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Smith, C. A. M.

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FREIGHT CAR DRAFT GEAR IMPACT PERFORMANCE CHARACTERISTICS AND THEIR EVALUATION CRITERIA

BY

C.A.M. SMITH
DIVISION OF MECHANICAL ENGINEERING

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FREIGHT CAR DRAFT GEAR IMPACT PERFORMANCE CHARACTERISTICS AND THEIR EVALUATION CRITERIA

by
C.A.M. SMITH

S.H.G. Connock, Head
Instruments Section

D.C. MacPhail
Director

SUMMARY

This Report describes field and theoretical studies on the dynamic behaviour of impacting freight cars and the influence of draft gear characteristics on this behaviour.

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FREIGHT CAR DRAFT GEAR IMPACT PERFORMANCE CHARACTERISTICS AND THEIR EVALUATION CRITERIA

1.0 INTRODUCTION

Because of the increasing tempo of railway freight traffic and the fragility of the goods carried, lading damage claims continue to increase on the North American continent; these amounted to $165,000,000 in 1966. Since claims are not made in all cases, the lading damage would have been well in excess of $200,000,000. It should be noted that this does not include cost of repair of associated damage to rolling stock, and represents not only a direct expense to the railways, but is accompanied by deterioration in customer relations, since the customer is subjected to the inconvenience of seeking compensation and delay in getting replacement merchandise.

Modern end-of-car draft gear devices, and special duty cars with other built-in arrangements for better protection of lading, are coming into service, but as yet there are no means and procedures for evaluation of their effectiveness and dynamic behaviour other than actual field trials. Sub-Committee A (Train Dynamics and Lading Damage) of the National Research Council Associate Committee on Railway Problems accordingly undertook a study of currently available draft gears with respect to their impact absorption characteristics, with a view to determining the relative performance of these designs and the eventual development of performance criteria to be specified for current and proposed designs, having regard both to freight yard protection and the dynamic behaviour of long trains.

Eight commercially available draft gears were tested in a loaded car with a 24-in gear pocket. Another end-of-car device, not of the 24-in pocket type, was also tested under similar conditions. Six of the 24-in pocket devices, and the non-pocket device, were retained for the empty car test program. A further abbreviated program on 24-in pocket devices, mostly incorporating rubber as the absorbing medium, which arrived too late for loaded car impacts, concluded this series of tests.

2.0 TEST PROGRAM

The impact tests were conducted at the NRC Railway Laboratory at Uplands, Ontario (near Ottawa), using a ramp track and the data recording facilities of the laboratory (see Frontispiece).

2.1 Procedure

In every case a loaded cary, referred to below as the striking or hammer car, was winched up the inclined track to a predetermined position from where it was released and allowed to strike a single standing test car, referred to as the struck or anvil car. The struck car was held until just prior to the impact by a wheel-gripping car retarder. After the impact the struck car was captured by reapplying the retarder and applying the car brakes. A slight reverse grade to the impact track was then utilized to return the hammer car to the foot of the ramp and the anvil car to its pre-impact position.

Variables recorded were: coupler force; draft gear travel; car acceleration; lading restraint beam strain, where applicable; and the pre- and post-impact velocities of both cars.

The severity of the impacts was gradually increased until failure of the lading restraint was imminent (in the loaded test), or until the coupler force exceeded 600,000 lb. In all, 21 configurations were tested in this way.

2.2 Equipment Used

The Hammer Car, CN Hopper Car No. 97541, loaded with gravel to 203,600 lb, was fitted with a friction draft gear for the first 17 configurations and with a rubber gear for the last four, to see if this would improve the repeatability of the data.

The Anvil Car, CP Coil Car No. 344409, was used to house all the 24-in pocket gears and weighed 181,180 lb for the loaded test and 61,090 lb empty.

The lading consisted of six coils of steel weighing about 10 tons each, secured in two groups of three, down the centre of the car, by four beams per group in such a manner that each coil was wedged between two beams.

Each of the lading restraint beams in the CP car consisted of an 8-in I beam at 17 lb/ft, with 3/8-in plate reinforcing each flange and wooden buffers front and back, bolted through the reinforced flanges. These buffers precluded the affixing of strain gauges to the extreme fibre, so that the maximum fibre strain had to be inferred by a geometric extrapolation. For a yield strength of 40,000 psi, the associated strain at the point of gauge attachment was 1,122 μ in/in. This beam strain was therefore taken as the condition for terminating each series of draft gear tests with a loaded test car, except where the progressive failure of the beams was of interest to the car owner (CPR). In the empty car draft gear test, the terminating condition was the achieving of 600,000 lb coupler force.

Anvil Car, CN Coil Car No. 190541, contained the non-pocket end-of-car cushioner and weighed 191,790 lb in the loaded configuration and 71,700 lb empty.

The instrumentation consisted of: simple strain-gauge bridges for strain, force, and acceleration measurements; potentiometer bridges for displacement measurement; and track-side fixed contacts closed by a brush mounted on the moving car for hammer car speed determination, all sending unamplified electrical signals to a galvanometer recorder. Each transducer channel was calibrated physically with the exception of the lading restraint beam strain, which was calculated from manufacturer's data. Velocities of both cars before and after the impact were measured on a strip camera built by NRC for this purpose (Ref. 1).

2.3 Loaded Car Test Program

The nine series of tests carried out on loaded cars are summarized in Table 1, Test Group A.

During the loaded car test program, it was found that the coupler force measurements (three independent measurements on each coupler) were sensitive to shank bending. Recalibrating the couplers, with shank bending introduced, showed that if the results of two of the bridges were averaged and the third neglected, much better agreement between the two couplers was achieved; this procedure was followed in all subsequent tests.

Series LM4 was terminated because of high beam strain reading (as were all the other loaded series); however it became clear in the analysis of data from Series LM3 that these premature high strains were due to more than one steel coil (of the group of 3) being restrained by the gauged beam. This was because the beam-coil-beam-coil-beam-coil-beam group had to be wedged tightly together and, had the load been hit harder and yielded this beam, the other beams would have taken their fair share of the load. Our termination criterion would have been valid as the strain went past 1100 μ in/in a second time. The discovery that the method of securing the beam had its shortcomings was of quite significant value.

2.4 Empty Car Test Program

The seven series of empty car tests conducted with certain gears used in the loaded car program are summarized in Table I, Test Group B. Unfortunately, owing to other commitments, two gears (M4 and M5) could not be held over for these tests and were returned to the manufacturer.

From Series EF1 on, it was decided to measure draft gear movement of the striking car as well as that of the struck car to facilitate finding the instant of closest approach.

2.5 Other Tests

Five test series were conducted using rubber draft gears in the struck car, the striking car, or both. These gears were not received in time to be included in the loaded car program, but were of interest because of the remarkably different characteristics they produced. A rubber gear was considered to have an advantage as a standard striking car gear, and will be so used in future at the NRC laboratory, since the characteristics of the struck car are shown more clearly if the striking car gear does not exhibit the slip-grab characteristics of a friction gear.

The configurations tested are outlined in Table I, Test Group C. The last gear in the Table is an experimental hydraulic gear and is not yet commercially available.

3.0 PERFORMANCE TEST RESULTS

Presentation of the results of 21 series of impacts posed quite a problem since so many comparisons were desirable. The measured and derived graphical presentations in Figures 1 to 11 (see Table I for cross reference) are grouped to show the loaded/empty comparisons, where possible. Table II, summarizing certain information of Table I, indicates which test results are strictly comparable. Comparisons between the gears of Test Groups A and B, Table I, are most readily drawn from Figures 12, 13, and 14. The peak value Tables are given in the Appendix, as indicated in the last column of Table I.

3.1 Experimental Data

A most desirable feature of a draft gear is a more gradual acceleration during impact than that of the general run of draft gears. We have therefore plotted acceleration against velocity of impact for each of the test series. These are to be found under the Figure numbers shown in the second last column in Table I. Because of the vibration caused by friction draft gears (slip-grab effect) the acceleration trace is somewhat difficult to read and interpret. Consequently, coupler force is also plotted as a measure of impact severity.

A cross plot of coupler force and draft gear movement is also shown for some impacts in each series because of the obvious relevance of this plot to energy absorption.

3.2 Calculated Results

In order to compare the energy-absorbing ability of draft gears, we have plotted both total energy loss (i.e., the kinetic energy before, minus that after, the collision) and energy absorbed by the draft gear (the area inside the draft gear force-displacement curve) for each impact. The difference between these curves must represent energy absorbed elsewhere than by the draft gear under test. The gravel in our hammer car is well compacted and a good portion of this "missing" energy must be the work done (in the loaded case) on the lading and the beams that restrain it.

The "bounciness", i.e., resilience, of a collision may be represented by the coefficient of restitution "e", defined as

$$e = \frac{V_2 - V_1}{U_1}$$

Here U_1 and V_1 are the velocities of the hammer car before and after the collision and V_2 is the velocity of the anvil car after the collision (assuming it was stationary before the impact). A value of 1 for this coefficient represents a perfectly elastic collision.

In Section 4, it is suggested that "r", the ratio $\frac{\text{Energy returned to a system}}{\text{Energy received from a system}}$ by a single draft gear, is to be preferred to e as a measure of draft gear resilience because it relates to one gear and not to the total system. Since, however, e is readily derived from speed measurements alone, and since only one draft gear change differentiates one series from a comparable one, any change in e will be due to the draft gear change. We have, in fact, plotted e as the measure of resilience in Figures 1 to 11.

It can be seen from Figures 12, 13, and 14, which compare forces, accelerations, and energy absorption for the generic groups for empty and loaded car impacts, that hydraulic gears have a significant advantage in the yard impact situation.

An iso-strain overprint in the upper left-hand graph on Figure 13 shows the effect of impact velocity and acceleration on restraining beam strain. These patterns are typical of the sort of curves to be expected from a general class of lading, as outlined in Reference 2.

4.0 THE MECHANICS OF A COLLISION

This Section is somewhat philosophical and does not bear directly on the results of the experiments. It does, however, lead up to some of the recommendations for performance specification.

First let us consider some definitions, symbols, and the conservation laws valid for an impact.

If U_1 = Velocity of hammer car before impact,
V_1 = Velocity of hammer car after impact,
V_2 = Velocity of struck car after impact,
W = Velocity of combination at closest approach,
M_1 and M_2 are the masses of the hammer and struck car respectively, and

e = Coefficient of Restitution,

$$= \frac{V_2 - V_1}{U_1} \text{ (by definition)} \qquad (1)$$

then Momentum Before Impact $= M_1U_1$

= Momentum at Closest Approach $= (M_1+M_2)\ W$ (2a)

= Momentum After Impact $= M_1V_1 + M_2V_2$

Momentum lost by hammer $= M_1\ (U_1-V_1)$

= Impulse during impact $= P = \int_{t_o}^{t_e} f dt$ (2b)

= Momentum gained by struck car $= M_2V_2$

Energy Before $= EB = \frac{1}{2}\ M_1U_1^2$

= Energy After $= EA = \frac{1}{2}\ M_1V_1^2 + \frac{1}{2}\ M_2V_2^2 + EL$ (3)

where EL = Energy Lost in impact (absorbed by draft gears, car structure, lading, and lading restraint).

4.1 The Significance of the Coefficient of Restitution in Terms of Energy and Momentum

First let us consider the significance of e in terms of the energy loss.

from (3) $$EL = \frac{1}{2}\ M_1\ (U_1^2-V_1^2) - \frac{1}{2}\ M_2V_2^2$$

divide by (2b) $$\frac{EL}{P} = \frac{1}{2}\ (U_1+V_1-V_2) = \frac{1}{2}\left[1 - \frac{(V_2-V_1)}{U_1}\right] U_1 \qquad (4)$$

or $$EL = \frac{(1-e)}{2}\ U_1P$$

i.e., Energy loss in terms of e, velocity, and momentum.

We must replace $P = M_2V_2$ with an expression involving only U_1, e, and Mass.

First eliminate V_1 from (1) and (2)

$$V_1 = \frac{M_1U_1 - M_2V_2}{M_1} = V_2 - U_1e$$

Collecting terms $U_1 (1+e) = V_2 \left(1+\frac{M_2}{M_1}\right)$ or $V_2 = \frac{U_1 (1+e) M_1}{(M_1+M_2)}$

Substitute this value for V_2 in (4).

Now $$EL = \frac{(1-e)}{2} U_1M_2V_2 = \frac{(1-e)}{2} U_1M_2 \left[U_1 (1+e) \frac{M_1}{M_1+M_2} \right]$$

$$\therefore \quad EL = (1-e^2) \left[\frac{1}{2} M_1U_1{}^2 \frac{M_2}{M_1+M_2} \right] \tag{5}$$

The quantity inside the last bracket is the kinetic energy relative to a co-ordinate system located at the system centre of gravity, i.e., moving with velocity $U_1 \frac{M_1}{M_1+M_2}$. It is, in fact, the total energy that can take part in a collision. We will call it E.T. We note that the ratio

$$\frac{EL}{ET} = 1 - e^2 \tag{6}$$

is a function of the coefficient of restitution only.

If we define "r" as the ratio

$$\frac{\text{Energy returned to the system by the draft gear}}{\text{Energy received from the system by the draft gear}}$$

we have a measure of resilience that, unlike e, is related to one gear only and not both.

In a maximum energy impact the denominator is defined as "C", the capacity of a gear, so the numerator becomes $C \cdot r$.

Now Energy received minus Energy returned is Energy absorbed in the gear, which equals EL in an impact where the gear under test does all the work.

So in a maximum energy one gear impact equation (6) becomes

$$\frac{EL}{ET} = \frac{C - Cr}{C} = 1 - e^2$$

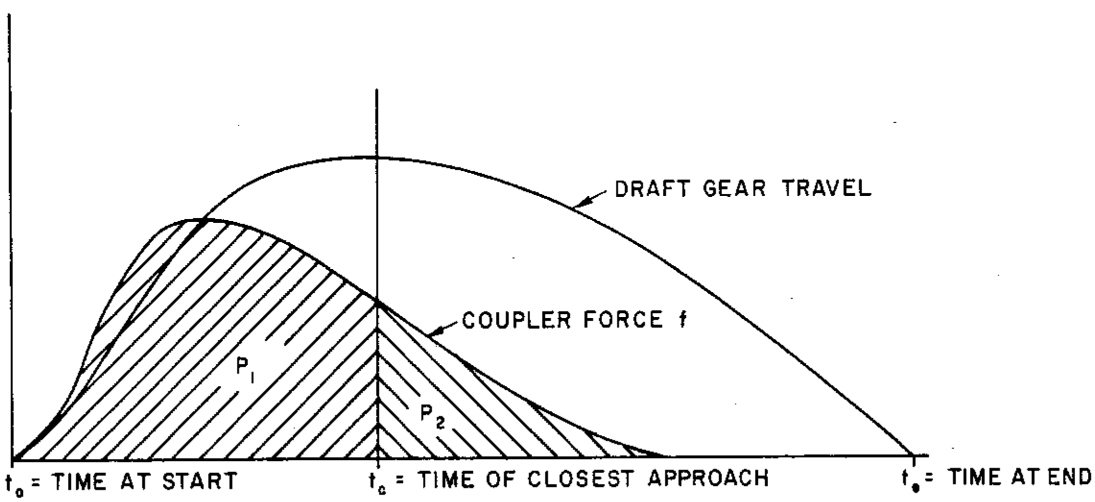
or

$$r = e^2$$

Secondly, let us consider the relationship of e to the momenta of the collision.

It is difficult to set out the energy relationships existing during a collision, as energy is being continuously converted to heat throughout the system. Fortunately the Conservation of Momentum relationships can be more precisely expressed.

Consider an impact where the draft gears do all the work and the shapes of the draft gear compression and coupler force curves are as shown plotted on time.



The momentum exchange up to the time of closest approach

$$M_1 \ (U_1 - W) = M_2 W = \int_{t_o}^{t_c} f dt. \qquad \text{Let us call this } P_1.$$

This change in momentum has brought the cars to the same speed W at closest approach. If a coupler force still exists at this time it will push the cars apart, and this further exchange is

$$M_1 \ (W-V_1) = M_2 \ (V_2-W) = \int_{t_c}^{t_e} f dt. \qquad \text{Let us call this } P_2.$$

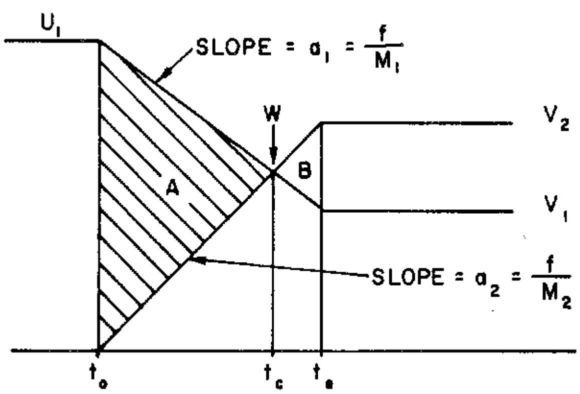
Then

$$\frac{P_2}{P_1} = \frac{W - V_1}{U_1 - W} = \frac{V_2 - W}{W}$$

Combining these ratio equations gives

$$\frac{P_2}{P_1} = \frac{V_2 - V_1}{U_1} = e \qquad (7)$$

Some further relationships with e can be developed by considering an idealized gear that produces a constant coupler force f during an impact, which in turn produces a constant acceleration of the cars involved. A diagram of Velocity vs. Time for such an impact is shown below.



Since triangles A and B are similar

$$\therefore \quad \frac{t_e - t_c}{t_c - t_o} = \frac{V_2 - V_1}{U_1} = e$$

and $$\frac{t_e - t_o}{t_c - t_o} = 1 + e$$

If we specify a maximum U_1, which will just completely use up the gear capacity dictated by the yard environment, and a maximum acceleration "a" dictated by our lading, and noting that the Area of Triangle A = twice the draft gear travel "d", if there are two gears, then we find

$$A = 2\,d = \frac{1}{2}\, U_1\, (t_c - t_o)$$

but

$$W = U_1 - a_1\, (t_c - t_o)$$

$$= a_2\, (t_c - t_o)$$

i.e.,

$$t_c - t_o = \frac{U_1}{a_1 + a_2}$$

$\therefore$

$$2\,d = \frac{1}{2} \left(\frac{U_1^{\,2}}{a_1 + a_2} \right)$$

and we see that the effect of $e > 0$ is to prolong the duration of the impact to

$$t_e - t_o = (t_c - t_o)\,(1+e) \qquad (8)$$

Further, the added "bounciness" of an $e >> 0$ may be a disadvantage as the cause of subsequent repeated collisions of the same cars in a string of cars.

The minimum duration of impact ($e = 0$) is the time to closest approach

$$t_c - t_o, \text{ i.e., } t_e = t_c$$

Putting realistic numbers in this system gives some interesting results.

If

$$U_1 \text{ max} = 12 \text{ ft/sec}$$

and if

$$a_1 = a_2 = 50 \text{ ft/sec}^2$$

then

$$2\,d = \frac{1}{2}\,\frac{144}{100}$$

$\therefore$

$$d = 0.36 \text{ ft} = 4\text{-}1/3 \text{ in}$$

(or 8-2/3 in if the other gear is assumed to be useless).

The time to closure, $\dfrac{U_1}{a_1 - a_2} = \dfrac{12}{100} = 0.12$ sec.

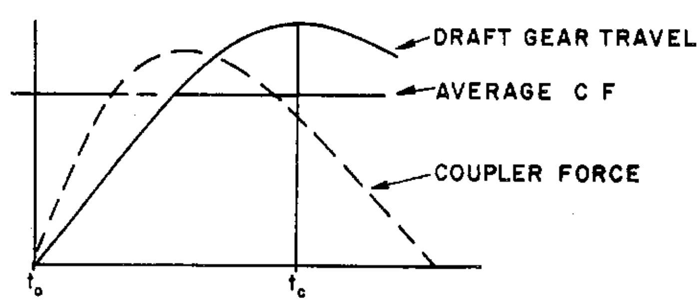
If car is loaded to 6,000 slugs all-up mass, then the coupler force

$$CF = M.a = 300,000 \text{ lb.}$$

If car is empty, say 2,000 slugs, then

$$CF = 100,000 \text{ lb.}$$

If a gear does not provide this ideal constant acceleration and has a shape as shown below, where the ratio average coupler force/peak coupler force is 0.7 say, so that $\dfrac{\text{the average acceleration}}{\text{peak acceleration}} = 0.7$,



then for the same conditions of average CF, travel, etc., as above, the lading will sense $\dfrac{50}{0.7} = 71$ ft/sec^2 acceleration.

This ratio of the average/peak coupler force up to the point of closest approach could be called the temporal efficiency of the gear η_t. The average to peak coupler force ratio, when force is plotted on gear travel instead of time, will be called, in what follows, spatial efficiency η_s.

4.2 The Effect of the Shape of the Force/Time Curve on Efficiency of a Draft Gear

The constraints within which a draft gear designer must work are the travel "D" that can be fitted into the existing pocket geometry, the velocity "U_1" at which one wants the capacity to be used up, and the mass "M" of the car to be protected. In selecting the force-producing phenomenon we require some insight into the effect of the force/time curve shape.

Given D, U_1, and M, let us consider the consequence of selecting a few arbitrary force/time shapes. Those shown in Figures 15 and 16 were selected because they were simple and could be readily integrated. In each case only the general shape of the force/time curve was specified. The requirement that all the travel D be used in the collision of velocity U_1, produces the equations from which time to closure t_c, and force peak f_m, were derived. Time and force are plotted in units $\frac{D}{U_1}$ sec, and $\frac{U^2M}{D}$ lb, respectively, to maintain generality.

Specifically, Figures 15 and 16 were derived in the following manner. In order to simplify the algebra, two cars of equal mass are assumed to approach the collision at $\frac{U_1}{2}$ ft/sec (or one car hits an immovable and incompressible object at $\frac{U_1}{2}$ ft/sec), equivalent to our hammer car striking an exactly similar standing car at U_1 ft/sec. From the general shape of the curve, force was written as a single parameter function of time, f(t), thus the deceleration was $\frac{f(t)}{M}$.

Then velocity $$V(t) = \frac{U_1}{2} - \frac{1}{M} \int_0^t f(t')\, dt'$$

and draft gear travel $$= D(t) = \int_0^t \frac{U_1}{2}\, dt' - \frac{1}{M} \int_0^t \int_0^{t'} f(t)\,dt\,dt'$$

These integrals were evaluated at $t = t_c$. By definition, at the time of closest approach, $V(t_c) = 0$ and draft gear closure $D(t_c) = D$, giving rise to two simultaneous equations from which the single force parameter and t_c were determined. In Figure 15 the force parameter was f max, and in Figure 16 it was the ratio of $\frac{f_2}{f_1} = K$ (see insert in Fig. 16).

It was noted that in every case the moment of the area of the force/time curve about the force axis is a constant value

$$= \frac{U_1 M}{2} \times \frac{2D}{U_1} = MD$$

This quantity would appear to be an invariant in a collision rather like momentum lost to closest approach.

The most obvious conclusion from Figures 15 and 16 is that the rectangular force/time curve gives the lowest peak force value. What is perhaps surprising is the difference between the peak value resulting from the rising force characteristics and that from the falling force characteristic. Most draft gears tested have a rising characteristic and thus give the hardest bump possible under the conditions. Though none of these characteristics may be exactly realizable in practical hardware, the advantages of a high force development at the beginning of the stroke indicates hydraulic viscous forces as a starting point.

We have not considered any of these cases past the time of closest approach. If $e \neq 0$, the collision continues past t_c, as discussed under Section 4.1.

Emphasis of the merit of a high initial force can be achieved by integration of the force value, but the procedure is a cumbersome one. Figure 17 shows how curves A, B, and C, in Figure 15 (i.e., the rectangle, and the two right-angled triangles) look when plotted against displacement instead of against time, together with their respective 'spatial' and 'temporal' efficiency ratings. Note here how the falling force characteristic scores over the rising force characteristic in the value of what we have called "the spatial efficiency" η_s.

4.3 Suggestions for Draft Gear Evaluation Criteria

Summing up the points raised in Section 4.2, the following definitions could be the basis for draft gear specification and evaluation:

C = the capacity of a gear (in ft lb) = energy stored in a gear in a maximum energy collision at the designed car loading

η_s = spatial efficiency of a gear = the ratio of the average to the peak coupler force when plotted on gear travel

D = draft gear travel just used up in the maximum energy collision (in ft)

M = designed car weight on rails (in slugs)

r = the ratio of energy returned/energy received, by a draft gear

U_1 = maximum impact velocity (design value) (in ft/sec).

In regard to the testing of gears to obtain their capacities, it should be noted that since most modern gears have a velocity-dependent force component in their characteristic (and others may in future have an acceleration-dependent component), the capacity of a gear should be specified and measured at a realistic speed of impact (and realistic value of the impacting mass).

5.0 CONCLUSIONS

(i) Amongst currently available draft gears, 24-in pocket or otherwise, the hydraulic devices provide the greatest protection against lading damage due to yard impacts.

(ii) The 'travel' of the gear should be as large as is practicable.

(iii) The 'spatial' efficiency should be as high as possible, which requires that the force should develop early in the travel without spikes or valleys in the force/time curve.

(iv) Measurement of the capacity of a draft gear must be made at realistic speeds.

(v) To improve lightly loaded car protection, acceleration-sensitive devices should be developed.

(vi) An effective evaluation of the performance of a draft gear is possible, given knowledge of

(a) Travel
(b) Capacity

(c) Spatial efficiency

(d) Ratio of the energy returned to the energy received, by a draft gear.

6.0 ACKNOWLEDGEMENTS

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TABLE I

DRAFT GEAR AND LOAD COMBINATIONS TESTED

Test Group	Type of Gear	Test Series Code	Type of Sill	Maximum Gear Travel in Buff	Load	Hammer Car Gear	Graphical Results	Peak Value Table
A	Friction	LF1	24" pocket	2-5/8"	60 Tons	Friction	Fig. 1	A-1
	Friction	LF2	24" pocket	3-1/4"	60 Tons	Friction	Fig. 2	A-2
	Hydraulic	LH1	24" pocket	6-3/8"	60 Tons	Friction	Fig. 3	A-3
	Hydraulic	LH2	Special	9"	60 Tons	Friction	Fig. 4	A-4
	Hydraulic Friction	LM1	24" pocket	3-1/4"	60 Tons	Friction	Fig. 5	A-5
	Rubber Friction	LM2	24" pocket	3-1/4"	60 Tons	Friction	Fig. 6	A-6
	Rubber Friction	LM3	24" pocket	4"	60 Tons	Friction	Fig. 7	A-7
	Hydraulic Friction	LM4	24" pocket	2-3/4"	60 Tons	Friction	Fig. 8	A-8
	Rubber Friction	LM5	24" pocket	3-1/4"	60 Tons	Friction	Fig. 8	A-9
B	Friction	EF1	24" pocket	2-5/8"	Nil	Friction	Fig. 1	A-10
	Friction	EF2	24" pocket	3-1/4"	Nil	Friction	Fig. 2	A-11
	Hydraulic	EH1	24" pocket	6-3/8"	Nil	Friction	Fig. 3	A-12
	Hydraulic	EH2	Special	9"	Nil	Friction	Fig. 4	A-13
	Hydraulic Friction	EM1	24" pocket	3-1/4"	Nil	Friction	Fig. 5	A-14
	Rubber Friction	EM2	24" pocket	3-1/4"	Nil	Friction	Fig. 6	A-15
	Rubber Friction	EM3	24" pocket	4"	Nil	Friction	Fig. 7	A-16
C	Rubber	ER1	24" pocket	3-1/4"	Nil	Friction	Fig. 9	A-17
	Rubber	RER1	24" pocket	3-1/4"	Nil	Rubber	Fig. 9 & 10	A-18
	Rubber	RER2	24" pocket	3-1/4"	Nil	Rubber	Fig. 10	A-19
	Rubber Friction	REM3	24" pocket	4"	Nil	Rubber	Fig. 11	A-20
	Hydraulic	REH3	24" pocket	6-3/8"	Nil	Rubber	Fig. 11	A-21

TABLE II

DRAFT GEAR AND LOAD COMBINATIONS TESTED

Striking Car Draft Gear	Load Condition	Type of Draft Gear Used in Struck Car			
		Friction (F)	Hydraulic (H)	Mixed (M)	Rubber (R)
Friction (F)	Loaded (L)	LF1 LF2	LH1 LH2	LM1 LM2 LM3 LM4 LM5	
Friction (F)	Empty (E)	EF1 EF2	EH1 EH2	EM1 EM2 EM4	ER1
Rubber (R)	Empty (E)		REH3	REM4	RER1 RER2

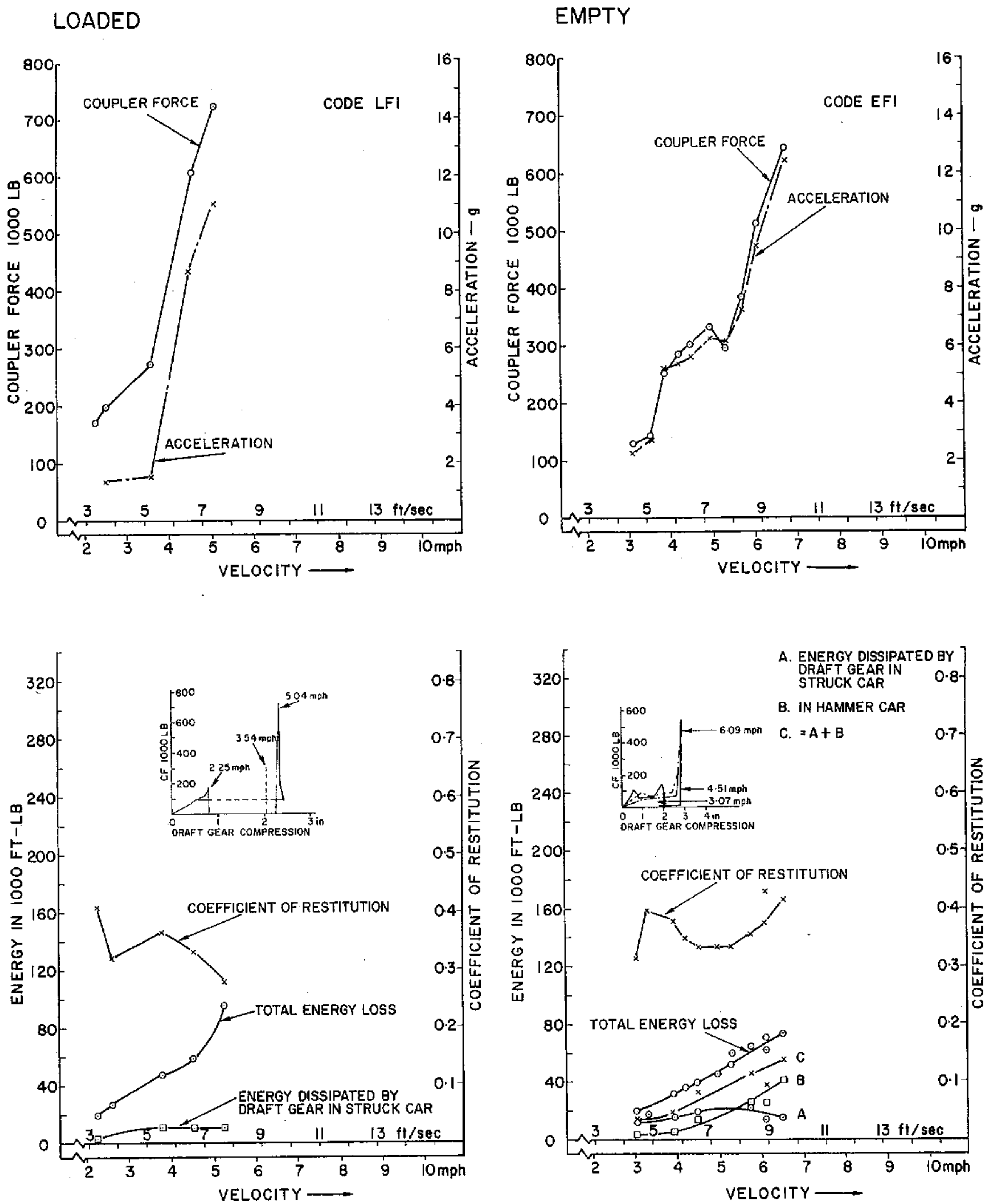


FIG. 1: NUMBER 1 FRICTION DRAFT GEAR PERFORMANCE

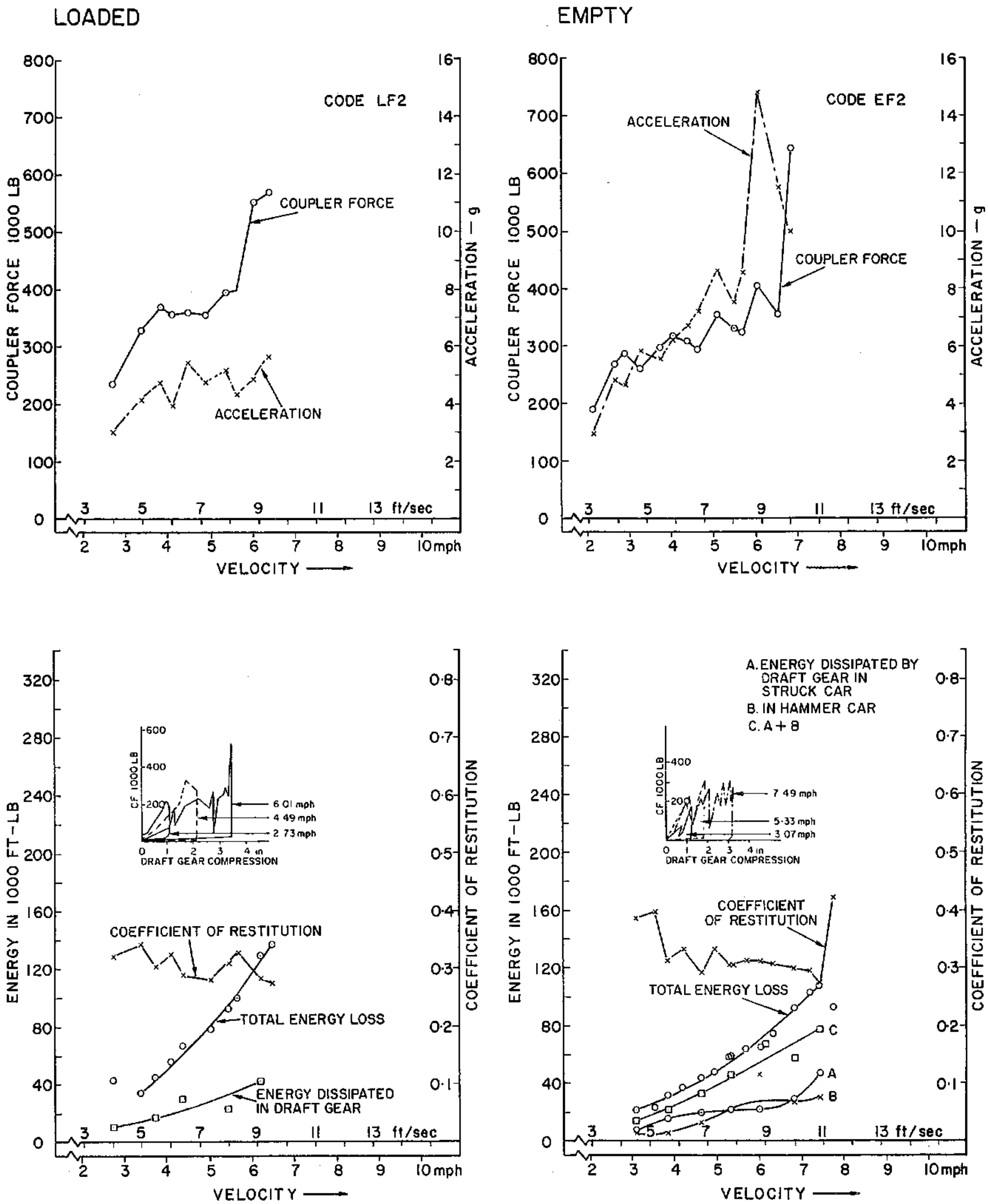


FIG.2: NUMBER 2 FRICTION DRAFT GEAR PERFORMANCE

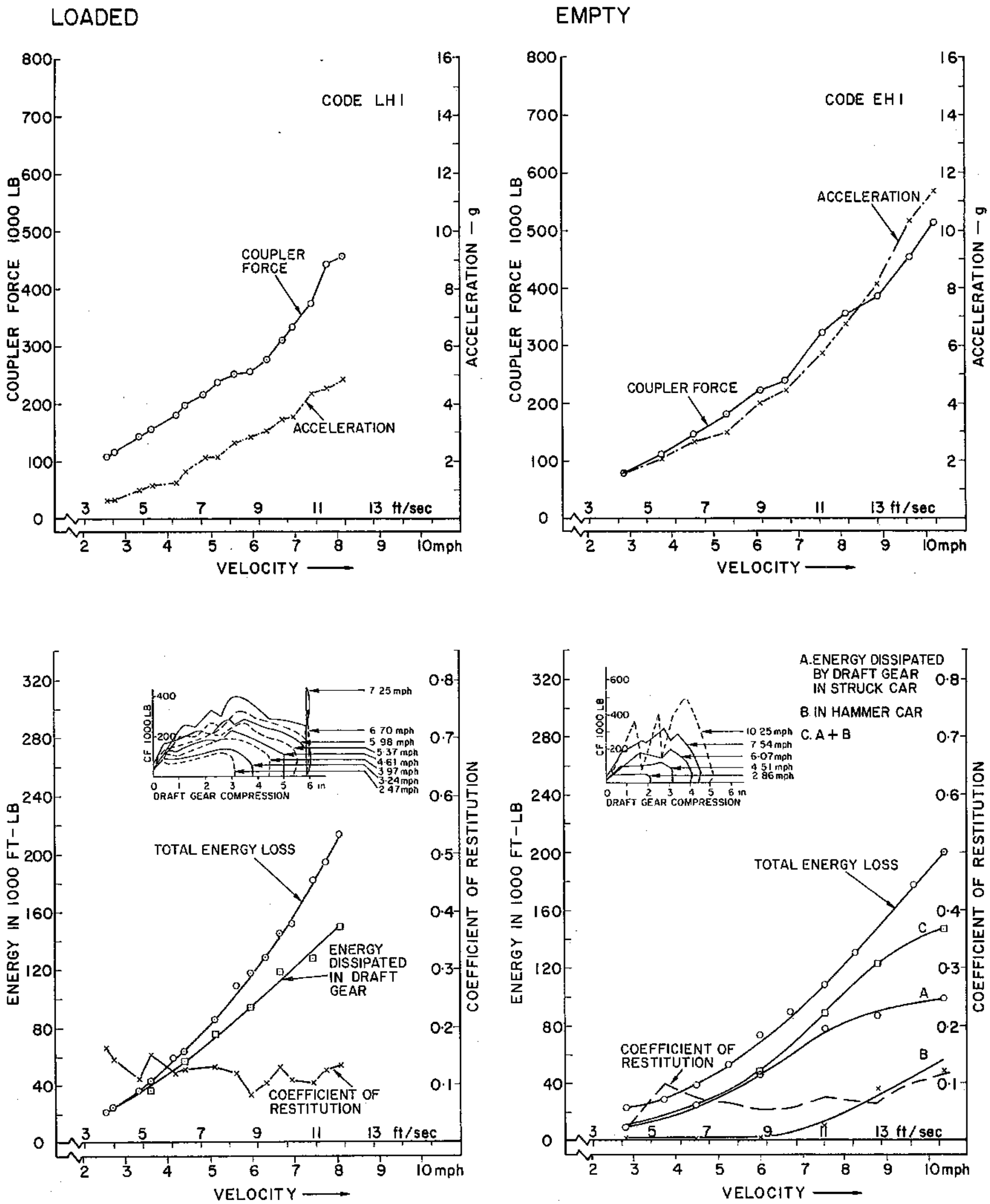


FIG. 3: NUMBER I HYDRAULIC DRAFT GEAR PERFORMANCE

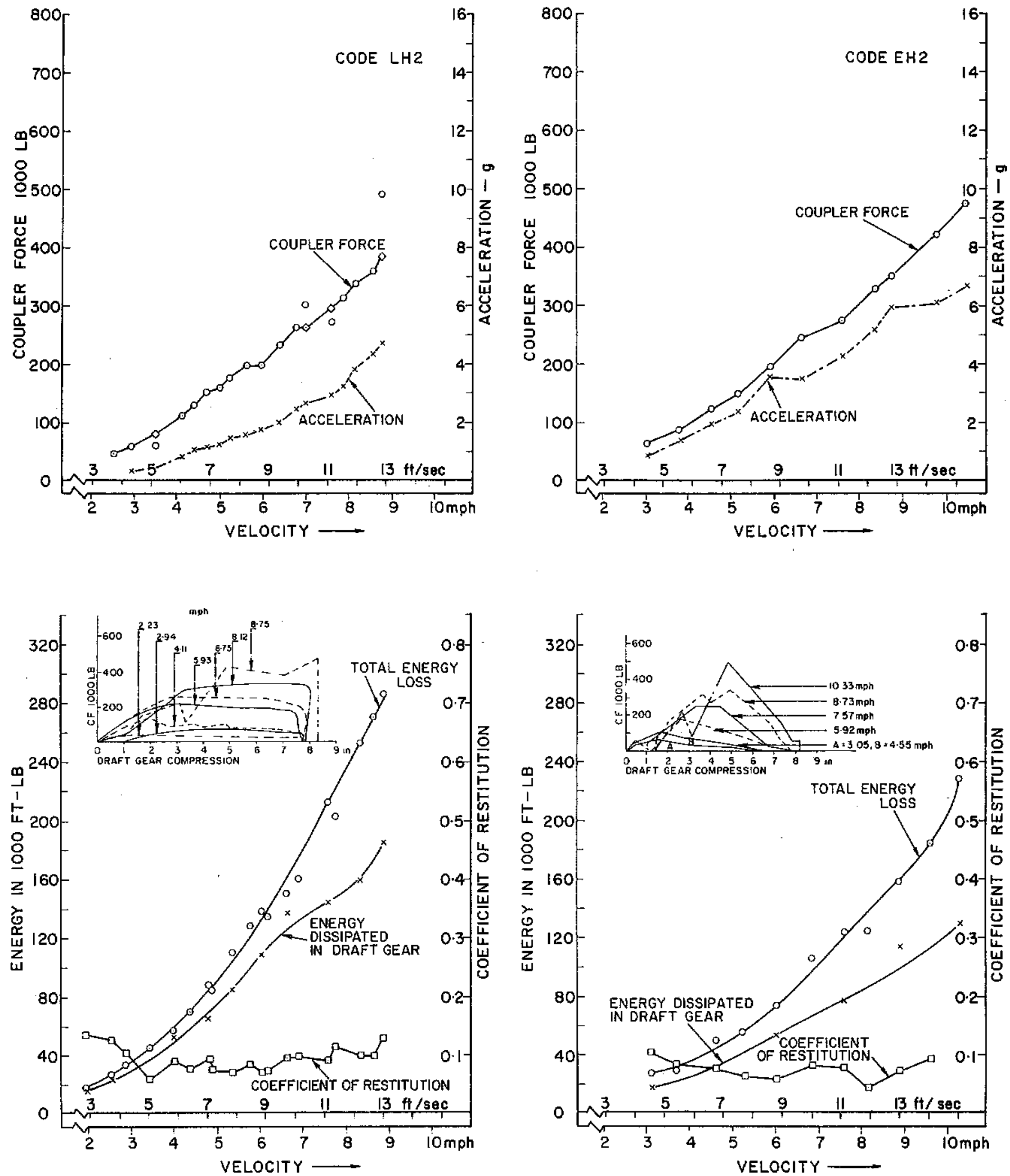


FIG. 4: NUMBER 2 HYDRAULIC DRAFT GEAR PERFORMANCE

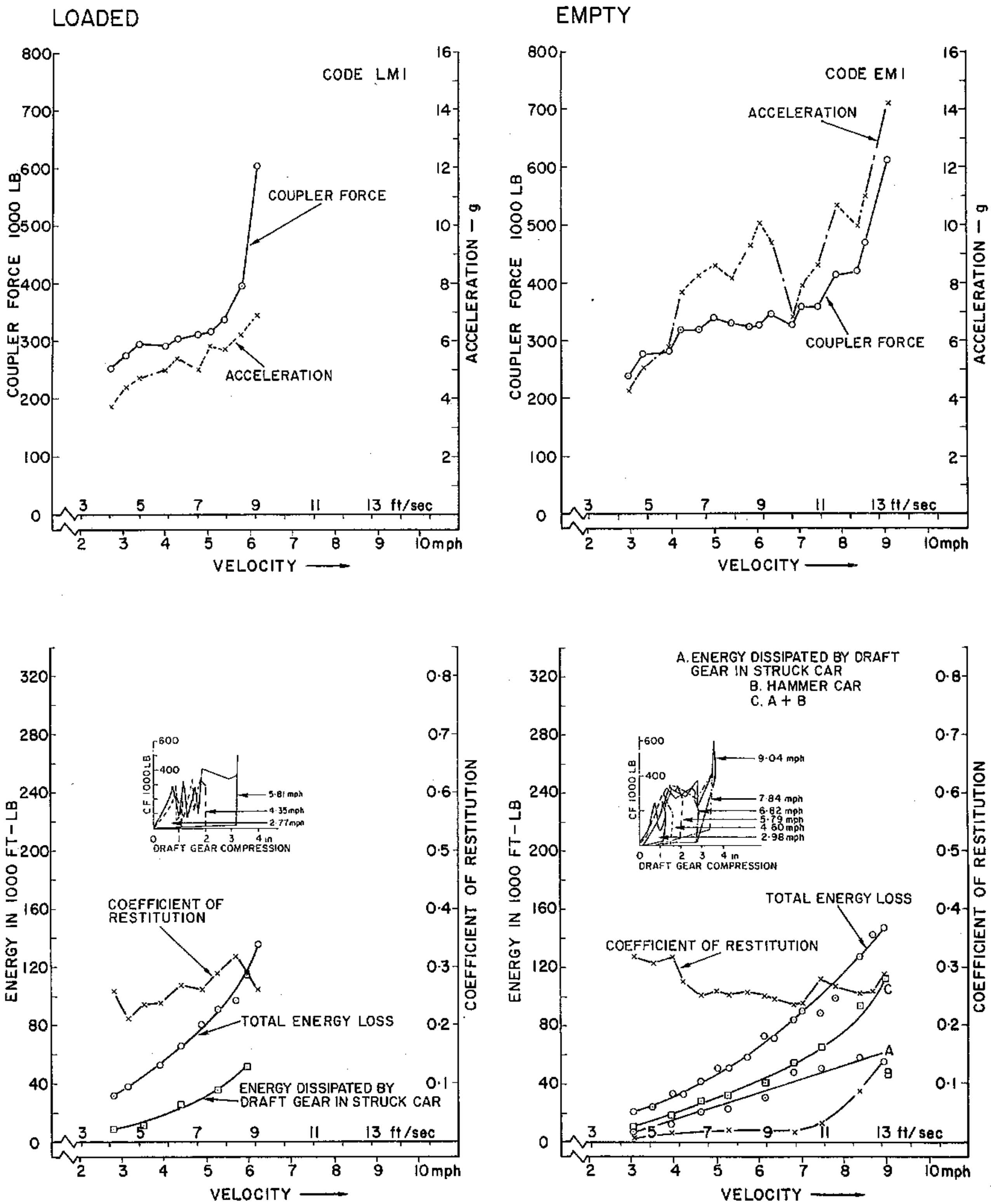


FIG. 5: NUMBER 1 MIXED DRAFT GEAR PERFORMANCE

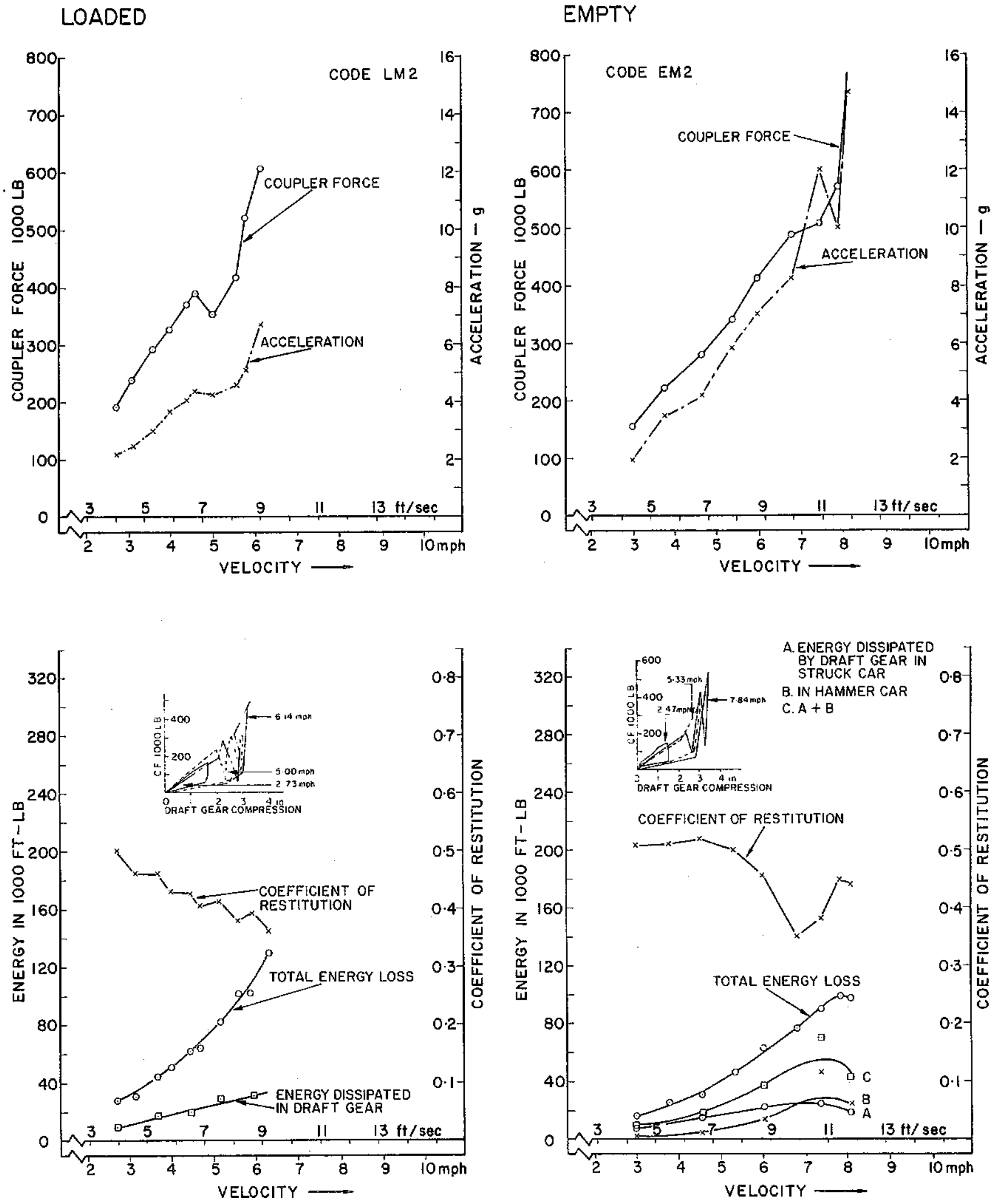


FIG. 6: NUMBER 2 MIXED DRAFT GEAR PERFORMANCE

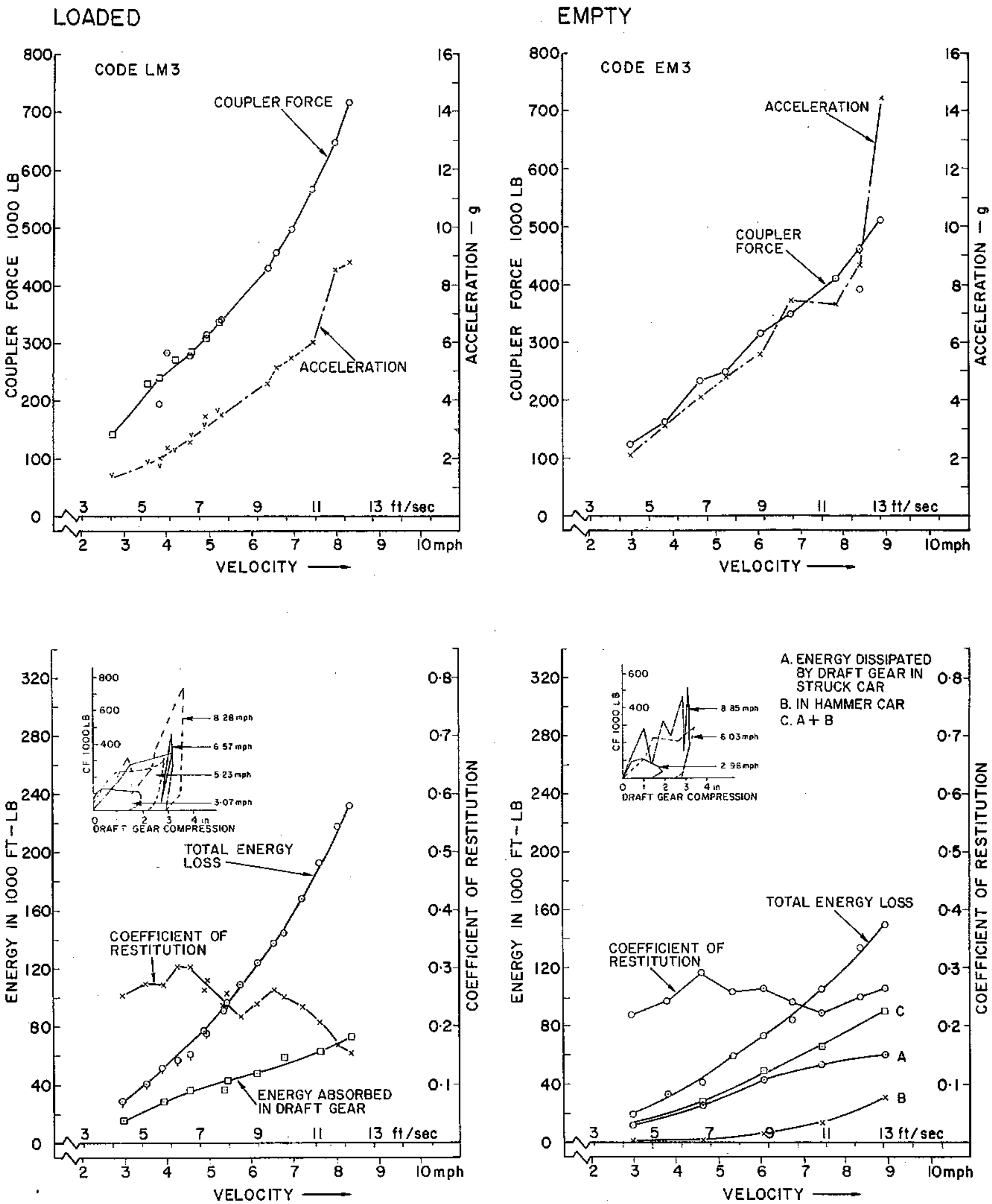


FIG. 7 : NUMBER 3 MIXED DRAFT GEAR PERFORMANCE

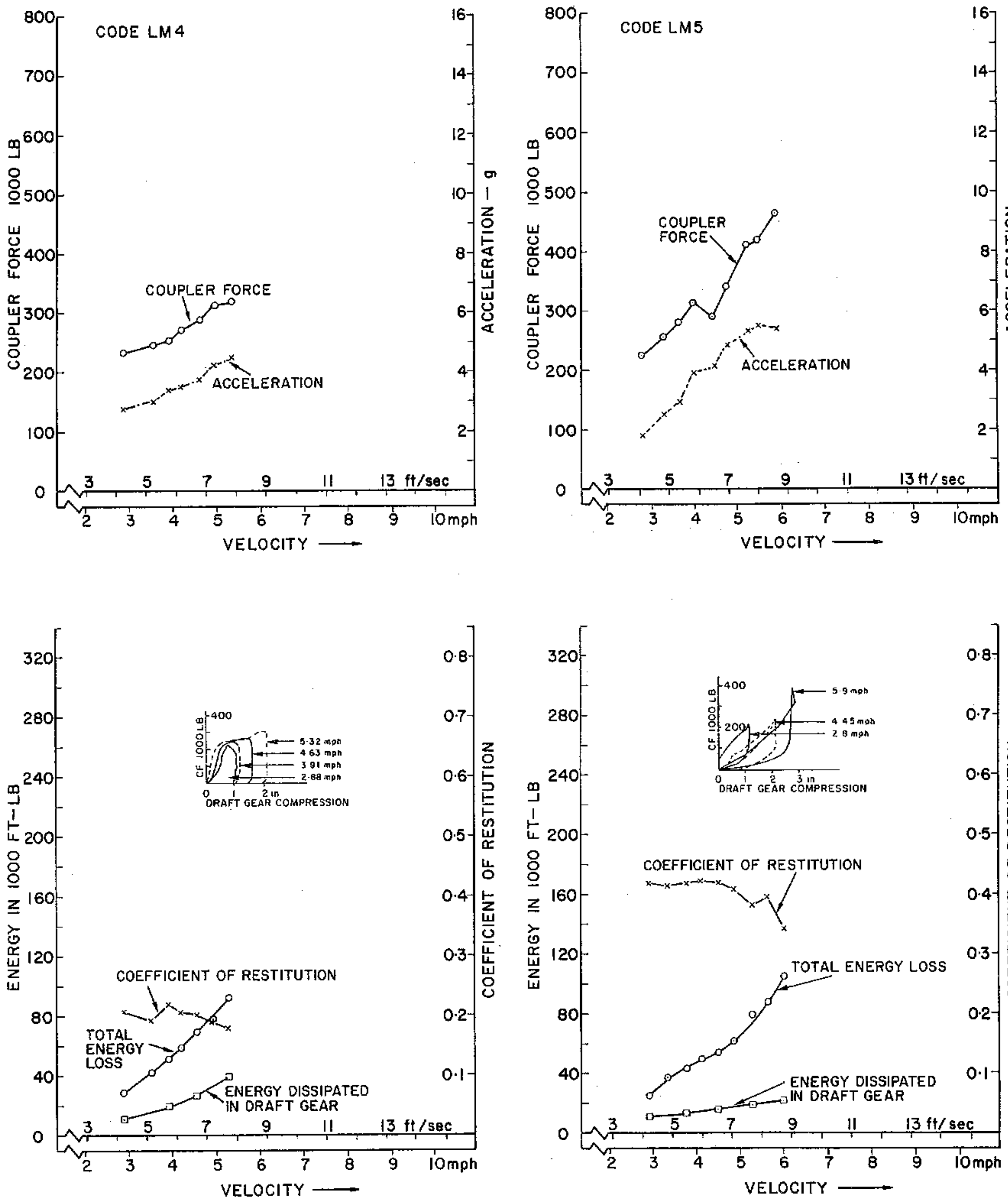


FIG. 8: NUMBER 4 AND 5 MIXED DRAFT GEAR PERFORMANCE (LOADED)

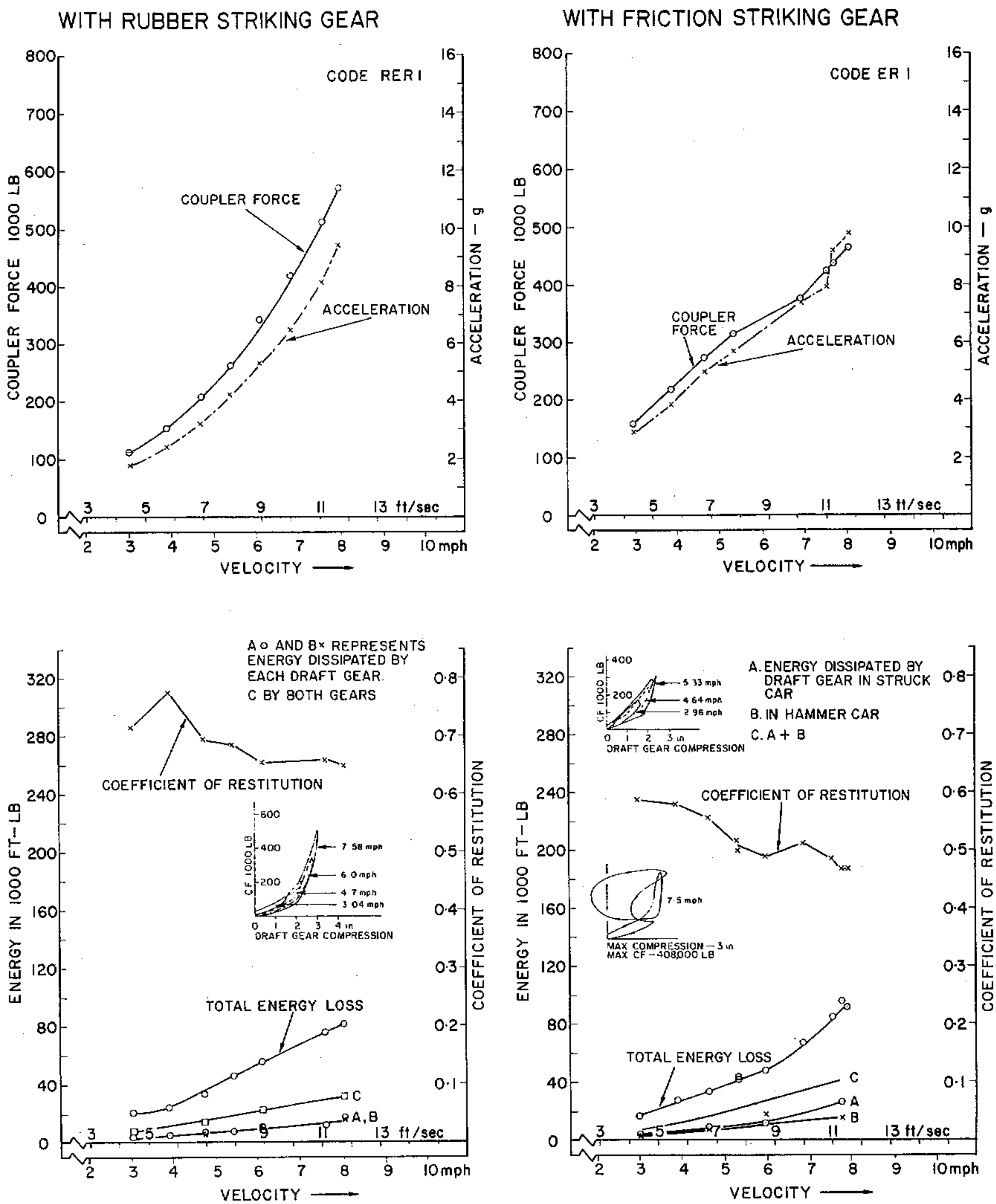


FIG. 9: NUMBER I RUBBER DRAFT GEAR PERFORMANCE (EMPTY)

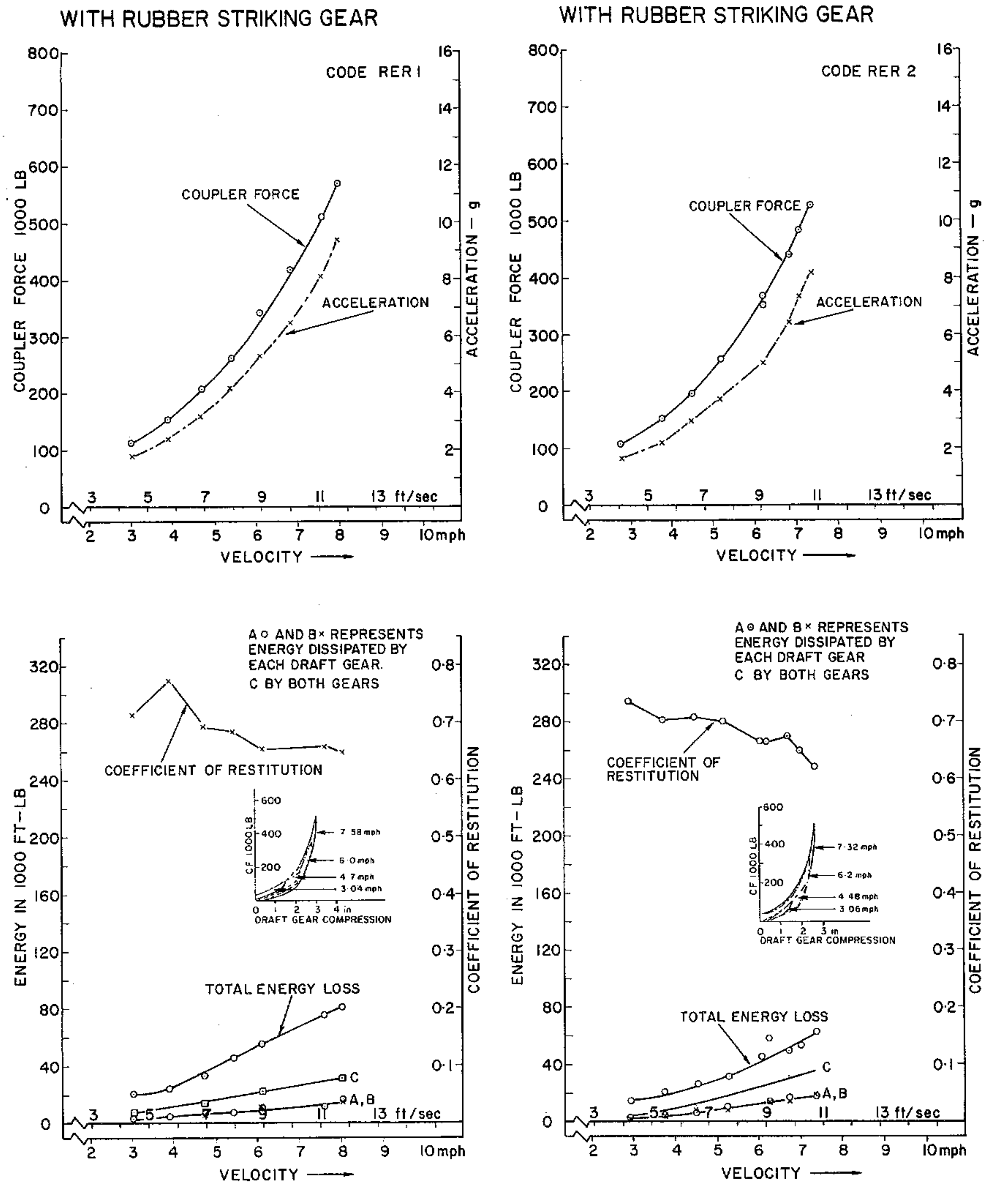


FIG. 10: NUMBER 1 AND 2 RUBBER DRAFT GEAR PERFORMANCE (EMPTY)

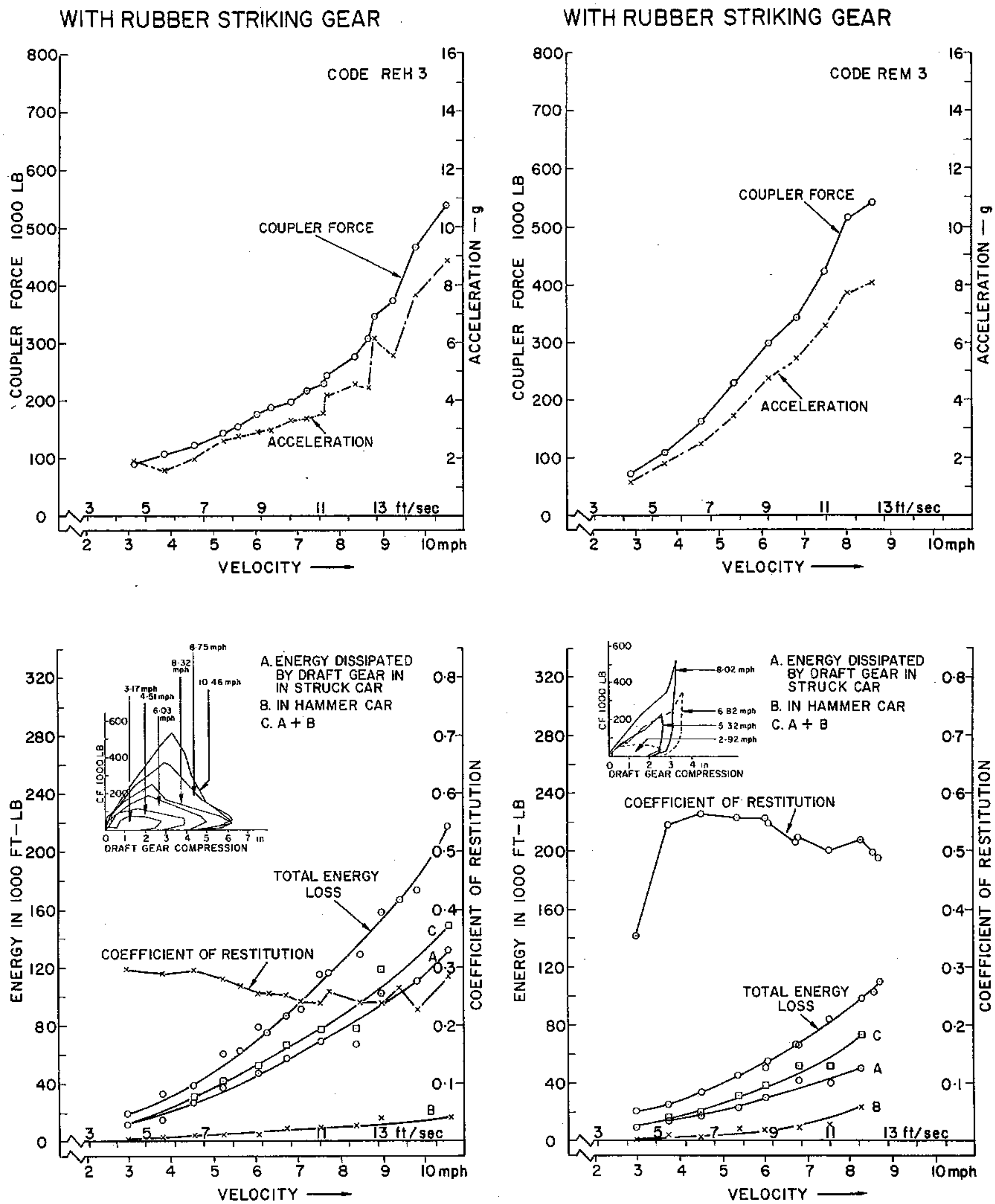


FIG. 11: H 3 AND M3 DRAFT GEAR PERFORMANCE (EMPTY)

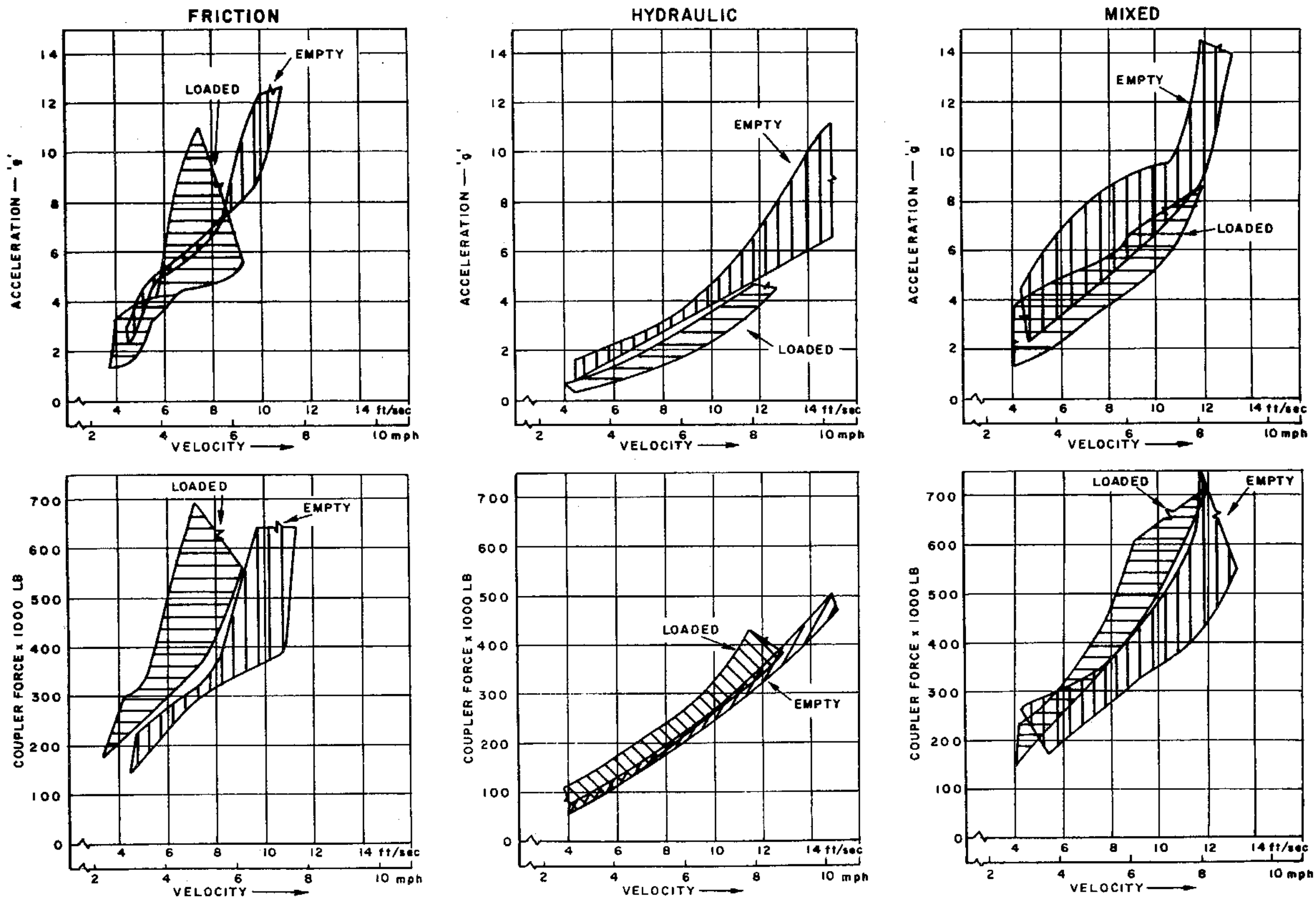


FIG. 12: ACCELERATION AND COUPLER FORCE ENVELOPE CHANGES WITH LOAD FOR THREE TYPES OF GEAR

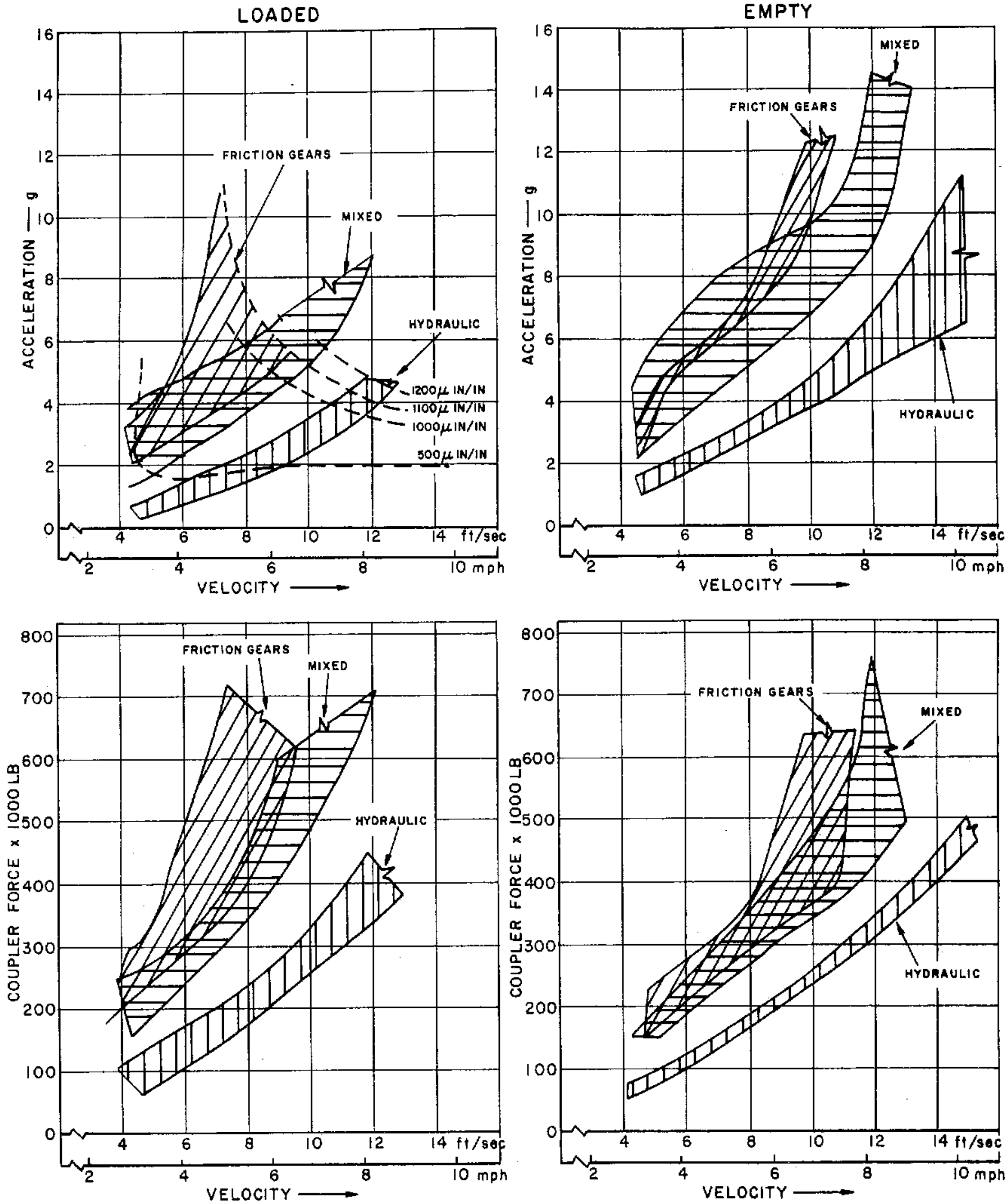


FIG. 13: ACCELERATION AND COUPLER FORCE ENVELOPE CHANGES WITH GEAR TYPE FOR TWO CONDITIONS OF LOADING

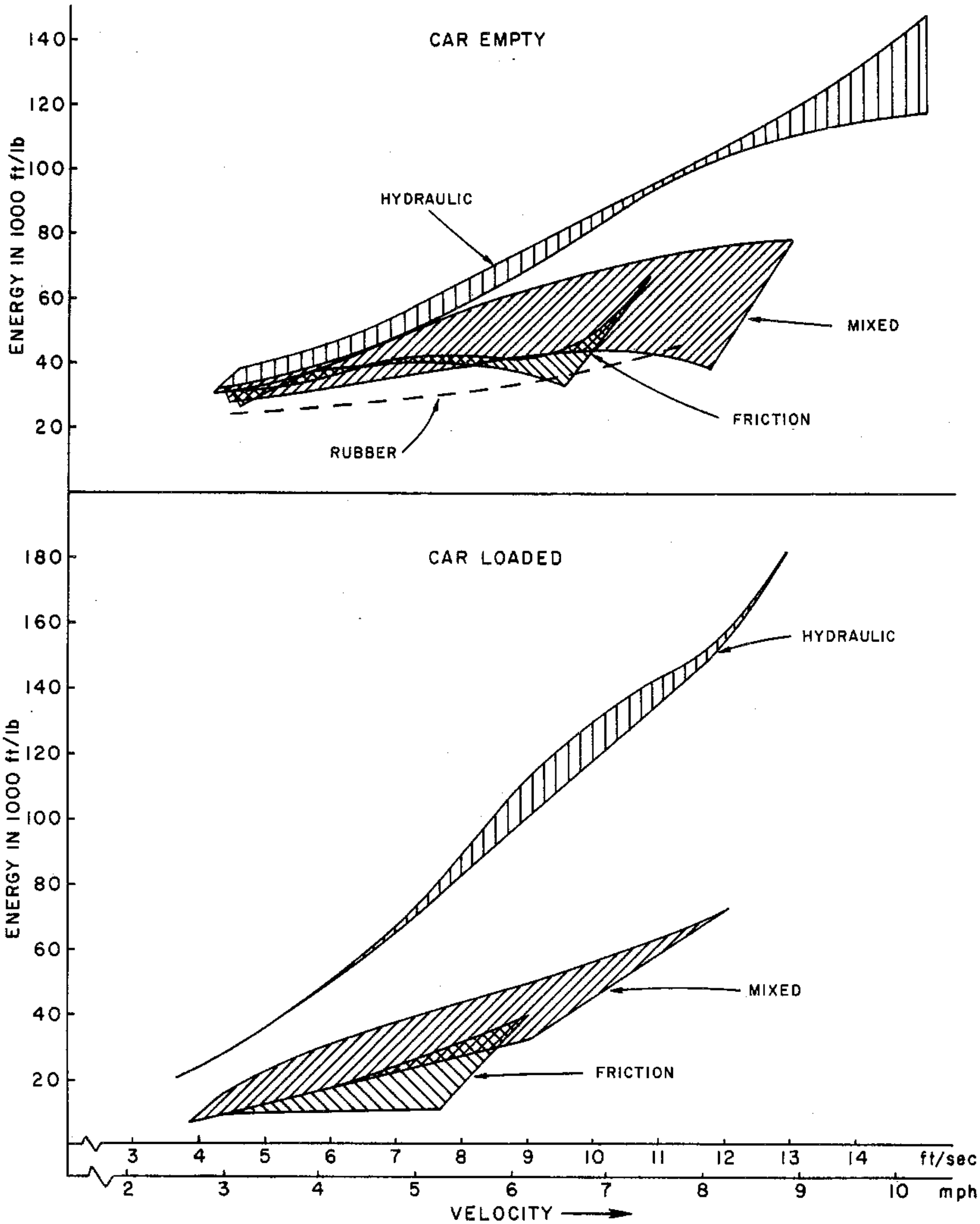


FIG. 14: ENERGY ABSORPTION CAPABILITY ENVELOPE WITH GEAR TYPE AND TWO CONDITIONS OF LOADING

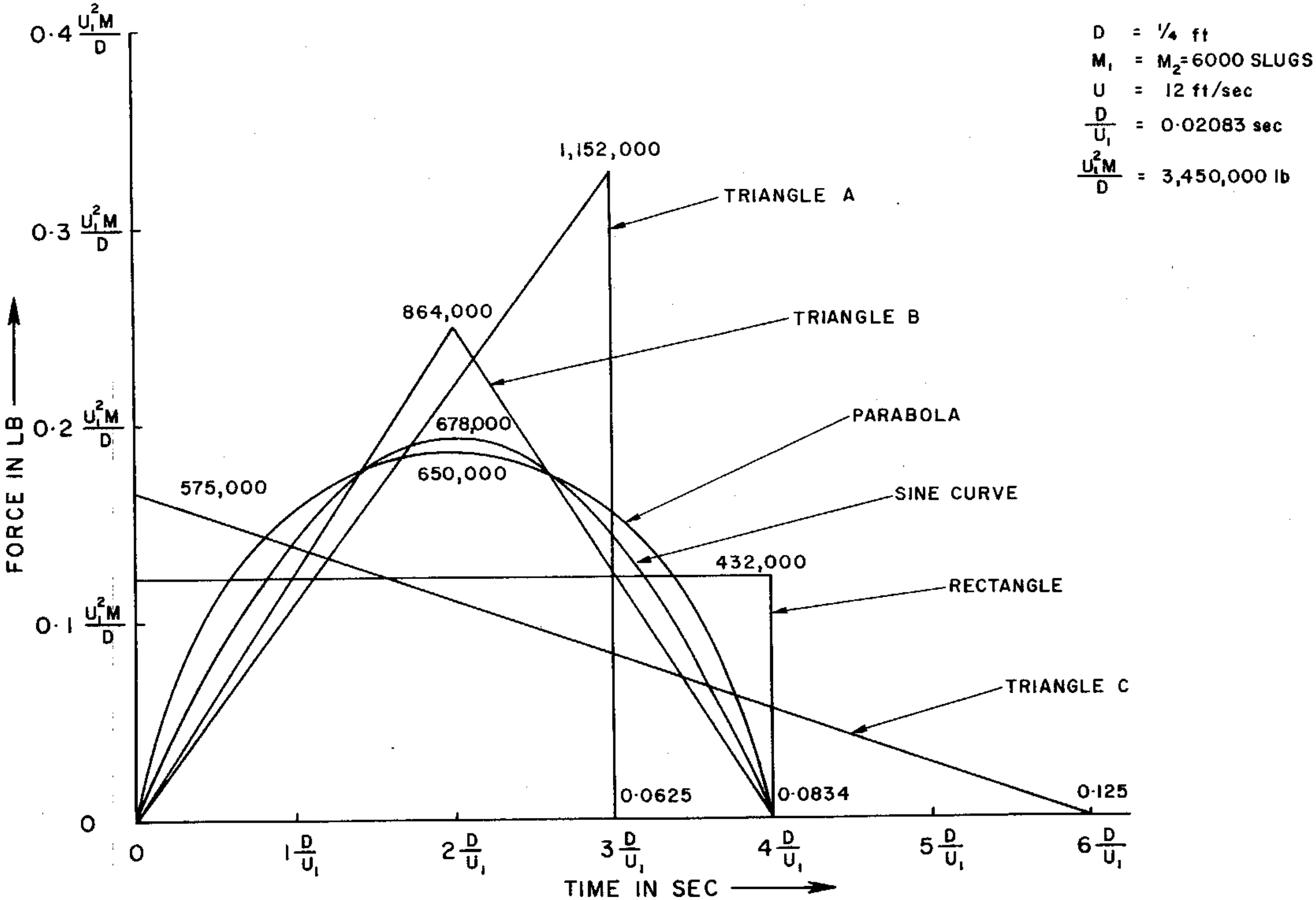
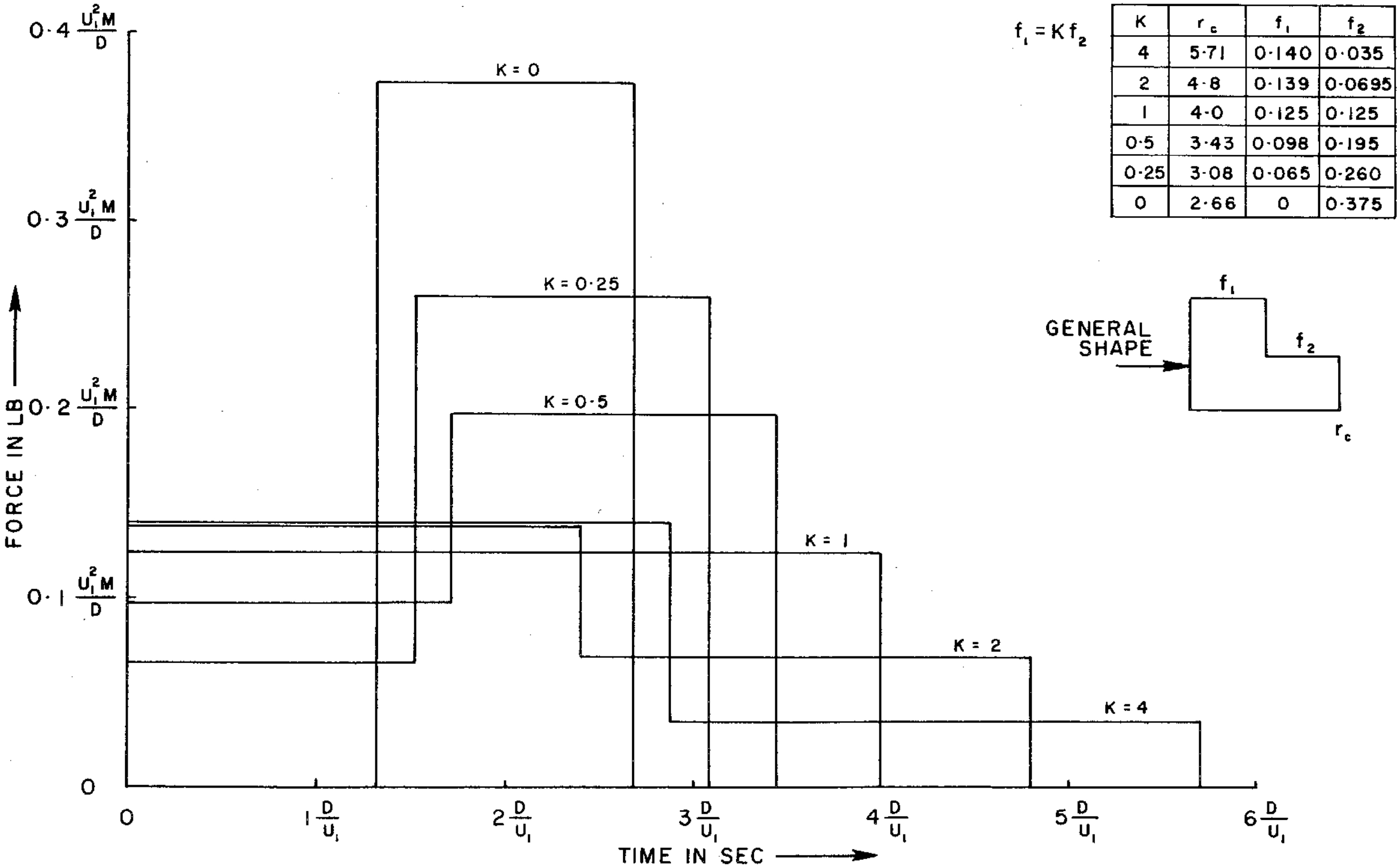


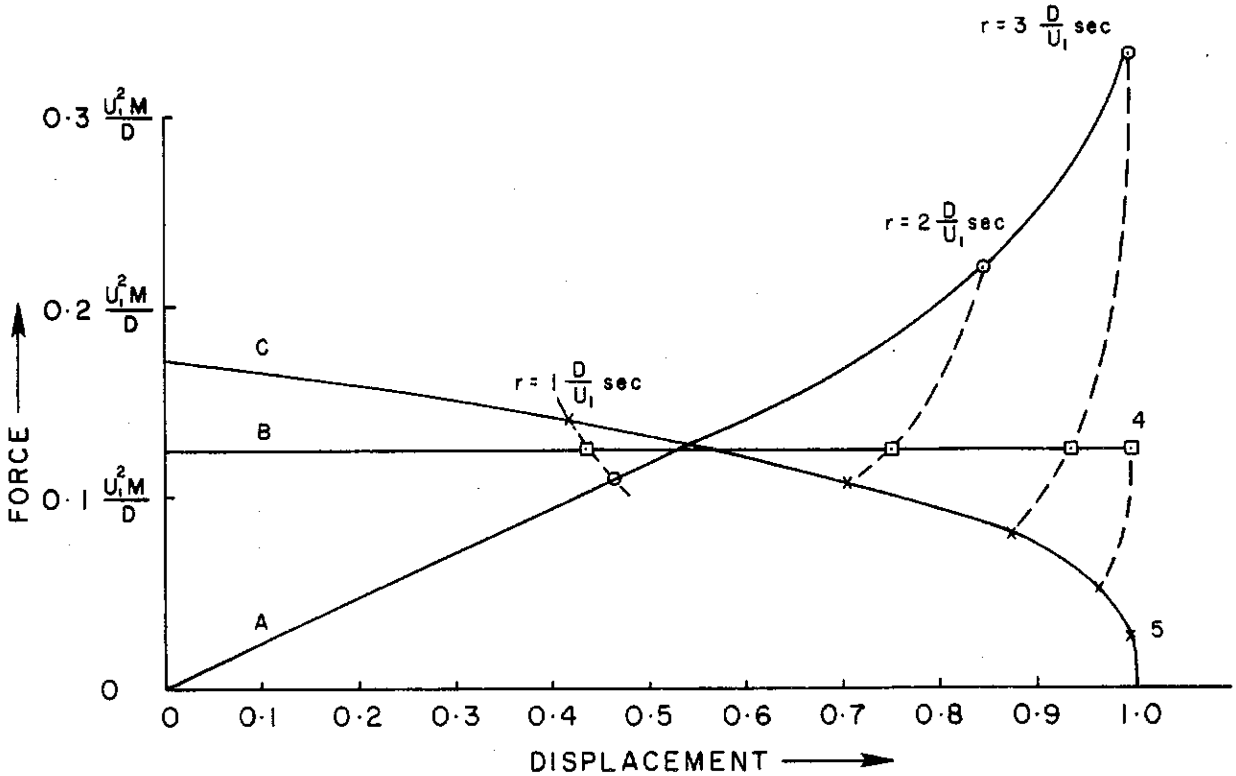
FIG. 15: HYPOTHETICAL FORCE TIME CURVES



$f_1 = K f_2$

K	r_c	f_1	f_2
4	5·71	0·140	0·035
2	4·8	0·139	0·0695
1	4·0	0·125	0·125
0·5	3·43	0·098	0·195
0·25	3·08	0·065	0·260
0	2·66	0	0·375

FIG. 16: HYPOTHETICAL FORCE TIME CURVES



<u>SPATIAL EFFICIENCY</u>

$$\eta_s = \frac{\text{AREA UNDER f-s CURVE}}{\text{f M} \times \text{D}}$$

CURVE A $= \frac{1}{8} \times \frac{3}{1} = 0{\cdot}37$

CURVE B $= \frac{1}{8} \times 8 = 1{\cdot}0$

CURVE C $= \frac{1}{8} \times 6 = 0{\cdot}75$

<u>TEMPORAL EFFICIENCY</u>

$$\eta_r = \frac{\text{AREA UNDER f-r CURVE}}{\text{f M} \times r_c}$$

CURVE A = 0·50

CURVE B = 1·00

CURVE C = 0·50

FIG. 17: FORCE DISPLACEMENT CURVES FOR THREE HYPOTHETICAL GEARS

APPENDIX A

As noted earlier, in order to improve the continuity of the main report, none of the raw data nor the many calculation sheets were included. However, the peak value Tables given in this Appendix will enable anyone who wishes to create further cross plots to do so.

TABLE A-1

PEAK VALUES FOR IMPACT SERIES

LF 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Movement in	Front Beam Strain μ in/in	Rear Beam Strain μ in/in	Long. Accel. "g"
1	0			No Results			
2	0	2.25	171	0.834	213	211.4	
3	0	2.50	199	1.09	273	352.5	+ 1.87 - 1.37
4	1			No Results			
5	1	3.54	272	2.01	410	310	+ 2.5 - 1.75
6	2	4.47	608	2.63	940	804	+ 9.06 - 5.5
7	3	5.04	724	2.39	1110	1170	+11.75 - 6.11

TABLE A-2

PEAK VALUES FOR IMPACT SERIES

LF 2

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Movement in	Front Beam Strain μ in/in	Rear Beam Strain μ in/in	Long. Accel. "g"
1	0	2.73	233	0.98	427	373	3.0
2	½	3.39	335	1.60	547	583	4.1 - 2
3	1	3.86	372	1.60	701	787	4.7 - 2.8
4	1½	4.11	359	2.02	740	787	3.9 - 2.3
5	2	4.49	363	2.20	654	654	5.4 - 4.1
6	2½	4.89	355	2.90	674	703	4.7 - 5.5
7	3	5.38	390	3.06	728	759	5.1 - 2.5
8	3½	5.62	393	3.17	774	1068	4.3 - 5.0
9	4	6.01	545	3.60	881	894	4.8 - 4.5
10	4½	6.36	602	3.88	867	1034	5.6 - 4.4

TABLE A-3

PEAK VALUES FOR IMPACT SERIES

LH 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Ext. Draft Gear in	Strain Gauge 1 Front Beam μ in/in	Strain Gauge 2 Rear Beam μ in/in	Accel. Long. "g"
1	0	2.58	109		50	20	0.6
2	0	2.74	122	3.11	94	87	0.6
3	½	3.32	154	3.55	257	262	0.9
4	1	3.60	162	3.69	282	322	1.1
5	1½	4.20	187	4.22	471	389	1.2
6	2	4.40	203	4.44	483	503	1.6
7	2½	4.86	221	4.77	543	584	2.1
8	3	5.16	250	5.02	565	617	2.1
9	3½	5.57	263	5.36	628	690	2.6
10	4	5.93	305	5.52	666	778	2.8
11	4½	6.31	289	5.76	704	865	3.0
12	5	6.68	322	5.95	816	885	3.4
13	5½	6.95	344	5.95	816	1070	3.5
14	6	7.39	378	5.98	1005	1085	4.3
15	6½	7.74	450	6.0	1100	1193	4.5
16	7	8.11	478	6.0	1212	1300	4.8

TABLE A-4

PEAK VALUES FOR IMPACT SERIES
LH 2

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Ext. Draft Gear in	Front Beam Strain μ in/in	Rear Beam Strain μ in/in	Long. Accel. "g"	Peak Coupler Force Hammer Car × 1000 lb
1	0	2.94	60	8.00	0	0	0.35	52.46
2	-½	3.51	60	7.93	0	0	0.47	80.15
3	1	4.11	112	7.88	0	0	0.89	101.52
4	1½	4.40	130	7.93	0	0	1.05	123.89
5	+2	4.68	152	7.96	0	130	1.18	133.37
6	-1	2.93	60	7.88	0	28	0.30	55.37
7	-2	2.54	49	7.86	0	22	0	45.89
8	-3	2.23	29	7.84	0	0	0	34.91
9	+2½	4.58	159	8.00	53	138	1.23	133.36
10	3	5.20	176	8.05	107	177	1.47	164.84
11	3½	5.59	199	8.00	213	222	1.59	171.29
12	4	5.93	197	8.00	272	271	1.76	203.63
13	4½	6.38	235	8.13	341	327	2.00	215
14	5	6.75	264	8.13	458	455	2.47	260.9
15	5½	6.94	304	8.13	613	564	2.59	263.58
16	6	7.55	272	8.09	758	715	2.94	295.17
17	6½	7.84	314	8.17	635	874	+3.23 -0.29	311.98
18	7	8.12	339	8.16	1066	1160	+3.82 -0.88	335.25
19	7½	8.51	360	8.16	1240	1275	+4.18 -1.41	355.09
20	8	8.75	492	8.42	1465	1605	+4.7 -1.47	385.56

TABLE A-5

PEAK VALUES FOR IMPACT SERIES
LM 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Ext. Draft Gear in	Strain Gauge 1 Front Beam μ in/in	Strain Gauge 2 Rear Beam μ in/in	Accel. Long. "g"
1	0	2.77	244	1.14	344	317	+3.6 -3.8
2	½	3.12	271	1.08	504	562	+4.3 -1.6
3	1	3.41	289	1.38	474	443	+4.6 -5.0
4	1½	4.04	290	1.67	539	584	+4.9 -4.9
5	2	4.35	297	1.96	539	552	+5.3 -3.6
6	2½	4.79	300	2.48	580	563	+4.9 -3.7
7	3	5.10	299	2.71	623	725	+5.7 -3.4
8	3½	5.43	318	3.19	623	900	+5.6 -4.3
9	4	5.81	389	3.29	760	816	+6.1 -5.0
10	4½	6.18	598	3.21	1000	1150	+6.8 -6.2

TABLE A-6

PEAK VALUES FOR IMPACT SERIES
LM 2

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Ext. Draft Gear in	Strain Gauge 1 Front Beam μ in/in	Strain Gauge 2 Rear Beam μ in/in	Accel. Long. "g"
1	0	2.73	193	1.76	380	422	+2.2 -0.9
2	½	3.12	238	1.98	445	458	+2.5 -0.4
3	1	3.60	286	2.11	587	620	+3.0 -0.7
4	1½	3.99	322	2.31	705	775	+3.7 -0.7
5	2	4.41	372	2.75	807	888	+4.1 -1.1
6	2½	4.61	388	2.71	652	690	+4.4 -6.7
7	3	5.00	352	2.75	712	648	+4.3 -3.9
8	3½	5.55	415	2.86	770	768	+4.6 -2.9
9	4	5.77	518	3.06	1010	1050	+5.1 -2.7
10	4½	6.14	606	3.08	1100	1320	+6.7 -3.6

TABLE A-7

PEAK VALUES FOR IMPACT SERIES

LM 3

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Movement in	Front Beam Strain μ in/in	Rear Beam Strain μ in/in	Long. Accel. "g"	Peak Coupler Force Hammer Car × 1000 lb
1	0	2.88	232	1.42	477	643	+2.72 -1.39	244
2	½	3.57	245	1.18	632	711	+3.03 -0.54	259
3	1	3.91	252	1.20	786	860	+3.39 -0.85	270
4	1½	4.19	271	1.38	894	982	+3.51 -1.21	288
5	2	4.63	287	1.60	1054	1104	+3.76 -1.75	304
6	2½	4.93	314	1.73	1162	1152	+4.12 -2.42	342
7	3	5.32	318	2.24	1310	1832*	+4.24 -2.00	328

* Permanent Set

TABLE A-8

PEAK VALUES FOR IMPACT SERIES
LM 4

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Movement in	Front Beam Strain μ in/in	Rear Beam Strain μ in/in	Long. Accel. "g"	Peak Coupler Force Hammer Car × 1000 lb
1	0	3.07	140	2.28	356	677	1.33	141
2	½	3.58	230	2.40	588	772	1.82	241
3	1	3.87	241	2.69	746	1029	+1.70 -0.35	247
4	1½	4.23	271	2.76	921	1340	+2.24 -0.97	273
5	2	4.62	285	2.78	-	-	+2.73 -1.51	293
6	2½	4.92	306	2.89	-	-	+3.06 -1.76	310
7	3	5.23	235	3.12	1560	-	+3.57 -1.88	351
8	1½	3.85	195	2.57	578	866	+2.00 -1.46	202
9	1½	4.03	283	2.79	726	954	+2.36 -0.73	269
10	2	4.57	279	2.79	881	1137	+2.55 -1.27	285
11	2½	4.95	314	3.01	982	1354	+3.45 -1.76	322
12	3	5.29	340	3.08	1124	880	+3.51 -1.76	347
13	3½	-	380	3.10	935	1428	+4.36 -2.06	381
14				No Record				
15	4	-	360	3.10	1015	751	+4.79 -4.85	381
16	4½	6.36	426	3.03	1109	935	+4.60 -4.85	436
17	5	6.57	457	3.06	1244	941	+5.15 -5.70	475
18	5½	6.94	499	3.47	1291	1200	+5.46 -5.52	521
19	6	7.45	568	3.47	1775	1578	+6.01 -4.60	575
20	6½	7.94	649	3.54	2150	-	+8.55 -3.68	675
21	7	8.28	719	3.54	2775	-	+8.80 -3.03	756

TABLE A-9

PEAK VALUES FOR IMPACT SERIES
LM 5

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Movement in	Front Beam Strain μ in/in	Rear Beam Strain μ in/in	Long. Accel. "g"
1	0	2.80	219	1.11	561	456	+ 1.8
2	½	3.29	254	1.45	708	600	+ 2.5
3	1	3.67	276	1.65	875	741	+ 2.9
4	1½	4.01	350	2.04	962	865	+ 3.9 - 1.5
5	2	4.45	386	2.09	800	492	+ 4.1 - 2.6
6	2½	4.76	345	2.38	748	640	+ 4.8 - 4.8
7	3	5.25	405	2.55	934	760	+ 5.3 - 3.6
8	3½	5.48	416	2.69	1035	879	+ 5.5 - 3.4
9	4	5.90	467	2.77	1161	1033	+ 5.4 - 1.2

TABLE A-10

PEAK VALUES FOR IMPACT SERIES
EF 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer in	Long. Accel. "g"
1	0	3.07	126	138	2.00	0.55	+ 2.28 - 0.55
2	½	3.50	144	152	2.63	0.38	+ 2.76
3	1	3.85	252	261	2.76	0.54	+ 5.1
4	1½	4.21	287	306	2.76	0.72	+ 5.38 - 0.55
5	2	4.51	305	304	2.76	1.49	+ 5.59 - 3.79
6	2½	4.94	332	310	2.90	1.98	+ 6.27 - 5.38
7	3		No Results				
8	3	5.28	295	276	3.04	2.56	+ 6.14 - 3.72
9	3½	5.68	384	414	2.90	-	+ 7.24 - 2.90
10	4		No Results				
11	4	6.09	511	550	3.01	2.44	+ 9.45 - 4.47
12	4½	6.69	642	652	2.84	2.59	+ 5.87 -13.18

TABLE A-11

PEAK VALUES FOR IMPACT SERIES
EF 2

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	3.07	189	177	1.25	1.44	+ 2.96 - 0.76
2	½	3.59	270	284	1.50	1.05	+ 4.83
3	1	3.83	288	305	1.66	0.55	+ 4.68 - 1.72
4	1½	4.22	261	282	1.83	1.32	+ 5.86 - 2.42
5	2	4.67	299	318	1.94	1.18	+ 5.58 - 2.07
6	2½	4.98	318	325	1.94	1.41	+ 6.21 - 1.93
7	3			No Results			
8	3	5.33	310	358	1.88	-	+ 6.76 - 3.86
9	3½	5.58	296	271	2.01	2.84	+ 7.24 - 6.21
10	4	6.03	356	384	2.24	3.73	+ 8.69 - 7.59
11	4½	6.44	332	336	2.38	2.59	+ 7.59 -10.35
12	5	6.63	327	362	2.19	2.59	+ 8.63 - 3.45
13	5½	6.97	406	448	2.78	2.76	+14.85 - 9.94
14	6	7.49	355	450	3.16	2.62	+11.59 - 6.34
15	6½	7.70	645	695	3.44	2.73	+10.05 - 5.59

TABLE A-12

PEAK VALUES FOR IMPACT SERIES
EH 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	2.86	78	100	2.2	0.55	+ 1.6
2	1	3.74	110	106	2.87	0.41	+ 2.06
3	2	4.51	146	141	3.28	0.50	+ 2.66
4	3	5.28	180	178	3.65	0.47	+ 2.99
5	4	6.07	221	218	3.86	0.73	+ 4.00
6	5	6.68	237	226	4.16	1.17	+ 4.46
7	6	7.54	322	307	4.50	1.17	+ 5.73
8	7	8.13	355	353	4.60	1.46	+ 6.73
9	8	8.87	384	368	4.85	3.06	+ 8.13 - 3.73
10	9	9.63	457	458	5.10	3.65	+10.31 - 4.67
11	10	10.25	512	421	5.19	3.80	+11.32 - 4.67

TABLE A-13

PEAK VALUES FOR IMPACT SERIES
EH 2

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Movement in	Long. Accel. "g"	Peak Coupler Force Hammer Car × 1000 lb
1	1	3.61	86	7.32	1.33	75
2	0	3.10	63	6.90	0.81	48
3	2	4.61	122	7.34	1.97	115
4	3	5.20	147	7.48	2.32	137
5	4	6.00	195	7.56	3.59	175
6	5		No Results			
7	5	6.81	246	7.93	3.48	215
8	6	7.56	275	7.82	4.24	250
9	7	8.11	328	7.84	5.16	306
10	8	8.85	349	7.90	5.97	328
11	9	9.50	421	8.06	+6.09 -1.11	378
12	10	10.25	476	8.17	6.66	436

TABLE A-14

PEAK VALUES FOR IMPACT SERIES

EM 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	2.98	239	237	0.97	0.60	4.27
2	½	3.32	277	266	1.15	0.95	5.04
3	1	3.94	282	284	1.03	0.86	5.71
4	1½	4.21	318	313	1.28	0.98	7.66
5	2	4.60	320	323	1.53	0.83	8.14
6	2½	4.97	341	345	1.55	0.89	8.62
7	3	5.41	332	347	1.80	0.92	8.20
8	3½	5.83	326	336	2.01	1.15	9.31
9	4	5.79	327	343	2.16	1.47	10.07
10	4½	6.31	349	372	2.53	1.03	9.40
11	5	6.82	329	336	2.83	1.12	6.83
12	5½	7.04	361	376	2.85	1.34	7.94
13	6	7.41	359	363	2.81	-	8.62
14	6½	7.84	416	419	3.47	-	10.70
15	7	8.32	421	403	3.50	2.70	10.00
16	7½	8.54	471	481	3.53	-	11.04
17	8	9.04	613	641	3.56	2.70	14.22

TABLE A-15

PEAK VALUES FOR IMPACT SERIES
EM 2

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	2.97	154	143	1.42	0.44	+ 1.94
2	1	3.72	220	214	2.00	0.58	+ 3.44
3	2	4.61	279	272	2.49	0.68	+ 4.07
4	3	5.33	340	333	2.74	0.97	+ 5.81
5	4	5.93	412	399	2.96	1.39	+ 7.00
6	5	6.75	477	449	3.12	2.63	+ 8.24 - 3.56
7	6	7.41	509	475	3.14	3.47	+12.00
8	7	8.10	775	805	3.48	4.00	+14.75
9	6½	7.84	572	585	3.31	2.55	+10.05 - 5.32

TABLE A-16

PEAK VALUES FOR IMPACT SERIES
EM 3

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	2.96	123	117	1.99	0.46	+ 2.03
2	1	3.77	161	160	2.43	0.49	+ 3.07
3	2	4.60	233	232	2.62	0.48	+ 4.06
4	3	5.20	248	255	3.04	0.71	+ 4.73
5	4	6.03	315	318	3.14	0.74	+ 5.54
6	5	6.75	348	356	3.14	1.26	+ 7.44
7	6	7.79	411	419	3.17	1.40	+ 7.32
8	7	8.36	391	462	3.75	3.39	+ 8.86 - 4.37
9	8	8.85	523	537	3.58	2.87	+14.33 - 7.44

TABLE A-17

PEAK VALUES FOR IMPACT SERIES
ER 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Hammer Car × 1000 lb	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	2.96	165	155	1.53	0.69	2.84
2	1	3.83	219	216	1.95	0.80	3.81
3	2	4.64	274	270	2.14	0.97	4.97
4	3	5.33	277	278	2.03	2.27	4.97
5	4	5.33	323	315	2.47	1.72	5.62
6	4	6.03	290	303	2.41	2.83	+5.75 -1.94
7	5	6.88	385	374	2.60	2.57	+7.36 -2.84
8	6	7.50	422	422	2.98	2.71	+7.88 -3.81
9	6½	8.03	466	464	2.96	-	+9.75 -5.24
10	6	7.67	441	435	2.52	3.00	+9.18 -5.49

TABLE A-18

PEAK VALUES FOR IMPACT SERIES
RER 1

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Hammer Car × 1000 lb	Peak Coupler Force Struck Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	3.04	-	114	1.64	1.69	1.81
2	1	3.90	-	153	2.05	1.74	2.45
3	2	4.70	219	207	2.19	1.86	3.23
4	3	5.41	-	262	2.36	2.20	4.20
5	4	6.00	353	341	2.63	2.57	5.30
6	5	6.81	435	419	2.66	2.97	6.46
7	6	7.58	531	510	2.80	3.00	8.14
8	6½	7.94	608	572	2.85	3.00	9.44

TABLE A-19

PEAK VALUES FOR IMPACT SERIES
RER 2

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	-	109	115	1.49	1.44	1.66
2	1	3.76	151	166	1.87	1.72	2.20
3	2	4.48	198	225	2.17	2.30	3.00
4	3	5.18	255	283	2.27	2.47	3.73
5	4	-	369	391	2.71	2.44	5.00
6	4	6.20	353	374	2.33	2.56	5.00
7	5	6.82	441	469	2.71	2.87	6.46
8	5½	7.10	485	511	2.71	2.87	7.32
9	6	7.32	527	559	2.57	2.76	8.16

TABLE A-20

PEAK VALUES FOR IMPACT SERIES
REM 3

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	2.92	70	75	2.44	0.98	1.14
2	1	3.72	106	123	2.38	1.44	1.79
3	2	4.58	160	172	2.44	1.81	2.48
4	3	5.32	230	230	2.60	2.21	3.45
5	4	No Results					
6	4	6.15	297	318	3.09	2.57	4.76
7	5	No Results					
8	5	6.82	341	354	3.85	2.47	5.45
9	6	7.49	423	444	3.11	2.59	6.56
10	7	8.02	516	549	3.22	2.76	7.73
11	7½	8.62	541	579	3.11	-	8.28
12	7½	8.52	544	574	3.36	2.79	7.92

TABLE A-21

PEAK VALUES FOR IMPACT SERIES

REH 3

Run No.	Ramp Position	Impact Speed mph	Peak Coupler Force Struck Car × 1000 lb	Peak Coupler Force Hammer Car × 1000 lb	Draft Gear Ext. Struck Car in	Draft Gear Ext. Hammer Car in	Long. Accel. "g"
1	0	3.17	89	92	2.68	1.11	1.92
2	1	3.87	106	113	3.14	1.28	1.54
3	2	4.51	121	135	3.89	1.74	2.00
4	3	5.24	143	156	4.43	2.00	2.61
5	3½	5.58	153	165	4.71	1.88	2.74
6	4	6.03	176	180	5.00	2.05	2.92
7	4½	6.37	187	196	5.15	1.77	3.00
8	5	6.82	195	211	5.28	1.74	3.31
9	5½	7.17	216	233	5.57	2.14	3.38
10	6	7.58	229	246	6.00	2.25	3.54
11	6½	7.66	245	264	5.85	1.85	4.15
12	7	8.32	275	302	6.11	2.12	4.57
13	7½	8.64	306	331	6.16	2.03	4.46
14	8	8.75	346	373	6.22	2.57	6.15
15	8½	9.22	373	403	6.05	2.31	5.69
16	9	9.74	466	498	5.31	2.68	7.68
17	10	10.46	539	576	6.05	2.63	8.84

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C.A.M. Smith. June 1968. 57 pp. (incl. tabs., figs., and app.).

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