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Some Theoretical Studies Concerning Oleo Damping Characteristics

by

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SOME THEORETICAL STUDIES CONCERNING OLEO DAMPING CHARACTERISTICS

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SUMMARY

The paper presents results o? a study that has been made to investigate the effect of damping characteristics on the performance of an oleo strut. Conventional oleo struts employ orifice dampers in the interests of providing high energy absorption for the design vertical velocity of descent case. It is shown that an equivalent strut i.e. one having the same maximum stroke, utilizing a damping mechanism providing a force proportional to the stroking velocity, instead of the square of this velocity, will benefit by a 10 per cent reduction in stress in the design case. Comparison of the performance of these two types of damper in the taxi phase of operation over a real profile shows that a linear' damper has better characteristics then an 'orifice' damper having the same damping constant in compression and recoil.

*Replaces R.A.E. Tech. Report No.66312 - A.R.C. 28905.

CONTENTS

1 INTRODUCTION

Over the past few years there has been an increase in undercarriage failures which has emphasised the need to design future undercarriages with longer fatigue lives. As a result, interest in fundamental design principles has been renewed. The present paper examines some of the consequences that stem from one of the significant parameters in undercarriage design, namely that of oleo damping. It presents the results of some calculations made to compare the performance of an undercarriage when the oleo damping characteristics are the conventional square law and when they are linear with stroking velocity.

The adoption of square law damping devices seems to have come about because of the fact that the pressure difference associated with the flow through an orifice produces a high resistance and consequently a powerful damping force that can easily be utilized to provide a practical design. By virtue of the fact that the orifice is small the Jet velocities and Reynold's Numbers are high and fully turbulent flow is developed so that the damping force is proportional to the square of stroking velocity. In practical orifice design the peak flow velocity in the orifice may, on occasions, be so high that the possibility of transonic flow and 'choking' must be considered+ As many undercarriages are designed to satisfy the energy absorption required at design landing velocity, damping is a maximum at the corresponding relatively high stroking velocities. A strut designed by these considerations will have low damping capacity at the low stroking velocities that occur in the taxi phase of operation.

An alternative method of providing damping can be conceived. A 'linear' damper in which the damping force is directly proportionalto stroking velocity. Using this method adequate damping capacity may be provided in both the landing and taxi phase of operation. There should not be the rapid fall-off in efficiency of such a damper at low stroke velocities that occurs with the orifice damper. The realization of such a damper in practice will lead to design problems and these are considered in the text.

Possible methods of constructing a linear damper are discussed in Section 4. In Sections 3.1 and 3.2 limited comparisons are made between the performance of a strut having linear and orifice damping characteristics in both the landing and taxying phase of the aircraft operation.

2 CALCULATIONS

The strut having linear damping characteristics was designed to a heavy landing case. The appropriate touch-down velocity being 8.86 ft/sec.

The mathematical model on which the calculations were based is shown in Fig.1. The shock strut axis was considered to be in the vertical plane throughout. It consisted of an upper mass representing the aircraft connected through an air spring and damper in parallel with the lower mass representing the wheel assembly, which was supported on the tyre spring. For all the landing cases considered there was assumed to be a lift force present which was equal to the dropping weight. During the taxi runs considered in this paper the lift was assumed to be zero. The effect of strut friction was not considered in any of the calculations made.

In the first of the landing calculations i.e. at 8.86 ft/sec the most accurate representation of the strut properties that was available was utilized. This meant for both struts polytropic air springing and exponential tyre characteristics were considered. The characteristics of the air spring were represented by -

$$F_a = p_{a_0} A_a \left(\frac{v_o}{v_o - A_a s} \right)^n$$

and the tyres by -

$$F_{v_g} = m' \left(\frac{Z_2}{d} \right)^r$$

where F_a is the pneumatic force

P_{a_0} the air pressure in the upper chamber for the fully extended strut

A_a the pneumatic area

V_o the air volume for the fully extended strut

s the stroke

n the effective polytropic exponent

F_{v_g} the vertical force applied to the tyre at the ground

Z_2 the vertical displacement of the lower mass from the position at the initial contact

d the overall diameter of the tyre

and m' and r constants with different values for the various regimes of the tyre deflection process.

is some 10 per cent greater than that for the linear damper. The peak is reached sooner in the stroke in the linear case.

It should be mentioned that in the American Paper[1] no information is given on the damping constant that is appropriate to the recoil stroke. In Ref.1 the concern was with the peak load generated and this occurs as we have seen in Fig.3 prior to the maximum stroke being achieved. In the first place therefore the recoil damping constant was taken to be equal to that on compression. Other calculations were made to investigate variations in this parameter and although such variations were arbitrary, the results indicate what may occur with a practical strut design.

Figs.4 and 5 show the strut force obtained in three cases, which may be considered to represent a normal, moderately heavy and severe landing case respectively. For the purpose of these and subsequent calculations, the tyre forces were taken to vary linearly with displacement. It has been mentioned above that this approximation introduced little error at a particular touch-down velocity. In view of this it was considered that efforts to obtain true tyre characteristics appropriate to other velocities was unwarranted. The figures show that -

(a) For the normal landing the orifice damper develops smaller peak load than the linear, but at the expense of a longer stroke.

(b) For the moderately heavy landing there is little to choose between the two dampers in terms of either peak load or stroke.

(a) For the severe landing the linear damper gives lower peak force, the maximum stroke being the same in both cases, and the curve of strut force against stroke is much nearer to the ideal step form.

The effect of increasing damping on the recoil stroke far the orifice damper is shown in Fig.4. It is to give a sharper out-off to the strut force, once the peak strut deflection has been reached. Table 1 gives details of the velocities and kinetic energies at the instant of touch-down, recoil and rebound. In the Table $\dot{z}_1$ and $\dot{z}_2$ are the velocities of the upper (sprung) and lower (unsprung) masses respectively. Recoil is defined as the instant at whioh the strut action changes from ccanpression to extension. Rebound that at which the tyre leaves the ground, and the kinetic energy that due to motion of the upper and lower masses. It can be seen that in general the orifice damper will dissipate more energy over the interval - touch-down to rebound, especially if a strut with a high recoil damping coefficient is considered. For the severe landing case more energy is absorbed in the compression stroke for the linear damper, but conversely more is given back in the rebound stroke than for the orifice damper with high recoil damping. At lower descent velocities less energy is absorbed by the linear damper in the compression stroke but the relative amount of energy fed back in the extension stroke is a function of both damper type and velocity. An interesting point emerges from these results, that for orifice dampers the effect of increased recoil damping is a progressively decreasing one, measured in terms of kinetic energy still present at rebound, as the touch-down velocity increases.

3.2 Taxying operation

3.2.1 Discrete (l-cosine) bumps

The results are shown in Figs.6 to 8 and are all concerned with the strut force developed on passage over various bumps. Fig.6 shows the effect of taxying at a particular speed over three bumps, 0.3 in, $1\frac{1}{2}$ in and 3 in high. These results show that generally the maximum force is produced slightly after the bump peak has been reached. The linear damper produces a small reduction in peak load for the highest bump case and slightly higher peak loads for the smaller bumps. The peak to trough swings exhibit the same tendencies as the peak loads produced by the two dampers. A feature of these results is the flattening in the orifice damper curves as the wheel moves off the bump.

Fig.7a and 7b show the effect of increasing the length of the highest bump to 50 ft at the same taxi speed. This produces a sharp reduction in the peak strut load compared with the corresponding $2\frac{1}{2}$ ft bump. The linear damper still gives a slightly lower peak. Similarly the force amplitude is slightly less for the linear damper than the orifice, which has low damping constant on the recoil stroke. There is bounce for both the linear damper and the orifice dampers having recoil damping constants higher than compression. The bounce time is less for the linear damper. A comparison of results at 100 ft/sec shows that the effect of increasing bump length is to lower the mean force level about which the oscillation occurs and to reduce slightly the amplitude of the swing. Figs.8a, b, c and d are concerned with the effect of changing speed on the strut response when passing over a bump of 3 in height and $2\frac{1}{2}$ ft length. The maximum reaction is developed at an intermediate velocity for both dampers, Figs.8a and b, this velocity is slightly higher for the orifice damper. There is little difference between the performance of the two dampers except

In the equation defining pneumatic force the effective polytropic exponent depends on the rate of compression and the rate of heat transfer from the air to the surrounding environment. A value of 1.12 was eventually chosen which was an average of the effective value for several landing gears'. Fcr . current designs in which the gas and oil tend to be separated by a diaphragm or alternatively the oil jet from the orifice is deflected from direct impingement on the gas, the value of 1.12 will be inappropriate. An exponent nearer to the adiabatic value is obtained and 1.3 maybe considered a typical figure: m' and r in the equation defining the vertical force were chosen on the basis of drop tests to give the appropriate hysteresis loop to account for the measured energy dissipation. The values appropriate to the 8.86 ft/sec touch-down speed are -

Region 1: $m' = 78.6 \times 10^3$ lb
$r = 1.34$ for $0 < Z_2 < 0.352$ ft

Region 2: $m' = 34.0 \times 10^3$ lb
$r = 0.89$ for $0.352 < Z_2 < 0.364$ ft

Region 3: $m' = 157.1 \times 10^3$ lb
$r = 1.73$ for $0.364 > Z_2 > 0.267$ ft

Region 4: $m' = 65.5 \times 10^3$ lb
$r = 1.34$ for $0.267 > Z_2 > 0$ ft

Subsequent calculations were based on linear tyre characteristics with no hysteresis, $F_{v_g} = 18500\ Z_2$ lb, as results of calculations of strut performance at 8.86 ft/sec on this basis by Milwitzky and Cook' showed very reasonable agreement with measured characteristics and those of the more refinedcalculations using the non-linear tyre characteristics.

Further landing cases were considered, in which the undercarriage touched down at velocities of 3, 7 and 11 ft/sec respectively and in which for the orifice damper the damping constant on the return stroke was varied.

The taxi aspect of undercarriage operation was considered in two ways.

(i) By operating at varying speeds over (P-cosine) bumps of varying heights and lengths, and

(ii) over an actual runway profile.

The latter part of the investigation is to-date limited in scope. The assumption was made in all these calculations that the aircraft had landed a sufficient length of time prior to the encounter with the bump for steady conditions to have been established, i.e. there was no vertical motion of a strut when the bump was reached. A further assumption made in the calculations was that the tyre force developed as the wheel passed over an obstacle was directly proportional to the height of the bump (modified by the displacement of the wheel itself) beneath the wheel axle. Unless otherwise indicated, damping coefficients in compression and recoil for the orifice dampers will be the same.

Data are available* of profile displacements measured at 2 ft intervals on 3000 ft of Runway 12 at Langley Field and this was used as input data. The variation in profile between the tabulated values was assumed to be linear. The aircraft speed over the profile was taken to be constant at 100 ft/sec. The profile is shown in Fig. 2.

Several methods for integrating the differential equations of motion were tried by Milwitzky and Cook[1]. One of time, the x-called quadratic procedure, was adopted here. The variation of displacement over two successive intervals of time is assumed to be quadratic. This allows the velocity and acceleration at the mid-point of the double intervals to be expressed in terms of its displacement and those of the points immediately prior and after in the form -

$$\dot{Z}_n = \frac{Z_{n+1} - Z_{n-1}}{2\varepsilon}$$

$$\ddot{Z}_n = \frac{Z_{n+1} - 2Z_n + Z_{n-1}}{\varepsilon^2}$$

where ε the intagration interval was taken to be 0.002 sec. This had been found to be satisfactory in the original paper and check calculations in this case with the interval reduced to 0.001 sec produced no detectable difference in results.

3 RESULTS

3.1 Landing operation

The calculated strut force is plotted against stroke for the two dampers in Big. 3. It can be seen that the peak force development by the orifice damper perhaps for the high taxi speeds, where the beneficial effect of the linear damper is beginning to show. Figs& and d show the effect of increased damping on the recoil stroke in the case of the orifice *damper.* Amplitude of reaotion increases and the mean level reduces with increased recoil damping, the effect being most pronounoed at the *lower taxi* speeds. It is possible therefore that current designs of undercarriage having recoil damping constants that are higher than on compression may be inadvertently aggravating a potential fatigue problem.

Current designs of undercarriages have recoil damping constants which are greater than those on the canpression stroke. Typical values range between 4 and 2.5 times greater. We may therefore expect from the basis of the above results that a linear damper will exhibit better characteristics in terms of peak force and force amplitude, than an orifice damper designed to have the same stroke for a heavy landing. These effects are not very marked, however, and in view of the fact that the input for the calculations was not a particularly real one it was decided that a more rational basis for assessing the relative merits of the two damper systems would be to make calculations in which the input was provided by an actual runway profile.

3.2.2 Runway profile

The results are shown in Figs.9a and b, where strut force developed as the runway is traversed is plotted against time. The initial encounter with the runway is equivalent to meeting a step 0.214 ft in height. The performance of the linear damper on this surface is markedly superior to that of the orifice damper with which it is compared. Salient features of interest regarding the figure are listed below:-

(i) The damping of the oscillation resulting from the initial step disturbance and of subsequent high peaks provided by the linear damper is much more powerful than that of the orifice.

(ii) A dominant low frequency response is revealed for both dampers. The aircraft oscillating as a rigid body in vertical translation on the tyre spring has a frequency approximately equal to that obtained with the linear damper; the frequency of oscillation for a linear damper case is about 2.0 to 2.4 cps and for the orifice damper 1.7 cps.

(iii) Over the smoother portions of the runway 4 to 10 sec and 15 to 22 sec there is little to choose between the two dampers, but over the remainder of the runway length the linear damper scores heavily. Peak forces are consistently less usually by significant amounts and amplitudes of oscillation are on average half those for the orifice damper.

(iv) Various other high frequencies are apparent in the response curves. All of these would be important in regard to the structural dynamic reponse. There is a particularly high frequency associated with this orifice damper, i.e. that having constant damping coefficient on compression and recoil.

(v) The particularly high response at around 23 seconds are associated. with a portion of the runway that is notoriously rough.

4 DESIGN OF THE LINEAR DAMPER

In theory damping that is linear with velocity of motion is obtained either by flow in a capillary or in an annulus. Both these methods were considered in the design of a strut on which the comparative calculations were based. It was eventually decided that the linear damper should be designed to have the same maximum stroke for a high velocity landing as the orifice damper with which it must Se compared. The design gave, as we have seen, a reduction in peak strut force far this condition of the order of 10 per cent. If the strut had been designed on the equivalence of peak reaction in the heavy landing case, then a reduction in stroke would have been achieved of the order of 5 per cent. On balance, the reduction in stress seemed preferable to the reduction in stroke and consequent slight saving in weight.

Using the well established results, (I) and (2) below, from fluid flow theory, it can be shown that the damping force provided by annular flow is of the order of 40 times greater than that for capillary flow through a single pipe having the same cross sectional area and length. For capillary flow the retarding force is -

$$F = \frac{128\,\rho\nu L A_h^2 \dot{s}}{\pi D_C^4} \qquad (1)$$

for annular flow the retarding force is -

$$F = \frac{12\,\rho\nu L A_h^2 \dot{s}}{\pi\, db^3} \qquad (2)$$

where ρ is the density of the hydraulic fluid
ν is the kinematic viscosity
L is the length of the channel

D_c is the capillary diameter
d is the internal diameter of the annulus
b is the thickness of the annulus
and A_h is the hydraulic area.

In view of the potentially more powerful damping action provided by the annular flow it was decided to adopt this method.

Certain conditions must be satisfied to ensure that a true linear damping action is obtained. These are listed below -

(i) The damping medium should be a perfect fluid - oils with viscosities less than 200 centistokes may be considered perfect in this respect. Any imperfections in the fluid will distort the response particularly at low speeds.

Temperature effects will obviously be important for the annulus type of damper proposed. Changes in temperature would result in variations in viscosity and consequently, their damping force. It is suggested that such variations may be overcome by careful design, e.g. the use of materials having different coefficients of expansion for the piston and cylinder.

(ii) Clearance between piston and cylinder is small relative to the piston diameter.

(iii) The piston should be long enough to avoid sharp edge orifice effects. If for sane reason this is not practicable it may still be possible to achieve the appropriate damping action by careful attention to inlet and outlet shapes to minimise losses.

(iv) Free area above the piston should be large so that oil velocity in this region approaches zero. Providing that the piston rod is small very little oil is displaced as the piston moves into the cylinder and oil velocity above and below the piston approaches zero. Ratios of piston to rod diameter greater than 3:1 reduce the oil velocity past the rod to a suitably small value.

(v) The piston should be maintained concentric with the cylinder.

(vi) At high speeds and damping factors, forces maybe high enough to drop the pressure on the piston below the vapour pressure of the fluid. Cavitation and aeration result and the damping force is no longer proportional to speed on the recoil stroke. We may note that orifice dampers arc possibly worse in this respect as peak loads may be greater under ultimate conditions and damping forces larger.

All these points are covered by the design that is proposed, Fig.10. The maximum stroking velocity reached by the linear damper is 6 ft/sec in the heavy 11 ft/sec landing. The corresponding Reynold's Number of the flow in the annulus is 1100 for ambient temperature conditions, accordingly, the appropriate laminar flow is obtained for all operations considered. The original strut design, with which the performance of the linear damper is compared in the calculations is shown in Fig.11.

5 CONCLUSIONS

From the theoretical work that has been done so far we are led to the conclusion that there appears to be some justification for a fresh approach to the design of undercarriage damping characteristics. A possibility investigated herein involves the use of a damper, whose reaction characteristics are proportional to stroking velocity rather than the velocity square characteristics of the conventional orifice damper. The results that are available to date show that reductions in strut force of the order of 10 per cant for heavy landings are possible, using a linear damper. Such reductions are achieved at the expense of an increase in strut force at lower descent velocities. It should be noted however, that these forces are less than those due to the static load and less than the peak forces developed in normal taxying. There is an increase in rebound kinetic energy for the linear damper (having equal damping coefficients on compression and recoil) compared with that for the orifice with high recoil damping at all vertical velocities of descent. The latter effect is most marked at low velocities where it might not be expected to be vitally important. Apart from the ultimate case (11 ft/sec drop) there seems to be a rough equivalence measured in terms of rebound kinetic energy between the performance in recoil of the linear damper and that of the orifice damper having three times the damping in recoil that it has in compression. The performance of the linear damper in the ultimate case is somewhat different in that recoil energy is higher than for all the orifice dampers considered. This result may be associated with a secondary effect due to the lower mass, possibly a resonance. It is noticeable that the shape of the linear curve, Fig.5, is a good deal different, (squarer) in this instance than that of all other strut force curves.

In regard to performance in the taxi phase of operation, the linear damper appears to have markedly superior properties in that damping of large disturbances is more effective, peak forces are smaller, and the oscillating force amplitudes are significantly smaller. The comparison may not be so favourable when cases involving higher values of recoil damping are considered, and this work remains to be done. Other calculations that are in progress aim to assess the effect of various values of steady lift, to study the response with no step at the beginning of the runway and further when the taxi run is started at a different point on the runway.

In theory, it seems possible to construct a linear damper but further work should be done to prove that this is a practicable proposition, should the calculations mentioned above prove to yield a favourable result.

6 ACKNOWLEDGMENTS

I am grateful to Mr. J. R. Sturgeon of Structures Department, R.A.E., for many valuable suggestions and helpful discussions on problems that arose during the course of the work leading up to the canposition of this paper.

Table 1

The velocities and kinetic energies at touch-down, recoil and rebound

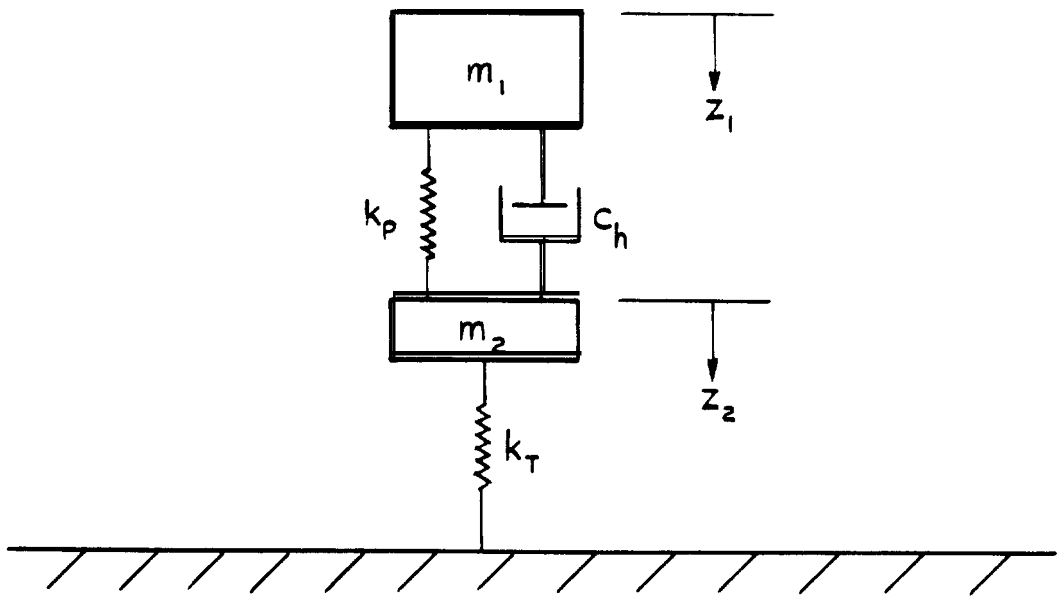
Case	Touch-down		Recoil				Rebound			
	Touch-down velocity ft/sec	Kinetic energy lb ft	$\dot{z}_1$ ft/sec	$\dot{z}_2$ ft/sec	Kinetic energy lb ft	t sec	$\dot{z}_1$ ft/sec	$\dot{z}_2$ ft/sec	Kinetic energy lb ft	t sec
Orifice damper, exp. tyre $D_R = D_c$	8.86	3100	-1.8	-1.8	126	0.181	-3.4	-1.7	437	0.295
Linear damper, exp. tyre	8.86	3100	-1.6	-1.6	110	0.186	-3.3	-1.95	415	0.292
Orifice damper, linear tyre $D_R = 0.5D_c$	3.0	356	-0.2	-0.2	1.6	0.193	-1.7	-0.1	108	0.493
$D_R = D_c$	3.0	356	-0.2	-0.2	1.6	0.193	-1.4	-0.1	73.5	0.417
$D_R = 5D_c$	3.0	356	-0.2	-0.2	1.6	0.193	-0.9	-0.3	31	0.333
$D_R = 50D_c$	3.0	356	-0.2	-0.2	1.6	0.193	-0.7	-0.5	19	0.291
Linear damper, linear tyre	3.0	356	-0.9	-0.9	32	0.199	-1.1	-0.5	46	0.239
Orifice damper, linear tyre $D_R = 0.5D_c$	7.6	1937	-1.5	-1.5	88	0.192				
$D_R = D_c$	7.6	1937	-1.5	-1.5	88	0.192	-2.5	-0.8	236	0.286

Table 1 (Contd.)

Case	Touch-down		Recoil				Rebound			
	Touch-down velocity ft/sec	Kinetic energy lb ft	$\dot{z}_1$ ft/sec	$\dot{z}_2$ ft/sec	Kinetic energy lb ft	t sec	$\dot{z}_1$ ft/sec	$\dot{z}_2$ ft/sec	Kinetic energy lb ft	t sec
$D_R = 5D_c$	7.0	1937	-1.5	-1.5	88	0.192	-2.2	-1.3	183	0.256
$D_R = 50D_c$	7.0	1937	-1.5	-1.5	88	0.192	-2.0	-1.7	156	0.242
Linear damper, linear tyre	7.0	1937	-1.75	-1.75	121	0.198	-2.3	-1.2	201	0.254
Orifice damper, linear tyre $D_R = 0.5D_c$	11.0	4790	-2.4	-2.4	245	0.165	-5.7	-2.8	1232	0.255
$D_R = D_c$	11.0	4790	-2.4	-2.4	245	0.165	-5.5	-3.3	1150	0.251
$D_R = 5D_c$	11.0	4790	-2.4	-2.4	254	0.165	-5.3	-4.1	1085	0.243
$D_R = 50D_c$	11.0	4790	-2.4	-2.4	245	0.165	-5.1	-4.6	1030	0.237
Linear damper, linear tyre	11.0	4790	-0.85	-0.85	29	0.153	-5.7	-3.8	1260	0.257

REFERENCES

No.	Author	Title, etc.
1	B. Milwitzky F. E. Cook	Analysis of landing gear behaviour. N.A.C.A. Report 1154, 1953
2	C.C. Tung J. Penzien R. Horonjeff	The effect of runway uneveness on the dynamic response of supersonic transports. N.A.S.A. CR-119, October, 1964



m_1 = UPPER MASS (THE AIRCRAFT)

m_2 = LOWER MASS (THE WHEEL UNIT)

z_1 = DISPLACEMENT OF UPPER MASS FROM TOUCHDOWN POSITION

z_2 = DISPLACEMENT OF LOWER MASS FROM TOUCHDOWN POSITION

k_p = PNEUMATIC SPRING STIFFNESS

k_T = TYRE STIFFNESS

c_h = HYDRAULIC DAMPING CONSTANT

FIG.1 THE TWO DEGREE OF FREEDOM SYSTEM USED IN THE CALCULATIONS

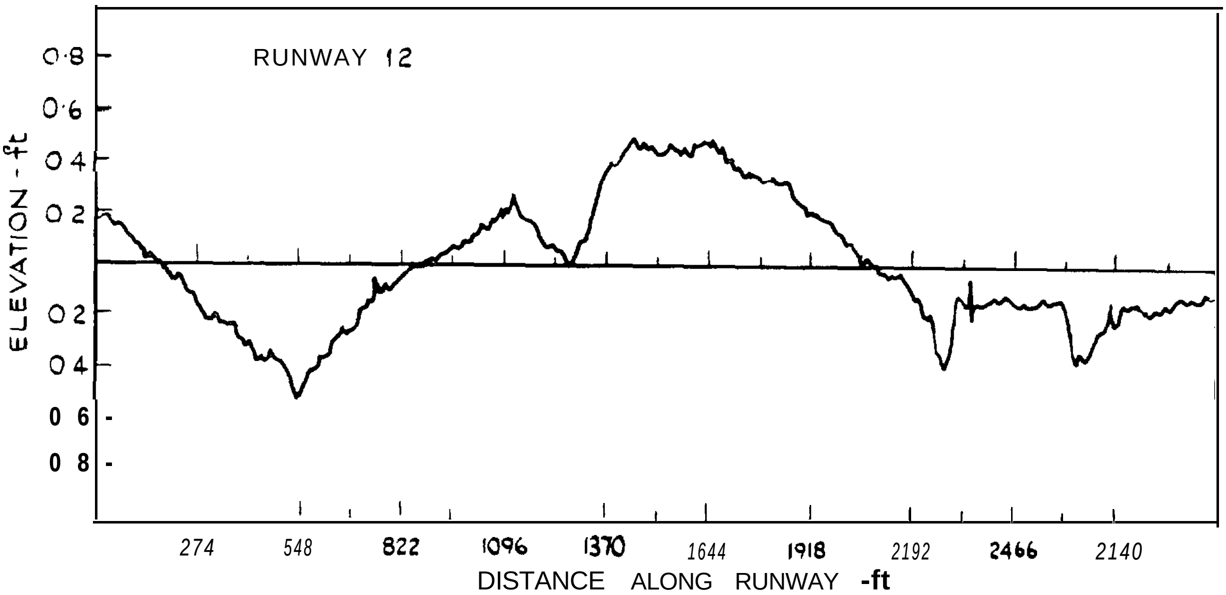


FIG.2 RUNWAY ELEVATION

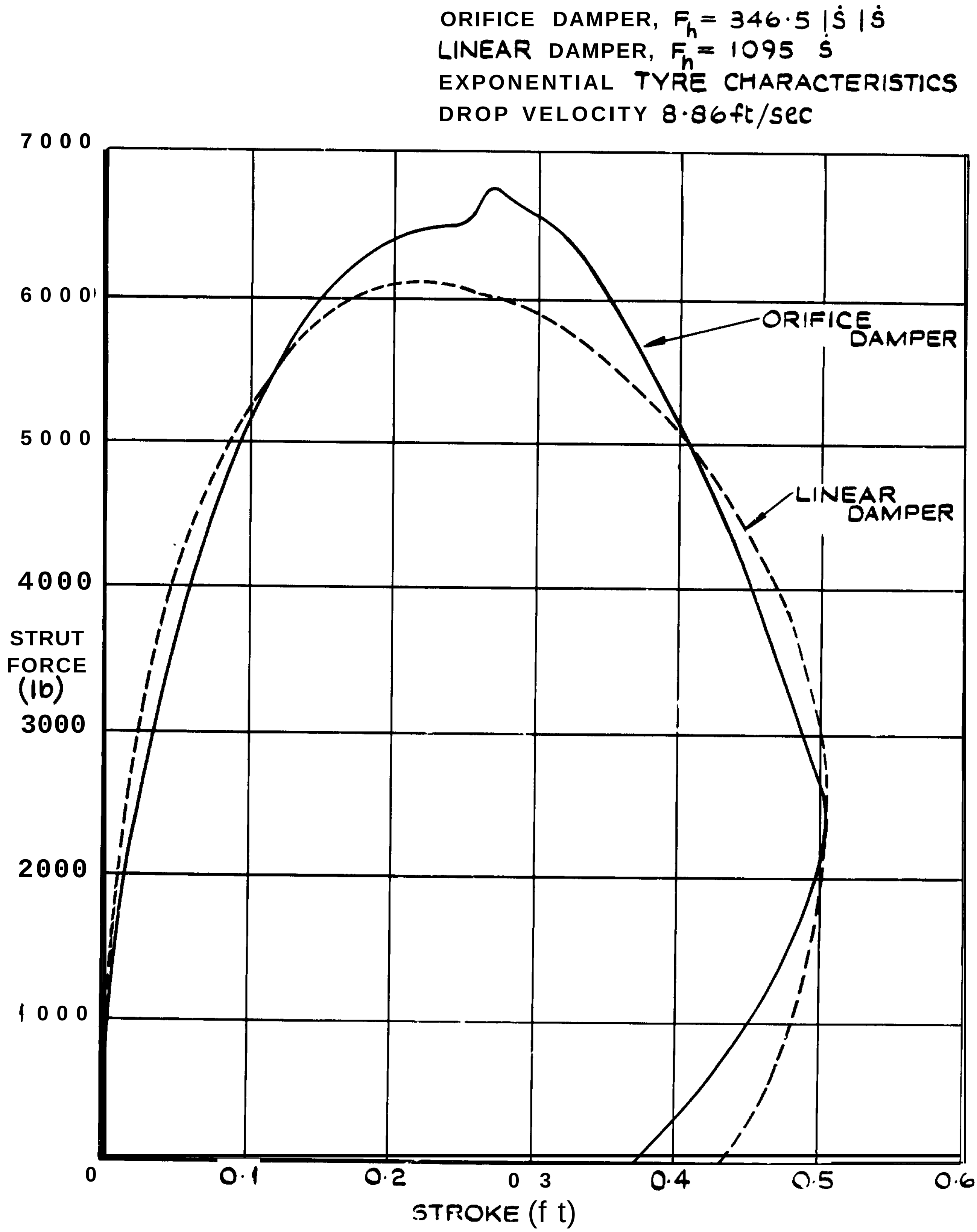
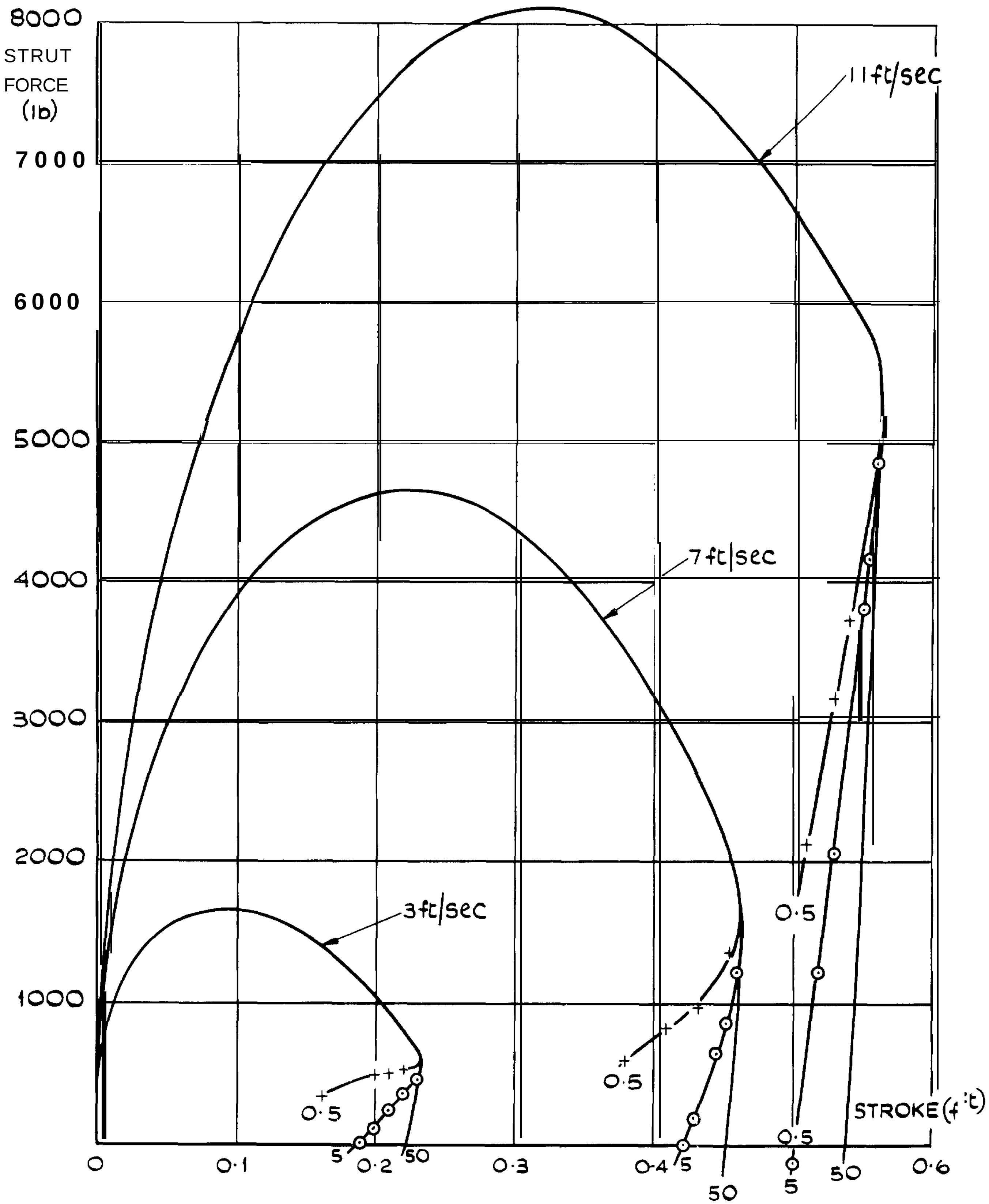


FIG.3 THE VARIATION OF STRUT FORCE WITH
STROKE FOR THE TWO DAMPERS



ORIFICE DAMPER, LINEAR TYAE CHARACTERISTICS. THREE VALUES OF TOUCHDOWN VELOCITY 3, 7 AND 11 ft/sec. DAMPING CHARACTERISTICS ON THE ENTENSION STROKE VARIED-THREE VALUES CONSIDERED 0·5, SAND 50 TIMES THATONTHE COMPRESSION. DAMPING FORCE $F_h = 346\cdot5\,|\dot{s}|\dot{s}$ OR A MODIFICATION. FIGURES AT END OF EACH CURVE GIVE APPROPRIATE DAMPING CHARACTERISTICS ON ENTENSION STROKE. ON COMPRESSION STROKE TO POINT WHERE CURVES DIVERGE

FIG. 4 THE VARIATION OF STRUT FORCE WITH STROKE FOR THREE ORIFICE DAMPERS AT THREE TOUCHDOWN SPEEDS

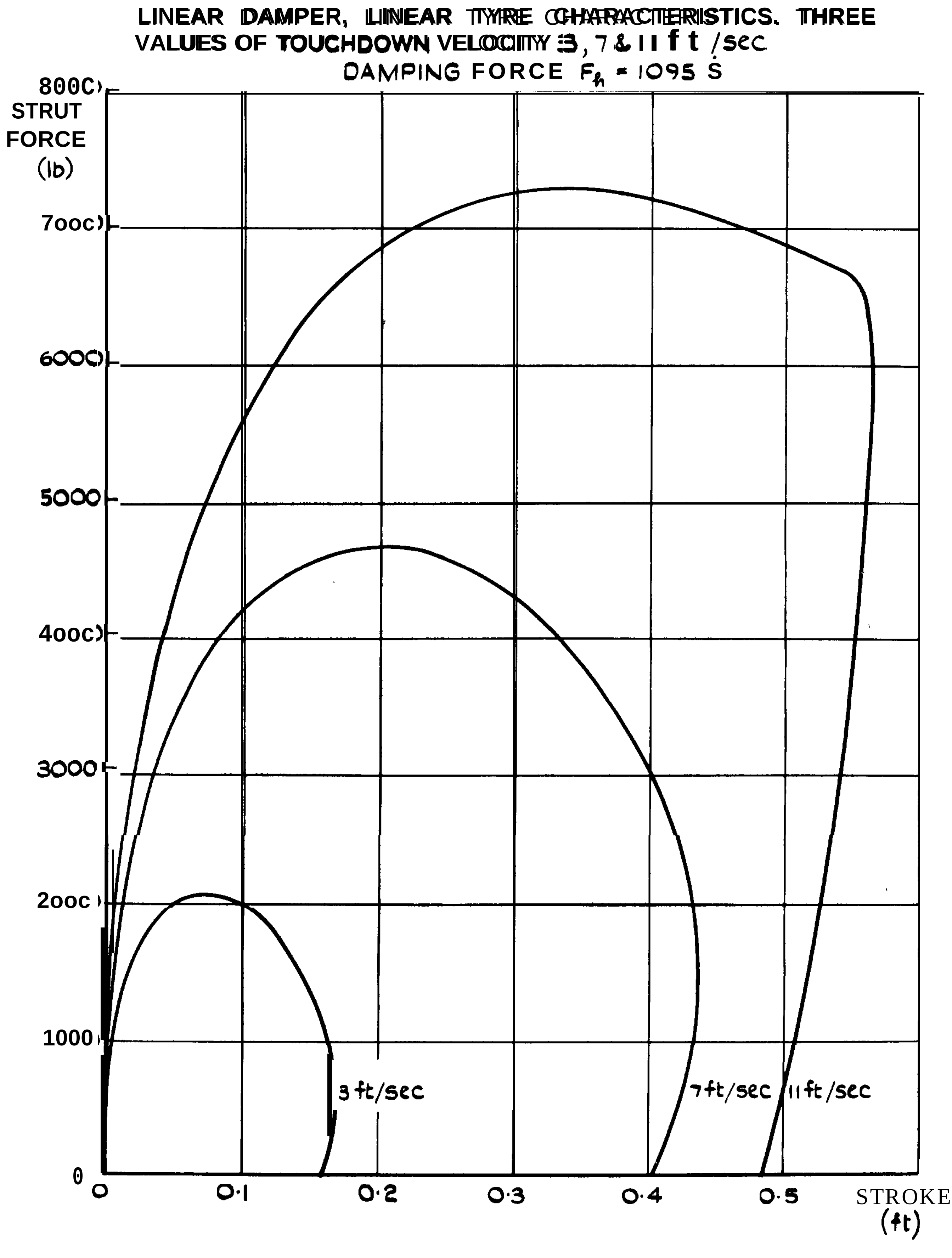


FIG.5 THE VARIATION OF STRUT FORCE WITH STROKE
FOR THE LINEAR DAMPER AT THREE TOUCHDOWN SPEEDS

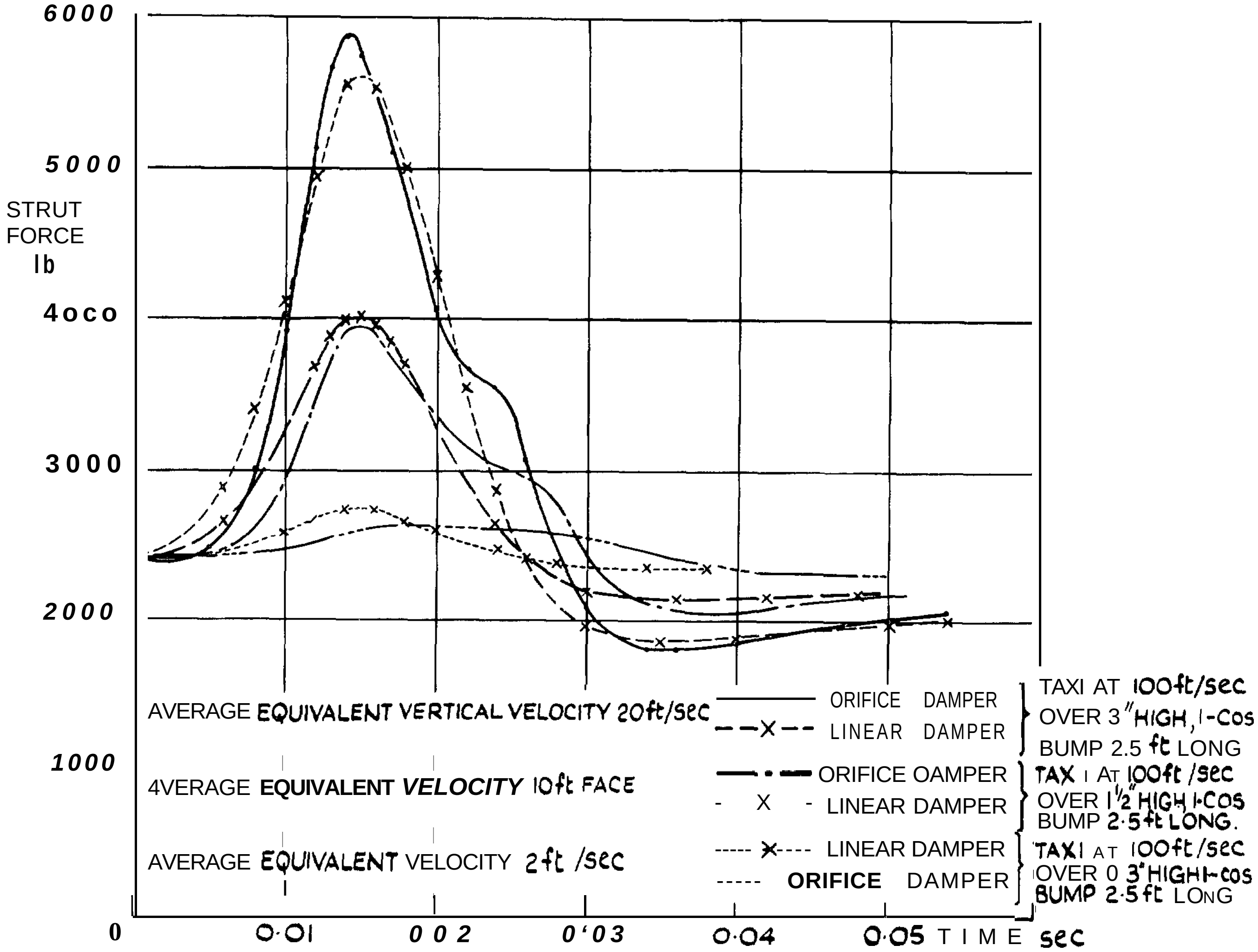


FIG.6 THE EFFECT OF BUMP HEIGHT ON STRUT FORCE

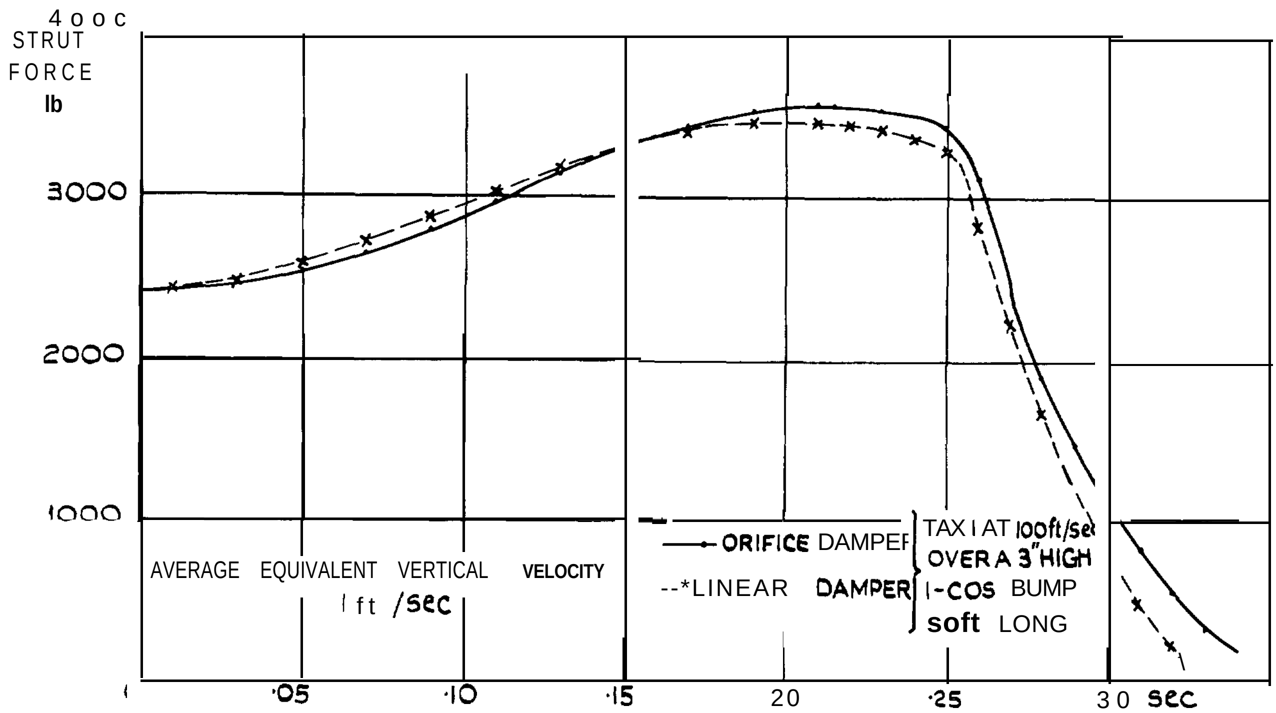
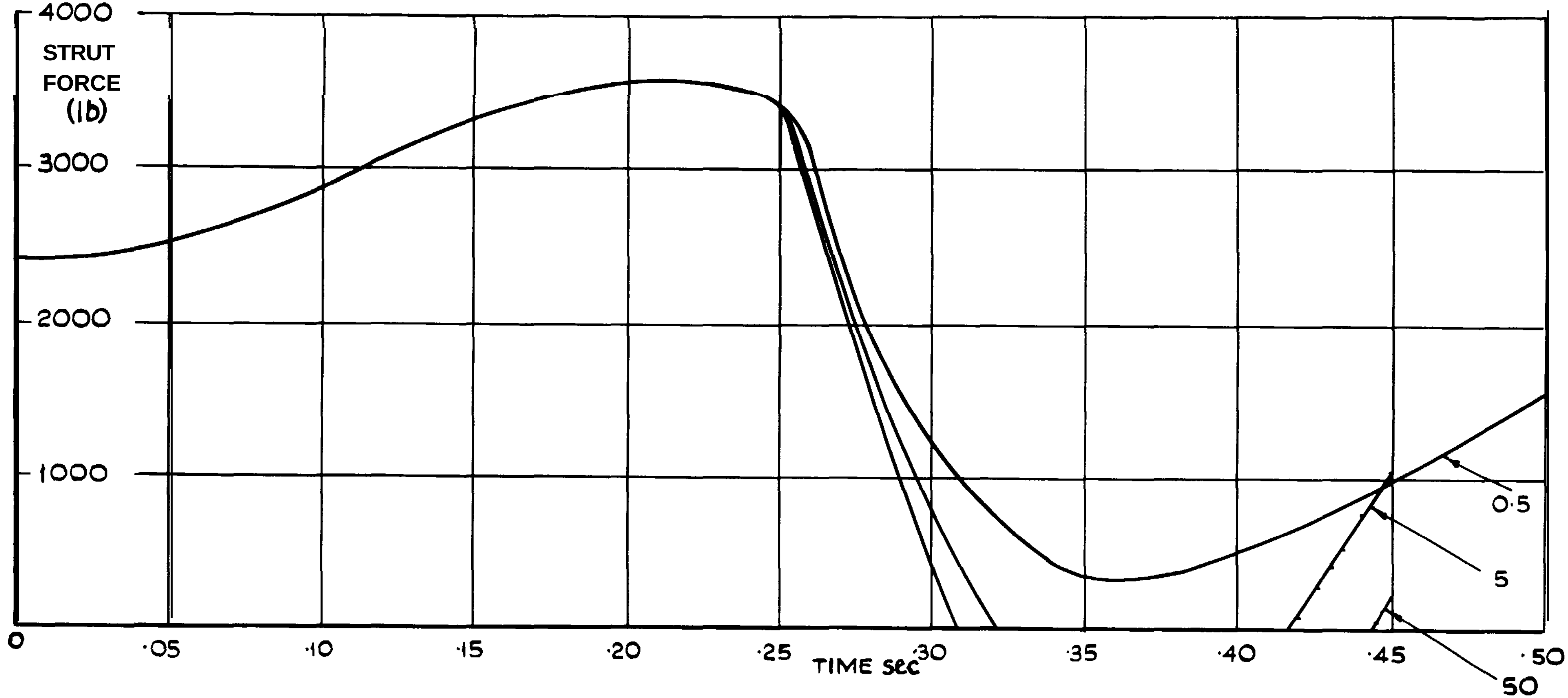


FIG.7a THE VARIATION OF STRUT FORCE WITH TIME FOR TAXI AT 100 ft /sec OVER A 3" HIGH, 1 - COSINE BUMP, 50 ft . LONG



ORIFICE DAMPER, LINEAR TYRE CHARACTERISTICS,
DAMPING ON THE EXTENSION STROKE VARIED

FIG.7 b THE VARIATION OF STRUT FORCE WITH TIME FOR
TAXI AT 100 ft/sec OVER A 3" HIGH, 1-COSINE BUMP, 50 ft LONG

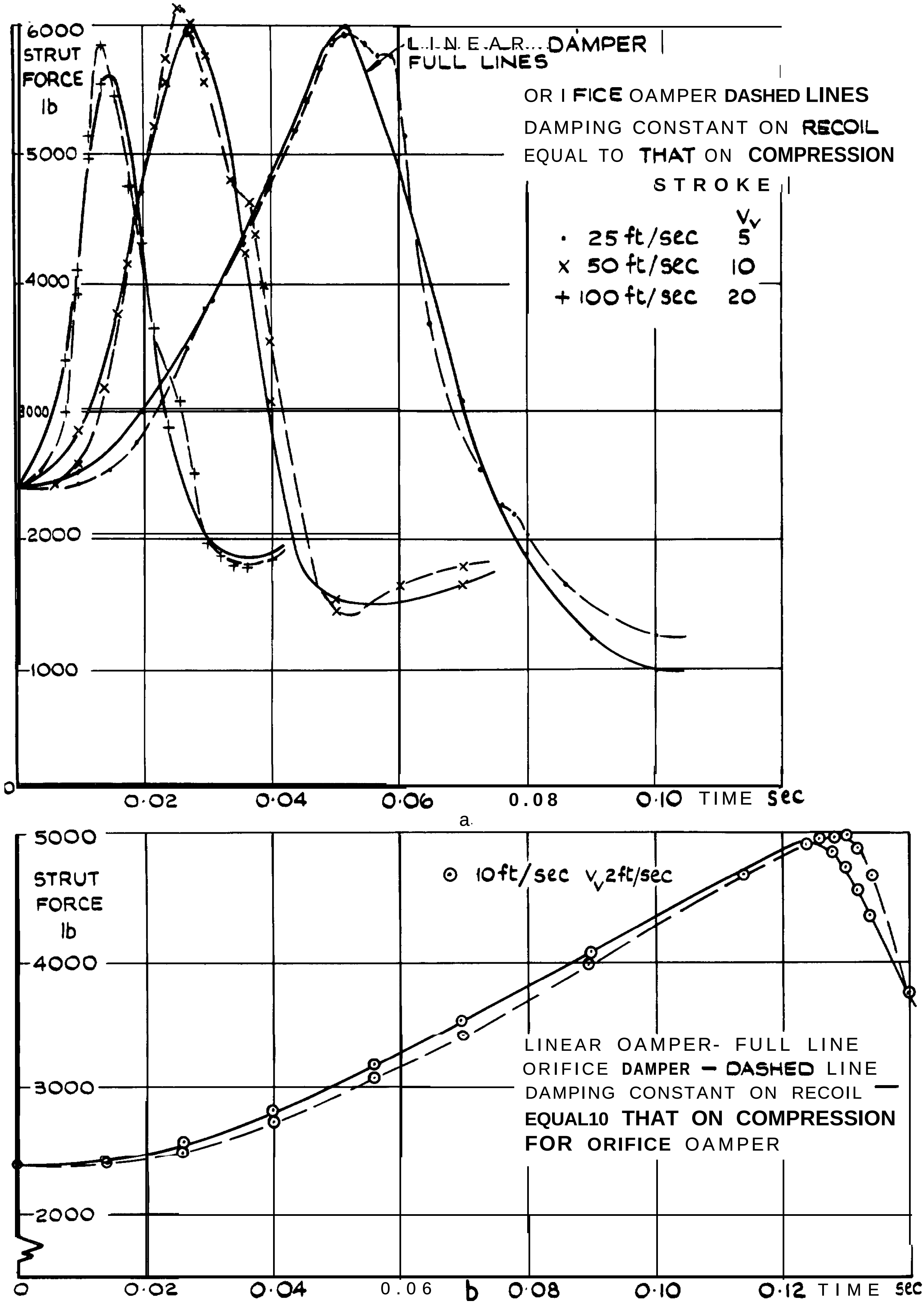


FIG.8 a & b THE VARIATION OF STRUT FORCE WITH TIME FOR SEVERAL DAMPERS FOR TAXI AT VARIOUS SPEEDS OVER A 3" HIGH, I — COSINE BUMP, $2\frac{1}{2}$ ft LONG

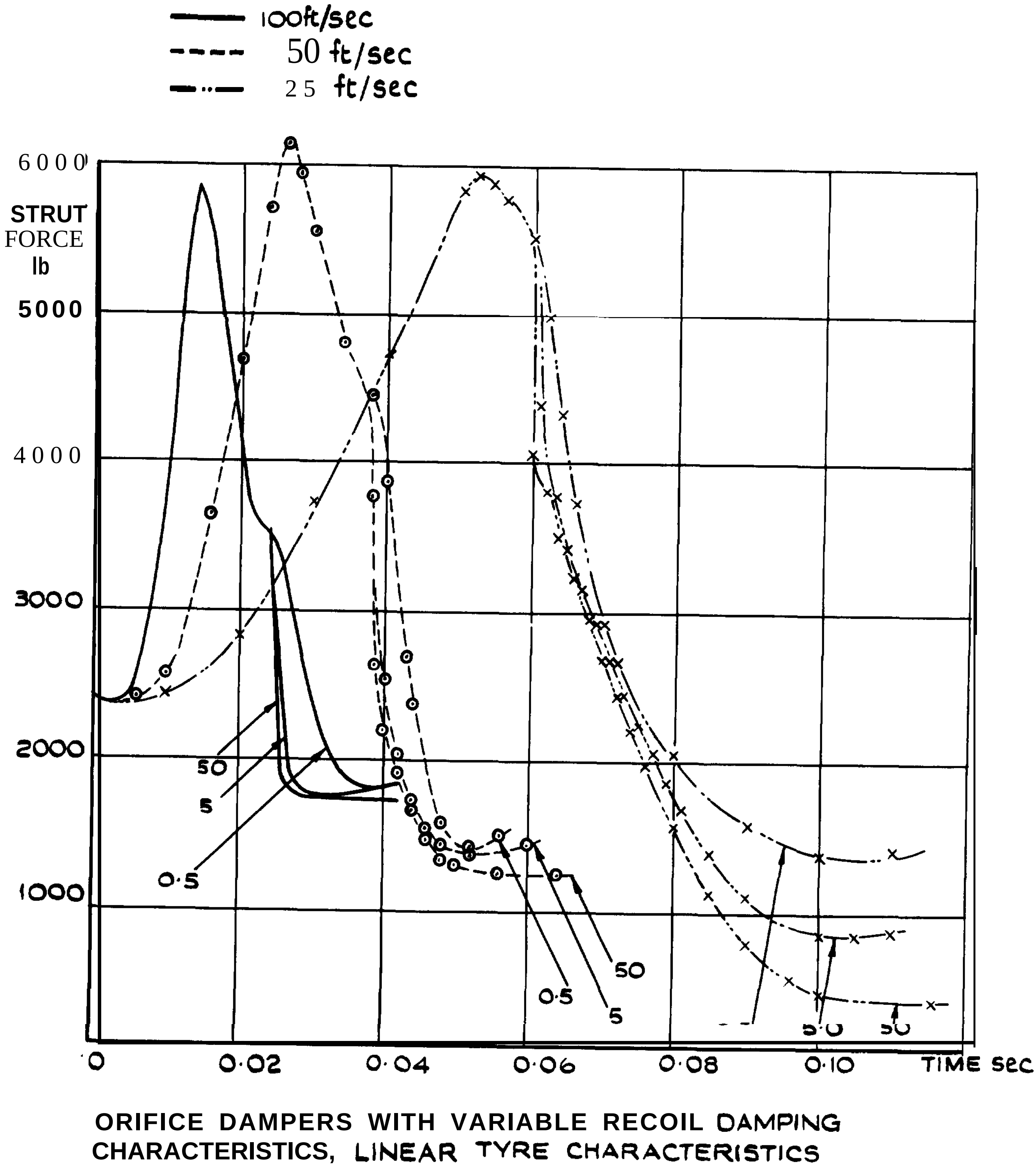


FIG.8 c THE **VARIATION OF STRUT FORCE WITH TIME FOR SEVERAL DAMPERS FOR TAXI** AT VARIOUS SPEEDS OVER A **3″ HIGH,** I-COSINE BUMP, **2½ ft LONG**

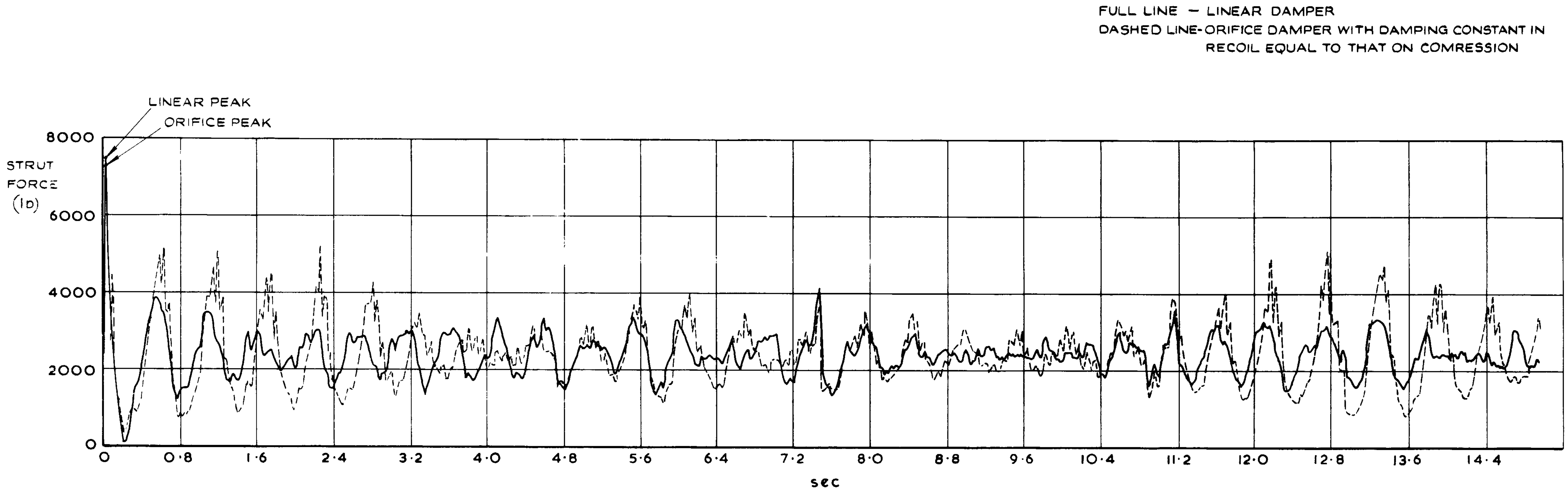


FIG.9 a THE VARIATION OF STRUT FORCE WITH TIME FOR THE LINEAR & ORIFICE DAMPER

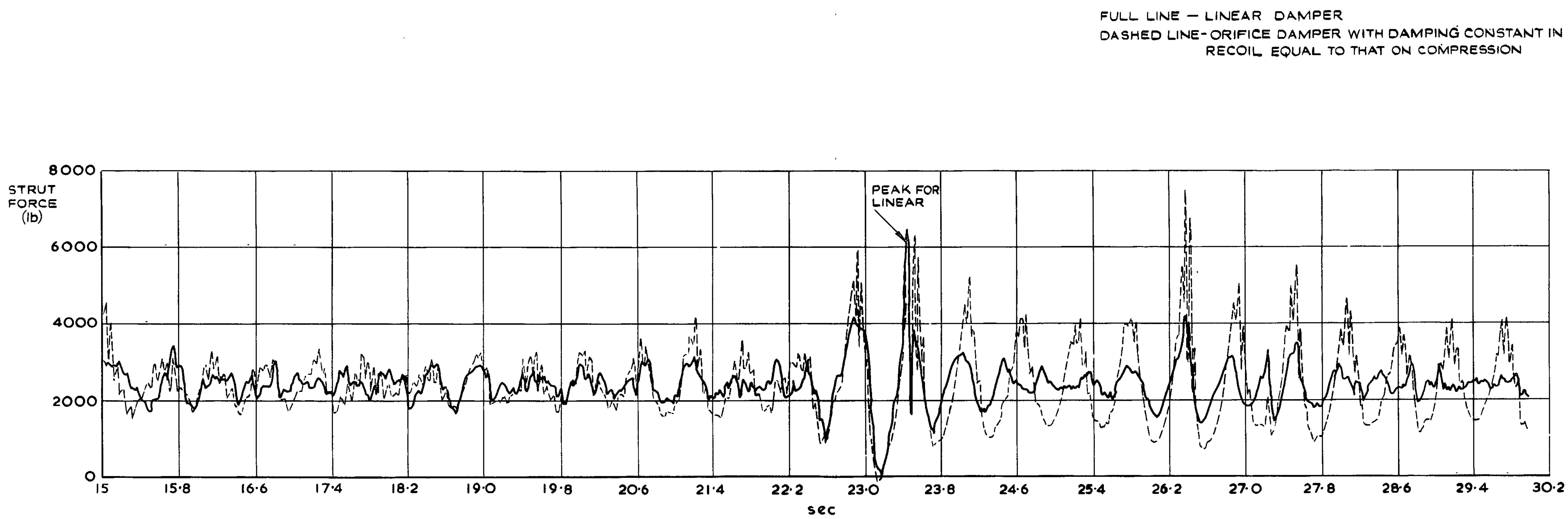


FIG.9 b THE VARIATION OF STRUT FORCE WITH TIME FOR THE LINEAR & ORIFICE DAMPER

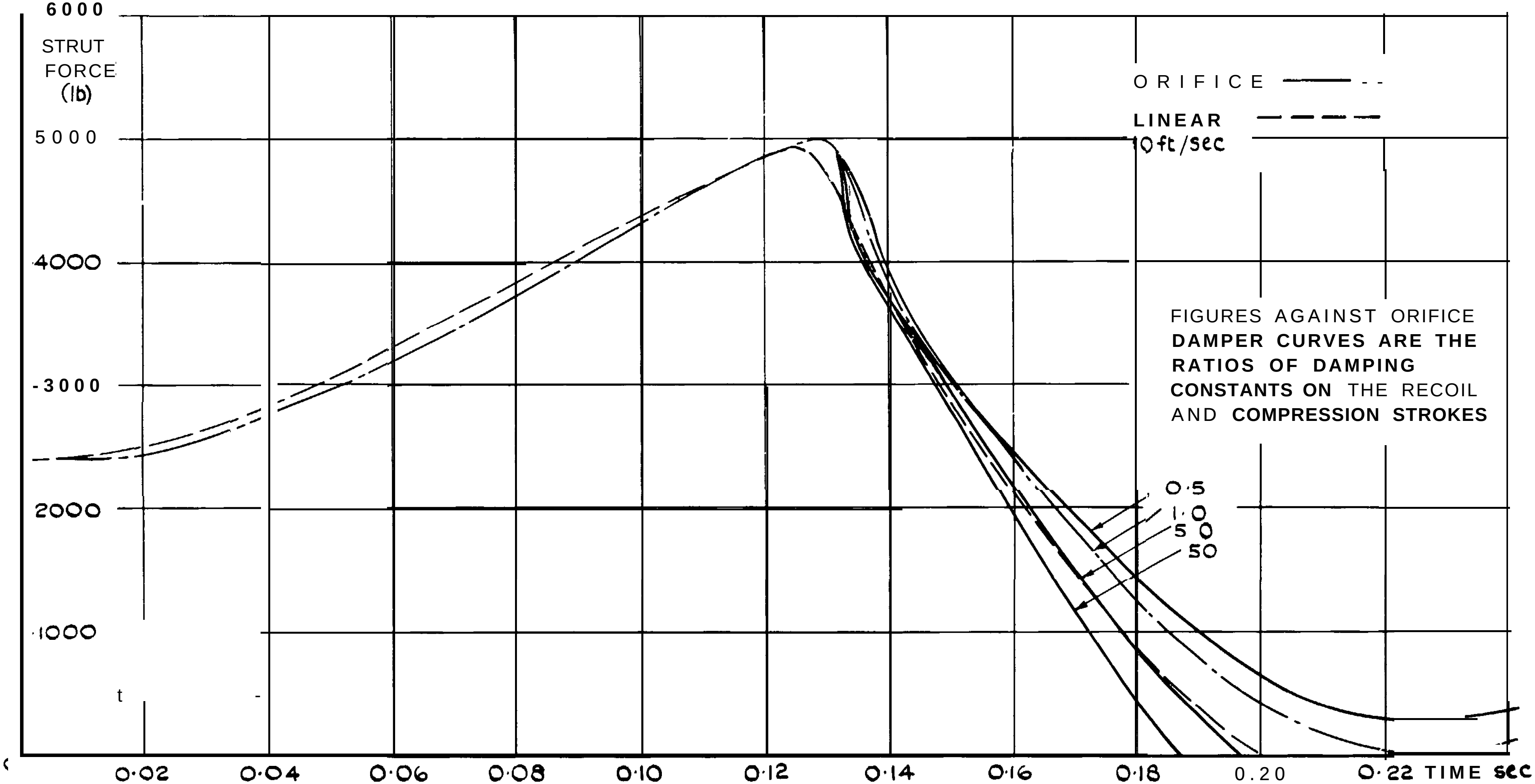
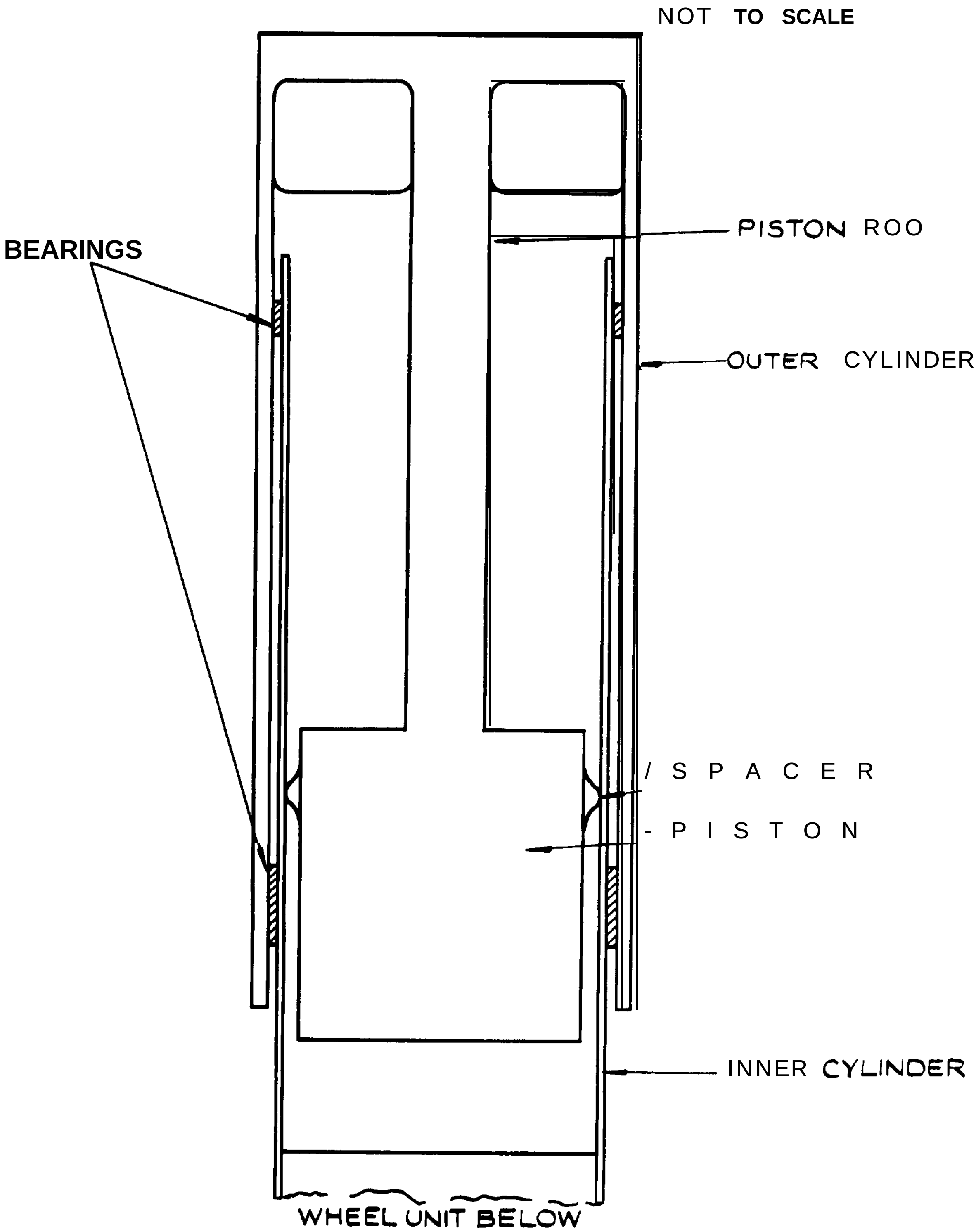


FIG. 8 d THE VARIATION OF STRUT FORCE WITH TIME FOR SEVERAL DAMPERS FOR TAXI AT VARIOUS SPEEDS OVER A 3' HIGH, I-COSINE BUMP, 2 ½ ft LONG



UPPER MASS M_1 = 2411 lb

STRUT CHARACTERISTICS

A_1 = 0·05761 sq ft

A_h = 0-04708 sq ft

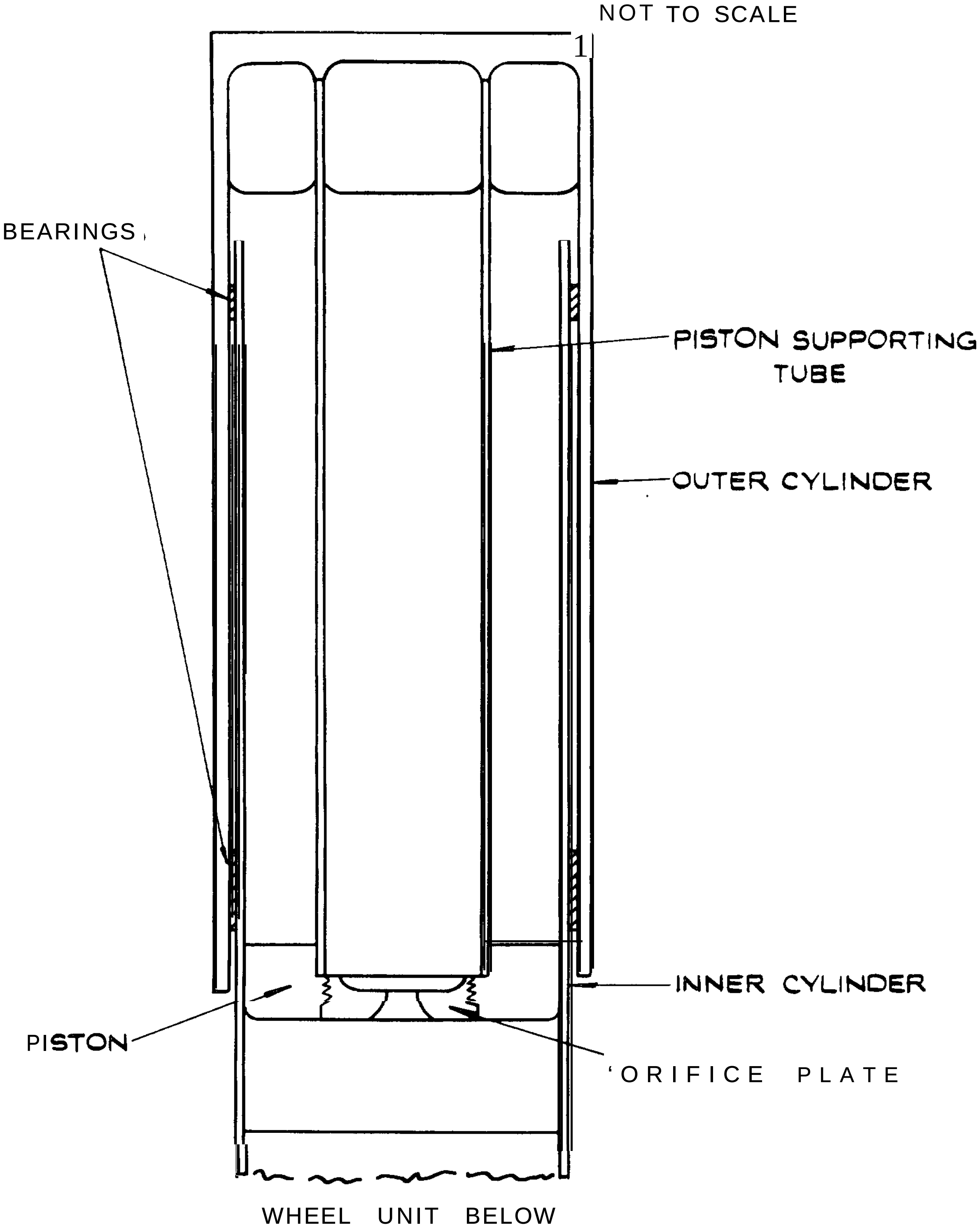
v_0 = 0·03545 cu ft

p_{a_0} = 6264 lb/sq ft

LOWER MASS M_2 = 131 lb

INNER CYLINDER INTERNAL DIA = 2·936″
PISTON DIAMETER = 2 842″
PISTON LENGTH = 8″
HYDRAULIC FLUID EEL 6
VISCOSITY OF FLUID = 125 CENTISTOKES AT AMBIENT TEMPERATURE.
PISTON ROD DIAMETER = ANY CONVENIENT VALUE LESS THAN 0·947″
PISTON ROD LENGTH = 10″
LENGTH OF OUTER CYLINDER 14″ (APPROX)
INNER DIAMETER Of OUTER CYLINDER 3 385″ (APPROX)

FIG.10 SKETCH OF ANNULUS TYPE SHOCK STRUT



UPPER MASS M_1 = 241 I lb LOWER MASS M_2 = 131 lb

STRUT CHARACTERISTICS

A_a = 0-05761 sq ft

A_h = 0 04708 sq ft

v_o = 0·03545 cu ft

p_{a_o} = 6264 lb/sq ft

PISTON OIAMETER = 2·936″

ORIFICE OIAMETER = 0·32″

ORIFICE THROAT FORMED BY PLATE 0·25″ THICK RADIUSED AT 0 25″ DOWN TO 0·32″ OIAMETER ENTRANCE

LENGTH OF OUTER CYLINDER 14″ (APPROX)

INNER DIAMETER OF OUTER CYLINDER 3·25″ (APPROX)

FIG.11 SKETCH OF ORIFICE TYPE SHOCK STRUT

in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough. Da.129528 K.4.

A.R.C. C.P. No.951
October 1966

629.13.012.563 :
629.13.015.11 :
533.6.013.423

Hall, H.

SOME THEORETICAL STUDIES CONCERNING OLEO DAMPING CHARACTERISTICS

The paper presents results of a study that has been made to investigate the effect of damping characteristics on the performance of an oleo strut. Conventional oleo struts employ orifice dampers in the interests of providing high energy absorption for the design vertical velocity of descent case. It is shown that an equivalent strut i.e. one having the same maximum stroke, utilizing a damning mechanism providing a force proportionalto the stroking velocity, instead of the square of this velocity, will benefit by a 10 per cent reduction in stress in the design case. Comparison of the performance of these

(Over)

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(Over)

DETACHABLE ABSTRACT CARDS

two types of damper in the taxi phase of operation over a real profile shows that a 'linear' damper has better characteristics than an 'orifice' damper having the same damping constant in compression and recoil.

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