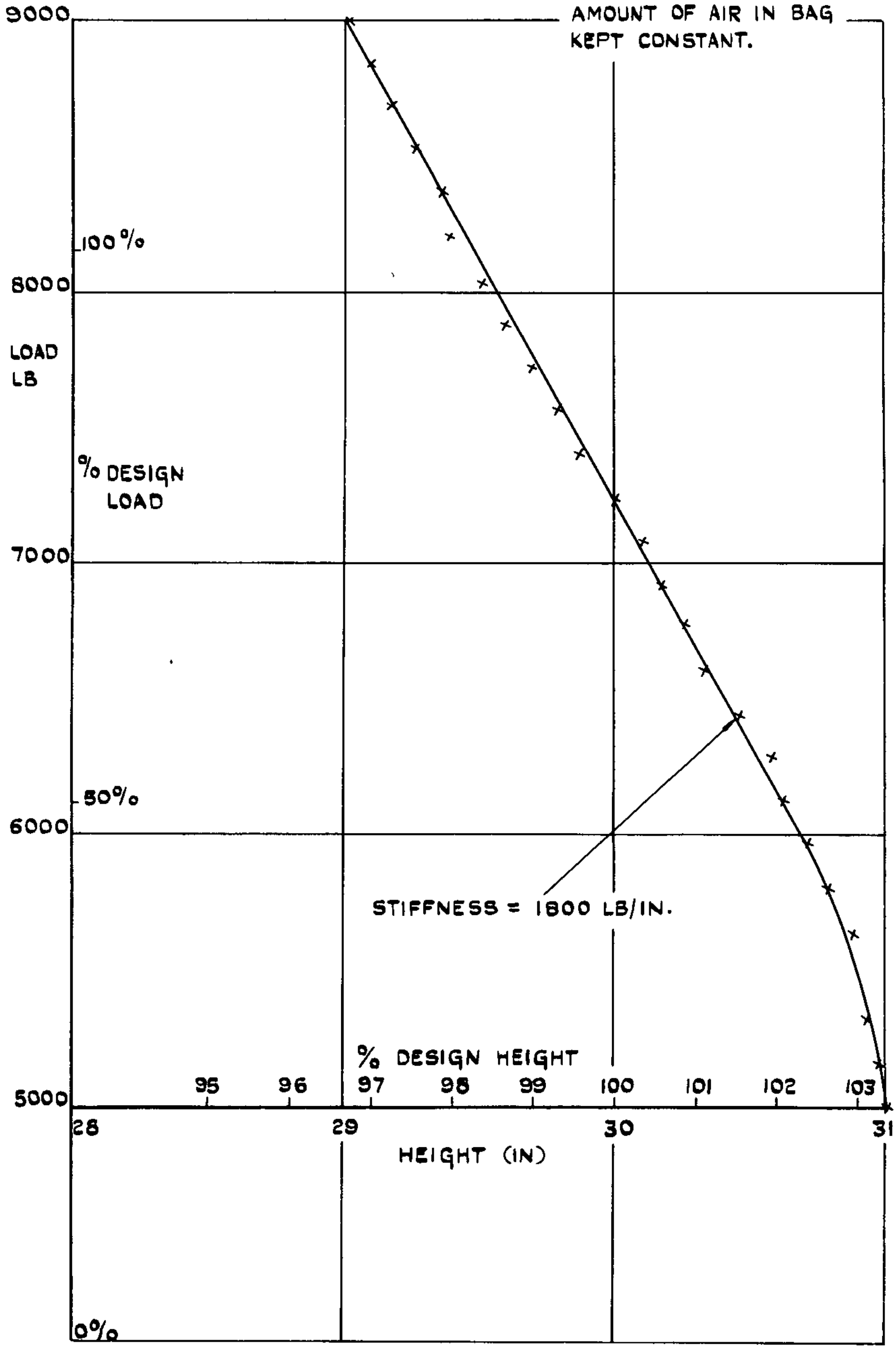


FIG. 4. BAG HEIGHT — LOAD CURVE EXPERIMENTAL

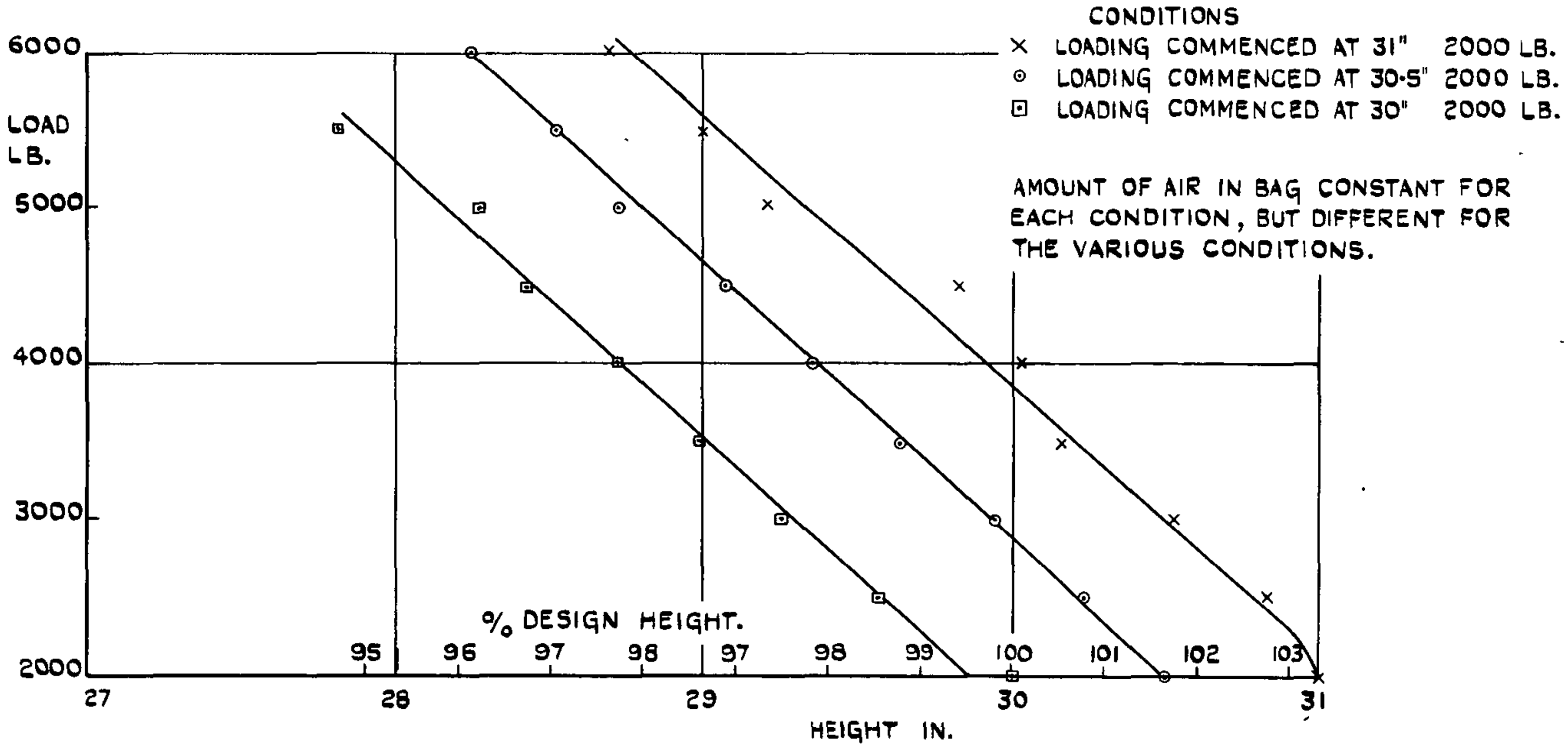


FIG. 5. BAG HEIGHT — LOAD CURVES FOR DIFFERENT INITIAL HEIGHTS EXPERIMENTAL

FIG. 5.

FIG. 6.

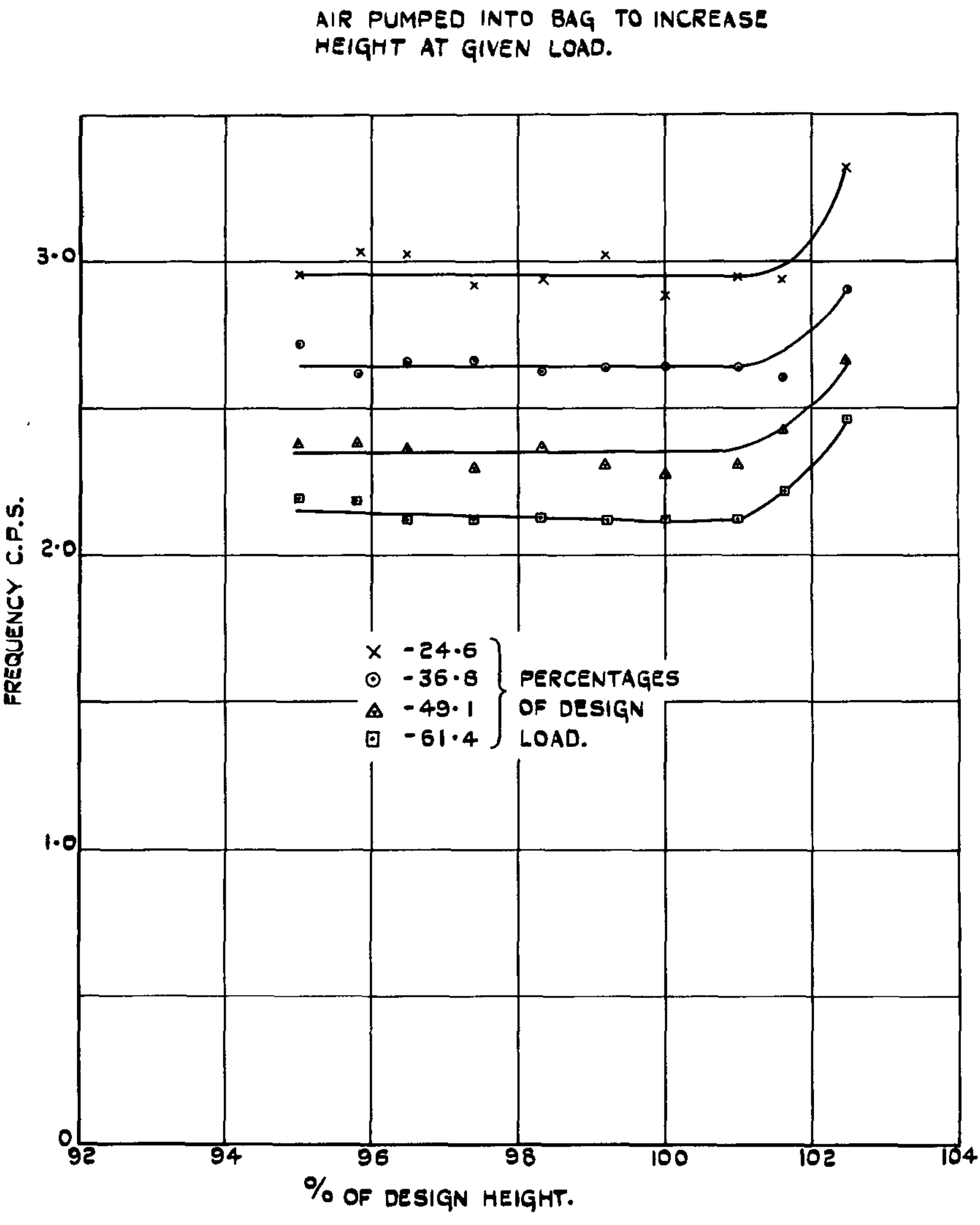
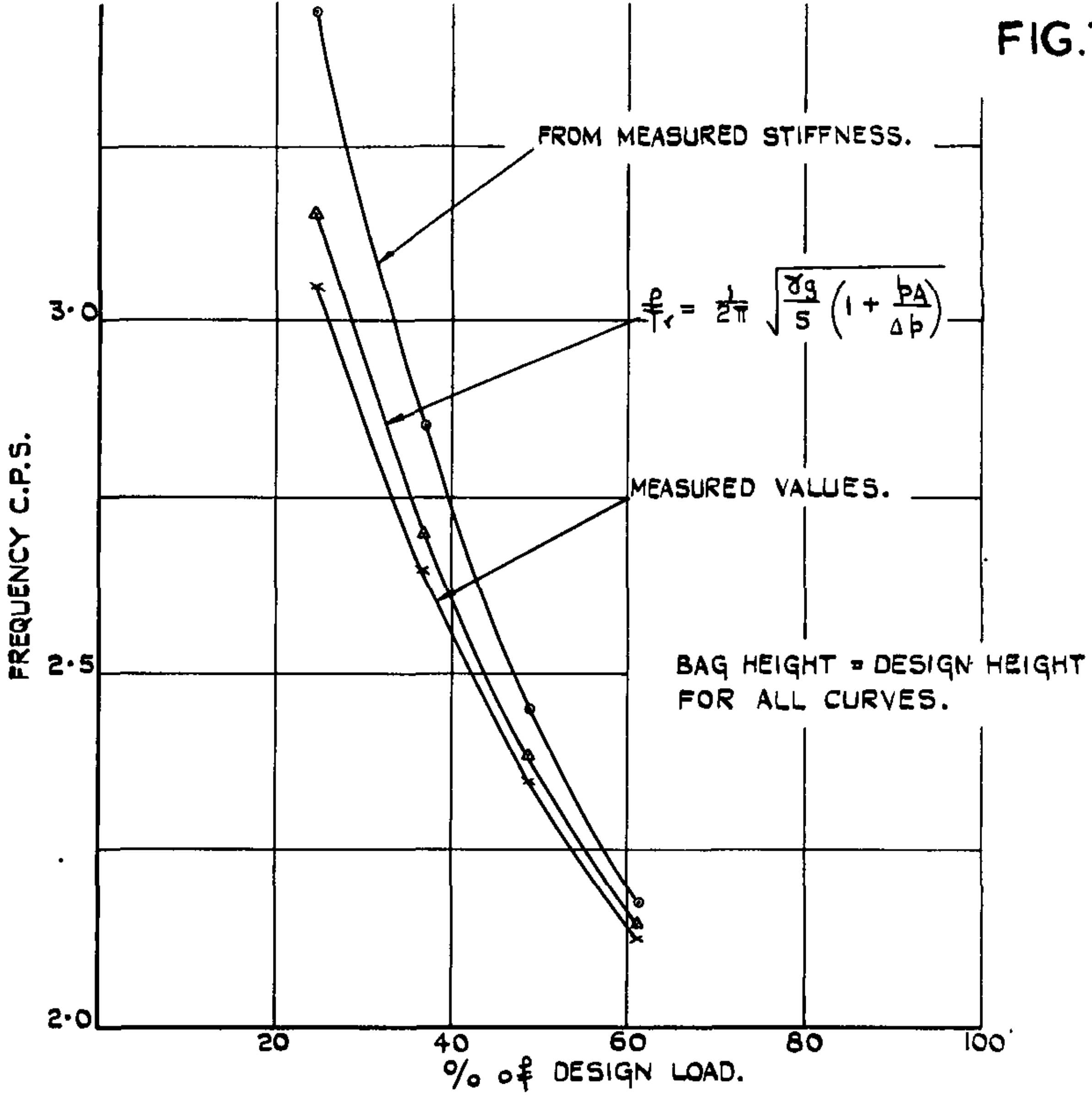


FIG. 6. BAG FREQUENCY – HEIGHT CURVES FOR VARYING LOAD EXPERIMENTAL.



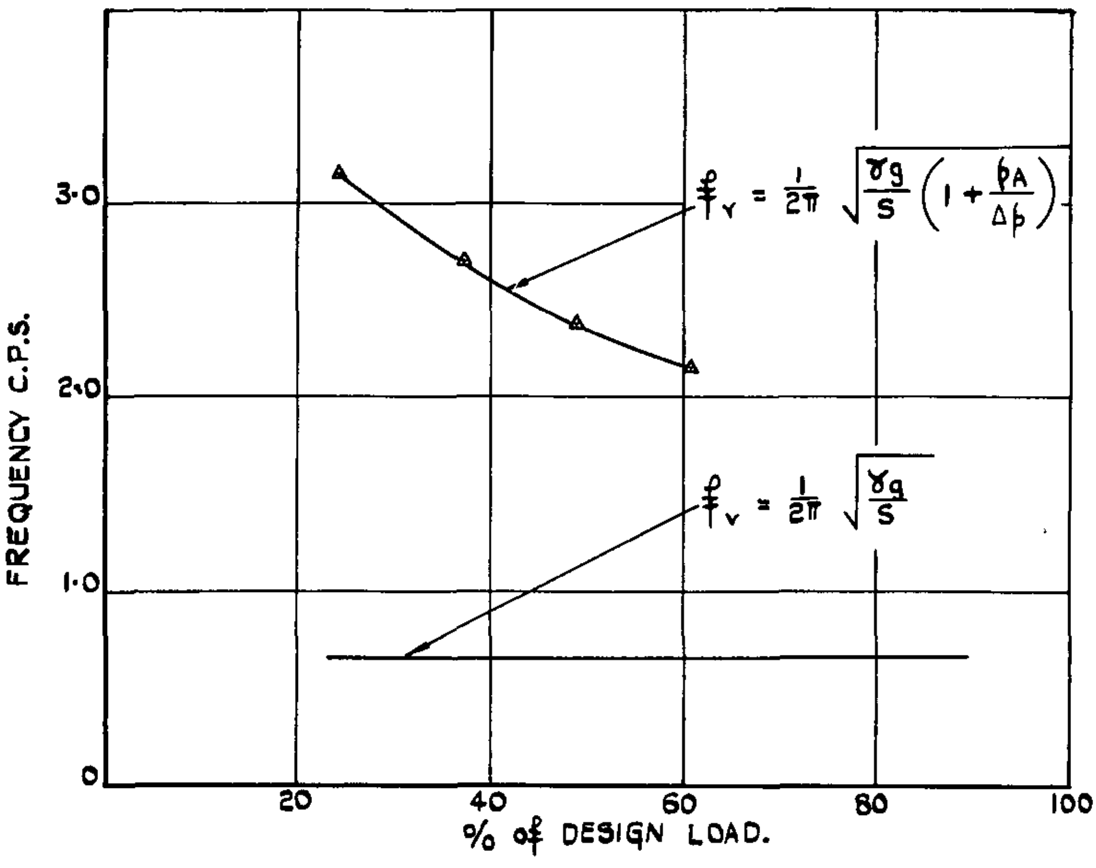


FIG. 7. BAG FREQUENCY — LOAD CURVES.
EXPERIMENTAL & THEORETICAL.

FIG. 8.

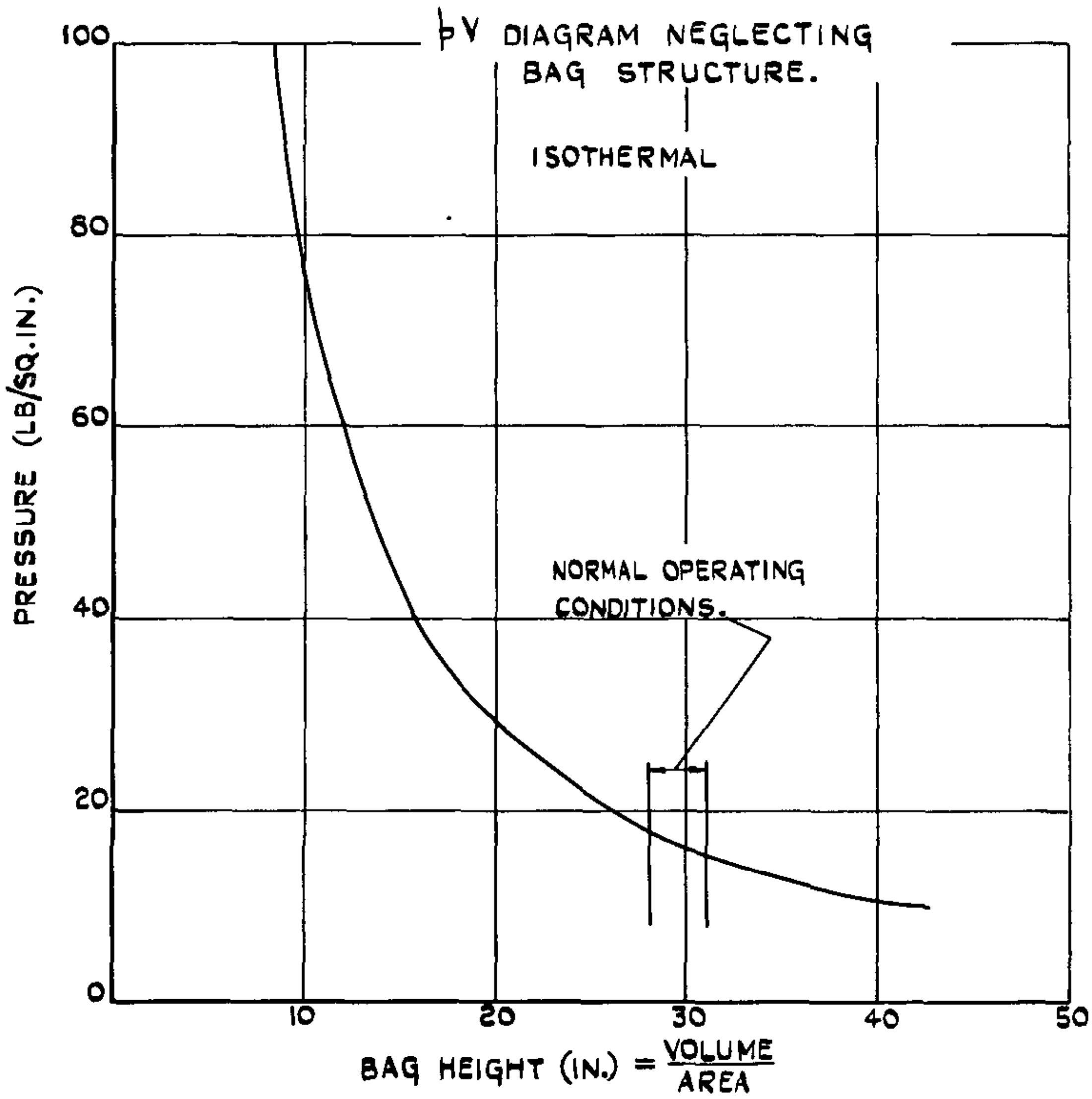


FIG. 8. BAG PRESSURE – HEIGHT CURVE. THEORETICAL.

C.P. No. 32
(12738)
A.R.C. Technical Report

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, LONDON, W C 2, 429 Oxford Street, LONDON, W 1,
P O Box 569, LONDON, S E 1,
13a Castle Street, EDINBURGH, 2 | 1 St Andrew's Crescent, CARDIFF
39 King Street, MANCHESTER, 2 | 1 Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 | 80 Chichester Street, BELFAST,
or from any Bookseller

1950
Price 1s. 3d. net

S.O. Code No. 23-9006-32