CONCEPT STUDY
FOR
TRACKED AMPHIBIAN PERSONNEL AND CARGO CARRIER
(LVTPX11)

CONTRACT NO. NObs-4464

VOLUME II

APPENDIX A: SUSPENSION ANALYSIS
B: [illegible] ANALYSIS
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...DED BY THE CHIEF, BUREAU OF SHIPS

ORDNANCE DIVISION

FINAL REPORT
Of a
CONCEPT STUDY
For a
TRACKED AMPHIBIAN PERSONNEL AND CARGO CARRIER
(LVTPX11)

VOLUME II

Prepared for

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By

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APPENDIX A

INTRODUCTION

Most suspension systems of military vehicles have been previously designed by using rough estimates based on performance data of earlier models. Pilot models were then designed and built, in order to further study the estimated suspension system. The suspension can be optimized faster and at a considerable cost savings by simulating the proposed system on an electronic computer. A better designed suspension will result from this simulation technique because of the possibility of modifying the design features until an optimum combination is attained.

This study describes in detail an electronic simulation technique used in optimizing the suspension for an LVT which has a proposed sprung weight of 32, 000 pounds and a pitching mass moment of inertia of 28, 400 slug-feet^2. Three basic suspension systems were studied in order to obtain a sufficient quantity of data to permit a qualitative analysis. These three basic configurations consist of eight road wheels mounted on four walking beams, twelve road wheels mounted on six walking beams, and twelve road wheels individually sprung with shock absorbers on the front and rear road wheel arms.

The three basic suspension configurations are analyzed to determine their performance under different conditions of vehicle speed and road profile for certain variations of design features and parameter values. Specifically, two torsion bar spring rates, one which yielded six inches of deflection under two g's of acceleration, and a second which yielded twelve inches of deflection under two g's of acceleration are studied. Shock absorber snubbing rates are varied from 508 pound seconds per foot to a much stiffer snubber with a rate of 1, 016 pound second per foot.

INTRODUCTION (Continued)

A mathematical analog has been developed by considering a two degree of freedom motion of the vehicle as it traverses over a standard APG test course with a sine wave cross section. The two sine wave courses consist of a 6 foot displacement period with a 3 inch amplitude and a 4 foot displacement period with a 2 inch amplitude.

The analysis has been simplified by considering the following items:

- Interaction of the track-blocks as they move between the road wheels has a negligible effect on the motion of vehicle.
- All road wheels are assumed to follow the selected APG course contours.
- The inertia of the road arms and road wheels is negligible.
- Elasticity of the road wheels is negligible.
- Change in suspension geometry is negligible.
- Wheels do not bottom out.

The assumptions,which were made to simplify the analysis, have been carefully checked by viewing slow motion movies of vehicles on the APG test course, computing the inertia and elasticity of suspension components, and checking total wheel motion to be sure they do not bottom out. These checks validated the assumptions which simplified the analysis and introduced negligible error in the results.

APPENDIX A

RESULTS

The vehicle with 6 walking beams and 12 road wheels with soft springs and hard shock absorbers provided the most comfortable ride of the 3 suspension combinations analyzed in this study. Ride comfort curves, which were developed by the U. S. Army Transportation Research Command in 1960, provided the basis for the final vehicle selection. The simulated vehicle which yielded the most comfortable ride was checked for bottoming out of the road arm against the bump stop and the maximum rectilinear acceleration of the vehicle driver or crew member was determined. A complete tabulation of the study results for steady state and transient are shown at the end of this analysis. A condensed tabulation of the results is included here for an approximate comparison of the steady state and transient vehicle response.

Comparison of the results of the three basic vehicles studied in this analysis using soft springs, hard shock absorbers, a vehicle speed of 20 mph, and a course bump height of 3 inches:

Result Item	4 Walking Beams	6 Walking Beams	Individually Sprung
STEADY STATE			
Pitch excursion	.195 degree	.188 degree	.81 degree
Vertical disp. of C.G.	.168 inch	.096 inch	.115 inch
Vertical disp. of driver	.224 inch	.372 inch	1.28 inches
Acceleration of driver	1.27 g's	1.454 g's	2.56 g's
Max. Vehicle wheel travel	3.095 inches	3.169 inches	3.565 inches
TRANSIENT RESPONSE			
Pitch excursion	.87 degree	.8 degree	1.25 degrees
Vertical disp. of C.G.	.42 inch	.312 inch	.4 inch
Vertical disp. of driver	1.32 inches	1.37 inches	1.62 inches
Vertical disp. of rear	1.43 inches	.935 inch	2.1 inches

APPENDIX A

NOTATIONS

W = Vehicle Weight (lbs)

g = Acceleration of gravity (ft/sec^2)

I = Vehicle mass moment of inertia

l_n = Horizontal distance from Vehicle c.g. to suspension pivot (ft)

k_n = Effective linear spring constant for the vehicle torsion bars (lbs/ft)

C_n = Hydraulic shock absorber (lbs-sec/ft)

X = Vertical translation of vehicle c.g. (ft)

Θ = Vehicle pitching rotation (radians)

$(\cdot)$ = "Dot" indicates a time derivative

A = Max. rise of the road bed above the mean (ft)

L = Wave length of road bed (ft)

v = Vehicle velocity (ft/sec)

a = Distance between wheels on the walking beams (ft)

w = Circular frequency = $2\pi v/L$

α_n = Phase angle (rad.)

b, d, e, f, h, j = Constants

m = Mass of the vehicle (slugs)

t = Time (sec)

ϕ = Phase relationship (rad)

APPENDIX A

CORRELATION OF SIMULATED DATA

Description of the 8 Wheel 4 Walking Beam Suspension

The weight of the vehicle is supported by eight road wheels, four on each side, which are attached to the hull through walking beams and torsion bars; the torsion bars have the effect of springs. The upward displacement of each road wheel is limited by a "bump stop". Shock absorbers are attached to the four walking beam arms and are used to damp out motion of the hull. The road wheels on each side of the vehicle ride on an endless track, which completes its circuit by passing over the drive sprocket at the rear of the vehicle, three support rollers along the side of the hull, and an adjusting idler wheel at the front of the vehicle. Track guides are built into each track block to prevent throwing of the track. The drive sprocket provides the means for applying power from the engine to produce vehicle motion.

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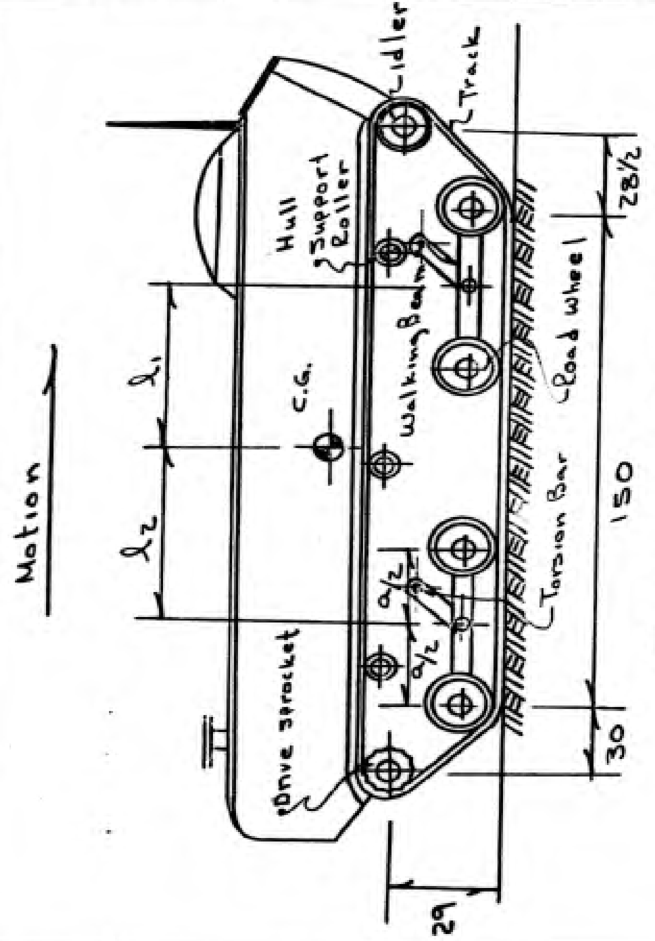

Suspension Features of the LVT with 8 Road Wheels Mounted on 4 Walking Beams

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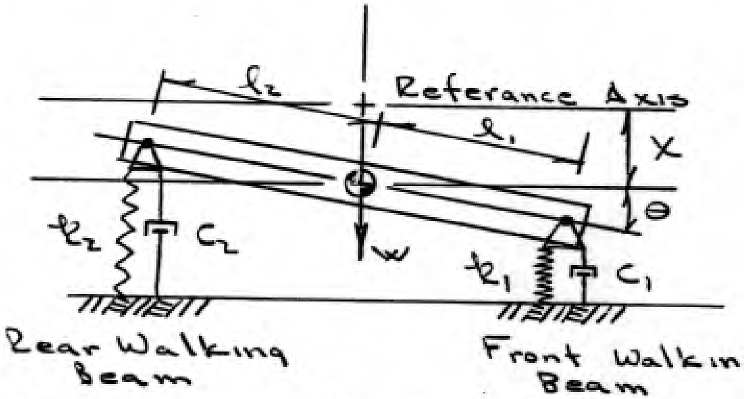
Application of the basic concepts of rigid body mechanics will allow the following idealized system to be formulated.



The vertical displacement from a mean ground line for the front walking beam will be:

$$X_1 = \frac{A}{2}\left[\sin \omega t + \sin(\omega t - \alpha_1)\right]$$

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The vertical displacement from a mean ground line for the rear walking beam will be:

$$X_2 = \frac{A}{2}\left[\sin(\omega t-\phi)+\sin(\omega t-\phi-\alpha_2)\right]$$

Differential equations which describe the motion of the vehicle while supported on 3 road wheels & 4 walking beams.

$$\frac{W}{g}\ddot{x} = -k_2(x-l_2\theta+X_2)-C_2(\dot{x}-l_2\dot{\theta}+\dot{X}_2)$$
$$-k_1(x+l_1\theta+X_1)-c_1(\dot{x}+l_1\dot{\theta}+\dot{X}_1)$$

$$I\ddot{\theta} = l_2\left[k_2(x-l_2\theta+X_2)+C_2(\dot{x}-l_2\dot{\theta}+\dot{X}_2)\right]$$
$$-l_1\left[k_1(x+l_1\theta+X_1)+c_1(\dot{x}+l_1\dot{\theta}+\dot{X}_1)\right]$$

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The general differential equations which describe the vehicle motion can be re-written as follows:

$$\frac{W}{g}\ddot{x}+k_2x-k_2l_2\theta+C_2\dot{x}-C_2l_2\dot{\theta}+k_1x$$
$$+k_1x+k_1l_1\theta+c_1\dot{x}+c_1l_1\dot{\theta}=$$
$$-k_2X_2-C_2\dot{X}_2-k_1X_1-c_1\dot{X}_1$$

$$\frac{W}{g}\ddot{x}+(k_1+k_2)x+(k_1l_1-k_2l_2)\theta+$$
$$(c_1+C_2)\dot{x}+(c_1l_1-C_2l_2)\dot{\theta}=$$
$$-k_1X_1-c_1\dot{X}_1-k_2X_2-C_2\dot{X}_2$$

The second differential equation can be re-written in the following form:

$$I\ddot{\Theta} - k_2 l_2 x + k_2 l_2^2 \Theta - c_2 l_2 \dot{x} + c_2 l_2^2 \dot{\Theta} +$$
$$k_1 l_1 x + k_1 l_1^2 \Theta + c_1 l_1 \dot{x} + c_1 l_1^2 \dot{\Theta} =$$
$$k_2 l_2 x_2 + c_2 l_2 \dot{x}_2 - k_1 l_1 x_1 - c_1 l_1 \dot{x}_1$$

$$I\ddot{\Theta} + (k_1 l_1 - k_2 l_2) x + (k_1 l_1^2 + k_2 l_2^2) \Theta +$$
$$(c_1 l_1 - c_2 l_2)\dot{x} + (c_1 l_1^2 + c_2 l_2^2)\dot{\Theta} =$$
$$-k_1 l x_1 - c_1 l_1 \dot{x}_1 + k_2 l_2 x_2 + c_2 l_2 \dot{x}_2$$

Subsitute :

$b = (k_1 + k_2)$

$d = (k_1 l - k_2 l_2)$

$e = (c_1 + c_2)$

$f = (c_1 l_1 - c_2 l_2)$

$h = (k_1 l_1^2 + k_2 l_2^2)$

$j = (c_1 l_1^2 + c_2 l_2^2)$

into equations for the

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vehicle displacement and pitching oscillations; the two equations are simplified to the two following expressions:

$$\ddot{x} + \frac{b}{m}x + \frac{d}{m}\Theta + \frac{e}{m}\dot{x} + \frac{f}{m}\dot{\Theta} =$$
$$\frac{1}{m}\left[-k_1 x_1 - c_1 \dot{x}_1 - k_2 x_2 - c_2 \dot{x}_2\right]$$

$$\ddot{\Theta} + \frac{d}{I}x + \frac{h}{I}\Theta + \frac{f}{I}\dot{x} + \frac{j}{I}\dot{\Theta} =$$
$$\frac{1}{I}\left[-k_1 l_1 x_1 - c_1 l_1 \dot{x}_1 + k_2 l_2 x_2 + c_2 l_2 \dot{x}_2\right]$$

When a sine-displacement function is considered with amplitude "A" at some displacement $x_{1,2}$ and a cycle length of "L", the equations which were origionally written to describe the vehicle motion can be re-written as follows:

$$X_1 = \frac{A}{2}\left[\sin \omega t + \sin(\omega t - \alpha_1)\right]$$

$$= \frac{A}{2}\left[\sin \frac{2\pi v}{L} t + \sin\left(\frac{2\pi v}{L} t - \frac{a}{L} 2\pi\right]\right.$$

$$X_2 = \frac{A}{2}\left[\sin(\omega t - \phi) + \sin(\omega t - \phi - \alpha_2)\right]$$

$$= \frac{A}{2}\left[\sin\left(\frac{2\pi v}{L} t - \frac{l_1 + l_2}{L} 2\pi\right) + \sin\left(\frac{2\pi v}{L} t - \frac{l_1 + l_2 + a}{L} 2\pi\right)\right]$$

$$\ddot{x} + \frac{b}{m} x + \frac{d}{m}\Theta + \frac{e}{m}\dot{x} + \frac{f}{m}\dot{\Theta} =$$

$$\frac{1}{m}\left[-k_1 \frac{A}{2}\left\{\sin \omega t + \sin(\omega t - \alpha_1)\right\} - c_1 \frac{A}{2}\omega\left\{\cos \omega t + \cos(\omega t - \alpha_1)\right\} - k_2 \frac{A}{2}\left\{\sin(\omega t + \phi) + \sin(\omega t - \phi - \alpha_2)\right\} - c_2 \frac{A}{2}\omega\left\{\cos(\omega t - \phi) + \cos(\omega t - \phi - \alpha_2)\right\}\right]$$

The second differential equation can be written as follows:

$$\ddot{\Theta} + \frac{d}{I} x + \frac{h}{I}\Theta + \frac{f}{I}\dot{x} + \frac{j}{I}\dot{\Theta} = \frac{1}{I}\left[-k_1 l_1 \frac{A}{2}\left\{\sin \omega t + \sin(\omega t - \alpha_1)\right\} - c_1 l_1 \frac{A}{2}\omega\left\{\cos \omega t + \cos(\omega t - \alpha_1)\right\} + k_2 l_2 \frac{A}{2}\left\{\sin(\omega t - \phi) + \sin(\omega t - \phi - \alpha_2)\right\} + c_2 l_2 \frac{A}{2}\omega\left\{\cos(\omega t - \phi) + \cos(\omega t - \phi - \alpha_2)\right\}\right]$$

Simplifying the right-hand side of the two differential equations will yield:

$$-\frac{k_1 A}{2}\left(\sin\omega t + \sin\omega t\cos\alpha_1 - \cos\omega t\sin\alpha_1\right)$$

$$-\frac{c_1 A\omega}{2}\left(\cos\omega t + \cos\omega t\cos\alpha_1 + \sin\omega t\sin\alpha_1\right)$$

$$-\frac{k_2 A}{2}\Big[\sin\omega t\cos\phi - \cos\omega t\sin\phi + \sin\omega t\cos(\phi+\alpha_2) - \cos\omega t\sin(\phi+\alpha_2)\Big]$$

$$-\frac{c_2 A\omega}{2}\Big[\cos\omega t\cos\phi + \sin\omega t\sin\phi + \cos\omega t\cos(\phi+\alpha_2) + \sin\omega t\sin(\phi+\alpha_2)\Big] =$$

$$\Bigg\{\Big[-\frac{k_1 A}{2} - \frac{k_1 A}{2}\cos\alpha_1 - \frac{c_1 A\omega}{2}\sin\alpha_1 - \frac{k_2 A}{2}\cos\phi - \frac{k_2 A}{2}\cos(\phi+\alpha_2) - \frac{c_2 A\omega}{2}\sin\phi - \frac{c_2 A\omega}{2}\sin(\phi+\alpha_2)\Big]\sin\omega t$$

$$+\Big[\frac{k_1 A}{2}\sin\alpha_1 - \frac{c_1 A\omega}{2} - \frac{c_1 A\omega}{2}\cos\alpha_1 + \frac{k_2 A}{2}\sin\phi + \frac{k_2 A}{2}\sin(\phi+\alpha_2) - \frac{c_2 A\omega}{2}\cos\phi - \frac{c_2 A\omega}{2}\cos(\phi+\alpha_2)\Big]\Bigg\}\cos\omega t$$

This equation can be re-written in the following form:

$$\Bigg\{\Big[-\frac{k_1 A}{2}(1+\cos\alpha_1) - \frac{c_1 A\omega}{2}\sin\alpha_1 - \frac{k_2 A}{2}\big(\cos\phi + \cos(\phi+\alpha_2)\big) - \frac{c_2 A\omega}{2}\big(\sin\phi + \sin(\phi+\alpha_2)\big)\Big]\sin\omega t + \Big[\frac{k_1 A}{2}\sin\alpha_1 - \frac{c_1 A\omega}{2}(1+\cos\alpha_1) + \frac{k_2 A}{2}\big(\sin\phi + \sin(\phi+\alpha_2)\big) - \frac{c_2 A\omega}{2}\big(\cos\phi + \cos(\phi+\alpha_2)\big)\Big]\cos\omega t\Bigg\}$$

$$= \Psi_1\sin\omega t + \Psi_2\cos\omega t$$

The right hand side of the second equation can likewise be re-written in the following form:

$$\Big[-\frac{k_1 \ell_1 A}{2}\left(\sin\omega t + \sin\omega t\cos\alpha_1 - \cos\omega t\sin\alpha_1\right) - \frac{c_1 \ell_1 A\omega}{2}\left(\cos\omega t + \cos\omega t\cos\alpha_1 + \sin\omega t\sin\alpha_1\right) +$$

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Right hand side of the second eq. Cont'd.

$$\frac{k_2 \ell_2 A}{2}\left(\sin\omega t \cos\phi - \cos\omega t \sin\phi + \sin\omega t \cos(\phi+\alpha_2)\right) +$$

$$\frac{c_2 \ell_2 A \omega}{2}\left(\cos\omega t \cos\phi + \sin\omega t \sin\phi + \cos\omega t \cos(\phi+\alpha_2) + \sin\omega t \sin(\phi+\alpha_2)\right)\Big]$$

This can be re-written in the following form:

$$\left[-\frac{k_1 \ell_1 A}{2}(1+\cos\alpha_1) - \frac{c_1 \ell_1 A \omega}{2}\sin\alpha_1 + \frac{k_2 \ell_2 A}{2}\left(\cos\phi + \cos(\phi+\alpha_2)\right) + \frac{c_2 \ell_2 A \omega}{2}\left(\sin\phi + \sin(\phi+\alpha_2)\right)\right]\sin\omega t +$$

$$\left[\frac{k_1 \ell_1 A}{2}\sin\alpha_1 - \frac{c_1 \ell_1 A \omega}{2}(1+\cos\alpha_1) - \frac{k_2 \ell_2 A}{2}\left(\sin\phi + \sin(\phi+\alpha_2)\right) + \frac{c_2 \ell_2 A \omega}{2}\left(\cos\phi + \cos(\phi+\alpha_2)\right)\right]\cos\omega t$$

$$= \psi_3 \sin\omega t + \psi_4 \cos\omega t$$

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Rectilinear vertical motion of the vehicle when coupled with vehicle pitching can be described by the following general differential equations:

Eq.-1:

$$\ddot{X} + \frac{e}{m}\dot{X} + \frac{b}{m}X + \frac{f}{m}\dot{\Theta} + \frac{d}{m} = \frac{1}{m}\left[\psi_1 \sin\omega t + \psi_2 \cos\omega t\right]$$

Eq.-2:

$$\ddot{\Theta} + \frac{j}{I}\dot{\Theta} + \frac{h}{I}\Theta + \frac{f}{I}\dot{X} + \frac{d}{I}X = \frac{1}{I}\left[\psi_3 \sin\omega t + \psi_4 \cos\omega t\right]$$

The coefficients for these general equations are specifically defined for a vehicle with 4 walking-beams & 8 road-wheels.

APPENDIX A

CORRELATION OF SIMULATED DATA (Continued)

Description of the 12 Wheel 6 Walking Beam Suspension

The weight of the vehicle is supported by twelve road wheels, six on each side, which are attached to the hull through walking beams, road arms, and torsion bars; the torsion bars have the effect of springs. The upward displacement of the front and rear walking beam is limited by a "bump stop". This "bump stop" provides a solid stop for the road arm and prevents further rotation. Shock absorbers are attached to the front and rear arms and are used to damp out motion of the hull. The road wheels on each side of the vehicle ride on an endless track, which completes its cycle by passing over the drive sprocket at the rear of the vehicle, three support rollers along the side of the hull, and an adjusting idler wheel at the front of the vehicle. The drive sprocket provides the means for applying power from the engine to produce vehicle motion.

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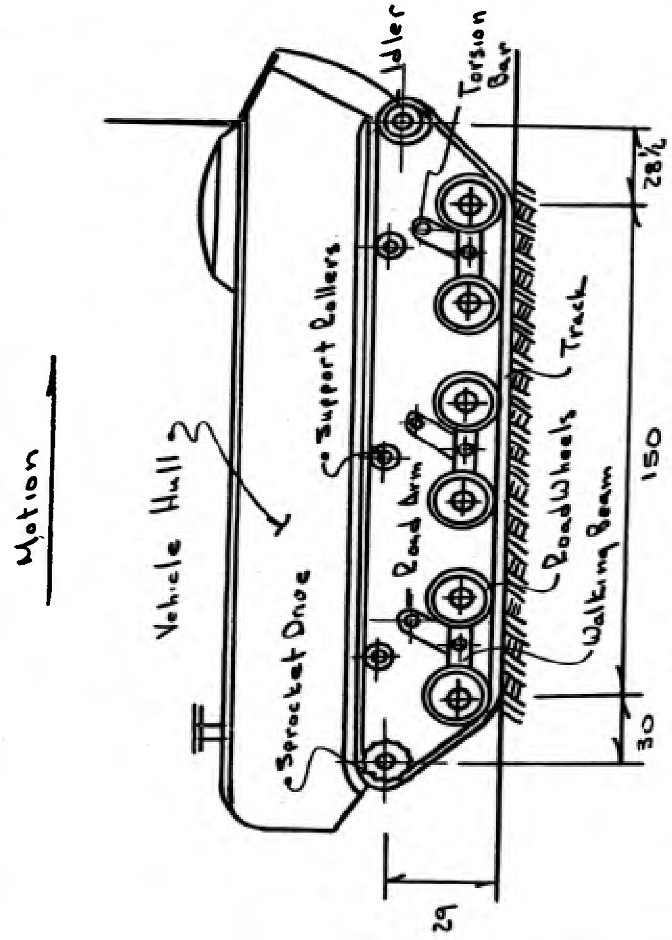

Suspension Features
of the
LVT with 12 Road Wheels
Mounted on 6 Walking Beams

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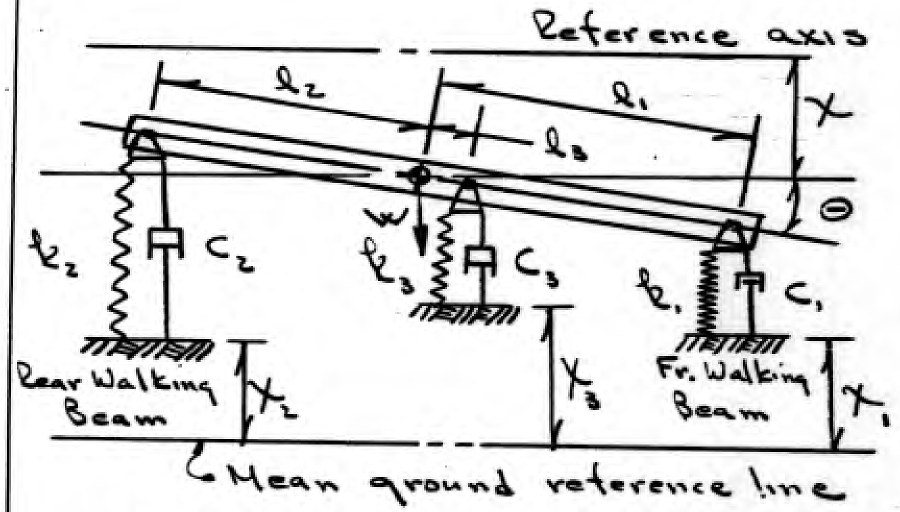
Application of the basic concepts of rigid body mechanics will allow the following idealized system to be formulated.



where $C_3 = 0$; there is no shock absorber attached to the center walking beam arm.

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Differential equations which describe the motion of the vehicle while supported on 12 road wheels & 6 walking beams.

Differential Equation - 1:

$$\frac{W}{g}\ddot{X} = -k(X+l_1\theta+X_1) - c_1(\dot{X}+l_1\dot{\theta}+\dot{X}_1) -$$

$$k_2(X-l_2\theta+X_2) - c_2(\dot{X}-l_2\dot{\theta}+\dot{X}_2) -$$

$$k_3(X+l_3\theta+X_3) - C_3(\dot{X}+l_3\dot{\theta}+\dot{X}_3)$$

Differential Equation - 2:

$$I\ddot{\theta} = l_2\left[k_2(X-l_2\theta+X_2)+c_2(\dot{X}-l_2\dot{\theta}+\dot{X}_2)\right] -$$

$$l_1\left[k_1(X+l_1\theta+X_1)+c_1(\dot{X}+l_1\dot{\theta}+\dot{X}_1)\right] -$$

$$l_3\left[k_3(X+l_3\theta+X_3)+c_3(\dot{X}+l_3\dot{\theta}+\dot{X}_3)\right]$$

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These two general differential equations can be rewritten and expanded as follows:

Differential Equation - 1:

$$m\ddot{x} + (c_1+c_2+c_3)\dot{X} + (k_1+k_2+k_3)X +$$

$$(c_1l_1 - c_2l_2 + c_3l_3)\dot{\theta} + (k_1l_1 - k_2l_2 + k_3l_3)\theta$$

$$= -k_1X_1 - c_1\dot{X}_1 - k_2X_2 - c_2\dot{X}_2 - k_3X_3 - C_3\dot{X}_3$$

Differential Equation - 2:

$$I\ddot{\theta} + (c_2l_2^2 + c_1l_1^2 + c_3l_3^2)\dot{\theta} + (k_2l_2^2 + k_1l_1^2 + k_3l_3^2)\theta +$$

$$(-c_2l_2 + c_1l_1 + c_3l_3)\dot{X} + (-k_2l_2 + k_1l_1 + k_3l_3)X =$$

$$k_2l_2X_2 + c_2l_2\dot{X}_2 - k_1l_1X_1 - c_1l_1\dot{X}_1 -$$

$$k_3l_3X_3 - c_3l_3\dot{X}_3$$

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Subsitute

$e = c_1 + c_2 + c_3$
$b = k_1 + k_2 + k_3$
$f = c_1 l_1 - c_2 l_2 + c_3 l_3$
$d = k_1 l_1 - k_2 l_2 + k_3 l_3$
$j = c_1 l_1^2 + c_2 l_2^2 + c_3 l_3^2$
$h = k_1 l_1^2 + k_2 l_2^2 + k_3 l_3^2$

into the equations which describe vehicle desplacement and pitching oscillations; the equations when simplified will yield the following :

Equation - 1 :

$$m\ddot{x} + e\dot{x} + bx + f\dot{\theta} + d\theta = -k_1 x_1 - c_1\dot{x}_1 - k_2 x_2 - c_2\dot{x}_2 - k_3 x_3 - c_3\dot{x}_3$$

Equation - 2 :

$$I\ddot{\theta} + j\dot{\theta} + h\theta + f\dot{x} + dx = -k_1 l_1 x_1 - c_1 l_1 \dot{x}_1 + k_2 l_2 x_2 + c_2 l_2 \dot{x}_2 - k_3 l_3 x_3 - C_3 l_3 \dot{x}_3$$

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When a sine-displacement function is considered the two equations can be written as:

where :

$$x_1 = \frac{A}{2}\left[\sin \omega t + \sin(\omega t - \alpha_1)\right]$$

$$x_2 = \frac{A}{2}\left[\sin(\omega t - \phi_1) + \sin(\omega t - \phi_1 - \alpha_2)\right]$$

$$x_3 = \frac{A}{2}\left[\sin(\omega t - \phi_2) + \sin(\omega t - \phi_2 - \alpha_3)\right]$$

and :

$$\omega = \frac{2\pi}{L} v \quad , \quad \alpha_1 = \alpha_2 = \alpha_3 = \frac{2\pi}{L} a$$

$$\phi_1 = 2\pi \frac{l_1 + l_2}{L} \quad , \quad \phi_2 = 2\pi \frac{l_1 - l_3}{L}$$

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Note that the derivatives for x_1, x_2 & x_3 are:

$$\dot{x}_1 = \frac{A}{2}\omega\left[\cos\omega t + \cos(\omega t - \alpha_1)\right]$$

$$\dot{x}_2 = \frac{A}{2}\omega\left[\cos(\omega t - \phi_1) + \cos(\omega t - \phi_1 - \alpha_2)\right]$$

$$\dot{x}_3 = \frac{A}{2}\omega\left[\cos(\omega t - \phi_2) + \cos(\omega t - \phi_2 - \alpha_3)\right]$$

Equation - 1 becomes:

$$m\ddot{x} + e\dot{x} + bx + f\dot{\theta} + d\theta = \frac{k_1A}{2}\left[\sin\omega t + \right.$$

$$\left.\sin(\omega t - \alpha_1)\right] - \frac{c_1A}{2}\omega\left[\cos\omega t + \cos(\omega t - \alpha_1)\right] -$$

$$\frac{k_2A}{2}\left[\sin(\omega t - \phi_1) + \sin(\omega t - \phi - \alpha_2)\right] -$$

$$\frac{c_2A}{2}\omega\left[\cos(\omega t - \phi_1) + \cos(\omega t - \phi_1 - \alpha_2)\right] -$$

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Equation - 1 Cont'd:

$$-\frac{k_3A}{2}\left[\sin(\omega t - \phi_2) + \sin(\omega t - \phi_2 - \alpha_3)\right] -$$

$$\frac{c_3A}{2}\omega\left[\cos(\omega t - \phi_2) + \cos(\omega t - \phi_2 - \alpha_3)\right]$$

Equation - 2 becomes:

$$I\ddot{\theta} + j\dot{\theta} + h\theta + f\dot{x} + dx = -\frac{k_1\ell_1A}{2}\left[\sin\omega t + \right.$$

$$\left.\sin(\omega t - \alpha_1)\right] - \frac{c_1\ell_1A}{2}\omega\left[\cos\omega t + \cos(\omega t - \alpha_1)\right] +$$

$$\frac{k_2\ell_2A}{2}\left[\sin(\omega t - \phi_1) + \sin(\omega t - \phi_1 - \alpha_2)\right] +$$

$$\frac{c_2\ell_2A}{2}\omega\left[\cos(\omega t - \phi_1) + \cos(\omega t - \phi_1 - \alpha_2)\right] -$$

$$\frac{k_3\ell_3A}{2}\left[\sin(\omega t - \phi_2) + \sin(\omega t - \phi_2 - \alpha_3)\right] -$$

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Equation - 2 (cont'd.):

$$-\frac{c_3 l_3 A}{2}\omega\left[\cos(\omega t-\phi_2)+\cos(\omega t-\phi_2-\alpha_3)\right]$$

These equations can be further simplified - Right hand side of equation - 1 :

$$-\frac{k_1 A}{2}\left[\sin\omega t+\sin\omega t\cos\alpha_1-\cos\omega t\sin\alpha_1\right]-$$

$$\frac{c_1 A}{2}\omega\left[\cos\omega t+\cos\omega t\cos\alpha_1+\sin\omega t\sin\alpha_1\right]-$$

$$\frac{k_2 A}{2}\left[\sin\omega t\cos\phi_1-\cos\omega t\sin\phi_1+\sin\omega t\cos(\phi_1+\alpha_2)-\cos\omega t\sin(\phi+\alpha_2)\right]-$$

$$\frac{c_2 A}{2}\omega\left[\cos\omega t\cos\phi_1+\sin\omega t\sin\phi_1+\cos\omega t\cos(\phi_1+\alpha_2)+\sin\omega t+\sin(\phi_1+\alpha_2)\right]$$

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Equation - 1 (cont'd.):

$$-\frac{k_3 A}{2}\left[\sin\omega t\cos\phi_2-\cos\omega t\sin\phi_2+\sin\omega t\cos(\phi_2+\alpha_3)-\cos\omega t\sin(\phi_2+\alpha_3)\right]-$$

$$\frac{c_3 A}{2}\omega\left[\cos\omega t\cos\phi_2+\sin\omega t\sin\phi_2+\cos\omega t\cos(\phi_2+\alpha_3)+\sin\omega t\sin(\phi_2+\alpha_3)\right]=$$

$$\left[-\frac{k_1 A}{2}(1+\cos\alpha_1)-\frac{c_1 A}{2}\omega\sin\alpha_1-\frac{k_2 A}{2}\left\{\cos\phi_1+\cos(\phi_1+\alpha_2)\right\}-\right.$$

$$\frac{c_2 A}{2}\omega\left\{\sin\phi_1+\sin(\phi_1+\alpha_2)\right\}-\frac{k_3 A}{2}\left\{\cos\phi_2+\cos(\phi_2+\alpha_3)\right\}-$$

$$\left.\frac{c_3 A}{2}\omega\left\{\sin\phi_2+\sin(\phi_2+\alpha_3)\right\}\right]\sin\omega t+$$

$$\left[\frac{k_1 A}{2}\sin\alpha_1-\frac{c_1 A}{2}\omega(1+\cos\alpha_1)+\frac{k_2 A}{2}\left\{\sin\phi_1+\sin(\phi_1+\alpha_2)\right\}\right.$$

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Equation – 1. (cont'd.)

$$- \frac{c_2 A}{2}\omega\left\{\cos\phi + \cos(\phi_1+\alpha_2)\right\} + \frac{k_3 A}{2}\left\{\sin\phi_2 + \sin(\phi_2+\alpha_3)\right\}$$

$$- \frac{c_3 A}{2}\omega\left\{\cos\phi_2 + \cos(\phi_2+\alpha_3)\right\}\Big]\cos\omega t \quad =$$

$$\psi_1 \sin\omega t + \psi_2 \cos\omega t$$

Equation – 2; right side of the equation simplification

$$\frac{k_1 l_1 A}{2}\left[\sin\omega t + \sin\omega t\cos\omega t - \cos\omega t\sin\alpha_1\right] -$$

$$\frac{c_1 l_1 A}{2}\omega\left[\cos\omega t + \cos\omega t\cos\alpha_1 + \sin\omega t\sin\alpha_1\right] +$$

$$\frac{k_2 l_2 A}{2}\Big[\sin\omega t\cos\phi_1 - \cos\omega t\sin\phi_1 + \sin\omega t\cos(\phi_1+\alpha_2) -$$
$$\cos\omega t\sin(\phi_1+\alpha_2)\Big] \quad +$$

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$$\frac{c_2 l_2 A}{2}\omega\Big[\cos\omega t\cos\phi_1 + \sin\omega t\sin\phi_1 + \cos\omega t\cos(\phi+\alpha_2) +$$
$$\sin\omega t\sin(\phi+\alpha_2)\Big] -$$

$$\frac{k_3 l_3 A}{2}\Big[\sin\omega t\cos\phi_2 - \cos\omega t\sin\phi_2 + \sin\omega t\cos(\phi_2+\alpha_3) -$$
$$\cos\omega t\sin(\phi_2+\alpha_3)\Big] -$$

$$\frac{c_3 l_3 A}{2}\omega\Big[\cos\omega t\cos\phi_2 + \sin\omega t\sin\phi_2 + \cos\omega t\cos(\phi_2+\alpha_3) +$$
$$\sin\omega t\sin(\phi_2+\alpha_3)\Big] =$$

$$\Big[-\frac{k_1 l_1 A}{2}(1+\cos\alpha_1) - \frac{c_1 l_1 A\omega}{2}\sin\alpha_1 + \frac{k_2 l_2 A}{2}\Big\{$$
$$\cos\phi_1 + \cos(\phi_1+\alpha_2)\Big\} + \frac{c_2 l_2 A\omega}{2}\Big\{\sin\phi_1 +$$
$$\sin(\phi_1+\alpha_2)\Big\} - \frac{k_3 l_3 A}{2}\left\{\cos\phi_2 + \cos(\phi_2+\alpha_3)\right\} -$$
$$\frac{c_3 l_3 A\omega}{2}\left\{\sin\phi_2 + \sin(\phi_2+\alpha_3)\right\}\Big]\sin\omega t \; +$$

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Equation-2 (cont'd.)

$$\Big[\frac{k_1 l_1 A}{2}\sin\alpha_1 - \frac{c_1 l_1 A\omega}{2}(1+\cos\alpha_1) - \frac{k_2 l_2 A}{2}\Big\{$$

$$\sin\phi_1 + \sin(\phi_1+\alpha_2)\Big\} + \frac{c_2 l_2 A\omega}{2}\Big\{\cos\phi_1 +$$

$$\cos(\phi_1+\alpha_2)\Big\} + \frac{k_3 l_3 A}{2}\Big\{\sin\phi_2 + \sin(\phi_2+\alpha_3)\Big\} -$$

$$\frac{c_3 l_3 A\omega}{2}\Big\{\cos\phi_2 + \cos(\phi_2+\alpha_3)\Big\}\Big]\cos\omega t =$$

$$\underline{\underline{\Psi_3 \sin\omega t + \Psi_4 \cos\omega t}}$$

CORRELATION OF SIMULATED DATA (Continued)

Description of the 12 Wheel each Individually Sprung Suspension

Twelve road wheels support the weight of the vehicle, six on each side, which are attached to the hull through road arms and torsion bars; the torsion bars have the effect of springs. The upward displacement of the twelve road arms is limited by a "bump stop". This "bump stop" provides a solid stop for the road arm and prevents further rotation. Shock absorbers are attached to the front and rear arms and are used to damp out motion of the hull. The road wheels on each side of the vehicle ride on an endless track, which completes its cycle by passing over the drive sprocket at the rear of the vehicle, three support rollers along the side of the hull, and an adjusting idler wheel at the front of the vehicle. The drive sprocket provides the means for applying power from the engine to produce vehicle motion.

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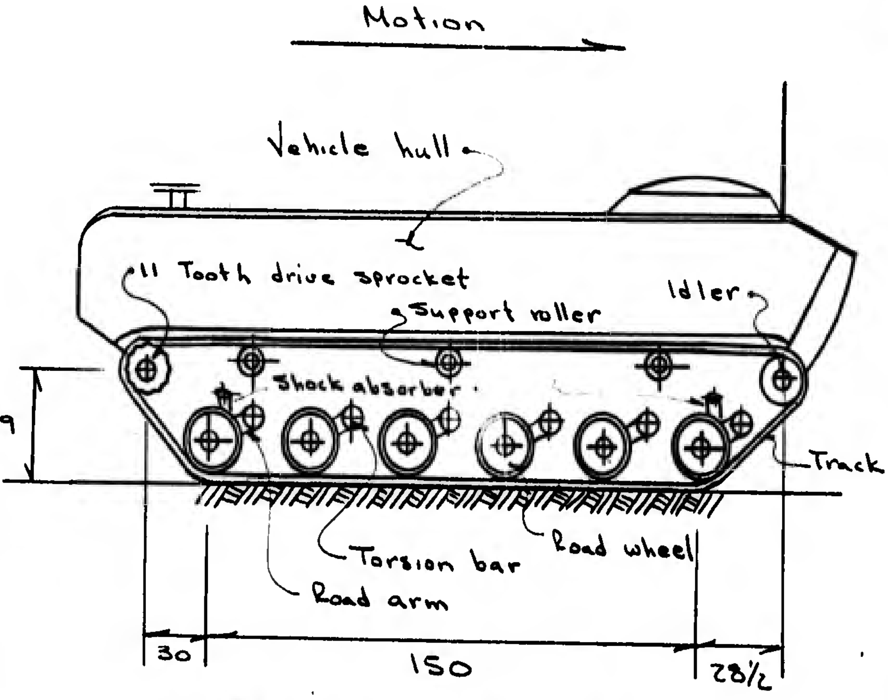

Suspension Features
of the
LVT with 12 Road Wheels Individually Sprung

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Load and stress analysis of: LVT Suspension

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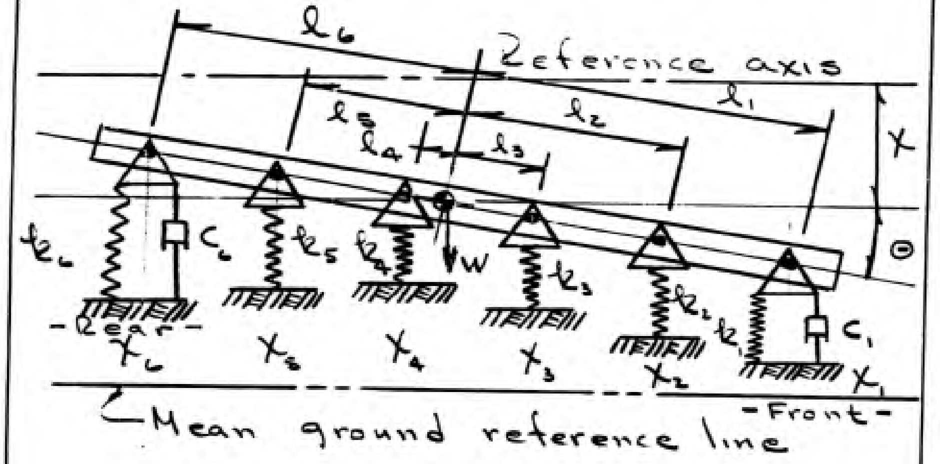
Application of the basic concepts of rigid body mechanics will allow the following idealized system to be formulated.



C_2, C_3, C_4, C_5 are all zero ∴ there are no shock absorbers attached to these 4 arms.

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Differential equations which describe the motion of the vehicle while supported on 12 road wheels each sprung by torsion bars.

Differential Equation - 1:

$$\frac{W}{g}\ddot{X} = -k(X+l_1\theta+X_1) - C_1(\dot{X}+l_1\dot{\theta}+\dot{X}_1) - k_2(X+l_2\theta+X_2) - k_3(X+l_3\theta+X_3) - k_4(X-l_4\theta+X_4) - k_5(X-l_5\theta+X_5) - k_6(X-l_6\theta+X_6) - C_6(\dot{X}-l_6\dot{\theta}+\dot{X}_6)$$

Differential Equation - 2:

$$I\ddot{\theta} = -l_1\left[k_1(X+l_1\theta+X_1)+C_1(\dot{X}+l_1\dot{\theta}+\dot{X}_1)\right] - l_2k_2(X+l_2\theta+X_2) - l_3k_3(X+l_3\theta+X_3) + l_4k_4(X-l_4\theta+X_4) + l_3k_5(X-l_5\theta+X_5) + l_6k_6(X-l_6\theta+X_6) + l_6C_6(\dot{X}-l_6\dot{\theta}+\dot{X}_6)$$

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These two general differential equations can be rewritten and expanded as follows:

Equation - 1:

$$m\ddot{x} + (c_1 + c_6)\dot{x} + (k_1 + k_2 + k_3 + k_4 + k_5 + k_6)x + (c_1 l_1 - c_6 l_6)\dot{\theta} + (k_1 l_1 + k_2 l_2 + k_3 l_3 - k_4 l_4 - k_5 l_5 - k_6 l_6)\theta = -k_1 x_1 - c_1 \dot{x}_1 - k_2 x_2 - k_3 x_3 - k_4 x_4 - k_5 x_5 - k_6 x_6 - c_6 \dot{x}_6$$

Equation - 2:

$$I\ddot{\theta} + (c_1 l_1^2 + c_6 l_6^2) + (k_1 l_1^2 + k_2 l_2^2 + k_3 l_3^2 + k_4 l_4^2 + k_5 l_5^2 + k_6 l_6^2)\theta + (k_1 l_1 + k_2 l_2 + k_3 l_3 - k_4 l_4 - k_5 l_5 - k_6 l_6)x + (c_1 l_1 - c_6 l_6)\dot{x} = -k_1 l_1 x_1 - c_1 l_1 \dot{x}_1 - k_2 l_2 x_2 - k_3 l_3 x_3 + k_4 l_4 x_4 + k_5 l_5 x_5 + k_6 l_6 x_6 + c_6 l_6 \dot{x}_6$$

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Subsitute

$e = c_1 + c_6$

$b = k_1 + k_2 + k_3 + k_4 + k_5 + k_6$

$f = c_1 l_1 - c_6 l_6$

$d = k_1 l_1 + k_2 l_2 + k_3 l_3 - k_4 l_4 - k_5 l_5 - k_6 l_6$

$j = c_1 l_1^2 + c_6 l_6^2$

$h = k_1 l_1^2 + k_2 l_2^2 + k_3 l_3^2 + k_4 l_4^2 + k_5 l_5^2 + k_6 l_6^2$

into the two differential equations.

Resulting equation - 1:

$$m\ddot{x} + e\dot{x} + bx + f\dot{\theta} + d\theta = -k_1 x_1 - c_1 \dot{x}_1 - k_2 x_2 - k_3 x_3 - k_4 x_4 - k_5 x_5 - k_6 x_6 - c_6 \dot{x}_6$$

Resulting equation - 2:

$$I\ddot{\theta} + j\dot{\theta} + h\theta + f\dot{x} + dx = -k_1 l_1 x_1 - c_1 l_1 \dot{x}_1 - k_2 l_2 x_2 - k_3 l_3 x_3 + k_4 l_4 x_4 + k_5 l_5 x_5 + k_6 l_6 x_6 + c_6 l_6 \dot{x}_6$$

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When a sine-displacement function is considered the two equations can be written as:

where :

$X_1 = A \sin \omega t$, $X_4 = A \sin(\omega t - \alpha_3)$

$X_2 = A \sin(\omega t - \alpha_1)$, $X_5 = A \sin(\omega t - \alpha_4)$

$X_3 = A \sin(\omega t - \alpha_2)$, $X_6 = A \sin(\omega t - \alpha_5)$

and :

$\omega = \frac{2\pi}{L} v$, $\alpha_3 = \frac{2\pi}{L}(3a)$

$\alpha_1 = \frac{2\pi}{L} a$, $\alpha_4 = \frac{2\pi}{L}(4a)$

$\alpha_2 = \frac{2\pi}{L}(2a)$, $\alpha_5 = \frac{2\pi}{L}(5a)$

and :

$\dot{X}_1 = A\omega \cos \omega t$, $\dot{X}_4 = A\omega \cos(\omega t - \alpha_3)$

$\dot{X}_2 = A\omega \cos(\omega t - \alpha_1)$, $\dot{X}_5 = A\omega \cos(\omega t - \alpha_4)$

$\dot{X}_3 = A\omega \cos(\omega t - \alpha_2)$, $\dot{X}_6 = A\omega \cos(\omega t - \alpha_5)$

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Equation -1 becomes:

$$m\ddot{X} + e\dot{X} + bX + f\dot{\theta} + d\theta = -k_1 A \sin \omega t - c_1 A\omega \cos \omega t - k_2 A \sin(\omega t - \alpha_1) - k_3 A \sin(\omega t - \alpha_2) - k_4 A \sin(\omega t - \alpha_3) - k_5 A \sin(\omega t - \alpha_4) - k_6 A \sin(\omega t - \alpha_5) - c_6 A\omega \cos(\omega t - \alpha_5)$$

Equation -2 becomes:

$$I\ddot{\theta} + j\dot{\theta} + h\theta + f\dot{X} + dX = -k_1 l_1 A \sin \omega t - c_1 l_1 A\omega \cos \omega t - k_2 l_2 A \sin(\omega t - \alpha_1) - k_3 l_3 A \sin(\omega t - \alpha_2) + k_4 l_4 A \sin(\omega t - \alpha_3) + k_5 l_5 A \sin(\omega t - \alpha_4) + k_6 l_6 A \sin(\omega t - \alpha_5) + c_6 l_6 A\omega \cos(\omega t - \alpha_5)$$

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Equation - 1 :

Simplifying the right hand side of the equation :

$$-k_1 A\sin\omega t - C_1 A\omega\cos\omega t - k_2 A(\sin\omega t\cos\alpha_1 - \cos\omega t\sin\alpha_1) - k_3 A(\sin\omega t\cos\alpha_2 - \cos\omega t\sin\alpha_2) - k_4 A(\sin\omega t\cos\alpha_3 - \cos\omega t\sin\alpha_3) - k_5 A(\sin\omega t\cos\alpha_4 - \cos\omega t\sin\alpha_4) - k_6 A(\sin\omega t\cos\alpha_5 - \cos\omega t\sin\alpha_5) - C_6 A\omega(\cos\omega t\cos\alpha_5 + \sin\omega t\sin\alpha_5) =$$

$$A\left[-k_1 - k_2\cos\alpha_1 - k_3\cos\alpha_2 - k_4\cos\alpha_3 - k_5\cos\alpha_4 - k_6\cos\alpha_5 - C_6\omega\sin\alpha_5\right]\sin\omega t + A\left[-C_1\omega + k_2\sin\alpha_1 + k_3\sin\alpha_2 + k_4\sin\alpha_3 + k_5\sin\alpha_4 + k_6\sin\alpha_5 - C_6\omega\cos\alpha_5\right]\cos\omega t =$$

$$\underline{\psi_1\sin\omega t + \psi_2\cos\omega t}$$

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Equation - 2 :

Simplifying the right hand side of the equation :

$$-k_1 l_1 A\sin\omega t - C_1 l_1 A\omega\cos\omega t - k_2 l_2 A(\sin\omega t\cos\alpha_1 - \cos\omega t\sin\alpha_1) - k_3 l_3 A(\sin\omega t\cos\alpha_2 - \cos\omega t\sin\alpha_2) + k_4 l_4 A(\sin\omega t\cos\alpha_3 - \cos\omega t\sin\alpha_3) + k_5 l_5 A(\sin\omega t\cos\alpha_4 - \cos\omega t\sin\alpha_4) + k_6 l_6 A(\sin\omega t\cos\alpha_5 - \cos\omega t\sin\alpha_5) + C_6 l_6 A\omega(\cos\omega t\cos\alpha_5 + \sin\omega t\sin\alpha_5)$$

$$= A\left[-k_1 l_1 - k_2 l_2\cos\alpha_1 - k_3 l_3\cos\alpha_2 + k_4 l_4\cos\alpha_3 + k_5 l_5\cos\alpha_4 + k_6 l_6\cos\alpha_5 + C_6 l_6\omega\sin\alpha_5\right]\sin\omega t + A\left[C_1 l_1\omega + k_2 l_2\sin\alpha_1 + k_3 l_3\sin\alpha_2 - k_4 l_4\sin\alpha_3 - k_5 l_5\sin\alpha_4 - k_6 l_6\sin\alpha_5 + C_6 l_6\omega\cos\alpha_5\right]\cos\omega t$$

$$= \underline{\underline{\psi_3\sin\omega t + \psi_4\cos\omega t}}$$

CORRELATION OF SIMULATED DATA (Continued)

Vehicle Forcing Functions

The general differential equations as written for each of the three basic vehicle configurations describe the motion of the vehicle as it travels over a sine wave course with an amplitude A at some horizontal displacement $X_{1, 2}$ and a total period of L.

These general equations will be solved using two specific sine wave forcing functions. The two sine wave cross-sectioned road beds, which will be used, are known as the Munson Washboard courses of the Automotive Division, D & PS located at the Aberdeen Proving Ground, Maryland. One washboard course has a period of 6 feet with a mean line amplitude of 3 inches. The second washboard course has a period of 4 feet with an amplitude of 2 inches when measured from the mean line of the sine wave.

Both road beds are made of reinforced concrete which is 12 inches thick. The two test courses used in this study are shown on the following two pages of this study.

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Prepared by L. Gerard Date 18 Sept 61 Page No. 35
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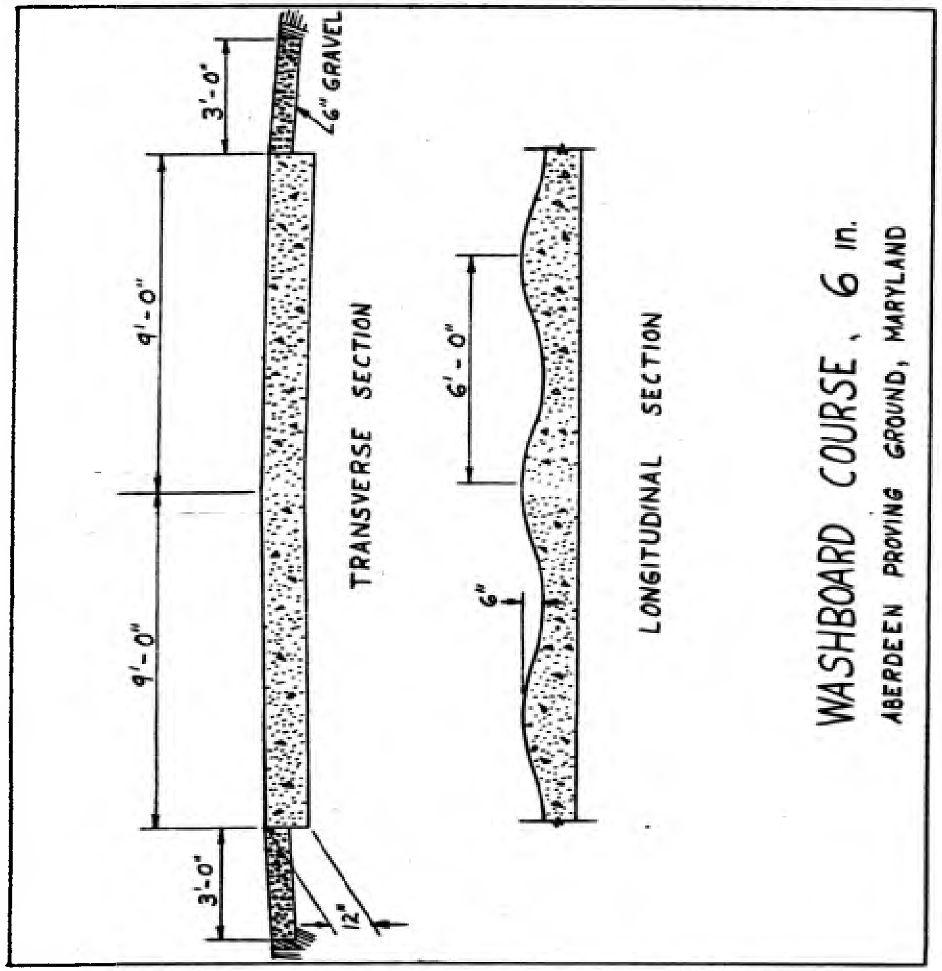

WASHBOARD COURSE, 6 in.
ABERDEEN PROVING GROUND, MARYLAND

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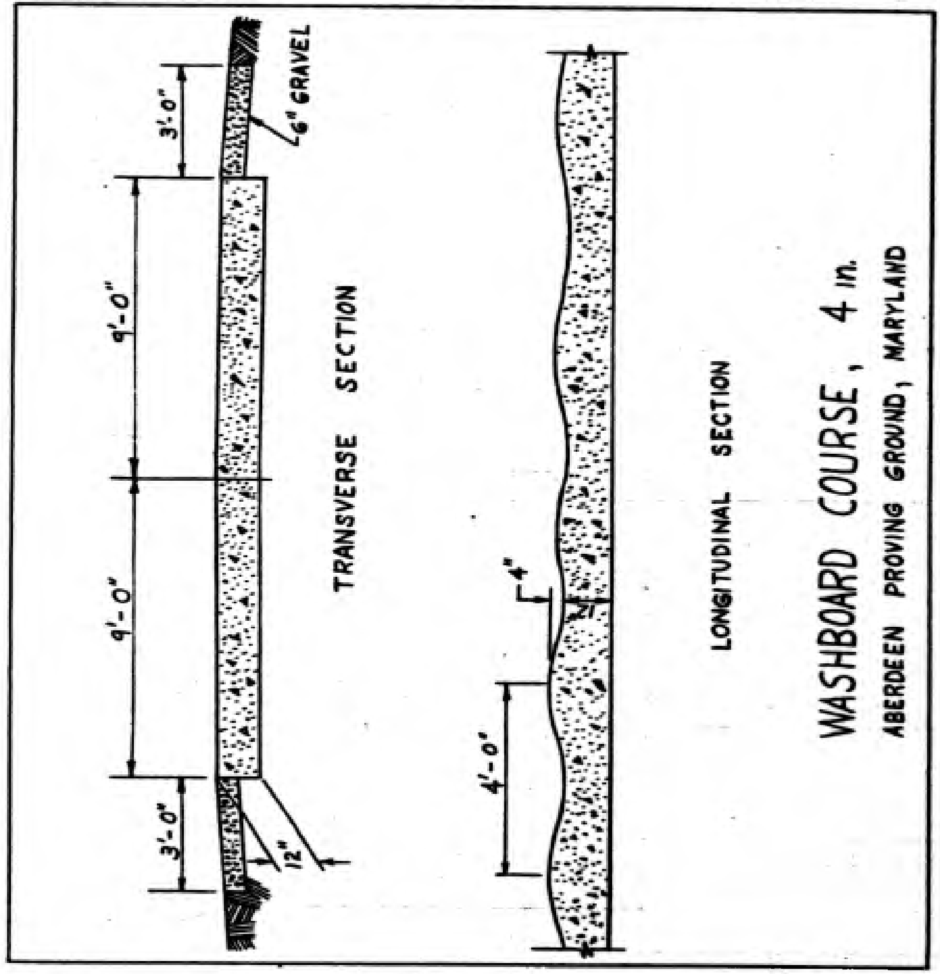

WASHBOARD COURSE, 4 in.
ABERDEEN PROVING GROUND, MARYLAND

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CORRELATION OF SIMULATED DATA (Continued)

Vehicle Constants

Computer input consists of the following vehicle constants:

- Suspension geometry
- Spring rates
- Shock absorber rates
- Maximum vehicle speed which is 20 mph
- Resonant vehicle speed which depends upon the course and suspension
- Vehicle mass
- Vehicle mass moment of inertia

The vehicle suspension is analyzed for two forcing functions which are the two washboard courses at the Aberdeen Proving Grounds.

All constants for the two coupled differential equations which define the motion of the vehicle while supported by four walking beams and eight road wheels are included in tabular form in this section.

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Load and stress analysis of: LVT Suspension

Prepared by W. BLYTHE Date 31 July '61 Page No. 37

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VEHICLE A: (4-walking beam, 8-road wheels)

SPRUNG WT. $\times \frac{1}{2}$ = $W = 32{,}000 \times \frac{1}{2} = 16{,}000$ lbs.

INERTIA ABOUT C.G. $\times \frac{1}{2}$ = $I = 0.284 \times 10^5 \times \frac{1}{2} = 0.142 \times 10^5$ ft. lb. sec²

$\ell_1 = 4.05$ ft.

$\ell_2 = 3.88$ ft

$a = 3.75$ ft

$m = \frac{W}{g} = \frac{16{,}000}{32.2} = 497$ lb. sec²/ft

$\ell_1 - \ell_2 = 4.05 - 3.88 = 0.17$ ft

$\ell_1^2 + \ell_2^2 = 16.4 + 15.1 = 31.5$ ft²

$(\ell_1 + \ell_2)2\pi = (7.93)2\pi = 49.7$ ft.

$(a)2\pi = (3.75)2\pi = 23.5$ ft.

SPRING RATES

1.) $\frac{2(32{,}000)}{0.5}$ $\frac{\text{lbs}}{\text{ft}}$ = $4k = 128{,}000$

$k = 32{,}000$ lb/ft.

2.) $k = 32{,}000 \, \frac{1}{2} = 16{,}000$ lb/ft

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Load and stress analysis of: LVT Suspension

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Determination of Resonant Velocity

The velocity at which the suspension system will exhibit resonance is easily obtained by considering the equations without damping:

$$(b - m\omega^2)B + dD = 0$$

$$dB + (h - I\omega^2)D = 0$$

The frequency equation is:

$$(b - m\omega^2)(h - I\omega^2) - d^2 = 0$$

$$\left(\frac{b}{m} - \omega^2\right)\left(\frac{h}{I} - \omega^2\right) - \frac{d^2}{mI} = 0$$

$$\omega^4 - \left(\frac{h}{I} + \frac{b}{m}\right)\omega^2 + \frac{bh}{mI} - \frac{d^2}{mI} = 0$$

Then

$$\omega^2 = \left[\left(\frac{h}{I} + \frac{b}{m}\right) \pm \sqrt{\frac{h^2}{I^2} + \frac{2hb}{mI} + \frac{b^2}{m^2} - \frac{4bh}{mI} + \frac{4d^2}{mI}}\right]\frac{1}{2}$$

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$$\omega^2 = \frac{1}{2}\left[\left(\frac{h}{I} + \frac{b}{m}\right) \pm \sqrt{\left(\frac{h}{I} - \frac{b}{m}\right)^2 + \frac{4d^2}{mI}}\right]$$

or

$$\omega^2 = \frac{1}{2}\left[\frac{K(l_1^2+l_2^2)}{I} + \frac{2K}{m} \pm \left\{\left(\frac{K(l_1^2+l_2^2)}{I} - \frac{2K}{m}\right)^2 + \frac{4K^2(l_1-l_2)^2}{mI}\right\}^{1/2}\right] = \frac{K}{2}\left[\frac{l_1^2+l_2^2}{I} + \frac{2}{m} \pm \left\{\left(\frac{l_1^2+l_2^2}{I} - \frac{2}{m}\right)^2 - \frac{4(l_1-l_2)^2}{mI}\right\}^{1/2}\right]$$

using $K_1 = 32{,}000$

$$\omega^2 = \frac{32{,}000}{2}\left[\frac{31.5}{(1.42)10^4} + \frac{2}{(.497)10^3} \pm \left\{\left(\frac{31.5}{(1.42)10^4} - \frac{2}{(.497)10^3}\right)^2 + \frac{4(0.17)^2}{(.497)10^3(1.42)10^4}\right\}^{1/2}\right] = 16{,}000\left[(22.2)10^{-4} + (4.03)10^{-3} \pm \left\{\left((22.2)10^{-4} - (4.03)10^{-3}\right)^2 + \frac{(11.5)10^{-2}}{(.705)10^7}\right\}^{1/2}\right]$$

$$\omega^2 = 16{,}000\left[(6.25)10^{-3} \pm \left\{(1.81)^2 10^{-6} + (16.4)10^{-9}\right\}^{1/2}\right]$$

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$$\omega^2 = 16{,}000\left[(6.25)10^{-3} \pm (3.27 + 0.0164)^{1/2}10^{-3}\right]$$

$$= (1.6)10^4\left[6.25 \pm 1.81\right]10^{-3}$$

$$= (16)(6.25 \pm 1.81)$$

$$\omega_1^2 = 16(8.06) = 129.0 \quad ; \quad \omega_1 = 10.9 \text{ rps}$$

$$\omega_2^2 = 16(44.4) = 71.0 \quad ; \quad \omega_2 = 8.4 \text{ rps}$$

using $K_2 = 16{,}000$:

$$\omega_1 = (0.707)(10.9) = 7.7 \text{ rps}$$

$$\omega_2 = (0.707)(8.4) = 5.92 \text{ rps}$$

consider:

$$\omega = \frac{2\pi V}{L}$$

or: $V = \dfrac{\omega L}{2\pi}$ and taking the lowest ω

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Prob. I.A.1.a.2

$$V = \frac{(8.4)6}{6.28} = 8.03 \text{ fps}$$

Prob. I.A.1.b.2

$$V = \frac{(8.4)4}{6.28} = 5.35 \text{ fps}$$

Prob. I.A.2.a.2

$$V = \frac{(5.92)6}{6.28} = 5.67 \text{ fps}$$

Prob. I.A.2.b.2

$$V = \frac{(5.92)4}{6.28} = 3.77 \text{ fps}$$

Prob. I A 3 a 2

$V = 8.03$ fps

Prob. I.A.3.b.2

$V = 5.35$ fps

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Prob. I.A.4.a.2

$V = 5.67$ fps

Prob. I.A.4.b.2

$V = 3.77$ fps

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Notation

I A I a I

- Part One
- Vehicles Studied:
  - A ≡ 8 wheels, 4 walking beams
  - B ≡ 12 wheels, 6 walking beams
  - C ≡ 12 wheels, individually sprung
- Spring Rates:
  - 1 ≡ 6" deflection under 2G's with shock at 508 lbs-sec/ft.
  - 2 ≡ 12" deflection under 2G's with shock at 508 lbs-sec/ft
  - 3 ≡ 6" deflection under 2G's with shock at 1016 lbs-sec/ft.
  - 4 ≡ 12" deflection under 2G's with shock at 1016 lbs-sec/ft
- Course:
  - a ≡ Sine wave; L = 6ft, A = 3 inches
  - b ≡ Sine wave; L = 4ft, A = 2 inches
- Velocities:
  - 1 ≡ 20 mph
  - 2 ≡ Resonant velocity

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Problem Number	$k_{1,2}$ lbs/ft	$c_{1,2}$ lb.sec/ft	v_1 ft/sec	A_1 ft.	L_1 ft.	b = 2(2)	d = 0.17(2)	
1	2	3	4	5	6	7	8	
I.A.1.a.1	32,000.	508.	29.3	0.25	6.0	64,000.	5,430.	
I.A.1.a.2	32,000.	508.	8.03	0.25	6.0	64,000.	5,430.	
I.A.1.b.1	32,000.	508.	29.3	0.167	4.0	64,000	5,430	
I.A.1.b.2	32,000.	508.	5.35	0.167	4.0	64,000	5,430	
I.A.2.a.1	16,000.	508.	29.3	0.25	6.0	32,000	2,720	
I.A.2.a.2	16,000.	508.	5.67	0.25	6.0	32,000	2,720	
I.A.2.b.1	16,000.	508.	29.3	0.167	4.0	32,000	2,720	
I.A.2.b.2	16,000.	508.	3.77	0.167	4.0	32,000	2,720	
I.A.3.a.1	32,000.	1016.	29.3	0.25	6.0	64,000	5,430	
I.A.3.a.2	32,000.	1016.	8.03	0.25	6.0	64,000	5,430	
I.A.3.b.1	32,000.	1016.	29.3	0.167	4.0	64,000	5,430	
I.A.3.b.2	32,000.	1016.	5.35	0.167	4.0	64,000	5,430	
I.A.4.a.1	16,000.	1016.	29.3	0.25	6.0	32,000	2,720	
I.A.4.a.2	16,000.	1016.	5.67	0.25	6.0	32,000	2,720	
I.A.4.b.1	16,000.	1016.	29.3	0.167	4.0	32,000	2,720	
I.A.4.b.2	16,000.	1016. HSJ	3.77	0.167	4.0	32,000	2,720	

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PROBLEM NUMBER	e = 2(3)	f = 0.17(3)	h = 31.5(2)	j = 31.5(3)	$d_{1,2}$ = 23.5/(6)	ϕ = 49.7/(6)	ω = 2π(4)/(6)
1	9	10	11	12	13	14	15
I.A.1.a.1	1016.	86.3	1,008,000.	16,000.	3.92	8.39	30.7
I.A.1.a.2	1016.	86.3	1,008,000.	16,000.	3.92	8.39	8.69
I.A.1.b.1	1016.	86.3	1,008,000.	16,000.	5.88	12.42	46.0
I.A.1.b.2	1016.	86.3	1,008,000.	16,000.	5.88	12.42	8.4
I.A.2.a.1	1016.	86.3	504,000	16,000.	3.92	8.39	30.7
I.A.2.a.2	1016.	86.3	504,000.	16,000.	3.92	8.39	5.74
I.A.2.b.1	1016.	86.3	504,000.	16,000.	5.88	12.42	46.0
I.A.2.b.2	1016.	86.3	504,000.	16,000.	5.88	12.42	5.92
I.A.3.a.1	2032.	172.6	1,008,000.	32,000.	3.92	8.39	30.7
I.A.3.a.2	2032.	172.6	1,008,000.	32,000.	3.92	8.39	8.69
I.A.3.b.1	2032.	172.6	1,008,000.	32,000.	5.88	12.42	46.0
I.A.3.b.2	2032.	172.6	1,008,000.	32,000.	5.88	12.42	8.4
I.A.4.a.1	2032.	172.6	504,000.	32,000.	3.92	8.39	30.7
I.A.4.a.2	2032.	172.6	504,000.	32,000.	3.92	8.39	5.74
I.A.4.b.1	2032.	172.6	504,000.	32,000.	5.88	12.42	46.0
I.A.4.b.2	2032.	172.6	504,000.	32,000.	5.88	12.42	5.92

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PROBLEM NUMBER	sin α	cos α	sin φ	cos φ	sin(φ+α)	cos(φ+α)	$\frac{K_1 A}{L}$ = ½(2)(5)
1	16	17	18	19	20	21	22
I.A.1a.1	-0.703	-0.711	+0.857	-0.515	-0.247	+0.969	4,000.
I.A.1.a.2	-0.104	-0.111	+0.857	-0.515	-0.247	+0.969	4,000.
I.A.1.b.1	-0.390	+0.721	-0.131	+0.990	-0.514	+0.858	2,670
I.A.1b2	-0.390	+0.921	-0.139	+0.990	-0.514	+0.858	2,670
I.A.2.a.1	-0.703	-0.711	+0.857	-0.515	-0.247	+0.969	2,000
I.A.2.a.2	-0.703	-0.711	+0.857	-0.515	-0.247	+0.969	2,000
I.A.2.b.1	-0.390	+0.921	-0.139	+0.990	-0.514	+0.858	1,335
I.A.2.b.2	-0.390	+0.921	-0.139	+0.990	-0.514	+0.858	1,335
I.A.3.a.1	-0.703	-0.711	+0.857	-0.515	-0.247	+0.969	4,000
I.A.3.a.2	-0.703	-0.711	+0.857	-0.515	-0.247	+0.969	4,000
I.A.3.b.1	-0.390	+0.921	-0.139	+0.990	-0.514	+0.858	2,670
I.A.3.b.2	-0.390	+0.921	-0.139	+0.990	-0.514	+0.858	2,670
I.A.4.a.1	-0.703	-0.711	+0.857	-0.515	-0.247	+0.969	2,000
I.A.4.a.2	-0.703	-0.711	+0.857	-0.515	-0.247	+0.969	2,000
I.A.4.b.1	-0.390	+0.921	-0.139	+0.990	-0.514	+0.858	1,335
I.A.4.b.2	-0.390	+0.921	-0.139	+0.990	-0.514	+0.858	1,335

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PROBLEM NUMBER	(22)(1+(17))	$\frac{C_1 A w}{2} = \frac{1}{2}(3)(5)(15)$	(24)(16)	(22)((19)+(21))	(24)((18)+(20))	$\psi_1 = -[(23)+(25)+(26)+(27)]$	(22)(16)	
1	23	24	25	26	27	28	29	
I.A.1.a.1	1,155.	1,950.	-1,370.	1,810.	1,190.	-2,785.	-2,810.	
I.A.1.a.2	1,155.	534.	-376.	1,810.	326.	-2,915.	-2,810.	
I.A.1.b.1	5,130.	1,950.	-760.	4,940.	-1,274.	-8,036.	-1040.	
I.A.1.b.2	5,130.	356.	-139.	4,940.	-232.	-9,699.	-1040.	
I.A.2.a.1	578.	1,950.	-1,370.	908.	1,190.	-1306.	-1405.	
I.A.2.a2.	578.	377.	-265.	908.	230.	-1451.	-1405.	
I.A.2.b.1	2,562.	1,950.	-760.	2,470.	-1,274.	-2998.	-520.	
I.A.2.b.2	2,562.	251.	-98.	2,470.	-164.	-4770.	-520.	
I.A.3.a.1	1,155.	3,900.	-2,740.	1,810.	2,380.	-2605.	-2810.	
I.A.3.a.2	1,155.	1,100.	-775.	1,810.	672.	-2862.	-2810.	
I.A.3.b.1	5,130.	3,900.	-1,520.	4,940.	-2,550.	-6000.	-1040.	
I.A.3.b.2	5,130.	712.	-2,780.	4,940.	-465.	-6725.	-1040.	
I.A.4.a.1	578.	3,900.	-2,740.	908.	2,380.	-1126.	-1405.	
I.A.4.a.2	578.	754	-530.	908.	460.	-1416.	-1405.	
I.A.4.b.1	2,562.	3,900.	-1,520.	2,470.	-2,550.	-962.	-520.	
I.A.4.b.2	2,562.	502.	-196.	2,470.	-328.	-4,508.	-520.	

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Problem Number	(24)(1+(17))	(22)[(18)+(20)]	24[(19)+(21)]	$\psi_2 = +[(29)-(30)+(31)-(32)]$	-4.05 (23)	-4.05 (25)	+3.88 (26)	
1	30	31	32	33	34	35	36	
I.A.1.a.1	564	+2440.	884.	-1,818	-4660	+5540	7020	
I.A.1.a.2	154	+2440	242	-766	-4660	+1520	7,020	
I.A.1.b.1	3750	-1740	3600	-10,130	-20,800	3080	19,200	
IA1b.2	684	-1740	657	-4121	-20,800	563	19,200	
IA2a1	564	1220	884	-1633	-2,340	5540	3520	
IA2a2	109	1220	171	-465	-2340	1070	3520	
IA2b1	3750	-871	3,600	-8,741	-10,400	3,080	9,580	
IA2b2	482	-871	464	-2,337	-10,400	397	9,580	
IA3a1	1130	2440	1770	-3270	-4,660	11,100	7,020	
IA3a2	318	2440	500	-1,188	-4660	3,140	7,020	
IA3b1	7500	-1,740	7200	-17,480	-20,800	6,160	19,200	
IA3b2	1370	-1740	1320	-5,470	-20,800	11,260	19,200	
IA4a1	1130	1220	1,770	-3,085	-2,340	11,100	3,520	
IA4a2	218	1220	342	-745	-2,340	2,150	3,520	
IA4b1	7500	-871	7200	-16,091	-10,400	6,160	9580	
IA4b2	965	-871	927	-3283	-10,400	794	9580	

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Problem Number	+3.88 (27)	$\psi_3 = +[(34)+(35)+(36)+(37)]$	+4.05 (29)	-4.05 (30)	-3.88 (31)	+3.88 (32)	$\psi_4 = +[(39)+(40)+(41)+(42)]$	
1	37	38	39	40	41	42	43	
IA1a1	4620	12,520	-11,400	-2,280	-9,460	3420	-19,720	
IA1a2	1265	+5145	-11,400	- 624	-9,460	940	-20,544	
IA1b1	-4940	-3460	-4210	-15,200	4,490	14,000	-920	
IA1b2	-900	-1937	-4210	-2770	4490	2550	+ 60	
IA2a1	4620	11,340	-5690	-2280	-4740	3,430	-9,280	
IA2a2	892	3,142	-5,690	-441	-4740	664	-7441	
IA2b1	-4940	-2680	-2,110	-15,200	3,380	14,000	+70	
IA2b2	- 636	-1,059	-2,110	-1,950	3,380	1,800	+1120	
IA3a1	9,240	22,700	-11,400	-4,570	-9,460	6860	-18,570	
IA3a2	2,610	8,110	-11,400	-1,290	-9,460	1,940	-20,210	
IA3b1	-9,900	-5,440	-4,210	-30,400	4,490	27,900	-2,220	
IA3b2	-1805	7855	-4,210	-5,550	4,490	5,120	- 150	
IA4a1	9240	21,520	-5690	-4,570	-4,740	6,860	-8140	
IA4a2	1785	5,115	-5690	-883	-4740	1,330	-9,983	
IA4b1	-9,900	-4560	-2110	-30,400	3,380	27,900	-1230	
IA4b2	-846	-872	-2,110	-3910	3,380	3,600	+ 960	

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Problem Number	m	e	b	f	d	ψ_1	ψ_2	
1	44	45	46	47	48	49	50	
IA1a1	497	1016	64,000	86.3	5,430	-2785	-1,818	
IA1a2	497	1016	64,000	86.3	5,430	-2915	- 766	
IA1b1	497	1016	64,000	86.3	5,430	-8036	-10,130	
IA1b2	497	1016	64,000	86.3	5,430	-9699	-4,121	
IA2a1	497	1016	32,000	86.3	2,720	-1306	-1,633	
IA2a2	497	1016	32,000	86.3	2,720	-1,451	- 465	
IA2b1	497	1016	32,000	86.3	2,720	-2,998	-8,741	
IA2b2	497	1016	32,000	86.3	2,720	-4770	-2,337	
IA3a1	497	2032	64,000	172.6	5,430	-2,605	-3,270	
IA3a2	497	2032	64,000	172.6	5,430	-2862	-1,188	
IA3b1	497	2032	64,000	172.6	5,430	-6000	-17,480	
IA3b2	497	2032	64,000	172.6	5,430	-6725	-5,470	
IA4a1	497	2032	32,000	172.6	2,720	-1126	-3,085	
IA4a2	497	2032	32,000	172.6	2,720	-1416	- 745	
IA4b1	497	2032	32,000	172.6	2,720	-962	-16,091	
IA4b2	497	2032	32,000	172.6	2,720	-4508	-3,283	

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Problem Number	I	j	h	f	d	ψ_3	ψ_4
1	51	52	53	54	55	56	57
IA1a1	14,200	16,000	1,008,000	86.3	5430	12,520	-19,720
IA1a2	14,200	16,000	1,008,000	86.3	5430	5,145	-20,544
IA1.b.1	14,200	16,000	1,008,000	86.3	5430	- 3,460	- 920
IA1b2	14,200	16,000	1,008,000	86.3	5430	-1,937	60
IA2a1	14,200	16,000	504,000	86.3	2720	11,340	- 9,280
IA2a2	14,200	16,000	504,000	86.3	2720	3,142	- 7,441
IA2b1	14,200	16,000	504,000	86.3	2720	- 2,680	70
IA2b2	14,200	16,000	504,000	86.3	2720	- 1,059	1,120
IA3a1	14,200	32,000	1,008,000	172.6	5430	22,700	- 18,570
IA3a2	14,200	32,000	1,008,000	172.6	5430	8,110	-20,210
IA3b1	14,200	32,000	1,008,000	172.6	5430	- 5,440	- 2,220
IA3b2	14,200	32,000	1,008,000	172.6	5430	7,855	- 150
IA4a1	14,200	32,000	504,000	172.6	2720	21,520	- 8,140
IA4a2	14,200	32,000	504,000	172.6	2720	5,115	-9,983
IA4b1	14,200	32,000	504,000	172.6	2720	- 4,560	-1,230
IA4b2	14,200	32,000	504,000	172.6	2720	- 872	960

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Problem Number	Coefficients of:							ω
	$\ddot{X}$	$\dot{X}$	X	$\dot{\theta}$	θ	Sin ωt	Cos ωt	
IA1a1	1	2.04	129	0.174	10.95	- 5.6	- 3.66	30.7
IA1a2	1	2.04	129	0.174	10.95	- 5.96	- 1.54	8.69
IA1b1	1	2.04	129	0.174	10.95	- 16.2	- 20.40	46.0
IA1b2	1	2.04	129	0.174	10.95	- 19.5	- 8.30	8.4
IA2a1	1	2.04	64.4	0.174	5.47	- 2.62	- 3.29	30.7
IA2a2	1	2.04	64.4	0.174	5.47	- 2.92	- 0.935	5.94
IA2b1	1	2.04	64.4	0.174	5.47	- 6.02	- 17.6	46.0
IA2b2	1	2.04	64.4	0.174	5.47	- 9.60	- 4.7	5.92
IA3a1	1	4.08	129	0.347	10.95	- 5.24	- 6.58	30.7
IA3a2	1	4.08	129	0.347	10.95	- 5.76	- 2.39	8.69
IA3b1	1	4.08	129	0.347	10.95	- 12.06	- 35.1	46.0
IA3b2	1	4.08	129	0.347	10.95	- 13.50	- 11.0	8.4
IA4a1	1	4.08	64.4	0.347	5.47	- 2.26	- 6.2	30.7
IA4a2	1	4.08	64.4	0.347	5.47	- 2.85	- 1.5	5.94
IA4b1	1	4.08	64.4	0.347	5.47	- 1.94	- 32.35	46.0
IA4b2	1	4.08	64.4	0.347	5.47	- 9.08	- 6.61	5.92

fmc CORPORATION

Load and stress analysis of: LVT Suspension

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Problem Numbem	Coefficents of:							
	$\ddot{\theta}$	$\dot{\theta}$	θ	$\dot{x}$	x	Sin ωt	Cos ωt	ω
IA1a1	1	1.13	71.0	0.00608	0.383	0.883	-1.39	30.7
IA1a2	1	1.13	71.0	0.00608	0.383	0.362	-1.445	8.69
IA1b1	1	1.13	71.0	0.00608	0.383	-0.244	-0.0648	46.0
IA1b2	1	1.13	71.0	0.00608	0.383	-0.136	0.00422	8.4
IA2a1	1	1.13	35.5	0.00608	0.1915	0.80	-0.654	30.7
IA2a2	1	1.13	35.5	0.00608	0.1915	0.222	-0.523	5.94
IA2b1	1	1.13	35.5	0.00608	0.1915	-0.189	0.00495	46.0
IA2b2	1	1.13	35.5	0.00608	0.1915	-0.0745	0.079	5.92
IA3a1	1	2.26	71.0	0.01215	0.383	1.60	-1.305	30.7
IA3a2	1	2.26	71.0	0.01215	0.383	0.571	-1.42	8.69
IA3b1	1	2.26	71.0	0.01215	0.383	-0.383	-0.156	46.0
IA3b2	1	2.26	71.0	0.01215	0.383	0.554	-0.0106	8.4
IA4a1	1	2.26	35.5	0.01215	0.1915	1.515	-0.572	30.7
IA4a2	1	2.26	35.5	0.01215	0.1915	0.36	-0.703	5.94
IA4b1	1	2.26	35.5	0.01215	0.1915	-0.321	-0.0867	46.0
IA4b2	1	2.26	35.5	0.01215	0.1915	-0.0614	0.0676	5.92

CORRELATION OF SIMULATED DATA (Continued)

Vehicle Constants

Computer input consists of the following vehicle constants:

- Suspension geometry
- Spring rates
- Shock absorber rates
- Maximum vehicle speed which is 20 mph
- Resonant vehicle speed which depends upon the course and suspension
- Vehicle mass
- Vehicle mass moment of inertia

The vehicle suspension is analyzed for two forcing functions which are the two washboard courses at the Aberdeen Proving Grounds.

All constants for the two coupled differential equations which define the vehicle motion while supported by twelve road wheels mounted on six walking beams are included in tabular form in this section.

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VEHICLE B: (12 road wheels / 6 walking beams)

SPRUNG WT. $\times \frac{1}{2}$ = W = 32,000 $\times \frac{1}{2}$ = 16,000 lbs.

INERTIA ABOUT C.G. $\times \frac{1}{2} = I = 0.284 \times 10^5 \times \frac{1}{2} = 0.142 \times 10^5$ ft.lb sec²

$l_1 = 4.925'$

$l_2 = 4.755'$

$l_3 = 0.085'$

$a = 2.42'$

$m = \frac{W}{g} = \frac{16,000}{32.2} = 497$ lb.sec²/ft.

$l_1 - l_2 = 4.925 - 4.755 = 0.17$ ft.

$l_1^2 + l_2^2 = 24.25 + 22.6 = 46.85$ ft²

$2\pi(a) = 2\pi(2.42) = 15.2$ ft.

$2\pi(l_1 + l_2) = 2\pi(9.68) = 60.8$ ft.

$2\pi(l_1 - l_3) = 2\pi(4.84) = 30.4$ ft.

SPRING RATES:

1.) $\frac{2(32,000)}{0.5} = 6k = 128,000$

$k = 21,400$ lb/ft.

2.) $k = 21,400 \times \frac{1}{2} = 10,700$ lb/ft.

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DETERMINATION OF RESONANT VELOCITY

$$\omega^2 = \frac{1}{2}\left[\left(\frac{h}{I} + \frac{b}{m}\right) \pm \sqrt{\left(\frac{h}{I} - \frac{b}{m}\right)^2 + \frac{4d^2}{mI}}\right]$$

OR, IN THIS CASE

$$\omega^2 = \frac{1}{2}\left[\frac{k(l_1^2+l_2^2+l_3^2)}{I} + \frac{3k}{m} \pm \left(\left(\frac{k(l_1^2+l_2^2+l_3^2)}{I} - \frac{3k}{m}\right)^2 + \frac{4k^2(l_1-l_2+l_3)^2}{mI}\right)^{1/2}\right]$$

$$= \frac{k}{2}\left[\frac{l_1^2+l_2^2+l_3^2}{I} + \frac{3}{m} \pm \left(\left(\frac{l_1^2+l_2^2+l_3^2}{I} - \frac{3}{m}\right)^2 + \frac{4(l_1-l_2+l_3)^2}{mI}\right)^{1/2}\right]$$

USING $k = 21,400$ lb/ft.

$$\omega^2 = \frac{21,400}{2}\left[\frac{46.85}{(1.42)10^4} + \frac{3}{(.497)10^3} \pm \left(\left(\frac{46.85}{(1.42)10^4} - \frac{3}{(.497)10^3}\right)^2 + \frac{4(0.255)^2}{(.497)(1.42)10^7}\right)^{1/2}\right]$$

$$= 10,700\left[(33.0)10^{-4} + (6.05)10^{-3} \pm \left(\left((33.0)10^{-4} - (60.5)10^{-4}\right)^2 + (36.9)10^{-9}\right)^{1/2}\right]$$

$$= 10,700\left[(9.35)10^{-3} \pm \left((7.55)10^{-6} + (0.037)10^{-6}\right)^{1/2}\right]$$

$$= 10,700\left[9.35 \pm 2.75\right]10^{-3} = 10.7(9.35 \pm 2.75)$$

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Resonant Velocities Cont'd:

$\omega_1^2 = 10.7\,(12.10) = 129.5\ ; \quad \omega_1 = 11.38$ cps

$\omega_2^2 = 10.7\,(6.60) = 70.6\ ; \quad \omega_2 = 8.4$ cps

$\omega_1 = 0.707\,(11.38) = 8.05$ cps

$\omega_2 = 0.707\,(8.4) = 5.94$ cps

Consider $\omega = \frac{2\pi V}{L}$

or $V = \frac{\omega L}{2\pi}$ and taking lowest ω

Prob. IB1a2

$$V = \frac{(8.05)\,6}{6.28} = 7.7 \text{ fps}$$

Prob. IB1b2

$$V = \frac{(8.05)\,4}{6.28} = 5.13 \text{ fps}$$

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Prob. IB2a2

$$V = \frac{(59.4)\,6}{6.28} = 5.68 \text{ fps}$$

Prob. IB2b2

$$V = \frac{(5.94)\,4}{6.28} = 3.78 \text{ fps}$$

Prob. IB3a2 $V = 7.7$ fps

Prob. IB3b2 $V = 5.13$ fps

Prob. IB4a1 $V = 5.68$ fps

Prob. IB4b1 $V = 3.78$ fps

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Notation

IAla1

Part One

- Velocities:
  - 1 ≡ 20 mph
  - 2 ≡ Resonant velocity
- Course:
  - a ≡ Sine wave ; L = 6 ft , A = 3 inches
  - b ≡ Sine wave ; L = 4 ft , A = 2 inches
- Spring Rates:
  - 1 ≡ 6" deflection under 2 G's with shock at 508 lbs-sec/ft.
  - 2 ≡ 12" deflection under 2 G's with shock at 508 lbs-sec/ft
  - 3 ≡ 6" deflection under 2 G's with shock at 1016 lbs-sec/ft.
  - 4 ≡ 12" deflection under 2 G's with shock at 1016 lbs-sec/ft
- Vehicles Studied:
  - A ≡ 8 wheels, 4 walking beams
  - B ≡ 12 wheels, 6 walking beams
  - C ≡ 12 wheels, individually sprung

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Problem Number	$f = 0.17(3)$	$d = 0.17(2)$	$j = 46.85(3)$	$h = 46.85(2)$	$\alpha_{1,2,3} = \frac{15.2}{(6)}$	$\phi_1 = \frac{60.8}{(6)}$	$\phi_2 = \frac{30.4}{(6)}$
1	9	10	11	12	13	14	15
IB1a1	86.4	3,640	23,800	10^6	2.53	10.13	5.07
IB1a2	86.4	3,640	23,800	10^6	2.53	10.13	5.07
IB1b1	86.4	3,640	23,800	10^6	3.8	15.2	7.6
IB1b2	86.4	3,640	23,800	10^6	3.8	15.2	7.6
IB2a1	86.4	1,820	23,800	500,000	2.53	10.13	5.07
IB2a2	86.4	1,820	23,800	500,000	2.53	10.13	5.07
IB2b1	86.4	1,820	23,800	500,000	3.8	15.2	7.6
IB2b2	86.4	1,820	23,800	500,000	3.8	15.2	7.6
IB3a1	172.6	3,640	47,600	10^6	2.53	10.13	5.07
IB3a2	172.6	3,640	47,600	10^6	2.53	10.13	5.07
IB3b1	172.6	3,640	47,600	10^6	3.8	15.2	7.6
IB3b2	172.6	3,640	47,600	10^6	3.8	15.2	7.6
IB4a1	172.6	1,820	47,600	500,000	2.53	10.13	5.07
IB4a2	172.6	1,820	47,600	500,000	2.53	10.13	5.07
IB4b1	172.6	1,820	47,600	500,000	3.8	15.2	7.6
IB4b2	172.6	1,820	47,600	500,000	3.8	15.2	7.6

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Problem Number	$\omega = 2\pi(4)/(6)$	Sin α	Cos α	Sin ϕ_1	Cos ϕ_1	Sin ϕ_2	Cos ϕ_2
1	16	17	18	19	20	21	22
IB1a1	30.7	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB1a2	8.06	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB1b1	46.0	-0.613	-0.790	0.481	-0.877	0.969	0.248
IB1b2	8.05	-0.613	-0.790	0.481	-0.877	0.969	0.248
IB2a1	30.7	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB2a2	5.95	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB2b1	46.0	-0.613	-0.790	0.481	-0.877	0.969	0.248
IB2b2	5.94	-0.613	-0.790	0.481	-0.877	0.969	0.248
IB3a1	30.7	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB3a2	8.06	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB3b1	46.0	-0.613	-0.790	0.481	-0.877	0.969	0.248
IB3b2	8.05	-0.613	-0.790	0.481	-0.877	0.969	0.248
IB4a1	30.7	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB4a2	5.95	0.574	-0.819	-0.652	-0.758	-0.936	0.352
IB4b1	46.0	-0.613	-0.790	0.481	-0.877	0.969	0.248
IB4b2	5.94	-0.613	-0.790	0.481	-0.877	0.969	0.248

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Problem Number	$\cos(\phi_1+\alpha_2)$	$\sin(\phi_1+\alpha_2)$	$\cos(\phi_2+\alpha_3)$	$\sin(\phi_2+\alpha_3)$	$\frac{KA}{2} = \frac{1}{2}(2)(5)$	$(27)[1+(18)]$	$\frac{cA\omega}{2} = \frac{1}{2}(3)(5)(16)$
1	23	24	25	26	27	28	29
IB1a1	0.995	0.0998	0.248	0.969	2,670	483	2,020
IB1a2	0.995	0.0998	0.248	0.969	2,670	483	513
IB1b1	0.987	0.159	0.398	-0.917	1,788	375	1,950
IB1b2	0.987	0.159	0.398	-0.917	1,788	375	331
IB2a1	0.995	0.0998	0.248	0.969	1,338	242	2,020
IB2a2	0.995	0.0998	0.248	0.969	1,338	242	378
IB2b1	0.987	0.159	0.398	-0.917	893	187	1,950
IB2b2	0.987	0.159	0.398	-0.917	893	187	252
IB3a1	0.995	0.0998	0.248	0.969	2,670	483	4,040
IB3a2	0.995	0.0998	0.248	0.969	2,670	483	1,026
IB3b1	0.987	0.159	0.398	-0.917	1,788	375	3900
IB3b2	0.987	0.159	0.398	-0.917	1,788	375	662
IB4a1	0.995	0.0998	0.248	0.969	1,338	242	4,040
IB4a2	0.995	0.0998	0.248	0.969	1,338	242	756
IB4b1	0.987	0.159	0.398	-0.917	893	187	3,900
IB4b2	0.987	0.159	0.398	-0.917	893	187	504

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Problem Number	(29)(17)	(27)[(20)+(23)]	(29)[(19)+(24)]	(27)[(22)+(25)]	ψ_1 = -[(28)+(30)+(31)+(32)+(33)]	(27)(17)	(29)[1+(18)]
1	30	31	32	33	34	35	36
IB1a1	1,160	633	-1,115	1,600	-2761	1530	366
IB1a2	294	633	- 283	1,600	-2761	1530	92.8
IB1b1	1,195	196.5	1,250	1,150	-4166.5	-1094	409
IB1b2	203	196.5	212	1,150	-2136.5	-1094	69.5
IB2a1	1,160	317	-1,115	803	-1407	766	366
IB2a2	217	317	- 209	803	-1370	766	68.5
IB2b1	1,195	98.2	1250	576	-3306.2	- 546	409
IB2b2	154	98.2	161	576	-1176.2	- 546	53
IB3a1	2,320	633	-2230	1600	-2806	1530	731
IB3a2	588	633	- 566	1600	-2738	1530	186
IB3b1	2,390	196.5	2500	1150	-6611.5	-1,094	819
IB3b2	406	196.5	424	1150	-2551.5	-1,094	139
IB4a1	2,320	317	-2230	803	-1452	766	731
IB4a2	434	317	- 417	803	-1379	766	137
IB4b1	2,390	98.2	2500	576	-5751.2	- 546	819
IB4b2	822	98.2	322	576	-2005.2	- 546	106

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Problem Number	(27)[(19)+(24)]	(29)[(20)+(23)]	(27)[(21)+(26)]	ψ_2 = +[(35)-(36)+(37)-(38)+(39)]	4.925 (28)	4.925 (30)	4.755 (31)
1	37	38	39	40	41	42	43
IB1a1	-1,470	266	67.6	-504.4	2380	5710	3,011
IB1a2	-1,470	69	16.9	- 84.9	2380	1450	3,011
IB1b1	1,140	214	101.4	524.4	1850	5880	934
IB1b2	1,140	36.4	17.2	- 42.7	1850	1000	934
IB2a1	- 739	266	67.6	-537.4	1190	5710	1,510
IB2a2	- 739	51.8	12.4	- 80.9	1190	1070	1,510
IB2b1	571	214	101.4	-497.6	920	5880	466
IB2b2	571	27.7	13.1	- 42.6	920	759	466
IB3a1	-1,470	554.	133	-1092	2380	11,400	3,011
IB3a2	-1,470	140.5	33.8	- 232.7	2380	2,900	3,011
IB3b1	1,140	429	203	-999	1850	11,800	934
IB3b2	1,140	72.8	34.4	- 131	1850	2,000	934
IB4a1	- 739	554	133	-1125	1190	11,400	1,510
IB4a2	- 739	105	25	- 190	1190	2,140	1,510
IB4b1	571	429	203	-1020	920	11,800	466
IB4b2	571	55.4	26.2	- 110.2	920	4,050	466

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PROBLEM NUMBER	4.755(32)	0.085(33)	$\psi_3 = +[-(41)-(42)+(43)+(44)-(45)]$	4.925(35)	4.925(36)	4.755(37)	4.755(38)	
1	44	-45	46	47	-48	-49	50	
I.B.1.a.1	-5,300.	136.	-10,515.	7,530.	1800.	-6,980.	1264.	
I.B.1.a.2	-1,345.	136.	-2,300.	7,530.	457.	-6,980.	328.	
I.B.1.b.1	5940.	97.8	-953.8	-5,390.	2018.	5,420.	1,020.	
I.B.1.b.2	1010.	97.8	-1003.8	-5,390.	342.	5,420.	173.	
I.B.2.a.1	-5,300.	68.2	-10,758.2	3,780.	1800.	-3,510.	1,264.	
I.B.2.a.2	-993.	68.2	-1,811.2	3,780.	337.5	-3,510.	246.	
I.B.2.b.1	5940.	49.	-443.	-2,690.	2018.	2,720.	1,020.	
I.B.2.b.2	765.	49.	-497.	-2,690.	261.	2,720.	131.6	
I.B.3.a.1	-10,600.	136.	-21,505.	7,530.	3600.	-6,980.	2630.	
I.B.3.a.2	-2700.	136.	-5,105.	7,530.	916.	-6,980.	667.	
I.B.3.b.1	11,900.	97.8	-913.8	-5,390.	4030.	5,420.	2040.	
I.B.3.b.2	2020.	97.8	-993.8	-5,390.	684.	5,420.	346.	
I.B.4.a.1	-10,600.	68.2	-21,748.2	3,780.	3600.	-3,510.	2630.	
I.B.4.a.2	-1,980.	68.2	-3,868.2	3,780.	675.	-3,510.	500.	
I.B.4.b.1	11,900.	49.	-403.	-2,690.	4030.	2,720.	2040.	
I.B.4.b.2	1,530.	49.	-3023.	-2,690.	522.	2,720.	263.	

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PROBLEM NUMBER	0.085(39)	$\psi_4 = +[(47)-(48)-(49)+(50)+(51)]$						
1	51	52						
I.B.1.a.1	5.75	14,980.						
I.B.1.a.2	1.36	14,382.						
I.B.1.b.1	8.62	-11,799.						
I.B.1.b.2	1.46	-10,978.						
I.B.2.a.1	5.75	6,760.						
I.B.2.a.2	1.055	7,200.						
I.B.2.b.1	8.62	-6,399.						
I.B.2.b.2	1.11	-5,538.						
I.B.3.a.1	11.3	13,551.						
I.B.3.a.2	2.87	14,264.						
I.B.3.b.1	17.2	-12,783.						
I.B.3.b.2	2.92	-11,145.						
I.B.4.a.1	11.3	6,331.						
I.B.4.a.2	2.12	7,117.						
I.B.4.b.1	17.2	-7,383.						
I.B.4.b.2	2.23	-5,667.						

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PROBLEM NUMBER	m	e	b	f	d	ψ_1	ψ_2	
1								
I.B.1.a.1	497	1016	64,100	86.4	3,640	-2761.	- 504.4	
I.B.1.a.2	497	1016	64,100	86.4	3,640	-2727.	- 84.9	
I.B.1.b.1	497	1016	64,100	86.4	3,640	- 4166.5	+524.4	
I.B.1.b.2	497	1016	64,100	86.4	3,640	-2136.5	- 42.7	
I.B.2.a.1	497	1016	32,100	86.4	1,820	-1407.	- 537.4	
I.B.2.a.2	497	1016	32,100	86.4	1,820	-1370	- 80.9	
I.B.2.b.1	497	1016	32,100	86.4	1,820	- 3306.2	- 497.6	
I.B.2.b.2	497	1016	32,100	86.4	1,820	-1176.2	- 42.6	
I.B.3.a.1	497	2032	64,100	172.6	3,640	-2806.	-1092.	
I.B.3.a.2	497	2032	64,100	172.6	3,640	-2738.	- 232.7	
I.B.3.b.1	497	2032	64,100	172.6	3,640	-6611.5	- 999.	
I.B.3.b.2	497	2032	64,100	172.6	3,640	-2551.5	- 131.4	
I.B.4.a.1	497	2032	32,100	172.6	1,820	-1452.	-1125.	
I.B.4.a.2	497	2032	32,100	172.6	1,820	- 1379.	- 190.	
I.B.4.b.1	497	2032	32,100	172.6	1,820	- 5751.2	-1020.	
I.B.4.b.2	497	2032	32,100	172.6	1,820	- 2005.2	-110.2	

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

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fmc

Load and stress analysis of LVT Suspension

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PROBLEM NUMBER	I	j	h	f	d	ψ_3	ψ_4	
I.B.1.a.1	14,200	23,800	10^6	86.4	3,640	-10,515.	14,980.	
I.B.1.a.2	14,200	23,800	10^6	86.4	3,640	-2,300.	14,382.	
I.B.1.b.1	14,200	23,800	10^6	86.4	3,640	- 953.8	-11,799.	
I.B.1.b.2	14,200	23,800	10^6	86.4	3,640	-1,003.8	-10,978.	
I.B.2.a.1	14,200	23,800	500,000	86.4	1,820	-10,758.2	6,760.	
I.B.2.a.2	14,200	23,800	500,000	86.4	1,820	-1,811.2	7,200.	
I.B.2.b.1	14,200	23,800	500,000	86.4	1,820	- 443.	-6,399.	
I.B.2.b.2	14,200	23,800	500,000	86.4	1,820	- 497.	-5,538.	
I.B.3.a.1	14,200	47,600	10^6	172.6	3,640	-21,505.	13,551.	
I.B.3.a.2	14,200	47,600	10^6	172.6	3,640	-5,105.	14,264.	
I.B.3.b.1	14,200	47,600	10^6	172.6	3,640	- 713.8	-12,783.	
I.B.3.b.2	14,200	47,600	10^6	172.6	3,640	- 993.8	-11,145.	
I.B.4.a.1	14,200	47,600	500,000	172.6	1,820	-21,748.2	6,331	
I.B.4.a.2	14,200	47,600	500,000	172.6	1,820	-3,868.2	7,117	
I.B.4.b.1	14,200	47,600	500,000	172.6	1,820	- 403.	-7,383.	
I.B.4.b.2	14,200	47,600	500,000	172.6	1,820	-3023.	-5,667.	

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Load and stress analysis of LVT Suspension
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Problem Number	Coefficients of: $\ddot{x}$	$\dot{x}$	x	$\dot{\theta}$	θ	$\sin\omega t$	$\cos\omega t$	ω
I.B.1.a.1	1	2.04	129.	0.174	7.32	-5.56	-1.01	30.7
I.B.1.a.2	1	2.04	129.	0.174	7.32	-5.49	-0.17	8.06
I.B.1.b.1	1	2.04	129.	0.174	7.32	-8.38	+1.05	46.
I.B.1.b.2	1	2.04	129.	0.174	7.32	-4.29	-0.086	8.05
I.B.2.a.1	1	2.04	64.5	0.174	3.66	-2.83	-1.08	30.7
I.B.2.a.2	1	2.04	64.5	0.174	3.66	-2.76	-0.163	5.95
I.B.2.b.1	1	2.04	64.5	0.174	3.66	-6.65	-1.00	46.
I.B.2.b.2	1	2.04	64.5	0.174	3.66	-2.36	-0.086	5.94
I.B.3.a.1	1	4.08	129.	0.347	7.32	-5.65	-2.2	30.7
I.B.3.a.2	1	4.08	129.	0.347	7.32	-5.5	-0.468	8.06
I.B.3.b.1	1	4.08	129.	0.347	7.32	-13.3	-2.01	46.
I.B.3.b.2	1	4.08	129.	0.347	7.32	-5.13	-0.264	8.05
I.B.4.a.1	1	4.08	64.5	0.347	3.66	-2.92	-2.26	30.7
I.B.4.a.2	1	4.08	64.5	0.347	3.66	-2.77	-0.382	5.95
I.B.4.b.1	1	4.08	64.5	0.347	3.66	-11.58	-2.05	46.
I.B.4.b.2	1	4.08	64.5	0.347	3.66	-4.03	-2.22	5.94

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Load and stress analysis of LVT Suspension
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Problem Number	Coefficients of: $\ddot{\theta}$	$\dot{\theta}$	θ	$\dot{x}$	x	$\sin\omega t$	$\cos\omega t$	ω
I.B.1.a.1	1	1.675	70.7	0.00608	0.256	-0.742	1.05	30.7
I.B.1.a.2	1	1.675	70.7	0.00608	0.256	-0.162	1.01	8.06
I.B.1.b.1	1	1.675	70.7	0.00608	0.256	-0.0671	-0.83	46.
I.B.1.b.2	1	1.675	70.7	0.00608	0.256	-0.0708	-0.772	8.05
I.B.2.a.1	1	1.675	35.3	0.00608	0.128	-0.758	+0.476	30.7
I.B.2.a.2	1	1.675	35.3	0.00608	0.128	-0.128	0.507	5.95
I.B.2.b.1	1	1.675	35.3	0.00608	0.128	-0.0312	-0.45	46.
I.B.2.b.2	1	1.675	35.3	0.00608	0.128	-0.035	-0.39	5.94
I.B.3.a.1	1	3.36	70.7	0.01215	0.256	-1.51	0.954	30.7
I.B.3.a.2	1	3.36	70.7	0.01215	0.256	-0.36	1.003	8.06
I.B.3.b.1	1	3.36	70.7	0.01215	0.256	-0.0643	-0.899	46.
I.B.3.b.2	1	3.36	70.7	0.01215	0.256	-0.07	-0.785	8.05
I.B.4.a.1	1	3.36	35.3	0.01215	0.128	-1.53	0.445	30.7
I.B.4.a.2	1	3.36	35.3	0.01215	0.128	-0.272	0.501	5.95
I.B.4.b.1	1	3.36	35.3	0.01215	0.128	-0.0284	-0.52	46.
I.B.4.b.2	1	3.36	35.3	0.01215	0.128	-0.213	-0.399	5.94

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

CORRELATION OF SIMULATED DATA (Continued)

Vehicle Constants

Computer input consists of the following vehicle constants:

- Suspension geometry
- Spring rates
- Shock absorber rates
- Maximum vehicle speed which is 20 mph
- Resonant vehicle speed which depends upon the course and suspension
- Vehicle mass
- Vehicle mass moment of inertia

The vehicle suspension is analyzed for two forcing functions which are the two washboard courses at the Aberdeen Proving Grounds.

All constants for the two coupled differential equations which define the vehicle motion while supported by twelve road wheels each individually sprung are included in tabular form in this section.

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Prepared by: W. BLYTHE Date: 8 Aug., '61 Page No. 70
Checked by: R Smith Dwg. No. Project No. 449

VEHICLE C: (12 road wheels ea individually sprung)

SPRUNG WT. $\times \frac{1}{2}$ = $W = 32{,}000 \times \frac{1}{2} = 16{,}000$ lbs.

INERTIA ABOUT C.G. $\times \frac{1}{2} = I = 0.284 \times 10^5 \times \frac{1}{2} = 0.142 \times 10^5$ ft. lb. sec.²

$l_1 = 6.13'$

$l_2 = 3.71'$

$l_3 = 1.29'$

$l_4 = 1.13'$

$l_5 = 3.55'$

$l_6 = 5.97'$

$a = 2.42'$

$m = \frac{W}{g} = \frac{16{,}000}{32.2} = 497$ lb sec²/ft.

$l_1 - l_6 = 0.16$ ft.

$l_1^2 + l_6^2 = 37.6 + 35.6 = 73.2$ ft²

$2\pi(a) = 15.2$ ft.

SPRING RATES

1.) $\frac{2(32{,}000)}{0.5} = 12k = 128{,}000$

$k = 10{,}700$ lb/ft.

2.) $k = 10{,}700 \times \frac{1}{2} = 5{,}350$ lb/ft.

Load and stress analysis of: LVT Suspension
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Determination of Resonant Velocity

As on P. 52, we consider:

$$\omega^2 = \frac{1}{2}\left[\frac{h}{I} + \frac{b}{m} \pm \sqrt{\left(\frac{h}{I} - \frac{b}{m}\right)^2 + \frac{4d^2}{mI}}\right]$$

or in this case

$$\omega^2 = \frac{1}{2}\left[\frac{K(l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2)}{I} + \frac{6K}{m} \pm \left\{\left(\frac{K(l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2)}{I} - \frac{6K}{m}\right)^2 + \frac{4K^2(l_1 + l_2 + l_3 - l_4 - l_5 - l_6)^2}{mI}\right\}^{1/2}\right]$$

$$\omega^2 = \frac{K}{2}\left[\frac{l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2}{I} + \frac{6}{m} \pm \left\{\left(\frac{l_1^2 + l_2^2 + l_3^2 + l_4^2 + l_5^2 + l_6^2}{I} - \frac{6}{m}\right)^2 +\right.\right.$$

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$$4 \, (l_1 + l_2 + l_3 - l_4 - l_5 - l_6)^2 \Big\}^{1/2} \Big]$$

using $K = 10{,}700$ lb/ft

$$\omega^2 = \frac{10{,}700}{2}\left[\frac{102.43}{(1.42)10^4} + \frac{6}{497} \pm \left\{\left(\frac{102.43}{(1.42)10^4} - \frac{6}{497}\right)^2 + \frac{4\,(0.48)^2}{(0.497)(1.42)10^7}\right\}^{1/2}\right]$$

$$\omega^2 = 5350\left[(7.22)10^{-3} + (12)10^{-3} \pm \left\{\left[(7.22)10^{-3} - (12)10^{-3}\right]^2 + (1.3)10^{-7}\right\}^{1/2}\right]$$

$$\omega^2 = \frac{K}{2}\left[(19.22)10^{-3} \pm \left[(22.8)10^{-6} + (0.13)10^{-6}\right]^{1/2}\right]$$

$$\omega^2 = 5{,}350 \quad (19.22 \pm 4.787)\ 10^{-3}$$

$$\omega^2 = 5.350\,(19.22 \pm 4.787)$$

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$\omega_1^2 = 5.35\,(24.007) = 128.4$; $\omega_1 = 11.34$ cps

$\omega_2^2 = 5.35\,(14.433) = 77.2$; $\omega_2 = 8.78$ cps

$\omega_1 = 7.07\ (11.34) = 8.02$ cps

$\omega_2 = 7.07\ (8.78) = 6.21$ cps

Consider $\omega = \frac{2\pi V}{L}$

or $V = \frac{\omega L}{2\pi}$ and taking lowest ω

Prob. IC1a2

$$V = \frac{(8.02)\,6}{6.28} = 7.67 \text{ fps}$$

Prob. IC1b2

$$V = \frac{(8.02)\,4}{6.28} = 5.11 \text{ fps}$$

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Prob. IC2a2

$$V = \frac{(6.21)\,6}{6.28} = 5.94 \text{ fps}$$

Prob. IC2b2

$$V = \frac{(6.21)\,4}{6.28} = 3.96 \text{ fps}$$

Prob. IC3a2 $V = 7.67$ fps

Prob. IC3b2 $V = 5.11$ fps

Prob. IC4a2 $V = 5.94$ fps

Prob IC4b2 $V = 3.96$ fps

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fmc CORPORATION Load and stress analysis of: LVT Suspension
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Notation

IAlal

Part One

- Velocities:
  - 1 ≡ 20 mph
  - 2 ≡ Resonant velocity
- Course:
  - a ≡ Sine wave ; L = 6ft , A = 3 inches
  - b ≡ Sine wave ; L = 4ft , A = 2 inches
- Spring Rates:
  - 1 ≡ 6" deflection under 2G's with shock at 508 lbs-sec/ft
  - 2 ≡ 12" deflection under 2G's with shock at 508 lbs-sec/ft
  - 3 ≡ 6" deflection under 2G's with shock at 1016 lbs-sec/ft
  - 4 ≡ 12" deflection under 2G's with shock at 1016 lbs-sec/ft
- Vehicles Studied:
  - A ≡ 8 wheels, 4 walking beams
  - B ≡ 12 wheels, 6 walking beams
  - C ≡ 12 wheels, individually sprung

Load and stress analysis of LVT Suspension
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PROBLEM NUMBER	$f = 0.16\ (3)$	$d = 448\ (2)$	$j = 73.1\ (3)$	$h = 102.43\ (2)$	$\omega = 2\pi \frac{(4)}{(6)}$	$\alpha_1 = \frac{15.2}{(6)}$	$\alpha_2 = 2\ (14)$	
1	9	10	11	12	13	14	15	
I.C.1.a.1	80.4	5,140	37,200	1,097,000	30.7	2.53	5.06	
I.C.1.a.2	80.4	5,140	37,200	1,097,000	8.03	2.53	5.06	
I.C.1.b.1	80.4	5,140	37,200	1,097,000	46.	3.8	7.6	
I.C.1 b 2	80.4	5,140	37,200	1,097,000	8.02	3.8	7.6	
I.C.2.a.1	80.4	2,570	37,200	548,000	30.7	2.53	5.06	
I.C.2.a.2	80.4	2,570	37,200	548,000	6.22	2.53	5.06	
I.C.2.b.1	80.4	2,570	37,200	548,000	46.	3.8	7.6	
I.C.2.b.2	80.4	2,570	37,200	548,000	6.19	3.8	7.6	
I.C.3.a.1	160.8	5,140	74,200	1,097,000	30.7	2.53	5.06	
I.C.3.a.2	160.8	5,140	74,200	1,097,000	8.03	2.53	5.06	
I C 3 b.1	160.8	5,140	74,200	1,097,000	46.	3.8	7.6	
I.C.3.b.2	160.8	5,140	74,200	1,097,000	8.02	3.8	7.6	
I.C.4.a.1	160.8	2,570	74,200	548,000	30.7	2.53	5.06	
I.C.4.a.2	160.8	2,570	74,200	548,000	6.22	2.53	5.06	
I.C.4.b.1	160.8	2,570	74,200	548,000	46.	3.8	7.6	
I.C.4.b.2	160.8	2,570	74,200	548,000	6.19	3.8	7.6	

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PROBLEM NUMBER	$\alpha_3 = 3\ (14)$	$\alpha_4 = 4\ (14)$	$\alpha_5 = 5\ (14)$	$\sin \alpha_1$	$\cos \alpha_1$	$\sin \alpha_2$	$\cos \alpha_2$	
1	16	17	18	19	20	21	22	
I.C.1.a.1	7.6	10.1	12.65	0.574	-0.819	-0.939	+0.342	
I.C.1.a.2	7.6	10.1	12.65	0.574	-0.819	-0.939	+0.342	
I.C.1.b.1	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	
I.C.1 b 2	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	
I.C.2.a.1	7.6	10.1	12.65	+0.574	-0.819	-0.939	+0.342	
I.C.2.a.2	7.6	10.1	12.65	+0.574	-0.819	-0.939	+0.342	
I.C.2.b.1	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	
I.C.2.b.2	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	
I.C.3.a.1	7.6	10.1	12.65	+0.574	-0.819	-0.939	+0.342	
I.C.3.a.2	7.6	10.1	12.65	+0.574	-0.819	-0.939	+0.342	
I.C.3.b.1	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	
I.C.3.b.2	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	
I.C.4.a.1	7.6	10.1	12.65	+0.574	-0.819	-0.939	+0.342	
I.C.4.a.2	7.6	10.1	12.65	+0.574	-0.819	-0.939	+0.342	
I.C.4.b.1	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	
I.C.4.b.2	11.4	15.2	19.0	-0.613	-0.790	+0.969	+0.248	

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PROBLEM NUMBER	$\sin\alpha_3$	$\cos\alpha_3$	$\sin\alpha_4$	$\cos\alpha_4$	$\sin\alpha_5$	$\cos\alpha_5$	$\lambda A = (2)(5)$
1	23	24	25	26	27	28	29
I.C.1.a.1	0.969	0.248	-0.629	-0.777	0.09	0.996	2,680
I.C.1.a.2	0.969	0.248	-0.629	-0.777	0.09	0.996	2,680
I.C.1.b.1	-0.917	0.398	+0.877	-0.480	0.159	0.987	1,790
I.C.1.b.2	-0.917	0.398	+0.877	-0.480	0.159	0.987	1,790
I.C.2.a.1	0.969	0.248	-0.629	-0.777	0.09	0.996	1,340
I.C.2.a.2	0.969	0.248	-0.629	-0.777	0.09	0.996	1,340
I.C.2.b.1	-0.917	0.398	+0.877	-0.480	0.159	0.987	895
I.C.2.b.2	-0.917	0.398	+0.877	-0.490	0.159	0.987	895
I.C.3.a.1	0.969	0.248	-0.629	-0.777	0.09	0.996	2,680
I.C.3.a.2	0.969	0.248	-0.629	-0.777	0.09	0.996	2,680
I.C.3.b.1	-0.917	0.398	+0.877	-0.490	0.159	0.987	1,790
I.C.3.b.2	-0.917	0.398	+0.877	-0.480	0.159	0.987	1,790
I.C.4.a.1	0.969	0.248	-0.629	-0.777	0.09	0.996	1,340
I.C.4.a.2	0.969	0.248	-0.629	-0.777	0.09	0.996	1,340
I.C.4.b.1	-0.917	0.393	+0.877	-0.480	0.159	0.987	895
I.C.4.b.2	-0.917	0.398	+0.877	-0.480	0.159	0.987	895

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fmc

Load and stress analysis of: LVT Suspension

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PROBLEM NUMBER	(29)(20)	(29)(22)	(29)(24)	(29)(26)	(29)(28)	$\frac{(31)(5)(13)}{(27)}$	$\psi_1 = -[(29)+(30)+(31)+(32)+(33)+(34)+(35)]$
1	30	31	32	33	34	35	36
I.C.1.a.1	-2,200	916	665	-2,080	2,670	351.	3002
I.C.1.a.2	-2,200	916	665	-2,080	2,670	90.6	-2786
I.C.1.b.1	-1,415	444	713	-860	1,770	620.	-3062
I.C.1.b.2	-1,415	444	713	-860	1,770	108.5	-2550
I.C.2.a.1	-1,100	458	332	-1,040	1,336	351.	-1677
I.C.2.a.2	-1,100	458	332	-1,040	1,336	711	-1397
I.C.2.b.1	-707	222	356	-430	884	620.	-1840
I.C.2.b.2	-707	222	356	-430	884	83.5	-1,303
I.C.3.a.1	-2,200	916	665	-2,080	2,670	701.	-3352
I.C.3.a.2	-2,200	916	665	-2,080	2,670	183.3	-2834
I.C.3.b.1	-1,415	444	713	-860	1,770	1240.	-3682
I.C.3.b.2	-1,415	444	713	-860	1,770	216.	-2658
I.C.4.a.1	-1,100	458	332	-1,040	1,336	701.	-2054
I.C.4.a.2	-1,100	458	332	-1,040	1,336	142.	-1495
I.C.4.b.1	-707	222	356	-430	884	1240.	-2460
I.C.4.b.2	-707	222	356	-430	884	167.	-1387

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PROBLEM NUMBER	(29) (19)	(29) (21)	(29)(23)	(29)(25)	(29)(27)	(3)(5)(13)(28)	A cw = (3)(5)(13)
1	37	38	39	40	41	42	43
I.C.1.a.1	1540	-2520	2,600	-1685	241	3890	+3900
I.C.1.a.2	1540	-2520	2,600	-1685	241	1003	+1007
I.C.1.b.1	-109.7	1735	-1,640	1570	284	3850	+3900
I.C.1.b.2	-109.7	1735	-1,640	1570	284	674	+ 683
I.C.2.a.1	769	-1260	1300	- 842	121	3890	+3900
I.C.2.a.2	769	-1260	1300	- 842	121	787	+ 790
I.C.2.b.1	-548	867	-820	785	142	3850	+3900
I.C.2.b.2	-548	867	- 820	785	142	518	+ 525
I.C.3.a.1	1540	-2520	2,600	-1685	241	7890	+7920
I.C.3.a.2	1540	-2520	2600	-1685	241	2028	+2035
I.C.3.b.1	-109.7	1735	-1640	1570	284	7700	+7800
I.C.3.b.2	-109.7	1735	-1640	1570	284	1340	+1360
I.C.4.a.1	769	-1260	1300	- 842	121	7890	+7920
I.C.4.a.2	769	-1260	1300	- 842	121	1573	+1580
I.C.4.b.1	- 548	867	-820	785	142	7700	+7800
I.C.4.b.2	- 548	867	-820	785	142	1037	+1050

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PROBLEM NUMBER	$\psi_2 = [(37)+(38)+(39)+(40)+(41)+(42)+(43)]$	6.13 (29)	3.71 (30)	1.29 (31)	1.13 (32)	3.55 (33)	5.97 (34)
1	44	45	46	47	48	49	50
I.C.1.a.1	166	+16,400	-8,160	+1,180	750	-7,380	15,920
I.C.1.a.2	172	+16,400	-8,160	+1,180	750	-7,380	15,920
I.C.1.b.1	1789	+11,000	∓3,820	+ 572	805	-3,050	10,580
I.C.1.b.2	1830	+11,000	∓3,820	+ 572	805	-3,050	10,580
I.C.2.a.1	78	+8,200	∓4,080	+ 590	375	-3,690	7,970
I.C.2.a.2	85	+8,200	- 4,080	+ 590	375	-3,690	7,970
I.C.2.b.1	376	+5,490	∓2,620	+ 286	402	-1,528	5,270
I.C.2.b.2	419	+5,490	∓2,620	+ 286	402	-1,528	5,270
I.C.3.a.1	146	+16,400	+8,160	+ 1,180	750	- 7,380	15,920
I.C.3.a.2	169	+16,400	-8,160	+1,180	750	-7,380	15,920
I.C.3.b.1	1739	+11,000	-3,820	+ 572	805	-3,050	10,580
I.C.3.b.2	1819	+11,000	∓3,820	+ 572	805	-3,050	10,580
I.C.4.a.1	58	+8,200	-4,080	+ 590	375	-3,690	7,970
I.C.4.a.2	81	+8,200	-4,080	+ 590	375	-3,690	7,970
I.C.4.b.1	326	+5,490	∓2,620	+ 286	402	-1,528	5,270
I.C.4.b.2	413	+5,490	∓2,620	+ 286	402	-1,528	5,270

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PROBLEM NUMBER	5.97 (35)	$\psi_3 = [(45)-(46)-(47)+(48)+(49)+(50)+(51)]$	(43)6.13	3.71(37)	1.29(38)	1.13 (39)	3.55 (40)
1	51	52	53	54	55	56	57
I.C.1.a.1	2100	1970	23,900	5,710	-3250	+2940	-5,970
I.C.1.a.2	541	411	6,160	5710	-3250	+2940	-5,970
I.C.1.b.1	3700	4283	23,900	-406.	2240	-1850	+5,570
I.C.1.b.2	648	1231	4,180	-406	2240	-1850	+5,570
I.C.2.a.1	2100	2045	23,900	2850	-1625	+1470	-2,990
I.C.2.a.2	425	370	4,840	2850	-1625	+1470	-2,990
I.C.2.b.1	3700	4688	23,900	-2035	1120	-926	+2780
I.C.2.b.2	499	1487	3,220	-2035	1120	-926	+2780
I.C.3.a.1	4180	4050	48,500	5,710	-3250	+2940	-5970
I.C.3.a.2	1093	963	12,480	5,710	-3250	+2940	-5,970
I.C.3.b.1	7400	7983	47,800	-406	2240	-1850	+5,570
I.C.3.b.2	1290	1873	8,340	-406	2240	-1850	+5,570
I.C.4.a.1	4180	4125	48,500	2850	-1625	+1470	-2,990
I.C.4.a.2	848	793	9,690	2850	-1625	+1470	-2,990
I.C.4.b.1	7400	8389	47,800	-2035	1120	-926	+2,780
I.C.4.b.2	998	1986	6,430	-2035	1120	+926	+2,780

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PROBLEM NUMBER	5.97 (41)	5.97 (42)	$\psi_4 = [(53)+(54)+(55)-(56)-(57)-(58)+(59)]$
1	58	59	60
I.C.1.a.1	+1,440	23,200	51,150
I.C.1.a.2	+1,440	6,000	16,210
I.C.1.b.1	+1,700	23,000	43,314
I.C.1.b.2	+1,700	4,020	4,614
I.C.2.a.1	+723	23,200	49,122
I.C.2.a.2	+723	4 700	11,562
I.C.2.b.1	+848	23,000	43,315
I.C.2.b.2	+848	3,090	2,693
I.C.3.a.1	+1,440	47,000	99,550
I.C.3.a.2	+1,440	12,150	28,680
I.C.3.b.1	+1,700	46,000	90,214
I.C.3.b.2	+1,700	8,000	12,754
I.C.4.a.1	+723	47,000	97,522
I.C.4.a.2	+723	9,390	21,102
I.C.4.b.1	+848	46,000	90,183
I.C.4.b.2	+848	6,190	9,003

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PROBLEM NUMBER	m	e	b	f	d	ψ_1	ψ_2	
1								
I.C.1.a.1	497	1016	64,200	80.4	5,140	-3002	166	
I.C.1.a.2	497	1016	64,200	80.4	5,140	-2786	172	
I.C.1.b.1	497	1016	64,200	80.4	5,140	-3062	1789	
I.C.1.b.2	497	1016	64,200	80.4	5,140	-2550	1830	
I.C.2.a.1	497	1016	32,100	80.4	2,570	-1677	78	
I.C.2.a.2	497	1016	32,100	80.4	2,570	-1397	85	
I.C.2.b.1	497	1016	32,100	80.4	2,570	-1840	376	
I.C.2.b.2	497	1016	32,100	80.4	2,570	-1303	419	
I.C.3.a.1	497	2032	64,200	160.8	5,140	-3352	146	
I.C.3.a.2	497	2032	64,200	160.8	5,140	-2834	169	
I.C.3.b.1	497	2032	64,200	160.8	5,140	-3682	1739	
I.C.3.b.2	497	2032	64,200	160.8	5,140	-2658	1819	
I.C.4.a.1	497	2032	32,100	160.8	2,570	-2054	58	
I.C.4.a.2	497	2032	32,100	160.8	2,570	-1495	81	
I.C.4.b.1	497	2032	32,100	160.8	2,570	-2460	326	
I.C.4.b.2	497	2032	32,100	160.8	2,570	-1387	413	

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fmc

Load and stress analysis of: LVT Suspension
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PROBLEM NUMBER	I	j	h	f	d	ψ_3	ψ_4	
1								
I.C.1.a.1	14,200	37,200	1,097,000	80.4	5,140	1970	51,150	
I.C.1.a.2	14,200	37,200	1,097,000	80.4	5,140	411	16,210	
I.C.1.b.1	14,200	37,200	1,097,000	80.4	5,140	4283	43,314	
I.C.1.b.2	14,200	37,200	1,097,000	80.4	5,140	1231	4,614	
I.C.2.a.1	14,200	37,200	548,000	80.4	2,570	2045	49,122	
I.C.2.a.2	14,200	37,200	548,000	80.4	2,570	370	11,562	
I.C.2.b.1	14,200	37,200	548,000	80.4	2,570	4688	43,315	
I.C.2.b.2	14,200	37,200	548,000	80.4	2,570	1487	2,693	
I.C.3.a.1	14,200	74,200	1,097,000	160.8	5,140	4050	99,550	
I.C.3.a.2	14,200	74,200	1,097,000	160.8	5,140	963	28,680	
I.C.3.b.1	14,200	74,200	1,097,000	160.8	5,140	7983	90,214	
I.C.3.b.2	14,200	74,200	1,097,000	160.8	5,140	1873	12,754	
I.C.4.a.1	14,200	74,200	548,000	160.8	2,520	4125	97,522	
I.C.4.a.2	14,200	74,200	548,000	160.8	2,570	793	21,102	
I.C.4.b.1	14,200	74,200	548,000	160.8	2,570	8388	90,183	
I.C.4.b.2	14,200	74,200	548,000	160.8	2,570	1986	9,003	

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Problem Number	Coefficients of: $\ddot{X}$	$\dot{X}$	X	$\dot{\theta}$	θ	Sin ωt	Cos ωt	ω
I.C.1.a.1	1	2.04	129.	0.162	10.34	-6.05	0.334	30.7
I.C.1.a.2	1	2.04	129.	0.162	10.34	-5.6	0.346	8.03
I.C.1.b.1	1	2.04	129.	0.162	10.34	-6.16	3.6	46.
I.C.1.b.2	1	2.04	129.	0.162	10.34	-5.13	3.68	8.02
I.C.2.a.1	1	2.04	64.5	0.162	5.17	-3.37	0.157	30.7
I.C.2.a.2	1	2.04	64.5	0.162	5.17	-2.81	0.171	6.22
I.C.2.b.1	1	2.04	64.5	0.162	5.17	-3.7	0.757	46.
I.C.2.b.2	1	2.04	64.5	0.162	5.17	-2.62	0.842	6.19
I.C.3.a.1	1	4.08	129.	0.323	10.34	-6.74	0.294	30.7
I.C.3.a.2	1	4.08	129.	0.323	10.34	-5.7	0.34	8.03
I.C.3.b.1	1	4.08	129.	0.323	10.34	-7.4	3.5	46.
I.C.3.b.2	1	4.08	129.	0.323	10.34	-5.34	3.66	8.02
I.C.4.a.1	1	4.08	64.5	0.323	5.17	-4.13	0.117	30.7
I.C.4.a.2	1	4.08	64.5	0.323	5.17	-3.01	0.163	6.22
I.C.4.b.1	1	4.08	64.5	0.323	5.17	-4.95	0.656	46.
I.C.4.b.2	1	4.08	64.5	0.323	5.17	-2.79	0.829	6.19

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

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Problem Number	Coefficients of: $\ddot{\theta}$	$\dot{\theta}$	θ	$\dot{X}$	X	Sin ωt	Cos ωt	ω
I.C.1.a.1	1	2.62	77.2	0.00566	0.362	0.139	3.6	30.7
I.C.1.a.2	1	2.62	77.2	0.00566	0.362	0.0289	1.14	8.03
I.C.1.b.1	1	2.62	77.2	0.00566	0.362	0.302	3.05	46.
I.C.1.b.2	1	2.62	77.2	0.00566	0.362	0.0867	0.325	8.02
I.C.2.a.1	1	2.62	38.6	0.00566	0.181	0.144	3.46	30.7
I.C.2.a.2	1	2.62	38.6	0.00566	0.181	0.026	0.813	6.22
I.C.2.b.1	1	2.62	38.6	0.00566	0.181	0.33	3.05	46.
I.C.2.b.2	1	2.62	38.6	0.00566	0.181	0.105	0.19	6.19
I.C.3.a.1	1	5.22	77.2	0.0113	0.362	0.285	7.01	30.7
I.C.3.a.2	1	5.22	77.2	0.0113	0.362	0.0678	2.02	8.03
I.C.3.b.1	1	5.22	77.2	0.0113	0.362	0.562	6.95	46.
I.C.3.b.2	1	5.22	77.2	0.0113	0.362	0.132	0.898	8.02
I.C.4.a.1	1	5.22	38.6	0.0113	0.181	0.29	6.87	30.7
I.C.4.a.2	1	5.22	38.6	0.0113	0.181	0.0558	1.49	6.22
I.C.4.b.1	1	5.22	38.6	0.0113	0.181	0.59	6.35	46.
I.C.4.b.2	1	5.22	38.6	0.0113	0.181	0.14	0.634	6.19

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

CORRELATION OF SIMULATED DATA (Continued)

Computer Simulation

The two coupled differential equations for each vehicle are further reduced for computer simulation. The reduced equations are shown on the following page.

This section also contains a block diagram of the analog computer set up. The triangular shaped boxes are integrating amplifiers which evaluate the various A_n and B_n constants. Lines drawn on the diagram indicate information motion in the circuits during the computing cycle.

Computer constants are shown in tabular form for the various case studies for each vehicle. Output scaling constants are also included in tabular form for each case study.

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Equation Reduction for Computer Simulation

$$\ddot{X} + a_1\dot{X} + a_2X + a_3\dot{\theta} + a_4\theta = a_5 \sin\omega t + a_6 \cos\omega t$$

$$\ddot{\theta} + b_1\dot{\theta} + b_2\theta + b_3\dot{X} + b_4X = b_5 \sin\omega t + b_6 \cos\omega t$$

let: $X \triangleq Ay$, $\theta \triangleq B\phi$, $t \triangleq C\tau$; $(\dot{\ }) = \frac{d}{dt}(\ )$

and $(\ )' = \frac{d}{d\tau}(\ )$

then: $$\frac{A}{C^2}y'' + \frac{a_1A}{C}y' + a_2Ay + \frac{a_3B}{C}\phi'$$

$$+ a_4B\phi = a_5 \sin c\omega t + a_6 \cos c\omega t$$

$$\frac{B}{C^2}\phi'' + \frac{b_1B}{C}\phi' + b_2B\phi + \frac{b_3A}{C}y' + b_4Ay$$

$$= b_5 \sin c\omega t + b_6 \cos c\omega t$$

$$y'' = -\left[a_1Cy' + a_2C^2y + a_3\frac{BC}{A}\phi' + a_4\frac{BC^2}{A}\phi\right]$$

$$+ \frac{a_5C^2}{A}\sin\Omega\tau + \frac{a_6C^2}{A}\cos\Omega\tau$$

$$\phi'' = -\left[b_1C\phi' + b_2C^2\phi + b_3\frac{AC}{B}y' + b_4\frac{AC^2}{B}y\right]$$

$$+ \frac{b_5C^2}{B}\sin\Omega\tau + \frac{b_6C^2}{B}\cos\Omega\tau$$

where $\Omega \triangleq c\omega$

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$$y'' = -\left[\alpha_1y' + \alpha_2y + \alpha_3\phi' + \alpha_4\phi\right] + \alpha_5 \sin\Omega\tau$$

$$+ \alpha_6 \cos\Omega\tau$$

$$\phi'' = -\left[\beta_1\phi' + \beta_2\phi + \beta_3y' + \beta_4y\right] + \beta_5 \sin\Omega\tau$$

$$+ \beta_6 \cos\Omega\tau$$

where

$\alpha_1 = a_1C$, $\alpha_2 = a_2C^2$, $\alpha_3 = a_3\frac{CB}{A}$

$\alpha_4 = a_4\frac{C^2B}{A}$, $\alpha_5 = a_5\frac{C^2}{A}$, $\alpha_6 = a_6\frac{C^2}{A}$

$\beta_1 = b_1C$, $\beta_2 = b_2C^2$, $\beta_3 = b_3\frac{CA}{B}$

$\beta_4 = b_4\frac{C^2A}{B}$, $\beta_5 = b_5\frac{C^2}{B}$, $\beta_6 = b_6\frac{C^2}{B}$

and

$A_7 = \alpha_1$, $A_8 = \alpha_2$, $A_9 = \alpha_3$

$A_{10} = \alpha_4$, $A_{11} = \Omega\alpha_5$, $A_{12} = -\alpha_6$

$A_{13} = \frac{\Omega^2}{100}$, $A_{14} = \beta_1$, $A_{15} = \beta_2$.

$A_{16} = \beta_3$, $A_{17} = \beta_4$, $A_{18} = \Omega\beta_5$

$A_{19} = -\beta_6$, $A_{20} = \Omega^2/100$

fmc CORPORATION

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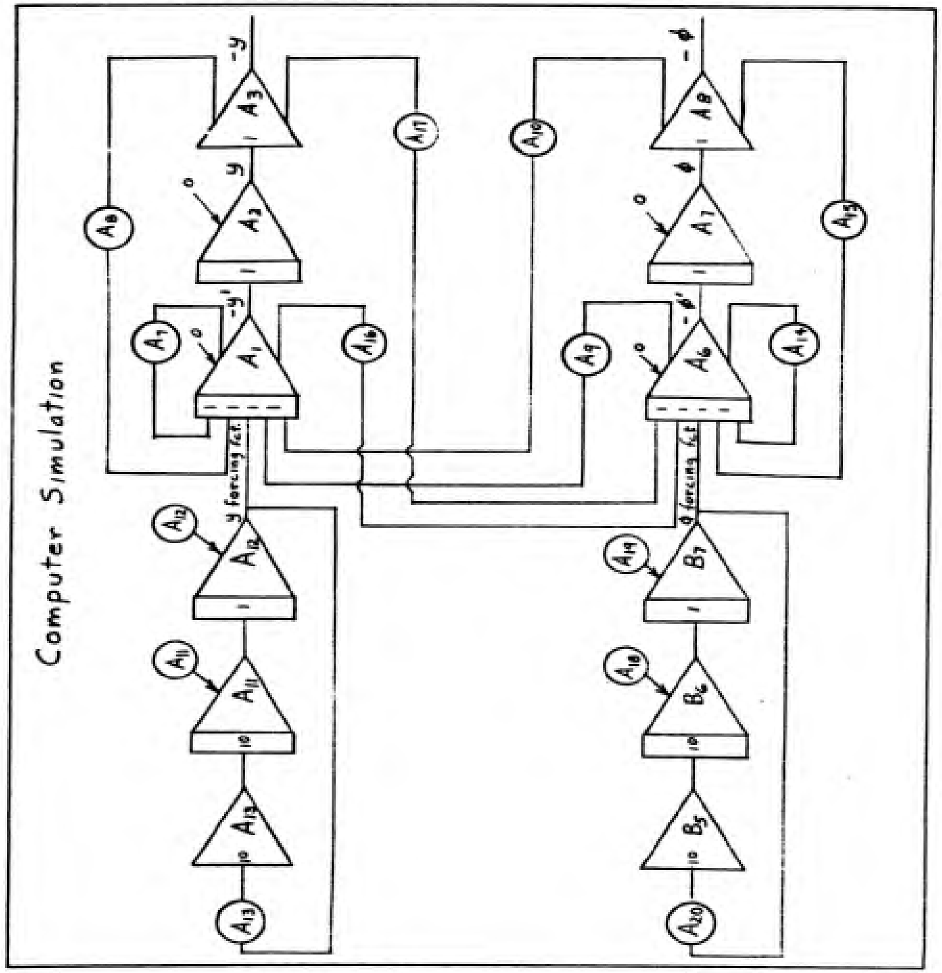
Computer Simulation

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fmc CORPORATION

Load and stress analysis of: LVT Suspension
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CASE	I A1a1(X)	I A1a2(X)
Ω	6.14	2.04
α_1	0.408	0.408
α_2	7.72	7.72
α_3	0.00432	0.00432
α_4	0.0819	0.0819
α_5	-14.76	-30.4
$\Omega\alpha_6$	-90.7	-62.0
α_6	-6.92	-7.20
A	$\frac{1}{10}$	$\frac{1}{20}$
B	$\frac{1}{80}$	$\frac{1}{160}$
C	$\frac{1}{5}$	$\frac{1}{5}$

CASE	I A1a1(X)	I A1a2(X)
Ω	6.14	2.04
β_1	0.2254	0.2254
β_2	4.268	4.268
β_3	0.00972	0.00972
β_4	0.184	0.184
β_5	-4.704	-5.25
$\Omega\beta_5$	-28.88	-10.72
β_6	9.12	18.92
A	$\frac{1}{10}$	$\frac{1}{20}$
B	$\frac{1}{80}$	$\frac{1}{160}$
C	$\frac{1}{5}$	$\frac{1}{5}$

Load and stress analysis of: LVT Suspension
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Notation

IA1a1

- Velocities:
  - 1 ≡ 20 mph
  - 2 ≡ Resonant velocity
- Course:
  - a ≡ Sine wave ; L = 6 ft , A = 3 inches
  - b ≡ Sine wave ; L = 4 ft , A = 2 inches
- Spring Rates:
  - 1 ≡ 6" deflection under 2 G's with shock at 508 lbs-sec/ft
  - 2 ≡ 12" deflection under 2 G's with shock at 508 lbs-sec/ft
  - 3 ≡ 6" deflection under 2 G's with shock at 1016 lbs-sec/ft
  - 4 ≡ 12" deflection under 2 G's with shock at 1016 lbs-sec/ft
- Vehicles Studied:
  - A ≡ 8 wheels, 4 walking beams
  - B ≡ 12 wheels, 6 walking beams
  - C ≡ 12 wheels, individually sprung
- Part One

Load and stress analysis of: LVT Suspension
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Scaling constants (8 road wheels / 4 walking beams)

CASE	Ω	α_1	α_2	α_3	α_4	α_5	$\Omega\alpha_5$	α_6	A	B	C
IA1a1	6.14	0.408	5.16	0.00696	0.0876	-11.2	-68.76	-7.32	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IA1a2	1.68	0.408	5.16	0.00696	0.0876	-23.84	-40.04	-6.16	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{5}$
IA1b1	4.60	0.204	1.29	0.00348	0.0219	-16.2	-74.5	-20.4	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{10}$
IA1b2	1.68	0.408	5.16	0.00696	0.0876	-32.4	-54.4	-16.6	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IA2a1	6.14	0.408	2.576	0.00696	0.04376	[illegible]	51.44	-10.53	$\frac{1}{80}$	$\frac{1}{400}$	$\frac{1}{5}$
IA2a2	1.188	0.408	2.576	0.00696	0.04376	-58.4	-69.4	-18.7	$\frac{1}{500}$	$\frac{1}{2500}$	$\frac{1}{5}$
IA2b1	4.60	0.204	0.644	0.00348	0.0109	-18.06	-83.1	-52.8	$\frac{1}{300}$	$\frac{1}{1500}$	$\frac{1}{10}$
IA2b2	1.184	0.408	2.576	0.00696	0.04376	-76.8	-90.88	-37.6	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$
IA3a1	6.14	0.816	5.16	0.01388	0.0876	-8.384	-51.52	-10.528	$\frac{1}{40}$	$\frac{1}{200}$	$\frac{1}{5}$
IA3a2	1.738	0.816	5.16	0.01388	0.0876	-9.216	-16.0	-3.824	$\frac{1}{40}$	$\frac{1}{200}$	$\frac{1}{5}$
IA3b1	4.60	0.408	1.29	0.00694	0.0219	-12.06	-55.5	-35.1	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{10}$
IA3b2	1.68	0.816	5.16	0.01388	0.0876	-27.0	-45.32	-22.0	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IA4a1	6.14	0.816	2.576	0.01388	0.04376	-3.616	-22.58	-9.92	$\frac{1}{40}$	$\frac{1}{200}$	$\frac{1}{5}$
IA4a2	1.188	0.816	2.576	0.01388	0.04376	-57.0	-67.76	-30.0	$\frac{1}{500}$	$\frac{1}{2500}$	$\frac{1}{5}$
IA4b1	4.60	0.408	0.644	0.00694	0.0109	-38.8	-17.84	-64.7	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{10}$
IA4b2	1.184	0.816	2.576	0.01388	0.04376	-72.64	-85.92	-52.88	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$

fmc CORPORATION

Load and stress analysis of: LVT Suspension
Prepared by M. Maltz Date 12 Sept. 61 Page No. 94
Checked by L. Gerard Dwg. No. ______ Project No. ΔΔ9

Scaling constants (Δ walking beams / 8 road wheels)

CASE	Ω	β_1	β_2	β_3	β_4	β_5	$\Omega\beta_5$	β_6	A	B	C
IA1a1	6.14	0.226	2.84	0.00608	0.0766	8.83	54.2	-13.9	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IA1a2	1.68	0.226	2.84	0.00608	0.766	7.24	12.16	-28.9	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{5}$
IA1b1	4.60	0.113	0.710	0.00304	0.01915	-1.22	-5.6	-0.324	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{10}$
IA1b2	1.68	0.226	2.84	0.00608	0.0766	-1.36	-22.84	0.00422	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IA2a1	6.14	0.226	1.42	0.00608	0.0383	12.8	78.6	-10.46	$\frac{1}{80}$	$\frac{1}{400}$	$\frac{1}{5}$
IA2a2	1.188	0.226	1.42	0.00608	0.0383	22.2	26.4	-52.3	$\frac{1}{500}$	$\frac{1}{2500}$	$\frac{1}{5}$
IA2b1	4.60	0.113	0.355	0.00304	0.009575	-2.835	-13.05	0.0741	$\frac{1}{300}$	$\frac{1}{1500}$	$\frac{1}{10}$
IA2b2	1.184	0.226	1.42	0.00608	0.0383	-2.98	-3.528	3.16	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$
IA3a1	6.14	0.452	2.84	0.01215	0.0766	12.8	78.56	-10.44	$\frac{1}{40}$	$\frac{1}{200}$	$\frac{1}{5}$
IA3a2	1.738	0.452	2.84	0.01215	0.0766	4.57	7.86	-11.37	$\frac{1}{40}$	$\frac{1}{200}$	$\frac{1}{5}$
IA3b1	4.60	0.226	0.710	0.00608	0.01915	-1.915	-8.8	-0.78	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{10}$
IA3b2	1.68	0.452	2.84	0.01215	0.0766	5.54	9.32	-0.106	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IA4a1	6.14	0.452	1.42	0.01215	0.0383	12.12	74.4	-4.576	$\frac{1}{40}$	$\frac{1}{200}$	$\frac{1}{5}$
IA4a2	1.184	0.452	1.42	0.1215	0.0383	36.0	42.8	-70.3	$\frac{1}{500}$	$\frac{1}{2500}$	$\frac{1}{5}$
IA4b1	4.60	0.226	0.355	0.00608	0.09575	-3.21	-14.75	-0.867	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{10}$
IA4b2	1.184	0.452	1.42	0.01215	0.0383	-2.456	-2.912	2.704	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

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fmc

Load and stress analysis of: LVT Suspension
Prepared by M. Maltz Date 6 Aug 61 Page No. 95
Checked by ______ Dwg. No. ______ Project No. ΔΔ9

A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}	CASE
.408	5.16	.0070	.0876	-68.76	-7.32	37.75	.226	2.84	.0061	.0766	+54.2	+13.9	37.75	1a1
.408	5.16	.0070	.0876	-40.04	-6.16	2.82	.226	2.84	.0061	.0766	+12.16	+28.9	2.82	1a2
.204	1.29	.0035	.0219	-74.5	+22.4	21.2	.113	.710	.0030	.0192	-5.6	+.324	21.2	1b1
.408	5.16	.0070	.0876	-84.4	+16.6	2.82	.226	2.84	.0061	.0766	-22.84	-.0042	2.82	1b2
.408	2.58	.0070	.0438	-51.44	+10.53	37.75	.226	1.42	.0061	.0383	+78.6	+10.46	37.75	2a1
.408	2.58	.0070	.0438	-65.4	+18.7	1.414	.226	1.42	.0061	.0383	+26.4	+52.3	1.414	2a2
.204	.644	.0035	.0109	-83.1	+52.8	21.2	.113	.355	.0030	.0096	-13.05	-.0741	21.2	2b1
.408	2.576	.0070	.0438	-90.88	+37.6	1.40	.226	1.42	.0061	.0383	-3.53	-3.16	1.40	2b2
.816	5.16	.0139	.0876	-51.52	+10.53	37.75	.452	2.84	.0122	.0766	+78.56	+10.44	37.75	3a1
.816	5.16	.0139	.0876	-16.0	+3.82	3.02	.452	2.84	.0122	.0766	+7.86	+11.37	3.02	3a2
.408	1.29	.0069	.0219	-55.5	-35.1	21.2	.226	.710	.0061	.0192	-8.8	+.78	21.2	3b1
.816	5.16	.0139	.0876	-45.32	+22.0	2.82	.452	2.84	.0122	.0766	+9.32	+.11	2.82	3b2
.816	2.58	.0139	.0438	-22.58	+9.92	37.75	.452	1.42	.0122	.0383	+74.4	+4.58	37.75	4a1
.816	2.58	.0139	.0438	-67.76	+30.0	1.414	.452	1.42	.0122	.0383	+42.8	+72.3	1.414	4a2
.408	.644	.0069	.0109	-17.64	+64.7	21.2	.226	.355	.0061	.0153	-14.75	+.87	21.2	4b1
.816	2.58	.0139	.0438	-85.92	+52.88	1.40	.452	1.42	.0122	.0383	-2.91	+2.70	1.40	4b2

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT Suspension
Prepared by M Maltz Date 6 Aug 61 Page No. 96
Checked by NOTE! 1cm = 2 major divisions Dwg. No. Project No. 449

Case	x (ft/cm)	$\dot{x}$ (ft/sec/cm)	θ (rad/cm)	$\dot{\theta}$ (rad/sec/cm)	t (sec/cm)
① 1a1	1/50	1/2	1/250	1/10	0.400
② 1a2	1/20	1/2	1/10	1/2	0.500
③ 1b1	1/50	1/2	1/500	1/50	0.200
④ 1b2	1/5	2.0	2/25	1.0	0.800
⑤ 2a1	1/80	1/8	1/400	1/40	0.400
⑥ 2a2	2/25	2/5	1/25	2/5	0.800
⑦ 2b1	1/60	1/3	1/1500	1/150	0.200
⑧ 2b2	1/4	5/4	1/100	1/20	0.800
⑨ 3a1	1/40	1/4	1/200	1/20	0.400
⑩ 3a2	1/20	5/8	1/200	1/2	0.800
⑪ 3b1	1/50	1/2	1/500	1/50	0.400
⑫ 3b2	1/5	2	1/50	1/5	0.800
⑬ 4a1	1/40	1/4	1/200	1/20	0.400
⑭ 4a2	1/25	1/2	1/25	1/5	0.800
⑮ 4b1	1/100	1/2	1/1000	1/100	0.200
⑯ 4b2	1/4	5/4	1/500	1/40	0.800

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT Suspension
Prepared by M. Maltz Date 12 Sept 61 Page No. 97
Checked by L. Gerard Dwg. No. Project No. 449

Scaling Constants (12 road wheels / 6 walking beams)

CASE	Ω	α_1	α_2	α_3	α_4	α_5	$\Omega\alpha_5$	α_6	A	B	C
IB1a1	6.14	0.408	5.16	0.00696	0.05856	-11.12	-68.36	-8.08	1/50	1/250	1/5
IB1a2	1.612	0.408	5.16	0.00692	0.05856	-43.92	-70.72	-1.36	1/200	1/1000	1/5
IB1b1	9.2	0.408	5.16	0.00696	0.05856	-8.38	-77.0	+1.05	1/25	1/125	1/5
IB1b2	1.61	0.408	5.16	0.00696	0.05856	-34.32	-55.2	-0.688	1/200	1/1000	1/5
IB2a1	6.14	0.408	2.58	0.00696	0.02928	-11.32	-69.52	-4.32	1/100	1/500	1/5
IB2a2	1.19	0.408	2.58	0.00696	0.02928	-11.04	-13.14	-0.652	1/100	1/500	1/5
IB2b1	9.2	0.408	2.58	0.00696	0.02928	-6.65	-61.2	-1.00	1/25	1/125	1/5
IB2b2	1.188	0.408	2.58	0.00696	0.02928	-47.2	-56.04	-1.72	1/500	1/2500	1/5
IB3a1	6.14	0.816	5.16	0.01388	0.05856	-11.30	-69.36	-4.4	1/50	1/250	1/5
IB3a2	1.612	0.816	5.16	0.01388	0.05856	-44.0	-70.88	-3.744	1/200	1/1000	1/5
IB3b1	9.2	0.816	5.16	0.01388	0.05856	-7.98	-73.44	-1.202	1/15	1/75	1/5
IB3b2	1.61	0.816	5.16	0.01388	0.05856	-41.04	-66.08	-2.112	1/200	1/1000	1/5
IB4a1	6.14	0.816	2.58	0.01388	0.02928	-5.84	-35.84	-4.52	1/50	1/250	1/5
IB4a2	1.19	0.816	2.58	0.01388	0.02928	-55.4	-65.92	-7.67	1/500	1/2500	1/5
IB4b1	9.2	0.816	2.58	0.01388	0.02928	-6.95	-64.0	-1.23	1/75	1/75	1/5
IB4b2	1.188	0.816	2.58	0.01388	0.02928	-40.3	-48.0	-22.2	1/250	1/1250	1/5

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

fmc CORPORATION

Load and stress analysis of: LVT Suspension

Prepared by M. Maltz Date 12 Sept 61 Page No. 98

Checked by L. Gerard Dwg. No. ______ Project No. 449

Scaling (12 road wheels / 6 walking beams)

CASE	Ω	β_1	β_2	β_3	β_4	β_5	$\Omega\beta_5$	β_6	A	B	C
IB1a1	6.14	0.335	2.828	0.00608	0.0512	-7.42	-45.6	10.5	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IB1a2	1.612	0.335	2.828	0.00608	0.0512	-6.48	-10.448	40.4	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$
IB1b1	9.2	0.335	2.828	0.00608	0.0512	-0.3355	-3.08	-4.15	$\frac{1}{25}$	$\frac{1}{125}$	$\frac{1}{5}$
IB1b2	1.61	0.335	2.828	0.00608	0.0512	-2.832	-4.56	-30.88	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$
IB2a1	6.14	0.335	1.412	0.00608	0.0256	-15.16	-93.04	9.52	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{5}$
IB2a2	1.19	0.335	1.412	0.00608	0.0256	-2.56	-3.05	40.56	$\frac{1}{100}$	$\frac{1}{500}$	$\frac{1}{5}$
IB2b1	9.2	0.335	1.412	0.00608	0.0256	-0.156	-1.434	-2.25	$\frac{1}{25}$	$\frac{1}{125}$	$\frac{1}{5}$
IB2b2	1.188	0.335	1.412	0.00608	0.0256	-3.5	-4.08	-39.0	$\frac{1}{300}$	$\frac{1}{2000}$	$\frac{1}{5}$
IB3a1	6.14	0.672	2.828	0.01215	0.0512	-15.1	-92.6	9.54	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IB3a2	1.612	0.672	2.828	0.01215	0.0512	-14.4	-23.2	40.12	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$
IB3b1	9.2	0.672	2.828	0.01215	0.0512	-0.1829	-1.776	-2.697	$\frac{1}{75}$	$\frac{1}{75}$	$\frac{1}{5}$
IB3b2	1.61	0.672	2.828	0.01215	0.0512	-2.8	-4.504	-31.4	$\frac{1}{200}$	$\frac{1}{1000}$	$\frac{1}{5}$
IB4a1	6.14	0.672	1.412	0.01215	0.0256	-15.3	-93.8	4.45	$\frac{1}{50}$	$\frac{1}{250}$	$\frac{1}{5}$
IB4a2	1.19	0.672	1.412	0.01215	0.0256	-27.2	-32.34	50.1	$\frac{1}{500}$	$\frac{1}{2500}$	$\frac{1}{5}$
IB4b1	9.2	0.672	1.412	0.01215	0.0256	-0.0852	-0.784	-1.56	$\frac{1}{75}$	$\frac{1}{75}$	$\frac{1}{5}$
IB4b2	1.188	0.672	1.412	0.01215	0.0256	-10.65	-12.67	-19.95	$\frac{1}{250}$	$\frac{1}{1250}$	$\frac{1}{5}$

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

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fmc

Load and stress analysis of: LVT Suspension

Prepared by M. Maltz Date 6 Aug 61 Page No. 99

Checked by ______ Dwg. No. ______ Project No. 449

$A_7^{\alpha_1}$	$A_8^{\alpha_2}$	$A_9^{\alpha_3}$	$A_{10}^{\alpha_4}$	A_{11}	A_{12}	A_{13}	$A_{14}^{\beta_1}$	$A_{15}^{\beta_2}$	$A_{16}^{\beta_3}$	$A_{17}^{\beta_4}$	A_{18}	$A_{19}^{\beta_6}$	A_{20}	Case
.408	5.16	.00696	.05832	-18.36	+8.08	37.75	.335	2.828	.00608	.0512	-45.6	-10.5	37.75	1a1
				-70.72	+1.36	2.6					-10.45	-40.4	2.6	1a2
				-77.0	-1.05	84.7					-3.08	+4.15	84.7	1b1
	↓		↓	-55.2	+.69	2.59		↓		↓	-4.56	+30.88	2.59	1b2
	2.58		.02928	-69.52	+4.32	37.75		1.412		.0256	-93.04	-9.52	37.75	2a1
				-13.14	+.65	1.42					-3.05	-40.56	1.42	2a2
				-6.12	+1.00	84.7					-1.43	+2.25	84.7	2b1
↓	↓	↓	↓	-52.04	+1.72	1.41	↓	↓	↓	↓	-1.08	+37.0	1.41	2b2
.816	5.16	.01388	.05832	-69.36	+4.4	37.75	.672	2.828	.01215	.0512	-92.6	-9.54	37.75	3a1
				-70.88	+3.74	2.6					-23.2	-40.12	2.6	3a2
				-73.44	+1.21	84.7					-1.78	+2.70	84.7	3b1
	↓		↓	-66.08	+2.11	2.59		↓		↓	-45.04	+31.4	2.59	3b2
	2.58		.02928	-35.84	+4.52	37.75		1.412		.0256	-93.8	-4.45	37.75	4a1
				-65.92	+7.64	1.42					-32.34	-50.1	1.42	4a2
				-64.	+1.23	84.7					-.784	-1.52	84.7	4b1
↓	↓	↓	↓	-48.0	+22.2	1.41	↓	↓	↓	↓	-12.67	+19.95	1.41	4b2

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT Suspension
Prepared by M. Maltz Date 14 Sept 61 Page No. 100
Checked by L. Gerard Dwg. No. Project No. 449

Scaling (12 road wheels/6 walking beams)

CASE	X	$\dot{X}$	θ	$\dot{\theta}$	Time
	ft/cm	ft/sec / cm	rad/cm	rad/sec / cm	sec/cm
IB1a1	1/50	1/5	1/250	1/25	0.400
IB1a2	1/10	1/2	1/20	1/4	0.800
IB1b1	1/25	1/5	1/125	1/25	0.400
IB1b2	1/20	1/2	1/20	1/4	0.800
IB2a1	1/100	1/10	1/500	1/50	0.400
IB2a2	1/10	1/2	1/10	1/2	0.800
IB2b1	1/25	1/5	1/125	1/25	0.400
IB2b2	1/25	1/2	1/50	1/10	0.800
IB3a1	1/50	1/5	1/250	1/25	0.400
IB3a2	1/20	1/2	1/50	1/4	0.800
IB3b1	1/15	1/3	1/75	1/15	0.400
IB3b2	1/20	1/2	1/20	1/4	0.800
IB4a1	1/50	1/10	1/250	1/25	0.400
IB4a2	1/25	1/2	1/50	1/10	0.800
IB4b1	1/15	1/3	1/75	1/15	0.400
IB4b2	1/25	1/10	1/25	1/5	0.800

Load and stress analysis of: LVT Suspension
Prepared by M. Maltz Date 14 Sept 61 Page No. 101
Checked by L. Gerard Dwg. No. Project No. 449

Scaling (12 road wheels individually sprung)

CASE	Ω	α_1	α_2	α_3	α_4	$\Omega\alpha_5$	$-\alpha_6$	A	B	C
IC1a1	6.14	0.408	5.16	0.0065	0.0827	-74.25	-0.67	1/50	1/250	1/5
IC1a2	1.606	0.408	5.16	0.0065	0.0827	-72.0	-2.77	1/200	1/1000	1/5
IC1b1	4.6	0.204	1.29	0.0032	0.0207	-56.8	-7.2	1/200	1/1000	1/10
IC1b2	1.604	0.408	5.16	0.0065	0.0827	-65.8	-29.44	1/200	1/1000	1/5
IC2a1	6.14	0.408	2.58	0.0065	0.0414	-41.35	-0.32	1/50	1/200	1/5
IC2a2	1.244	0.408	2.58	0.0065	0.0414	-70.0	-3.42	1/500	1/2500	1/5
IC2b1	4.6	0.204	0.645	0.0032	0.0103	-34.2	-1.51	1/200	1/1000	1/10
IC2b2	1.238	0.408	2.58	0.0065	0.0414	-65.0	-16.84	1/500	1/2500	1/5
IC3a1	6.14	0.816	5.16	0.0129	0.0827	-11.35	-0.30	1/25	1/125	1/5
IC3a2	1.606	0.816	5.16	0.0129	0.0827	-73.4	-2.72	1/200	1/1000	1/10
IC3b1	4.6	0.408	1.29	0.0065	0.0207	-68.1	-7.0	1/200	1/1000	1/10
IC3b2	1.604	0.816	5.16	0.0129	0.0827	-68.2	-29.28	1/200	1/1000	1/5
IC4a1	6.14	0.816	2.58	0.0129	0.0414	-25.32	-0.12	1/25	1/125	1/5
IC4a2	1.244	0.816	2.58	0.0129	0.0414	-37.5	-1.63	1/250	1/1250	1/5
IC4b1	4.6	0.408	0.645	0.0065	0.0103	-45.6	-1.31	1/200	1/1000	1/10
IC4b2	1.238	0.816	2.58	0.0129	0.0414	-69.0	-16.58	1/500	1/2500	1/5

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Load and stress analysis of: LVT Suspension
Prepared by M. Maltz Date 14 Sept 61 Page No. 102
Checked by L. Gerard Dwg. No. Project No. 449

Scaling (12 road wheels individually sprung)

CASE	Ω	β_1	β_2	β_3	β_4	$\Omega\beta_5$	$-\beta_6$	$\frac{c^2}{A}$	$\frac{c^2}{B}$	Ω^2
IC1a1	6.14	0.524	3.088	0.0057	0.0724	8.54	-36.0	2	10	37.75
IC1a2	1.606	0.524	3.088	0.0057	0.0724	1.86	-45.6	8.0	40	2.58
IC1b1	4.6	0.262	0.772	0.0028	0.0181	13.9	-30.5	2.0	10	21.2
IC1b2	1.604	0.524	3.088	0.0057	0.0724	5.57	-13.0	8.0	40	2.57
IC2a1	6.14	0.524	1.544	0.0057	0.0362	8.85	-34.6	4.0	20	37.75
IC2a2	1.244	0.524	1.544	0.0057	0.0362	3.24	-81.3	20	100	1.55
IC2b1	4.6	0.262	0.386	0.0028	0.0090	15.19	-30.50	2	10	21.2
IC2b2	1.238	0.524	1.544	0.0057	0.0362	13.0	-19.0	20	100	1.53
IC3a1	6.14	1.044	3.088	0.0113	0.0724	8.75	-35.05	1	5	37.75
IC3a2	1.606	1.044	3.088	0.0113	0.0724	4.35	-80.8	8	40	2.58
IC3b1	4.6	0.524	0.772	0.0056	0.0181	25.85	-63.5	2	10	21.2
IC3b2	1.604	1.044	3.088	0.0113	0.0724	8.47	-35.92	8	40	2.57
IC4a1	6.14	1.044	1.544	0.0113	0.0362	8.9	-34.35	1	5	37.75
IC4a2	1.244	1.044	1.544	0.0113	0.0362	3.48	-74.5	10	50	1.55
IC4b1	4.6	0.524	0.386	0.0056	0.009	27.2	-63.5	2	10	21.2
IC4b2	1.238	1.044	1.544	0.0113	0.0362	17.24	-63.4	20	100	1.53

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Load and stress analysis of: LVT Suspension
Prepared by M Maltz Date 15 Sept 61 Page No. 103
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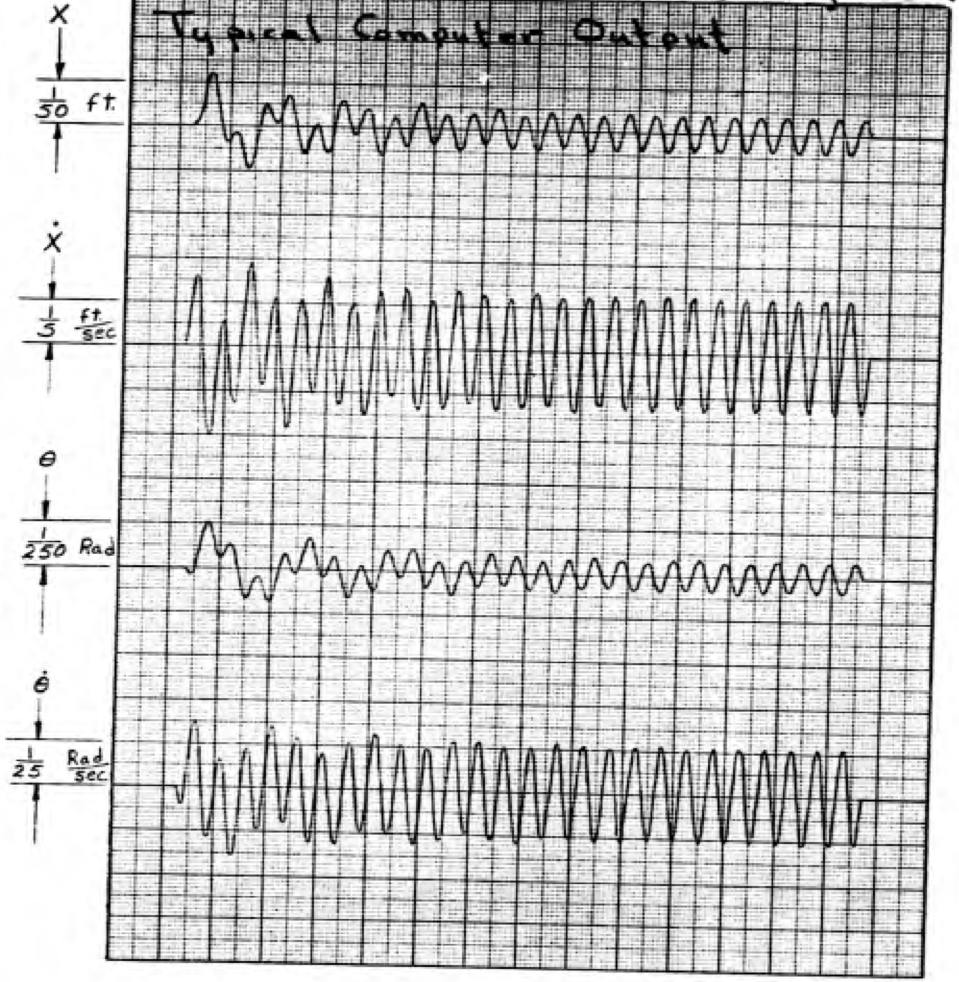
Scaling (12 road wheels ind. sprung)

CASE	X	$\dot{X}$	θ	$\dot{\theta}$	Time
	ft/cm	$\frac{ft/sec}{cm}$	rad/cm	$\frac{rad/sec}{cm}$	sec/cm
IC1a1	$\frac{1}{50}$	$\frac{1}{5}$	$\frac{1}{250}$	$\frac{1}{10}$	0.400
IC1a2	$\frac{1}{20}$	$\frac{1}{2}$	$\frac{1}{20}$	$\frac{1}{4}$	0.800
IC1b1	$\frac{1}{200}$	$\frac{1}{10}$	$\frac{1}{1000}$	$\frac{1}{20}$	0.200
IC1b2	$\frac{1}{20}$	$\frac{1}{2}$	$\frac{1}{100}$	$\frac{1}{10}$	0.800
IC2a1	$\frac{1}{50}$	$\frac{1}{5}$	$\frac{1}{125}$	$\frac{1}{5}$	0.400
IC2a2	$\frac{1}{10}$	$\frac{1}{2}$	$\frac{1}{50}$	$\frac{1}{5}$	0.800
IC2b1	$\frac{1}{200}$	$\frac{1}{10}$	$\frac{1}{1000}$	$\frac{1}{20}$	0.200
IC2b2	$\frac{1}{10}$	$\frac{1}{2}$	$\frac{1}{125}$	$\frac{1}{25}$	0.800
IC3a1	$\frac{1}{25}$	$\frac{1}{5}$	$\frac{1}{125}$	$\frac{1}{5}$	0.400
IC3a2	$\frac{1}{20}$	1	$\frac{1}{50}$	$\frac{1}{2}$	0.400
IC3b1	$\frac{1}{100}$	$\frac{1}{4}$	$\frac{1}{500}$	$\frac{1}{10}$	0.200
IC3b2	$\frac{1}{20}$	$\frac{1}{2}$	$\frac{1}{100}$	$\frac{1}{10}$	0.800
IC4a1	$\frac{1}{25}$	$\frac{1}{5}$	$\frac{1}{125}$	$\frac{1}{5}$	0.400
IC4a2	$\frac{1}{25}$	$\frac{2}{5}$	$\frac{1}{25}$	$\frac{1}{5}$	0.800
IC4b1	$\frac{1}{100}$	$\frac{1}{4}$	$\frac{1}{500}$	$\frac{1}{10}$	0.200
IC4b2	$\frac{1}{25}$	$\frac{1}{2}$	$\frac{1}{50}$	$\frac{1}{10}$	0.800

LVT Suspension
18 Sept 61
EE Smith Pg 104


Typical Computer Output

Load and stress analysis of: LVT SUSPENSION
Prepared by W Blythe Date 15 AUG '61 Page No. 105
Checked by R Smith Dwg. No. Project No. 449

DETERMINATION OF MAXIMUM DISPLACEMENT AT 7 FEET FROM C.G.:

$$X = x_m \sin\omega t + 7\theta_m \sin(\omega t - \alpha)$$
$$= x_m \sin\omega t + 7\theta_m \sin(\omega t - \omega t_1)$$
$$= x_m \sin\omega t + 7\theta_m \left[\sin\omega t \cos\omega t_1 - \cos\omega t \sin\omega t_1\right]$$
$$= \left[x_m + 7\theta_m \cos\omega t_1\right] \sin\omega t - 7\theta_m \sin\omega t_1 \cos\omega t$$

THEN

$$X_{max} = \left[(x_m + 7\theta_m \cos\omega t_1)^2 + (7\theta_m \sin\omega t_1)^2\right]^{1/2}$$

WHERE

x_m = MAX. X DISPLACEMENT, FROM GRAPH
θ_m = " θ " , " "
ω = CIRCULAR FREQUENCY
t_1 = REAL TIME PHASE LAG, FROM GRAPH

over

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 15 Sept 61 Page No. 106
Checked by Dwg. No. Project No. 449

Notation

IAIa1

Part One

- Velocities:
  - 1 ≡ 20 mph
  - 2 ≡ Resonant velocity
- Course:
  - a ≡ Sine wave; L = 6ft, A = 3 inches
  - b ≡ Sine wave; L = 4ft, A = 2 inches
- Spring Rates:
  - 1 ≡ 6" deflection under 2G's with shock at 508 lbs-sec/ft
  - 2 ≡ 12" deflection under 2G's with shock at 508 lbs-sec/ft
  - 3 ≡ 6" deflection under 2G's with shock at 1016 lbs-sec/ft
  - 4 ≡ 12" deflection under 2G's with shock at 1016 lbs-sec/ft
- Vehicles Studied:
  - A ≡ 8 wheels, 4 walking beams
  - B ≡ 12 wheels, 6 walking beams
  - C ≡ 12 wheels, individually sprung

APPENDIX A

DATA REDUCTION

The computer output consisted of vertical rectilinear translation of the vehicle's center of gravity, the vertical rectilinear velocity of the vehicle's center of gravity, the angle of pitch, and the pitch velocity of the vehicle. This information was obtained from the four channel output of the analog computer for all 48 case studies.

Pertinent vehicle data was reduced from the computer output by applying the basic concepts of rigid body mechanics. This data consists of the following items:

- Front and rear wheel travel relative to the vehicle for steady state and transient response.
- Vertical rectilinear acceleration of the vehicle's center of gravity and the driver's seat.
- Pitch acceleration of the vehicle.
- Time rate of acceleration change at the driver's seat which is defined as the ride comfort factor.

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Load and stress analysis of: LVT SUSPENSION
Prepared by W Blythe Date 15 AUG '61 Page No. 105
Checked by R Smith Dwg. No. ____ Project No. 449

DETERMINATION OF MAXIMUM DISPLACEMENT AT 7 FEET FROM C.G.:

$$\mathrm{X} = x_m \sin\omega t + 7\theta_m \sin(\omega t - \alpha)$$
$$= x_m \sin\omega t + 7\theta_m \sin(\omega t - \omega t_1)$$
$$= x_m \sin\omega t + 7\theta_m \left[\sin\omega t \cos\omega t_1 - \cos\omega t \sin\omega t_1\right]$$
$$= \left[x_m + 7\theta_m \cos\omega t_1\right] \sin\omega t - 7\theta_m \sin\omega t_1 \cos\omega t$$

THEN

$$\mathrm{X}_{max} = \left[(x_m + 7\theta_m \cos\omega t_1)^2 + (7\theta_m \sin\omega t_1)^2\right]^{1/2}$$

WHERE

x_m = MAX. X DISPLACEMENT, FROM GRAPH
θ_m = " θ " , " "
ω = CIRCULAR FREQUENCY
t_1 = REAL TIME PHASE LAG, FROM GRAPH

over

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Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 15 Sept 61 Page No. 106
Checked by ____ Dwg. No. ____ Project No. 449

Notation

I A I a I

- Part One
  - Vehicles Studied:
    - A ≡ 8 wheels, 4 walking beams
    - B ≡ 12 wheels, 6 walking beams
    - C ≡ 12 wheels, individually sprung.
  - Spring Rates:
    - 1 ≡ 6" deflection under 2 G's with shock at 508 lbs-sec/ft
    - 2 ≡ 12" deflection under 2 G's with shock at 508 lbs-sec/ft
    - 3 ≡ 6" deflection under 2 G's with shock at 1016 lbs-sec/ft
    - 4 ≡ 12" deflection under 2 G's with shock at 1016 lbs-sec/ft
  - Course:
    - a ≡ Sine wave; L = 6ft, A = 3 inches
    - b ≡ Sine wave; L = 4ft, A = 2 inches
  - Velocities:
    - 1 ≡ 20 mph
    - 2 ≡ Resonant velocity

Load and stress analysis of: LVT SUSPENSION
Prepared by L. GERARD Date 16 AUG. '61 Page No. 107
Checked by R.S.H. Drg. No. Project No. 449

STEADY STATE RESPONSE

PROBLEM NUMBER	X_m	θ_m	$7\theta_m$	ω	t_1	$\alpha = \omega t_1$	$\cos \alpha$
1	2	3	4	5	6	7	8
I.A.1.a.1	0.008	0.002	0.014	30.7	0.076	2.33	-0.688
I.A.1.a.2	0.083	0.16	1.12	8.69	0.096	0.834	0.676
I.A.1.b.1	0.0126	0.0001	0.0007	46.0	0.01	0.46	0.896
I.A.1.b.2	0.3	0.128	0.895	8.4	0.176	1.48	0.091
I.A.2.a.1	0.005	0.001	0.007	30.7	0.08	2.44	-0.764
I.A.2.a.2	0.083	0.082	0.574	5.94	0.024	0.142	0.990
I.A.2.b.1	0.007	0.0001	0.0007	46.0	0.0015	0.069	0.997
I.A.2.b.2	0.345	0.012	0.084	5.92	0.464	2.74	-0.920
I.A.3.a.1	0.01	0.0024	0.0168	30.7	0.069	2.12	-0.522
I.A.3.a.2	0.096	0.08	0.56	8.69	0.086	0.747	0.733
I.A.3.b.1	0.018	0.0002	0.0014	46.0	0.004	0.184	0.983
I.A.3.b.2	0.26	0.0334	0.234	8.4	0.208	1.75	0.178
I.A.4.a.1	0.007	0.0017	0.0119	30.7	0.073	2.24	-0.620
I.A.4.a.2	0.078	0.060	0.42	5.94	0.16	0.95	0.582
I.A.4.b.1	0.0155	0.00016	0.00112	46.0	0.006	0.276	0.962
I.A.4.b.2	0.30	0.0044	0.0308	5.92	0.024	0.142	0.990

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT SUSPENSION
Prepared by L. GERARD Date 16 AUG. '61 Page No. 108
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STEADY STATE RESPONSE

PROBLEM NUMBER	$\sin \alpha$	(4)(8)	(2)+(10)	(4)(9)	$(11)^2$	$(12)^2$	(13)+(14)	$X_m = (15)^{1/2}$
1	9	10	11	12	13	14	15	16
I.A.1.a.1	0.725	-0.00964	-0.00164	0.0101	2.69×10^{-6}	1.02×10^{-4}	1.05×10^{-4}	0.01021
I.A.1.a.2	0.736	0.758	0.841	0.824	7.05×10^{-1}	6.8×10^{-1}	1.385	1.176
I.A.1.b.1	0.444	0.000627	0.0132	0.000311	1.74×10^{-4}	9.66×10^{-8}	1.74×10^{-4}	0.0132
I.A.1.b.2	0.996	0.0314	0.3814	0.891	1.45×10^{-1}	7.95×10^{-1}	0.94	0.97
I.A.2.a.1	0.645	-0.00535	-0.00035	0.00451	1.22×10^{-7}	2.04×10^{-5}	2.05×10^{-5}	0.00453
I.A.2.a.2	0.141	0.568	0.651	0.081	4.24×10^{-1}	6.56×10^{-3}	0.43	0.656
I.A.2.b.1	0.069	0.000698	0.0077	0.0000493	5.92×10^{-5}	2.43×10^{-9}	5.4×10^{-5}	0.0077
I.A.2.b.2	+0.391	-0.0772	+0.268	-0.0328	7.2×10^{-2}	1.08×10^{-3}	0.073	0.270
I.A.3.a.1	0.853	-0.00877	0.00123	0.0143	1.51×10^{-6}	2.04×10^{-4}	2.05×10^{-4}	0.0143
I.A.3.a.2	0.679	0.41	0.496	0.38	2.46×10^{-1}	1.44×10^{-1}	0.39	0.624
I.A.3.b.1	0.183	0.00137	0.01937	0.000256	3.75×10^{-4}	6.55×10^{-8}	3.75×10^{-4}	0.01937
I.A.3.b.2	0.984	0.0416	0.3016	0.23	9.1×10^{-2}	5.24×10^{-2}	0.1439	0.379
I.A.4.a.1	0.784	-0.00737	-0.00037	0.00932	1.37×10^{-7}	8.73×10^{-5}	8.74×10^{-5}	0.00934
I.A.4.a.2	0.813	0.202	0.28	0.342	7.84×10^{-2}	1.17×10^{-1}	0.1954	0.442
I.A.4.b.1	0.272	0.00108	0.01658	0.000304	2.74×10^{-4}	9.24×10^{-6}	2.84×10^{-4}	0.0166
I.A.4.b.2	0.141	0.0305	0.3305	0.0102	1.09×10^{-1}	1.04×10^{-4}	.109	0.33

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

fmc CORPORATION

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 7 Sept 61 Page No. 111
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Steady state displacement at road wheel X_4

Problem Number	$\frac{D_4(10)}{7}$	(2)+(17)	$\frac{D_4(12)}{7}$	$(18)^2$	$(19)^2$	$X_4 = [(20)+(21)]^{1/2}$ (ft)	X_4 (inches)	TOTAL WHEEL TRAVEL
1	17	18	19	20	21	22	23	24
IA1a1	-0.00792	0.00008	0.0083	6.4×10^{-9}	6.89×10^{-5}	0.0083	0.0996	3.0996
IA1a2	0.623	0.706	0.677	4.98×10^{-1}	4.58×10^{-1}	0.978	11.736	14.736
IA1b1	0.000515	0.0131	0.000256	1.71×10^{-4}	6.66×10^{-8}	0.0131	0.157	2.157
IA1b2	0.0669	0.3669	0.732	1.35×10^{-1}	5.36×10^{-1}	0.819	9.828	11.828
IA2a1	-0.0044	0.0006	0.00371	3.6×10^{-7}	1.38×10^{-5}	0.00376	0.04512	3.04512
IA2a2	0.467	0.55	0.0666	3.02×10^{-1}	4.44×10^{-3}	0.554	6.648	9.648
IA2b1	0.000574	0.0057	0.0000405	3.25×10^{-8}	1.64×10^{-9}	0.0057	0.0684	2.0684
IA2b2	-0.0634	0.281	-0.0269	7.9×10^{-2}	7.24×10^{-4}	0.282	3.384	5.384
IA3a1	-0.00721	0.00279	0.0117	7.78×10^{-6}	1.37×10^{-4}	0.012	0.144	3.144
IA3a2	0.337	0.423	0.312	1.78×10^{-1}	9.73×10^{-2}	0.524	6.288	9.288
IA3b1	0.00113	0.0191	0.00021	3.65×10^{-4}	4.41×10^{-8}	0.0191	0.229	2.229
IA3b2	0.0342	0.294	0.189	8.64×10^{-2}	3.57×10^{-2}	0.35	4.20	6.20
IA4a1	0.00606	0.0131	0.00766	1.72×10^{-4}	5.87×10^{-5}	0.0152	0.1824	3.1824
IA4a2	0.166	0.244	0.281	5.95×10^{-2}	7.9×10^{-4}	0.245	2.94	5.94
IA4b1	0.000888	0.0164	0.00025	2.69×10^{-4}	6.25×10^{-8}	0.0164	0.1968	2.1968
IA4b2	0.0251	0.325	0.0084	1.06×10^{-1}	7.06×10^{-5}	0.325	3.9	5.90

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

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fmc FOOD MACHINERY AND CHEMICAL CORPORATION

Load and stress analysis of: LVT SUSPENSION
Prepared by L. GERARD Date 24 AUG. '61 Page No. 112
Checked by RS:H Dwg. No. ______ Project No. 449

TRANSIENT RESPONSE

PROBLEM	HOR. DIST.	X			θ			X (X)+(7θ)	X (X)-(7θ)
NUMBER	cm.	DIST. cm.	SCALE	ft.	DIST. cm.	SCALE	7θ (ft.)	FRONT (ft.)	REAR (ft.)
I.A.1.a.1	0.0	+ 0.7	$\frac{1}{50}\frac{ft}{cm}$	0.014	+ 0.22	$\frac{1}{250}\frac{Rad}{cm}$	+ 0.00615	+ 0.02015	+0.00785
	0.1	+ 1.24	↓	0.0248	- 0.20	↓	-0.0056	+0.0192	+0.0304
	0.2	+ 1.05		0.021	- 1.00		-0.028	-0.007	+0.049*
	0.3	- 0.1		-0.001	- 1.36		- 0.038	-0.039*	+0.037
	0.4	- 0.2		- 0.004	- 1.05		- 0.0294	- 0.0334	+0.0254
	1.5	+ 0.15		0.003	+ 1.0		+ 0.0280	+ 0.0310	- 0.025
	1.6	+ 0.6		0.012	+ 0.95		+ 0.0266	+ 0.0386	- 0.0146
	1.7	+ 0.7		0.014	+ 0.25		+ 0.007	+ 0.021	+ 0.007
I.A.1.b.1.	0.0	+ 2.2	$\frac{1}{50}\frac{ft.}{cm.}$	0.044	+ 0.3	$\frac{1}{500}\frac{Rad}{cm}$	0.0042	+0.0482*	+0.0398*
	0.1	+ 1.92	↓	0.0384	+ 0.32	↓	0.0042	+0.0426	+0.0342
	0.2	+ 1.3		0.026	+ 2.9		0.00406	+0.03006	-0.02194
I.A.2.a.1	0.0	+ 1.22	$\frac{1}{80}\frac{ft}{cm}$	0.0152	- 0.9	$\frac{1}{400}\frac{Rad}{cm}$	-0.0157	-0.0005	+ 0.0309
	0.1	+ 0.95	↓	0.0119	- 1.5	↓	-0.0262	-0.0143	+0.0387*
	0.15	+ 0.65		0.00811	- 1.62		-0.0284	-0.02029	+0.0565
	0.5	+ 0.6		0.0075	- 1.3		-0.0228	-0.0153	+0.0303

* · X_{max}

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT SUSPENSION
Prepared by: L. GERARD Date 24 AUG '61 Page No. 113
Checked by: RS:H Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM NUMBER	HOR. DIST. cm.	X DIST. cm.	X SCALE	X ft.	θ DIST. cm.	θ SCALE	7θ (ft.)	X (X)+(7θ) FRONT (ft.)	X (X)-(7θ) REAR (ft.)
I.A.2.a.1 (Con't)	0.7	- 0.5	$\frac{1}{80}\frac{ft}{cm.}$	-0.00625	- 1.35	$\frac{1}{400}\frac{Rad}{cm}$	-0.0236	- 0.02985	+ 0.01745
	0.8	- 0.73		-0.00913	- 0.6		-0.0105	-0.01963	+0.00137
	1.4	- 0.30		-0.00375	+1.51		+0.0264	+0.03015	-0.03015
	1.5	+ 0.20		+0.0025	+1.35		+0.0236	+0.0261	-0.0211
	1.9	+ 0.22		+0.00275	+ 1.62		+0.0283	+0.03105*	-0.02555
	2.0	+ 0.70		+0.00875	+ 1.2		+0.0210	+0.02975	- 0.01225
	2.1	+ 0.60		+0.0075	+ 0.5		+0.00875	+0.01625	- 0.00125
I.A.2.b.1	0.0	+1.6	$\frac{1}{60}\frac{ft}{cm}$	+ 0.0267	+ 0.85	$\frac{1}{1500}\frac{Rad}{cm}$	+0.00397	+ 0.03067	+0.02273
	0.1	+1.62		+0.027	+ 1.0		+0.00466	+0.03166*	+0.02234
	0.2	+ 1.2		+0.02	+ 1.1		+0.00513	+0.02513	+0.01487
	1.8	- 1.31		-0.0218	+0.12		+0.00056	-0.02125	-0.02236
	-0.6	+1.6		+ 0.0267	+ 0.5		+0.00233	+0.02903	+0.02437*
I.A.3.a.1	-0.2	+1.1	$\frac{1}{40}\frac{ft}{cm}$	+0.0275	- 0.55	$\frac{1}{200}\frac{Rad}{cm}$	-0.0193	+0.0082	+0.0468
	- 0.1	+0.85		+0.0212	- 1.3		-0.0455	-0.0243	+0.0667*
	0.0	+0.2		+0.005	-1.5		-0.0525	-0.0475	+0.0575
	0.1	-0.3		-0.0075	-1.15		-0.0402	-0.0477*	+0.0327

* - X max

Load and stress analysis of: LVT SUSPENSION
Prepared by: L. GERARD Date 24 AUG. '61 Page No. 114
Checked by: RS:H Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM NUMBER	HOR. DIST. cm.	X DIST. cm.	X SCALE	X ft.	θ DIST cm.	θ SCALE	7θ (ft.)	X (X)+(7θ) FRONT (ft)	X (X)-(7θ) REAR (ft.)
I.A.3.a.1 (Con't)	0.7	- 0.4	$\frac{1}{40}\frac{ft}{cm}$	-0.010	+ 0.8	$\frac{1}{200}\frac{Rad}{cm}$	+0.028	+ 0.018	-0.038
	0.8	+ 0.2		+0.005	+ 1.0		+0.035	+0.040	-0.030
	0.9	+ 0.44		+0.011	+ 0.55		+0.0193	+0.0303	-0.0083
	1.3	+0.35		+0.00875	+ 0.8		+0.023	+0.03675	-0.01425
I.A.3.b.1	0.0	+ 2.2	$\frac{1}{50}\frac{ft}{cm}$	+0.044	+0.31	$\frac{1}{500}\frac{Rad}{cm}$	+0.00434	+0.04834*	+0.03966*
	0.1	+ 1.3		+0.026	+0.43		+0.00601	+0.03201	-0.006
	0.54	- 1.44		-0.0288	+0.20		+0.0028	-0.026	-0.0316
I.A.4.a.1	-0.2	+ 0.7	$\frac{1}{40}\frac{ft}{cm}$	+0.0175	- 0.7	$\frac{1}{200}\frac{Rad}{cm.}$	-0.0245	-0.007	+0.0420
	-0.1	+ 0.5		+0.0125	- 1.35		-0.0472	-0.0341	+0.0597*
	0.0	+ 0.2		+0.005	-1.51		-0.053	-0.048	+0.058
	0.1	- 0.06		-.0015	-1.25		-0.0437	-0.0452	+ 0.0422
	0.2	+0.12		+0.003	-1.00		-0.035	-0.032	+0.038
	0.3	+0.33		+0.00825	-1.10		-0.0385	-0.03025	+0.04675
	0.4	+0.20		+0.005	-1.4		-0.049	-0.044	+0.054
	0.5	-0.25		-0.006	-1.4		-0.049	-0.055*	+0.043
	0.6	-0.40		-0.010	- 0.75		-0.0263	-0.0363	+0.0163

* - X max

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Load and stress analysis of LVT SUSPENSION

Prepared by L. GERARD Date 23 AUG '61 Page No. 115

Checked by RS-H Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM	HOR DIST.	X			θ			$\overline{\underline{X}}$ (X)+(7θ)	$\overline{\underline{X}}$ (X)-(7θ)
NUMBER	cm.	DIST. cm.	SCALE	ft.	DIST cm.	SCALE	7θ (ft.)	FRONT (ft.)	REAR (ft.)
I.A.4.b.1	0.0	+2.42	$\frac{1}{100}\frac{ft}{cm}$	+0.0242	+0.5	$\frac{1}{1000}\frac{Rad}{cm}$	+0.0035	+0.0277*	+0.0207
	0.1	+1.3	↓	+0.013	+0.65	↓	+0.00455	+0.01755	+0.0085
	0.35	-2.6		-0.026	+0.55		+0.00385	-0.02215	-0.02985*
	0.5	-1.5		-0.015	+0.575		+0.00402	-0.01098	-0.019
	0.75	+1.8		+0.018	+1.0		+0.007	+0.025	+0.011

* - $\overline{\underline{X}}_{max}$

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

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Load and stress analysis of LVT SUSPENSION

Prepared by L. GERARD Date 17 AUG '61 Page No. 116

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STEADY - STATE RESPONSE

PROBLEM	X	θ	$\overline{\underline{X}}$	$\ddot{x}$	$\ddot{\theta}$	$\ddot{\overline{\underline{X}}}$	$\overline{\underline{X}}$	$\dddot{x}$	$\dddot{\theta}$	$\dddot{\overline{\underline{X}}}$
NUMBER	ft.	rad.	ft.	ft/sec²	rad/sec²	ft./sec²	gs	ft/sec³	rad/sec³	ft/sec³
I.A.1.a.1	0.008	0.002	0.01021	7.52	1.88	9.63	1.3	231.	57.8	296.
I.A.1.a.2	0.083	0.16	1.176	6.27	12.1	88.8	3.76	54.5	105.0	771.
I.A.1.b.1	0.0126	0.0001	0.0132	26.7	0.21	28.0	1.868	1230.	9.7	1280.
I.A.1.b.2	0.3	0.128	0.97	21.2	9.0	68.5	3.13	177.0	75.6	575.
I.A.2.a.1	0.005	0.001	0.00453	4.70	0.94	4.27	1.133	144.0	28.8	131.
I.A.2.a.2	0.083	0.082	0.656	2.93	2.89	23.1	1.72	17.4	17.1	137.
I.A.2.b.1	0.007	0.0001	0.0077	14.9	0.21	16.3	1.51	685.	9.7	750.
I.A.2.b.2	0.345	0.012	0.270	12.1	0.42	9.45	1.294	71.6	2.48	56.
I.A.3.a.1	0.01	0.0024	0.0143	9.41	2.26	13.5	1.42	289.	69.4	415.
I.A.3.a.2	0.086	0.08	0.624	6.49	6.03	47.0	2.46	56.2	52.5	410.
I.A.3.b.1	0.018	0.0002	0.01937	38.2	0.42	40.9	2.27	1750.	19.3	1880.
I.A.3.b.2	0.26	0.0334	0.379	18.3	2.35	26.8	1.83	1540	19.7	225.
I.A.4.a.1	0.007	0.0017	0.00934	6.58	1.60	8.8	1.273	201.	49.2	270.
I.A.4.a.2	0.078	0.060	0.442	2.75	2.12	15.6	1.485	16.3	12.6	92.5
I.A.4.b.1	0.0155	0.00016	0.0166	32.8	0.34	35.2	2.09	1510.	15.6	1620.
I.A.4.b.2	0.30	0.0044	0.33	10.5	0.154	11.6	1.36	62.2	0.91	68.5

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT Suspension
Prepared by L. GERARD Date 21 AUG 61 Page No. 117
Checked by R. Smith Dwg. No. Project No. 449

DETERMINATION OF MAXIMUM DISPLACEMENT AT 7 FEET FROM C. G. :

$$\begin{aligned} X &= X_m \sin \omega t + 7\theta_m \sin(\omega t - \alpha) \\ &= X_m \sin \omega t + 7\theta_m \sin(\omega t - \omega t_1) \\ &= X_m \sin \omega t + 7\theta_m [\sin \omega t \cos \omega t_1 - \cos \omega t \sin \omega t_1] \\ &= [X_m + 7\theta_m \cos \omega t_1] \sin \omega t - 7\theta_m \sin \omega t_1 \cos \omega t \end{aligned}$$

THEN

$$X_{max} = \left[(X_m + 7\theta_m \cos \omega t_1)^2 + (7\theta_m \sin \omega t_1)^2\right]^{1/2}$$

WHERE

X_m = MAX. X DISPLACEMENT, FROM GRAPH

θ_m = " θ " , " "

ω = CIRCULAR FREQUENCY

t_1 = REAL TIME PHASE LAG, FROM GRAPH

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 15 Sept 61 Page No. 118
Checked by R. Smith Dwg. No. Project No. 449

Notation

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- Part One
  - Vehicles Studied:
    - A ≡ 8 wheels, 4 walking beams
    - B ≡ 12 wheels, 6 walking beams
    - C ≡ 12 wheels, individually sprung
  - Spring Rates:
    - 1 ≡ 6" deflection under 2 G's with shock at 508 lbs-sec/ft
    - 2 ≡ 12" deflection under 2 G's with shock at 508 lbs-sec/ft
    - 3 ≡ 6" deflection under 2 G's with shock at 1016 lbs-sec/ft
    - 4 ≡ 12" deflection under 2 G's with shock at 1016 lbs-sec/ft
  - Course:
    - a ≡ Sine wave ; L = 6 ft , A = 3 inches
    - b ≡ Sine wave ; L = 4 ft , A = 2 inches
  - Velocities:
    - 1 ≡ 20 mph
    - 2 ≡ Resonant velocity

Load and stress analysis of LVT Suspension
Prepared by L. GERARD Date 21 Aug. '61 Page No. 119
Checked by RS:H Dwg. No. Project No. 449

STEADY STATE RESPONSE

PROBLEM NUMBER 1	X_m 2	θ_m 3	$7\theta_m$ 4	ω 5	t_1 6	$\alpha = \omega t_1$ 7	$\cos\alpha$ 8
I.B.1.a.1	0.008	0.0014	0.0098	30.7	0.032	0.982	0.557
I.B.1.a.2	0.085	0.07	0.49	8.06	0.28	2.26	-0.636
I.B.1.b.1	0.004	0.0004	0.0028	46.0	0.0696	3.2	-0.998
I.B.1.b.2	0.0585	0.053	0.371	8.05	0.11	0.885	0.633
I.B.2.a.1	0.0031	0.00097	0.0068	30.7	0.009	0.276	0.962
I.B.2.a.2	0.102	0.187	1.31	5.95	0.465	2.76	-0.928
I.B.2.b.1	0.0028	0.00024	0.00168	46.0	0.048	2.21	-0.596
I.B.2.b.2	0.066	0.0374	0.262	5.94	0.052	0.309	0.952
I.B.3.a.1	0.0066	0.00196	0.0137	30.7	0.0000		
I.B.3.a.2	0.0745	0.0364	0.255	8.06	0.24	1.93	-0.351
I.B.3.b.1	0.00667	0.000267	0.00187	46.0	0.06	2.76	-0.928
I.B.3.b.2	0.0635	0.0363	0.254	8.05	0.0000		
I.B.4.a.1	0.004	0.00164	0.0115	30.7	0.0000		
I.B.4.a.2	0.07	0.027	0.189	5.95	0.336	2.00	-0.416
I.B.4.b.1	0.00533	0.00133	0.00933	46.0	0.020	0.92	0.606
I.B.4.b.2	0.0112	0.0536	0.375	5.94	0.058	0.344	0.941

Load and stress analysis of LVT Suspension
Prepared by L. GERARD Date 21 Aug. '61 Page No. 120
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STEADY STATE RESPONSE

PROBLEM NUMBER 1	$\sin\alpha$ 9	(4)(8) 10	(2)+(10)' 11	(4)(9) 12	$(11)^2$ 13	$(12)^2$ 14	(13)+(14) 15	$X_m = (15)^{1/2}$ 16
I.B.1.a.1	0.831	0.00546	0.01346	0.00815	1.81×10^{-4}	6.64×10^{-5}	2.47×10^{-4}	0.0157
I.B.1.a.2	0.772	-0.312	-0.227	0.378	5.15×10^{-2}	1.43×10^{-1}	0.1945	0.441
I.B.1.b.1	-0.058	-0.00279	0.00121	0.000162	1.46×10^{-6}	2.62×10^{-8}	1.486×10^{-6}	0.00122
I.B.1.b.2	0.774	0.235	0.2935	0.109	8.61×10^{-2}	1.19×10^{-2}	0.0980	0.313
I.B.2.a.1	0.272	0.00655	0.00965	0.00185	9.31×10^{-6}	3.42×10^{-6}	1.27×10^{-5}	0.00357
I.B.2.a.2	0.372	-1.22	-1.118	0.487	1.25	2.37×10^{-1}	1.487	1.22
I.B.2.b.1	0.803	-0.001	0.0018	0.00135	3.24×10^{-6}	1.82×10^{-6}	5.06×10^{-6}	0.00225
I.B.2.b.2	0.304	0.25	0.316	0.0796	9.98×10^{-2}	6.34×10^{-3}	0.10614	0.326
I.B.3.a.1								0.0203
I.B.3.a.2	0.936	-0.0895	-0.015	0.239	2.25×10^{-4}	5.71×10^{-2}	0.057325	0.239
I.B.3.b.1	0.372	-0.00174	0.00493	0.000695	2.43×10^{-5}	4.83×10^{-7}	2.478×10^{-5}	0.00497
I.B.3.b.1								0.3175
I.B.4.a.1								0.0155
I.B.4.a.2	0.409	-0.0786	-0.0086	0.172	7.4×10^{-5}	2.96×10^{-2}	0.02967	0.1722
I.B.4.b.1	0.796	0.00566	0.01099	0.00743	1.43×10^{-4}	5.52×10^{-5}	0.0001982	0.01408
I.B.4.b.2	0.338	0.353	0.3642	0.127	1.33×10^{-1}	1.61×10^{-2}	0.1491	0.386

fmc CORPORATION

Load and stress analysis of LVT Suspension

Prepared by L. Gerard Date 8 Sept 61 Page No. 121

Checked by R. Smith Dwg. No. ____ Project No. 449

Vehicle B

Determination of maximum displacement at each road wheel.

From the LVT drawing:

$l_1 = 4.925$

$l_2 = 4.755$ ft.

$l_3 = 0.085$ ft.

$a = 2.42$ ft.

Horizontal distance from C.G. to road wheels:

$D_1 = l_1 + \frac{a}{2} = 4.925 + \frac{2.42}{2} = 6.135$ ft.

$D_2 = l_1 - \frac{a}{2} = 4.925 - \frac{2.42}{2} = 3.715$ ft.

$D_3 = l_3 + \frac{a}{2} = 0.085 + \frac{2.42}{2} = 1.295$ ft.

$D_4 = l_3 - \frac{a}{2} = 0.085 - \frac{2.42}{2} = 1.125$ ft.

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Load and stress analysis of LVT Suspension

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$D_5 = l_2 - \frac{a}{2} = 4.755 - \frac{2.42}{2} = 3.54$ ft.

$D_6 = l_2 + \frac{a}{2} = 4.755 + \frac{2.42}{2} = 5.965$ ft.

As on page 13.1:

$$X_{max} = \left[(x_m + D\theta_m \cos wt_1)^2 + (D\theta_m \sin wt_1)^2\right]$$

X_1 = displacement at D_1

X_2 = " " D_2

X_3 = " " D_3

X_4 = " " D_4

X_5 = " " D_5

X_6 = " " D_6

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Load and stress analysis of LVT Suspension

Prepared by L. GERARD Date 25 AUG. 61 Page No. 123

Checked by R.S.H. Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM	HOR DIST.	X			θ			X (X) + (7θ)	X (X) − (7θ)
NUMBER	cm.	DIST. cm.	SCALE	ft.	DIST. cm.	SCALE	7θ (ft.)	FRONT (ft.)	REAR (ft.)
I.B.1.a.1	0.0	+1.1	1/50 ft/cm	+0.022	+0.0	1/250 Rad/cm	+0.00	+0.022	+0.022
	0.1	+1.2	↓	+0.024	+0.5	↓	+0.014	+0.038	+0.010
	0.2	+0.6		+0.012	+1.0		+0.028	+0.040	−0.016
	0.7	−0.5		−0.010	+0.52		+0.0146	+0.0046	−0.0246
	0.8	−0.92		−0.0184	+0.25		+0.007	−0.0114	−0.0254
	0.9	−0.8		−0.016	−0.35		−0.0098	−0.0258	−0.0062
	1.0	−0.13		−0.026	−0.68		−0.019	−0.045*	−0.007
	1.1	−0.5		−0.010	+0.45		+0.0126	+0.0026	−0.0226
	1.55	+0.7		+0.014	−0.6		−0.0168	−0.0028	+0.0308*
I.B.1.b.1	0.0	+0.45	1/25 ft/cm	+0.018	+0.02	1/125 Rad/cm	+0.00112	+0.01912*	+0.01688*
	0.8	−0.25	↓	−0.010	−0.09	↓	−0.00504	−0.01504	−0.00496
I.B.2.a.1	0.0	+1.28	1/100 ft/cm	+0.0128	+1.30	1/500 Rad/cm	+0.0182	+0.0310	−0.0054
	0.1	+1.24	↓	+0.0124	+1.95	↓	+0.0273	+0.0397*	−0.0149
	0.6	+0.35		+0.0035	+1.9		+0.0266	0.0301	−0.0231*
	0.7	−0.3		−0.003	+1.4		+0.0196	+0.0166	−0.0226
	1.9	+0.2		+0.002	−1.4		−0.0196	−0.0176	+0.0216

* - X_{max}

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

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Load and stress analysis of LVT SUSPENSION

Prepared by L. GERARD Date 25 AUG. 61 Page No. 124

Checked by R.S.H. Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM	HOR. DIST	X			θ			X (X) + (7θ)	X (X) − (7θ)
NUMBER	cm.	DIST cm	SCALE	ft.	DIST. cm.	SCALE	7θ (ft.)	FRONT (ft.)	REAR (ft.)
I.B.2.b.1	0.0	+0.4	1/25 ft/cm	+0.016	+0.05	1/125 Rad/cm	+0.0028	+0.0188	+0.0132
	0.35	+0.42	↓	+0.0168	+0.05	↓	+0.0028	+0.0196*	+0.0140*
I.B.3.a.1	0.0	+1.04	1/50 ft/cm	+0.0208	+1.30	1/250 Rad/cm	+0.0364	+0.0572	−0.0156
	0.1	+0.75	↓	+0.015	+1.66	↓	+0.0465	+0.0615*	−0.0315
	0.2	+0.2		+0.004	+1.35		+0.0378	+0.0418	−0.0338*
I.B.3.b.1	0.0	+0.38	1/75 ft/cm	+0.0253	+0.02	1/75 Rad/cm	+0.00187	+0.02717*	+0.02343*
I.B.4.a.1	0.0	+0.67	1/50 ft/cm	+0.0134	+1.55	1/250 Rad/cm	+0.0434	+0.0568	−0.030
	0.1	0.45	↓	+0.009	+1.72	↓	+0.0481	+0.0571*	−0.0391
	0.2	0.20		+0.004	+1.35		+0.0378	+0.0418	−0.0338
	0.5	+0.30		+0.006	+1.52		+0.0425	+0.0485	−0.0365
	0.6	0.00		0.00	+1.4		+0.0392	+0.0392	−0.0392*
I.B.4.b.1	0.0	+0.37	1/75 ft/cm	+0.0247	+0.46	1/75 Rad/cm	+0.043	+0.0677	−0.0183
	0.35	+0.37	↓	+0.0247	+0.59	↓	+0.055	+0.0797*	−0.0303
	0.7	+0.08		+0.00533	+0.42		+0.0392	+0.04453	−0.03387*

* - X_{max}

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

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Load and stress analysis of: LVT SUSPENSION
Prepared by L. GERARD Date 23 AUG. '61 Page No. 125
Checked by R Smith Dwg. No. Project No. 449

DETERMINATION OF MAXIMUM DISPLACEMENT AT 7 FEET FROM C.G. :

$$\underline{X} = x_m \operatorname{Sin} wt + 7\theta_m \operatorname{Sin}(wt - \alpha)$$

$$= x_m \operatorname{Sin} wt + 7\theta_m \operatorname{Sin}(wt - wt_1)$$

$$= x_m \operatorname{Sin} wt + 7\theta_m [\operatorname{Sin} wt \cos wt_1 - \cos wt \sin wt_1]$$

$$= [x_m + 7\theta_m \cos wt_1] \operatorname{Sin} wt - 7\theta_m \sin wt_1 \cos wt$$

THEN

$$\underline{X}_{max} = [(x_m + 7\theta_m \cos wt_1)^2 + (7\theta_m \operatorname{Sin} wt_1)^2]^{1/2}$$

WHERE

x_m = MAX. X DISPLACEMENT, FROM GRAPH
θ_m = " θ " , " "
w = CIRCULAR FREQUENCY
t_1 = REAL TIME PHASE LAG, FROM GRAPH

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Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 15 Sept 61 Page No. 126
Checked by R Smith Dwg. No. Project No. 449

Notation

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Part One

- Velocities:
  - 1 ≡ 20 mph
  - 2 ≡ Resonant velocity
- Course:
  - a ≡ Sine wave ; L = 6ft , A = 3 inches
  - b ≡ Sine wave ; L = 4ft , A = 2 inches
- Spring Rates:
  - 1 ≡ 6" deflection under 2G's with shock at 508 lbs-sec/ft
  - 2 ≡ 12" deflection under 2G's with shock at 508 lbs-sec/ft
  - 3 ≡ 6" deflection under 2G's with shock at 1016 lbs-sec/ft
  - 4 ≡ 12" deflection under 2G's with shock at 1016 lbs-sec/ft
- Vehicles Studied:
  - A ≡ 8 wheels, 4 walking beams
  - B ≡ 12 wheels, 6 walking beams
  - C ≡ 12 wheels, individually sprung

Load and stress analysis of LVT SUSPENSION
Prepared by L. GERARD Date 23 AUG. '61 Page No. 127
Checked by R Smith Dwg. No. Project No. 449

STEADY STATE RESPONSE

PROBLEM NUMBER 1	X_m 2	θ_m 3	$7\theta_m$ 4	ω 5	t_1 6	$\alpha = \omega t_1$ 7	Cos α 8
I.C. 1.a.1	0.0068	0.00376	0.0263	30.7	0.020	0.61	0.820
I.C. 1.a.2	0.0805	0.0445	0.311	8.03	0.264	2.12	-0.522
I.C. 1.b.1	0.0032	0.00139	0.00973	46.	0.010	0.46	0.896
I.C. 1.b.2	0.0875	0.0122	0.0854	8.02	0.24	1.92	-0.342
I.C. 2.a.1	0.0035	0.0036	0.0252	30.7	0.020	0.614	0.817
I.C. 2.a.2	0.100	0.0448	0.314	6.22	0.384	2.39	-0.731
I.C. 2.b.1	0.0017	0.00137	0.0096	46.	0.014	0.644	0.799
I.C. 2.b.2	0.092	0.0124	0.0868	6.19	0.44	2.72	-0.912
I.C. 3.a.1	0.008	0.00744	0.0521	30.7	0.04	1.22	0.344
I.C. 3.a.2	0.077	0.043	0.301	8.03	0.134	1.08	0.471
I.C. 3.b.1	0.0038	0.00204	0.0143	46.	0.014	0.645	0.799
I.C. 3.b.2	0.0808	0.019	0.133	8.02	0.24	1.92	-0.342
I.C. 4.a.1	0.0048	0.00707	0.0496	30.7	0.024	0.736	0.741
I.C. 4.a.2	0.08	0.044	0.308	6.22	0.352	2.19	-0.580
I.C. 4.b.1	0.0023	0.0024	0.0143	46.0	0.02	0.92	0.606
I.C. 4.b.2	0.0756	0.0188	0.132	6.19	0.336	2.08	-0.487

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of LVT SUSPENSION
Prepared by L. GERARD Date 23 AUG. '61 Page No. 128
Checked by R Smith Dwg. No. Project No. 449

STEADY STATE RESPONSE

PROBLEM NUMBER 1	Sin α 9	(4)(8) 10	(2) + (10) 11	(4)(9) 12	$(11)^2$ 13	$(12)^2$ 14	(13)+(14) 15	$X_m = (15)^{1/2}$ 16
I.C. 1.a.1	0.573	2.16×10^{-2}	2.84×10^{-2}	1.51×10^{-2}	8.06×10^{-4}	2.28×10^{-4}	0.001034	0.0322
I.C. 1.a.2	0.853	-1.62×10^{-1}	-8.15×10^{-2}	2.65×10^{-1}	6.65×10^{-3}	7.02×10^{-2}	0.07685	0.277
I.C. 1.b.1	0.444	8.71×10^{-3}	1.191×10^{-2}	4.32×10^{-3}	1.42×10^{-4}	1.87×10^{-5}	0.0001607	0.01267
I.C. 1.b.2	0.940	-2.92×10^{-2}	5.83×10^{-2}	8.02×10^{-2}	3.4×10^{-3}	6.43×10^{-3}	0.00983	0.0991
I.C. 2.a.1	0.576	0.0206	0.0241	0.0145	5.8×10^{-4}	2.1×10^{-4}	0.00079	0.0281
I.C. 2.a.2	0.683	-2.2×10^{-1}	-0.12	2.14×10^{-1}	1.44×10^{-2}	4.58×10^{-2}	0.0602	0.249
I.C. 2.b.1	0.600	0.00767	0.00937	0.00576	8.78×10^{-5}	3.32×10^{-5}	0.000121	0.011
I.C. 2.b.2	0.409	-7.91×10^{-2}	0.0129	3.55×10^{-2}	1.66×10^{-4}	1.26×10^{-3}	0.001426	0.0377
I.C. 3.a.1	0.939	1.8×10^{-2}	0.026	4.90×10^{-2}	6.76×10^{-4}	2.4×10^{-3}	0.003076	0.0554
I.C. 3.a.2	0.882	1.42×10^{-1}	0.219	2.66×10^{-1}	4.8×10^{-2}	7.07×10^{-2}	0.1187	0.344
I.C. 3.b.1	0.601	1.14×10^{-2}	0.0152	8.6×10^{-3}	2.31×10^{-4}	7.4×10^{-5}	0.000304	0.01744
I.C. 3.b.2	0.940	-4.55×10^{-2}	0.0343	1.25×10^{-1}	1.18×10^{-3}	1.56×10^{-2}	0.01678	0.1295
I.C. 4.a.1	0.671	0.0368	0.0416	0.0333	1.73×10^{-3}	1.11×10^{-3}	0.00284	0.0533
I.C. 4.a.2	0.814	-1.79×10^{-1}	-0.099	2.51×10^{-1}	9.8×10^{-3}	6.3×10^{-2}	0.0728	0.27
I.C. 4.b.1	0.796	0.00867	0.01097	0.0114	1.2×10^{-4}	1.3×10^{-4}	0.00025	0.0158
I.C. 4.b.2	0.873	-6.42×10^{-2}	0.0114	1.15×10^{-1}	1.3×10^{-4}	1.32×10^{-2}	0.01333	0.1155

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 11 Sept 61 Page No. 129
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Vehicle C

Determination of maximum displacement at each road wheel.

From the LVT drawing:

$l_1 = D_1 = 6.13$ ft

$l_2 = D_2 = 3.71$ ft

$l_3 = D_3 = 1.29$ ft

$l_4 = D_4 = 1.13$ ft

$l_5 = D_5 = 3.55$ ft

$l_6 = D_6 = 5.97$ ft

$D_{1,2,3\ldots}$ = Horizontal distance from C.G. to road wheels.

As on page 14.1:

$$X_{1,2,3\ldots} = \left[(X_m + D_{1,2\ldots}\theta_m \cos \omega t_1)^2 + (D_{1,2\ldots}\theta_m \sin \omega t_1)^2\right]$$

where $X_{1,2,3\ldots}$ = displacement at $D_{1,2,3\ldots}$

Load and stress analysis of: LVT Suspension
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Steady State displacement at road wheel X_3

Problem Number	$\frac{D_3(10)}{7}$	(2)+(17)	$\frac{D_3(12)}{7}$	$(18)^2$	$(19)^2$	$X_3 = [(20)+(21)]^{\frac{1}{2}}$ (ft)	X_3 (inches)	TOTAL WHEEL TRAVEL
1	17	18	19	20	21	22	23	24
IC1a1	0.00398	0.01078	0.00278	1.18×10^{-4}	7.73×10^{-6}	0.0112	0.134	3.134
IC1a2	-0.0299	0.0506	0.0488	2.56×10^{-3}	2.38×10^{-3}	0.0798	0.957	3.957
IC1b1	0.00161	0.00481	0.000796	2.32×10^{-5}	6.34×10^{-7}	0.00488	0.0585	2.0585
IC1b2	-0.00538	0.0821	0.0148	6.75×10^{-3}	2.19×10^{-4}	0.0835	0.100	2.100
IC2a1	0.00379	0.00729	0.00267	5.32×10^{-5}	7.13×10^{-6}	0.00776	0.093	3.093
IC2a2	-0.0406	0.0594	0.0394	3.53×10^{-3}	1.55×10^{-3}	0.0713	0.855	3.855
IC2b1	0.00141	0.00311	0.00106	9.67×10^{-5}	1.12×10^{-6}	0.00989	0.1186	2.1186
IC2b2	-0.0146	0.0774	0.00655	5.99×10^{-3}	4.29×10^{-5}	0.0776	0.93	2.93
IC3a1	0.00333	0.01133	0.00903	1.28×10^{-4}	8.15×10^{-5}	0.0142	0.17	3.17
IC3a2	0.0261	0.1031	0.049	1.06×10^{-2}	2.40×10^{-3}	0.114	1.37	4.37
IC3b1	0.0021	0.0059	0.00159	3.48×10^{-5}	2.53×10^{-6}	0.0061	0.073	2.073
IC3b2	-0.0084	0.0724	0.0230	5.24×10^{-3}	5.29×10^{-4}	0.076	0.91	2.073
IC4a1	0.00678	0.0116	0.00615	1.35×10^{-4}	3.78×10^{-5}	0.0131	0.156	3.156
IC4a2	0.0330	0.1130	0.0463	1.28×10^{-2}	2.14×10^{-3}	0.122	1.46	4.46
IC4b1	0.0016	0.0039	0.00210	1.52×10^{-5}	4.41×10^{-6}	0.00443	0.0531	2.0531
IC4b2	-0.0118	0.0638	0.0212	4.07×10^{-3}	4.49×10^{-4}	0.0213	0.255	2.255

Load and stress analysis of: LVT SUSPENSION
Prepared by: L. GERARD Date: 28 AUG. '61 Page No.: 131
Checked by: 2Smith Dwg. No.: Project No.: 449

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

TRANSIENT RESPONSE

PROBLEM NUMBER	HOR DIST. cm.	X DIST. cm.	X SCALE	X ft.	θ DIST. cm.	θ SCALE	7θ (ft.)	X (X)+(7θ) FRONT (ft.)	X (X)-(7θ) REAR (ft.)
I.C.1.a.1	0.0	+0.72	$\frac{1}{50}\frac{ft}{cm}$	+0.0144	-1.58	$\frac{1}{250}\frac{Rad}{cm.}$	-0.0442	-0.0298	+0.0586*
	0.1	+1.18	↓	+0.0236	-0.7	↓	-0.0196	+0.0040	+0.0432
	0.2	+1.0	↓	+0.02	+0.7	↓	+0.0196	+0.0396*	+0.0004
	0.3	+0.4	↓	+0.008	+1.1	↓	+0.0308	+0.0388	-0.0228
	0.8	-0.75	↓	-0.015	+1.4	↓	+0.0392	+0.0242	-0.0542
I.C.1.b.1	0.0	+1.2	$\frac{1}{200}\frac{ft}{cm.}$	+0.006	-2.47	$\frac{1}{1000}\frac{Rad.}{cm.}$	-0.0173	-0.0113	+0.0233
	0.1	+2.1	↓	+0.0105	-1.9	↓	-0.0133	-0.0028	+0.0238*
	0.2	+2.5	↓	+0.0125	-0.65	↓	-0.00455	+0.00795	+0.01705
	0.3	+2.45	↓	+0.01225	+0.5	↓	+0.0035	+0.01575	+0.0087
	1.0	+0.8	↓	+0.004	+1.81	↓	+0.0127	+0.0167*	-0.0087
	1.7	-1.35	↓	-0.00675	+2.2	↓	+0.0154	+0.00865	-0.02215
	3.0	+1.7	↓	+0.0085	+1.0	↓	+0.007	+0.0155	+0.0015
I.C.2.a.1	0.0	+0.38	$\frac{1}{50}\frac{ft}{cm}$	+0.0076	-0.8	$\frac{1}{125}\frac{Rad}{cm}$	-0.0448	-0.0372	+0.0524*
	0.1	+0.69	↓	+0.0138	-0.4	↓	-0.0224	-0.0086	+0.0362
	0.2	+0.68	↓	+0.0136	+0.2	↓	+0.0112	+0.0248	+0.0024
	0.25	+0.58	↓	+0.0116	+0.3	↓	+0.0167	+0.0283	-0.0051

* - X_{max}

Load and stress analysis of: LVT SUSPENSION
Prepared by: L. GERARD Date: 2? AUG. '61 Page No.: 132
Checked by: 2Smith Dwg. No.: Project No.: 449

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

TRANSIENT RESPONSE

PROBLEM NUMBER	HOR DIST. cm.	X DIST. cm.	X SCALE	X ft.	θ DIST. cm.	θ SCALE	7θ (ft.)	X (X)+(7θ) FRONT (ft)	X (X)-(7θ) REAR (ft)
I.C.2.a.1 (Con't)	0.7	+0.2	$\frac{1}{50}\frac{ft}{cm.}$	+0.004	+0.6	$\frac{1}{125}\frac{Rad}{cm.}$	+0.0336	+0.0376*	-0.0296
	1.3	-0.4	↓	-0.008	+0.58	↓	+0.0325	+0.0245	-0.0405
I.C.2.b.1	0.2	+0.9	$\frac{1}{200}\frac{ft}{cm}$	+0.0045	-2.5	$\frac{1}{1000}\frac{Rad}{cm}$	-0.0175	-0.0130*	+0.0220
	0.3	+1.5	↓	+0.0075	-2.2	↓	-0.0154	-0.0079	+0.0229*
	1.0	+1.82	↓	+0.0091	-1.5	↓	-0.0105	-0.0014	+0.0195
	1.2	+1.40	↓	+0.007	+0.85	↓	+0.00575	+0.01275	+0.00125
	3.9	+0.33	↓	+0.00165	+1.50	↓	+0.0105	+0.01215	-0.00885
	4.6	+0.9	↓	+0.0045	+1.20	↓	+0.0084	+0.0129	-0.0039
I.C.3.a.1	0.3	+0.4	$\frac{1}{25}\frac{ft}{cm.}$	+0.016	-1.37	$\frac{1}{125}\frac{Rad}{cm.}$	-0.0767	-0.0607	+0.0927*
	0.5	+0.52	↓	+0.0208	+0.7	↓	+0.0392	+0.0600	-0.0184
	0.6	+0.21	↓	+0.0084	+1.1	↓	+0.0615	+0.0699*	-0.0531
	1.1	-0.22	↓	-0.0088	+1.22	↓	+0.0693	+0.0515	-0.0771
I.C.3.b.1	0.4	+0.9	$\frac{1}{100}\frac{ft}{cm.}$	+0.009	-2.5	$\frac{1}{500}\frac{Rad}{cm.}$	-0.035	-0.026*	+0.044*
	0.5	+1.35	↓	+0.0135	-2.0	↓	-0.028	-0.0145	-0.0415
	0.6	+1.48	↓	+0.0148	-1.25	↓	-0.0175	-0.0027	+0.0323
	1.44	0.00	↓	0	+1.5	↓	+0.021	+0.021	-0.021

* - X_{max}

Load and stress analysis of: LVT SUSPENSION
Prepared by L. GERARD Date 28 AUG '61 Page No. 133
Checked by R Smith Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM NUMBER	HOR. DIST. cm.	X DIST. cm.	X SCALE	X ft.	θ DIST. cm.	θ SCALE	7θ (ft.)	Ẋ (X) + (7θ) FRONT (ft.)	Ẋ (X) - (7θ) REAR (ft.)
I.C.4.a.1	0.2	+0.3	1/25 ft./cm.	+0.012	-1.35	1/125 Rad/cm.	-0.0756	-0.0636	+0.0876 *
	0.3	+0.4	↓	+0.016	-0.6	↓	-0.0336	-0.0176	+0.0496
	0.45	+0.3	↓	+0.012	+0.82	↓	+0.0459	+0.0679 *	-0.0339
	0.96	-0.08	↓	-0.0032	+1.18	↓	+0.066	+0.0628	-0.0692
	1.5	-0.15	↓	-0.006	+1.1	↓	+0.0615	+0.0555	-0.0675
I.C.4.b.1	0.1	+0.7	1/100 ft/cm.	+0.007	-2.5	1/500 Rad/cm.	-0.035	-0.028 *	+0.042 *
	0.2	+1.0	↓	+0.01	-2.0	↓	-0.028	-0.018	+0.038
	1.1	+0.6	↓	+0.006	+0.6	↓	+0.0084	+0.0144	-0.0024
	1.8	-0.1	↓	-0.001	+1.4	↓	+0.0196	+0.0186	-0.0206
	2.45	-0.4	↓	-0.004	+1.6	↓	+0.0224	+0.0184	-0.0264

* - $\dot{X}_{max}$

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 15 Sept 61 Page No. 134
Checked by R Smith Dwg. No. Project No. 449

Notation

I A I a I

- Velocities:
  - 1 ≡ 20 mph
  - 2 ≡ Resonant velocity
- Course:
  - a ≡ Sine wave ; L = 6ft , A = 3 inches
  - b ≡ Sine wave ; L = 4ft , A = 2 inches
- Spring Rates:
  - 1 ≡ 6" deflection under 2G's with shock at 508 lbs-sec/ft
  - 2 ≡ 12" deflection under 2G's with shock at 508 lbs-sec/ft
  - 3 ≡ 6" deflection under 2G's with shock at 1016 lbs-sec/ft
  - 4 ≡ 12" deflection under 2G's with shock at 1016 lbs-sec/ft
- Vehicles Studied:
  - A ≡ 8 wheels, 4 walking beams
  - B ≡ 12 wheels, 6 walking beams
  - C ≡ 12 wheels, individually sprung
- Part One

FMC CORPORATION—ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

fmc CORPORATION

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 7 Sept 61 Page No. 135
Checked by DSmith Dwg. No. ______ Project No. 449

Steady state displacement at road wheel X_1

Problem Number	$\frac{D_1(10)}{7}$	(2)+(17)	$\frac{D_1(12)}{7}$	$(18)^2$	$(19)^2$	$X_1 = [(20)+(21)]^{\frac{1}{2}}$ (ft)	X_1 (Inches)	TOTAL WHEEL TRAVEL
1	17	18	19	20	21	22	23	24
IA1a1	-0.00816	-0.00016	0.00855	2.56×10^{-8}	7.31×10^{-5}	0.00856	0.103	3.103
IA1a2	0.642	0.725	0.698	5.26×10^{-1}	4.87×10^{-1}	1.006	12.072	15.072
IA1b1	0.00053	0.01313	0.000263	1.72×10^{-4}	6.91×10^{-8}	0.0131	0.1572	2.1572
IA1b2	0.0689	0.3689	0.754	1.36×10^{-1}	5.68×10^{-1}	0.838	10.05	12.05
IA2a1	-0.00453	0.00047	0.00382	2.21×10^{-7}	1.46×10^{-5}	0.00385	0.0462	3.0462
IA2a2	0.481	0.564	0.0686	3.18×10^{-1}	4.71×10^{-3}	0.568	6.816	9.816
IA2b1	0.00059	0.00759	0.0000417	5.76×10^{-5}	1.74×10^{-9}	0.00759	0.0911	2.0911
IA2b2	-0.0654	+0.280	-0.0278	7.84×10^{-2}	7.73×10^{-4}	0.281	3.372	5.372
IA3a1	-0.00743	0.00257	0.121	6.6×10^{-6}	1.46×10^{-2}	0.121	1.452	4.452
IA3a2	0.347	0.433	0.322	1.87×10^{-1}	1.04×10^{-1}	0.539	6.47	9.47
IA3b1	0.00116	0.01916	0.000217	3.67×10^{-4}	4.71×10^{-4}	0.029	0.348	2.348
IA3b2	0.0352	0.295	0.195	8.7×10^{-2}	3.8×10^{-2}	0.353	4.236	6.236
IA4a1	-0.00624	0.00076	0.00789	5.77×10^{-7}	6.23×10^{-5}	0.00792	0.095	3.095
IA4a2	0.171	0.249	0.290	6.2×10^{-2}	8.41×10^{-2}	0.382	4.584	7.584
IA4b1	0.00091	0.01641	0.000257	2.69×10^{-4}	6.6×10^{-4}	0.031	0.372	2.372
IA4b2	0.0258	0.3258	0.00864	1.06×10^{-1}	7.46×10^{-5}	0.326	3.912	5.912

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fmc

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 24 Aug '61 Page No. 136
Checked by DSmith Dwg. No. ______ Project No. 449

Transient Response

Problem Number	X_m	θ_m	$7\theta_m$	Front X	Rear X
	ft.	rad.	ft.	ft.	ft.
I.A.1.a.1	-0.026	-0.0054	-0.0378	-0.039	-0.047
I.A.1.b.1	+0.044	+0.00076	+0.00531	+0.0482	+0.0399
I.A.2.a.1	+0.0154	+0.00408	+0.0336	+0.03105	+0.0331
I.A.2.b.1	+0.028	-0.000734	-0.00513	+0.03166	+0.02437
I.A.3.a.1	+0.0255	-0.00765	-0.0535	-0.0477	+0.0667
I.A.3.b.1	-0.044	-0.00088	0.00616	+0.04834	-0.03966
I.A.4.a.1	+0.0175	-0.0076	-0.0531	-0.055	+0.0597
I.A.4.b.1	-0.025	-0.001	+0.007	+0.0277	-0.02935

Load and stress analysis of: LVT SUSPENSION
Prepared by: L. GERARD Date: 25 AUG '61 Page No. 137
Checked by: R Smith Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM NUMBER	X_m	θ_m	$7\theta_m$	X FRONT	X REAR
	ft.	rad.	ft.	ft.	ft.
I.B. 1.a.1	+0.024	+0.00404	+0.0283	-0.045	+0.0308
I.B. 1.b.1	+0.018	+0.0008	+0.0056	+0.01912	+0.01688
I.B. 2.a.1	+0.013	-0.00394	+0.0276	+0.0397	-0.0231
I.B. 2.b.1	+0.0164	+0.00064	+0.00448	+0.0196	+0.0140
I.B. 3.a.1	+0.021	+0.0066	+0.0461	+0.0615	-0.0338
I.B. 3.b.1	+0.0254	+0.000667	+0.00466	+0.02717	+0.02343
I.B. 4.a.1	+0.0134	+0.00696	+0.0487	+0.0571	-0.0392
I.B. 4.b.1	+0.0247	+0.00787	+0.055	+0.0797	-0.03387

Load and stress analysis of: LVT SUSPENSION
Prepared by: L. GERARD Date: 28 AUG '61 Page No. 138
Checked by: R Smith Dwg. No. Project No. 449

TRANSIENT RESPONSE

PROBLEM NUMBER	X_m	θ_m	$7\theta_m$	FRONT X	REAR X
	ft	rad.	ft.	ft.	ft.
I.C. 1.a.1	+0.0234	-0.00616	-0.0431	+0.0396	+0.0586
I.C. 1.b.1	+0.0126	-0.00248	-0.0174	+0.0167	+0.0238
I.C. 2.a.1	+0.0142	-0.00608	-0.0425	+0.0376	+0.0524
I.C. 2.b.1	+0.0092	-0.0025	-0.0175	-0.0130	+0.0229
I.C. 3.a.1	+0.0244	-0.011	-0.077	+0.0699	+0.0927
I.C. 3.b.1	+0.0143	-0.005	-0.035	-0.026	+0.044
I.C. 4.a.1	+0.0172	-0.01095	-0.0766	+0.0679	+0.0876
I.C. 4.b.1	+0.0103	-0.0051	-0.0357	-0.028	+0.042

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 8 Sept 61 Page No. 139
Checked by R Smith Dwg. No. ______ Project No. 449

Steady State displacement at road wheel X_1

Problem Number	$\frac{D_1(10)}{7}$	(2)+(17)	$\frac{D_1(12)}{7}$	$(18)^2$	$(19)^2$	$X_1 = [(20)+(21)]^{1/2}$ (ft)	X_1 (inches)	TOTAL WHEEL TRAVEL
1	17	18	19	20	21	22	23	24
IB1 a1	0.00478	0.01278	0.00714	1.63×10^{-4}	5.1×10^{-5}	0.0146	0.175	3.175
IB1 a2	-0.273	-0.188	0.331	3.53×10^{-2}	1.1×10^{-1}	0.381	4.572	7.572
IB1 b1	-0.00244	0.00156	-0.000142	2.43×10^{-6}	2.02×10^{-8}	0.00156	0.0187	2.0187
IB1 b2	0.206	0.2645	0.0955	6.99×10^{-2}	9.12×10^{-3}	0.281	3.372	5.372
IB2 a1	0.00574	0.00884	0.00162	7.81×10^{-5}	2.62×10^{-6}	0.00899	0.108	3.108
IB2 a2	-1.07	-0.968	0.427	9.37×10^{-1}	1.82×10^{-1}	1.06	12.72	15.72
IB2 b1	-0.000876	0.00193	0.00118	3.72×10^{-6}	1.39×10^{-6}	0.0698	0.8376	2.8376
IB2 b2	0.219	0.285	0.0697	8.12×10^{-2}	4.86×10^{-3}	0.293	3.516	5.516
IB3 a1						0.0186	0.223	3.223
IB3 a2	-0.0784	-0.0039	0.209	1.52×10^{-5}	4.37×10^{-2}	0.209	2.508	5.508
IB3 b1	-0.00152	0.00515	0.000609	2.65×10^{-5}	3.71×10^{-7}	0.00518	0.06216	2.06216
IB3 b2						0.2862	3.434	5.434
IB4 a1						0.01406	0.1687	3.1687
IB4 a2	-0.0688	0.0012	0.151	1.44×10^{-6}	2.28×10^{-2}	0.151	1.812	4.812
IB4 b1	0.00496	0.0103	0.00651	1.06×10^{-4}	4.24×10^{-5}	0.0122	0.1464	2.1464
IB4 b2	0.309	0.320	0.111	1.02×10^{-1}	1.23×10^{-2}	0.338	4.056	6.056

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Load and stress analysis of: LVT Suspension
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Steady State displacement at road wheel X_1

Problem Number	$\frac{D_1(10)}{7}$	(2)+(17)	$\frac{D_1(12)}{7}$	$(18)^2$	$(19)^2$	$X_1 = [(20)+(21)]^{1/2}$ (ft)	X_1 (inches)	TOTAL WHEEL TRAVEL
1	17	18	19	20	21	22	23	24
IC1 a1	0.0189	0.0257	0.0132	6.6×10^{-4}	1.74×10^{-4}	0.0289	0.347	3.347
IC1 a2	-0.142	0.0615	0.232	3.78×10^{-3}	5.38×10^{-2}	0.24	2.88	5.88
IC1 b1	0.00763	0.0108	0.00378	1.17×10^{-4}	1.43×10^{-5}	0.0115	0.138	2.138
IC1 b2	-0.0256	0.0619	0.0703	3.83×10^{-3}	4.94×10^{-3}	0.0936	1.1232	3.1232
IC2 a1	0.018	0.0215	0.0127	4.62×10^{-4}	1.61×10^{-4}	0.0269	0.0324	3.0324
IC2 a2	-0.193	-0.093	0.187	8.65×10^{-3}	3.5×10^{-2}	0.209	2.51	5.51
IC2 b1	0.00672	0.00842	0.00505	7.09×10^{-5}	2.55×10^{-5}	0.00982	0.1178	2.1178
IC2 b2	-0.0693	0.0227	0.0311	5.15×10^{-4}	9.67×10^{-4}	0.0385	0.462	2.462
IC3 a1	0.0158	0.0238	0.0429	5.66×10^{-4}	1.84×10^{-3}	0.049	0.588	3.588
IC3 a2	0.124	0.201	0.233	4.04×10^{-2}	5.43×10^{-2}	0.312	3.74	6.74
IC3 b1	0.00999	0.01379	0.00753	1.90×10^{-4}	5.67×10^{-5}	0.0157	0.188	2.188
IC3 b2	-0.0399	0.0409	0.1095	1.67×10^{-3}	1.2×10^{-2}	0.117	1.404	3.404
IC4 a1	0.0322	0.037	0.0292	1.37×10^{-3}	8.53×10^{-4}	0.0471	0.565	3.565
IC4 a2	-0.157	-0.077	0.2198	5.93×10^{-3}	4.83×10^{-2}	0.233	2.796	5.796
IC4 b1	0.00759	0.00989	0.00999	9.78×10^{-5}	9.98×10^{-5}	0.01405	0.1686	2.1686
IC4 b2	0.0562	0.0194	0.1007	3.76×10^{-4}	1.014×10^{-2}	0.1025	1.23	3.123

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SAN JOSE, CALIFORNIA

Load and stress analysis of LVT SUSPENSION
Prepared by L. GERARD Date 22 AUG '61 Page No. 141
Checked by R Smith Drg. No. Project No. 449

STEADY - STATE RESPONSE

PROBLEM	X	θ	$\overline{\underline{X}}$	$\ddot{X}$	$\ddot{\theta}$	$\ddot{\overline{\underline{X}}}$	$\ddot{\overline{\underline{X}}}$	$\dddot{X}$	$\dddot{\theta}$	$\dddot{\overline{\underline{X}}}$
NUMBER	ft.	rad.	ft.	ft/sec²	rad./sec²	ft/sec²	g's	ft/sec³	rad/sec³	ft/sec³
I.B.1.a.1	0.008	0.0014	0.0157	7.55	1.32	14.8	1.46	232.	40.5	454.
I.B.1.a.2	0.085	0.07	0.441	5.51	4.55	28.6	1.89	44.4	36.6	230.
I.B.1.b.1	0.004	0.0004	0.00122	8.46	0.846	2.58	1.08	389.	38.9	119.
I.B.1.b.2	0.0585	0.053	0.313	3.79	3.44	20.3	1.63	30.5	27.7	163.
I.B.2.a.1	0.0031	0.00097	0.00357	2.92	0.914	3.36	1.104	89.6	28.	103.
I.B.2.a.2	0.102	0.187	1.22	3.61	6.62	43.1	2.34	21.5	39.4	257.
I.B.2.b.1	0.0028	0.00024	0.00225	5.92	0.507	4.76	1.148	271.	23.3	219.
I.B.2.b.2	0.066	0.0374	0.326	2.33	1.32	11.5	1.357	13.8	7.84	68.3
I.B.3.a.1	0.0066	0.00196	0.0203	6.21	1.85	19.1	1.593	191.	56.8	586.
I.B.3.a.2	0.0745	0.0364	0.239	4.84	2.37	15.5	1.481	39.0	19.1	125.
I.B.3.b.1	0.00667	0.000267	0.00497	14.1	0.565	10.5	1.327	650.	26.0	483.
I.B.3.b.2	0.0635	0.0363	0.3175	4.11	2.35	20.6	1.64	33.1	18.9	166.
I.B.4.a.1	0.004	0.00164	0.0155	3.77	1.54	14.6	1.454	116.	47.3	449
I.B.4.a.2	0.07	0.027	0.1722	2.48	0.955	6.10	1.19	14.8	5.68	36.3
I.B.4.b.1	0.00533	0.00133	0.01408	11.3	2.81	29.8	1.925	520	129.	1370
I.B.4.b.2	0.0112	0.0536	0.386	0.395	1.89	13.6	1.423	2.35	11.2	81.0

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of LVT SUSPENSION
Prepared by L. GERARD Date 23 AUG '61 Page No. 142
Checked by R Smith Drg. No. Project No. 449

STEADY - STATE RESPONSE

PROBLEM	X	θ	$\overline{\underline{X}}$	$\ddot{X}$	$\ddot{\theta}$	$\ddot{\overline{\underline{X}}}$	$\ddot{\overline{\underline{X}}}$	$\dddot{X}$	$\dddot{\theta}$	$\dddot{\overline{\underline{X}}}$
NUMBER	ft.	rad.	ft.	ft/sec²	rad/sec²	ft/sec²	g's	ft/sec³	rad/sec³	ft/sec³
I.C.1.a.1	0.0068	0.00376	0.0322	6.4	3.54	30.4	1.943	196.	108.	932.
I.C.1.a.2	0.0805	0.0445	0.277	5.19	2.87	17.9	1.555	41.6	23.1	144.
I.C.1.b.1	0.0032	0.00139	0.01267	6.77	2.94	26.8	1.832	312.	135	1230
I.C.1.b.2	0.0875	0.0122	0.0991	5.62	0.785	6.37	1.198	45.	6.3	51.1
I.C.2.a.1	0.0035	0.0036	0.0281	3.30	3.39	26.5	1.823	101.	104.	814.
I.C.2.a.2	0.100	0.0448	0.249	3.87	1.73	9.64	1.3	24.1	10.8	60.
I.C.2.b.1	0.0017	0.00137	0.011	3.60	2.90	23.3	1.723	166.	133.	1070.
I.C.2.b.2	0.092	0.0124	0.0377	3.52	0.475	1.44	1.045	21.8	2.94	8.9
I.C.3.a.1	0.008	0.00744	0.0554	7.54	7.00	52.1	2.62	231.	215.	1605.
I.C.3.a.2	0.077	0.043	0.344	4.96	2.77	22.2	1.69	39.8	22.2	178.
I.C.3.b.1	0.0038	0.00204	0.01744	8.04	4.31	36.9	2.14	370.	198.	1700.
I.C.3.b.2	0.0808	0.019	0.1295	5.2	1.22	8.33	1.26	41.7	9.8	66.8
I.C.4.a.1	0.0048	0.00707	0.0533	4.52	6.66	50.1	2.56	139.	204.	1540.
I.C.4.a.2	0.08	0.044	0.27	3.1	1.7	10.4	1.324	19.3	10.6	65.
I.C.4.b.1	0.0023	0.0024	0.0158	4.87	5.08	33.4	2.04	224	234	1530
I.C.4.b.2	0.0756	0.0188	0.1155	2.9	0.72	4.42	1.137	17.9	4.45	27.3

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

Load and stress analysis of: LVT Suspension
Prepared by L. Gerard Date 5 Sept 61 Page No. 143
Checked by R Smith Dwg. No. ______ Project No. 449

Problem Number	$K_{1,2,3}$ lbs/ft	$(C_3 \equiv 0)$ $C_{1,2}$ lb. sec./ft.	V ft/sec	A ft.	L ft.	e = 2 (3)	b = 3 (2)	
1	2	3	4	5	6	7	8	
IB1a1	21,400	508	29.3	0.25	6	1016	64,100	
IB1a2	21,400	508	7.7	0.25	6	1016	64,100	
IB1b1	21,400	508	29.3	0.167	4	1016	64,100	
IB1b2	21,400	508	5.13	0.167	4	1016	64,100	
IB2a1	10,700	508	29.3	0.25	6	1016	32,100	
IB2a2	10,700	508	5.68	0.25	6	1016	32,100	
IB2b1	10,700	508	29.3	0.167	4	1016	32,100	
IB2b2	10,700	508	3.78	0.167	4	1016	32,100	
IB3a1	21,400	1016	29.3	0.25	6	2032	64,100	
IB3a2	21,400	1016	7.7	0.25	6	2032	64,100	
IB3b1	21,400	1016	29.3	0.167	4	2032	64,100	
IB3b2	21,400	1016	5.13	0.167	4	2032	64,100	
IB4a1	10,700	1016	29.3	0.25	6	2032	32,100	
IB4a2	10,700	1016	5.68	0.25	6	2032	32,100	
IB4b1	10,700	1016	29.3	0.167	4	2032	32,100	
IB4b2	10,700	1016	3.78	0.167	4	2032	32,100	

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Load and stress analysis of LVT Suspension
Prepared by L. Gerard Date 9 AUG. 61 Page No. 144
Checked by R Smith Dwg. No. ______ Project No. 449

PROBLEM NUMBER	$k_{1,2,3,4,5,6}$ lbs/ft	$C_{1,6}$ lb. sec/ft	v ft/sec.	A ft.	L ft.	e = 2 (3)	b = 6 (2)	
1	2	3	4	5	6	7	8	
I.C.1.a.1	10,700	508	29.3	0.25	6	1016	64,200	
IC.1a2	10,700	508	7.67	0.25	6	1016	64,200	
IC1.b.1.	10,700	508	29.3	0.167	4	1016	64,200	
I.C1.b2	10,700	508	5.11	0.167	4	1016	64,200	
IC2.a.1	5,350	508	29.3	0.25	6	1016	32,100	
I.C.2.a.2	5,350	508	5.94	0.25	6	1016	32,100	
I.C.2.b.1	5,350	508	29.3	0.167	4	1016	32,100	
I.C.2.b.2	5,350	508	3.96	0.167	4	1016	32,100	
I.C.3.a.1	10,700	1016	29.3	0.25	6	2032	64,200	
I.C.3.a.2	10,700	1016	7.67	0.25	6	2032	64,200	
I.C.3.b.1	10,700	1016	29.3	0.167	4	2032	64,200	
I.C.3.b.2	10,700	1016	5.11	0.167	4	2032	64,200	
I.C.4.a.1	5,350	1016	29.3	0.25	6	2032	32,100	
I.C.4.a.2	5,350	1016	5.94	0.25	6	2032	32,100	
IC.4.b.1	5,350	1016	29.3	0.167	4	2032	32,100	
I.C.4.b2	5,350	1016	3.96	0.167	4	2032	32,100	

FOOD MACHINERY AND CHEMICAL CORPORATION ORDNANCE DIVISION

APPENDIX A

STUDY RESULTS

The vehicle with six walking beams and twelve road wheels with a soft spring and a hard shock is the most comfortable riding vehicle.

This result was determined by analyzing the ride comfort curves, plots of amplitude vs frequency, provided by the U. S. Army Transportation Research Command for the vehicles analyzed in this study. This result was verified by studying the tabulations of vehicle ride data, which are included in this result summary section.

Pertinent vehicle data for all cases studied in this analysis is presented in a tabular form for both steady state and transient response of the vehicle. A careful analysis of this information will yield a maximum absolute acceleration imposed on the driver of 1.925 g's and a maximum wheel travel of 6.056 inches relative to the vehicle.

Load and stress analysis of: LVT Suspension with 8 Wheels, 4 Walking Beams Dwg. No. Steady State Page No. 145
Prepared by L Gerard Date 19 Sept 61 Checked by Date Project No. 499

SYSTEM	BUMP HEIGHT	VEHICLE SPEED	PITCH TOTAL EXCURSION	VERT. DISP. of C. G. TOTAL EXCURSION	VERT. DISP. at DRIVER'S SEAT TOTAL EXCURSION	MAXIMUM PITCH ACCELERATION	MAX. VERT. ACCEL. (g's)		TOTAL WHEEL TRAVEL	Case No.
	(inches)	(FPS)/MPH	(degrees)	(feet)	(feet)	(rad./sec^2)	at C. G.	at DRIVER'S SEAT	(inches)	—
HARD SPRING SOFT SHOCK	3	29.3/20	0.23	0.016	0.02041	1.88	1.234	1.3	3.103	IA4a1
"	3	8.03/5.5	18.3	0.166	2.352	12.10	1.195	3.76	15.072	IA4a2
"	2	29.3/20	0.0115	0.0252	0.0264	0.21	1.83	1.868	2.1572	IA4b1
"	2.	5.35/3.6	14.7	0.60	1.94	9.00	1.658	3.13	12.05	IA4b2
SOFT SPRING SOFT SHOCK	3	29.3/20	0.115	0.010	0.00906	0.94	1.146	1.133	3.04	IA2a1
"	3	5.67/3.9	9.40	0.166	1.312	2.89	1.088	1.72	9.816	IA2a2
"	2	29.3/20	0.0115	0.014	0.0154	0.21	1.46	1.51	2.0911	IA2b1
"	2	3.77/2.6	1.38	0.69	0.54	0.42	1.376	1.294	5.372	IA2b2
HARD SPRING HARD SHOCK	3	29.3/20	0.275	0.02	0.0286	2.26	1.29	1.42	4.452	IA3a1
"	3	8.03/5.5	9.16	0.172	1.248	6.03	1.20	2.46	9.47	IA3a2
"	2	29.3/20	0.023	0.036	0.03874	0.42	2.20	2.27	2.348	IA3b1
"	2	5.35/3.6	3.83	0.52	0.758	2.35	1.57	1.83	6.236	IA3b2
SOFT SPRING HARD SHOCK	3	29.3/20	0.195	0.014	0.01868	1.60	1.20	1.273	3.095	IA1a1
"	3	5.67/3.9	6.90	0.156	0.884	2.12	1.085	1.485	7.584	IA1a2
"	2	29.3/20	0.0183	0.031	0.0332	0.34	2.00	2.09	2.372	IA1b1
"	2	3.77/2.6	0.505	0.60	0.66	0.154	1.327	1.36	5.912	IA1b2
		SOFT SPRING – 12" DEFLECTION UNDER 2g's			SOFT SHOCK – 508 lbs-sec/ft					
		HARD SPRING – 6"		" "	HARD SHOCK – 1016 lbs-sec/ft					

Load and stress analysis of: LVT Suspension with 12 Wheels. 6 Walking Beams Dwg. No. Steady State Page No. 146
Prepared by L Gerard Date 19 Sept 61 Checked by ______ Date ______ Project No. 449

SYSTEM	BUMP HEIGHT	VEHICLE SPEED	PITCH TOTAL EXCURSION	VERT. DISP. of C. G. TOTAL EXCURSION	VERT. DISP. at DRIVER'S SEAT TOTAL EXCURSION	MAXIMUM PITCH ACCELERATION	MAX. VERT. ACCEL. (g's) abs.		TOTAL Fr. WHEEL TRAVEL	Case No.
	(inches)	(fps)/MPH	(degrees)	(feet)	(feet)	(rad/sec²)	at C.G.	at DRIVER'S SEAT	(inches)	—
HARD SPRING SOFT SHOCK	3	29.3/20	0.16	0.016	0.0314	1.32	1.234	1.46	3.175	IB4a1
"	3	7.7/5.2	8.0	0.170	0.882	4.55	1.171	1.89	7.572	IB4a2
"	2	29.3/20	0.0458	0.008	0.00244	0.846	1.263	1.08	2.0197	IB4b1
"	2	5.13/3.5	6.06	0.117	0.626	3.44	1.118	1.53	5.372	IB4b2
SOFT SPRING SOFT SHOCK	3	29.3/20	0.111	0.0062	0.00714	0.914	1.09	1.104	3.108	IB2a1
"	3	5.68/3.9	21.4	0.204	2.44	6.62	1.115	2.34	15.72	IB2a2
"	2	29.3/20	0.0275	0.0056	0.0045	0.507	1.184	1.148	2.8376	IB2b1
"	2	3.78/2.6	4.3	0.132	0.632	1.32	1.072	1.357	5.516	IB2b2
HARD SPRING HARD SHOCK	3	29.3/20	0.224	0.0132	0.0406	1.85	1.193	1.593	3.223	IB3a1
"	3	7.7/5.25	4.16	0.149	0.478	2.37	1.15	1.481	5.508	IB3a2
"	2	29.3/20	0.03	0.01334	0.00994	0.565	1.437	1.327	2.06216	IB3b1
"	2	5.13/3.5	4.15	0.127	0.635	2.35	1.128	1.64	5.434	IB3b2
SOFT SPRING HARD SHOCK	3	29.3/20	0.188	0.008	0.031	1.54	1.117	1.454	3.1687	IB1a1
"	3	5.68/3.9	3.10	0.14	0.3444	0.955	1.076	1.19	4.812	IB1a2
"	2	29.3/20	0.152	0.01066	0.0282	2.81	1.35	1.925	2.1464	IB1b1
"	2	3.78/2.6	6.14	0.0224	0.772	1.89	1.0122	1.423	6.056	IB1b2
		SOFT SPRING – 12" DEFLECTION UNDER 2g's			SOFT SHOCK – 508 lbs-sec/ft					
		HARD SPRING – 6" " " "			HARD SHOCK – 1016 lbs-sec/ft					

fmc Load and stress analysis of: LVT Suspension · with 12 Wheels Individually Sprung Dwg. No. Steady State Page No. 147
Prepared by L Gerard Date 20 Sept 61 Checked by Date Project No. 449

SYSTEM	BUMP HEIGHT	VEHICLE SPEED	PITCH TOTAL EXCURSION	VERT. DISP. of C.G. TOTAL EXCURSION	VERT. DISP. at DRIVER'S SEAT TOTAL EXCURSION	MAXIMUM PITCH ACCELERATION	MAX. VERT. ACCEL. (g's) abs.		TOTAL Fr. WHEEL TRAVEL	Case No
	(inches)	(fps)/MPH	(degrees)	(feet)	(feet)	(rad/sec^2)	at C.G.	at DRIVERS SEAT	(inches)	—
HARD SPRING SOFT SHOCK	3	29.3/20	0.43	0.0136	0.0644	3.54	1.20	1.943	3.347	Ic4a1
"	3	7.67/5.2	5.10	0.161	0.554	2.87	1.161	1.555	5.88	Ic4a2
"	2	29.3/20	0.159	0.0064	0.02534	2.94	1.21	1.832	2.138	Ic4b1
"	2	5.11/3.5	1.40	0.175	0.198	0.785	1.175	1.198	3.1232	Ic4b2
SOFT SPRING SOFT SHOCK	3	29.3/20	0.41	0.007	0.056	3.39	1.103	1.823	3.0324	Ic2a1
"	3	5.94/4	5.13	0.20	0.498	1.73	1.12	1.30	5.51	Ic2a2
"	2	29.3/20	0.157	0.0034	0.022	2.90	1.112	1.723	2.1178	Ic2b1
"	2	3.96/2.7	1.42	0.184	0.0248	0.475	1.11	1.045	2.462	Ic2b2
HARD SPRING HARD SHOCK	3	29.3/20	0.85	0.016	0.1108	7.00	1.244	2.62	3.588	Ic3a1
"	3	7.67/5.2	4.93	0.154	0.688	2.77	1.154	1.69	6.74	Ic3a2
"	2	29.3/20	0.234	0.0076	0.03488	4.31	1.25	2.14	2.188	Ic3b1
"	2	5.11/3.5	2.18	0.1616	0.259	1.22	1.162	1.26	3.404	Ic3b2
SOFT SPRING HARD SHOCK	3	29.3/20	0.81	0.0096	0.1066	6.66	1.141	2.56	3.565	Ic1a1
"	3	5.94/4	5.04	0.16	0.54	1.70	1.096	1.324	5.796	Ic1a2
"	2	29.3/20	0.275	0.0046	0.0316	5.08	1.152	2.04	2.1686	Ic1b1
"	2	3.96/2.7	2.16	0.1512	0.231	0.72	1.09	1.137	3.123	Ic1b2
		SOFT SPRING — 12" DEFLECTION UNDER 2g's			SOFT SHOCK — 508 lbs-Sec/ft					
		HARD SPRING - 6" " " "			HARD SHOCK - 1016 lbs-Sec/ft					

fmc

Load and stress analysis of: LVT Suspension ; Transient Response

Prepared by L Gerard Date 21 Sept 61 Checked by R. Smith Dwg. No. Date Sept 25, 61

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SYSTEM	BUMP HEIGHT	VEHICLE SPEED	PITCH TOTAL EXCURSION	VERT. DISP. of C.G. TOTAL EXCURSION	VERT. DISP. at DRIVER'S SEAT TOTAL EXCURSION	VERT. DISP. at REAR TOTAL EXCURSION	Total Front wheel Travel	Code		
	(inches)	(fps)/MPH	(degrees)	(feet)	(feet)	(feet)	inches			
8 WHEELS, 4 WALKING BEAMS										
HARD SPRING	3	29.3/20	0.62	0.052	0.078	0.098	3.66	1A4a1		
SOFT SHOCK	2	29.3/20	0.087	0.088	0.0964	0.0796	2.33	1A4b1		
SOFT SPRING	3	29.3/20	0.468	0.0308	0.0621	0.076	3.372	1A2a1		
SOFT SHOCK	2	29.3/20	0.084	0.056	0.0623	0.0486	3.38	1A2b1		
HARD SPRING	3	29.3/20	0.876	0.051	0.0954	0.133	3.57	1A3a1		
HARD SHOCK	2	29.3/20	0.100	0.088	0.0966	0.079	2.58	1A3b1		
SOFT SPRING	3	29.3/20	0.87	0.035	0.110	0.119	3.47	1A1a1		
HARD SHOCK	2	29.3/20	0.115	0.050	0.055	0.059	2.576	1A1b1		
12 WHEELS, 6 WALKING BEAMS										
HARD SPRING	3	29.3/20	0.463	0.048	0.090	0.0616	3.684	1B4a1		
SOFT SHOCK	2	29.3/20	0.092	0.036	0.038	0.033	2.956	1B4b1		
SOFT SPRING	3	29.3/20	0.45	0.026	0.079	0.046	3.476	1B2a1		
SOFT SHOCK	2	29.3/20	0.073	0.0328	0.039	0.028	2.235	1B2b1		
HARD SPRING	3	29.3/20	0.756	0.042	0.123	0.067	3.738	1B3a1		
HARD SHOCK	2	29.3/20	0.0765	0.050	0.054	0.046	2.326	1B3b1		
SOFT SPRING	3	29.3/20	0.800	0.026	0.114	0.078	3.738	1B3a1		
HARD SHOCK	2	29.3/20	0.900	0.049	0.159	0.067	2.326	1B3b1		
12 WHEELS, INDIVIDUALLY SPRUNG										
HARD SPRING	3	29.3/20	0.706	0.0468	0.079	0.117	3.814	1C4a1		
SOFT SHOCK	2	29.3/20	0.284	0.0252	0.033	0.047	2.336	1C4b1		
SOFT SPRING	3	29.3/20	0.700	0.0284	0.075	0.105	3.452	1C2a1		
SOFT SHOCK	2	29.3/20	0.286	0.0184	0.026	0.045	2.156	1C2b1		
HARD SPRING	3	29.3/20	1.26	0.0488	0.139	0.185	3.840	1C3a1		
HARD SHOCK	2	29.3/20	0.573	0.0296	0.052	0.088	2.312	1C3b1		
SOFT SPRING	3	29.3/20	1.25	0.0344	0.135	0.175	3.475	1C1a1		
HARD SHOCK	2	29.3/20	0.584	0.0206	0.056	0.084	2.200	1C1b1		

SOFT SPRING - 12" DEFLECTION UNDER 2g's

HARD SPRING - 6" " " "

SOFT SHOCK - 508 lbs - sec/ft

HARD SHOCK - 1016 lbs - Sec/ft

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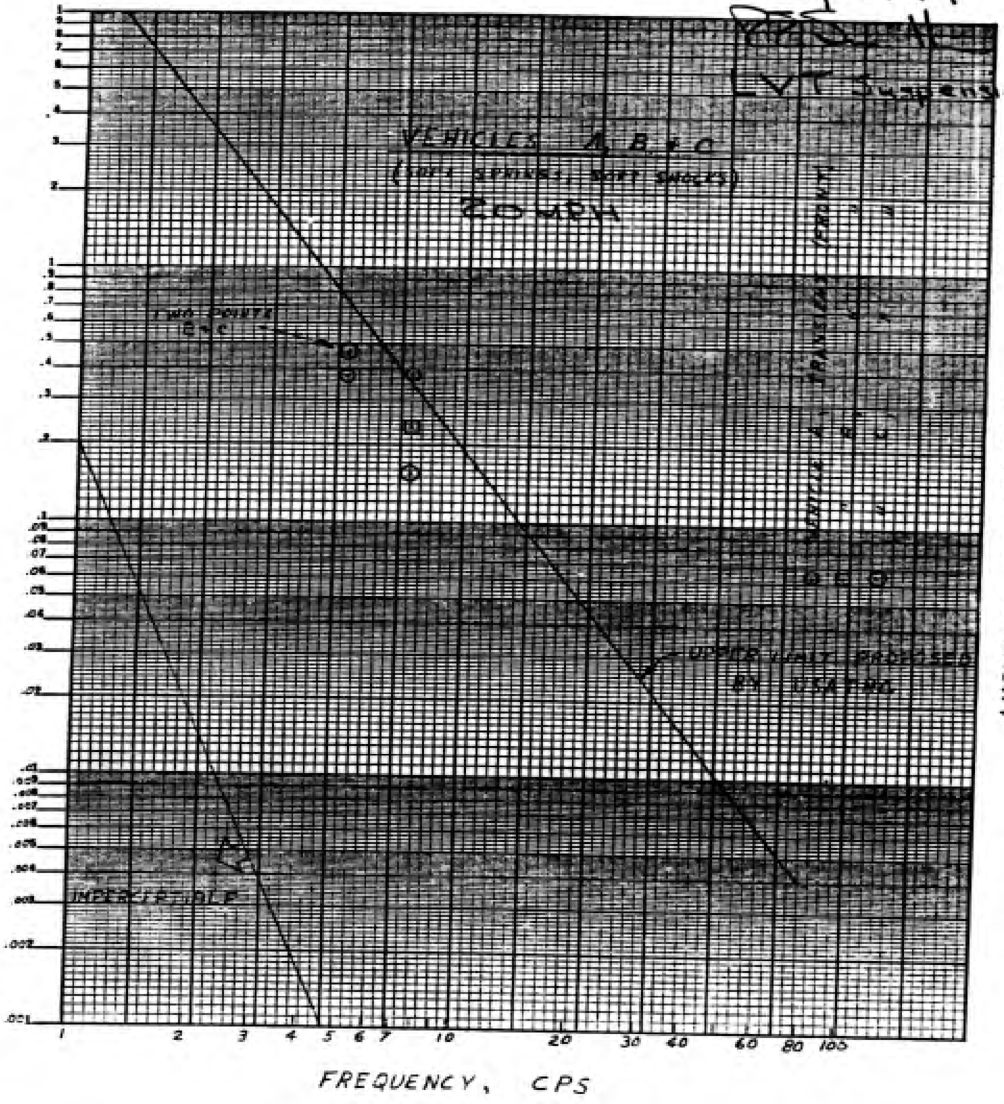
LVT Suspension



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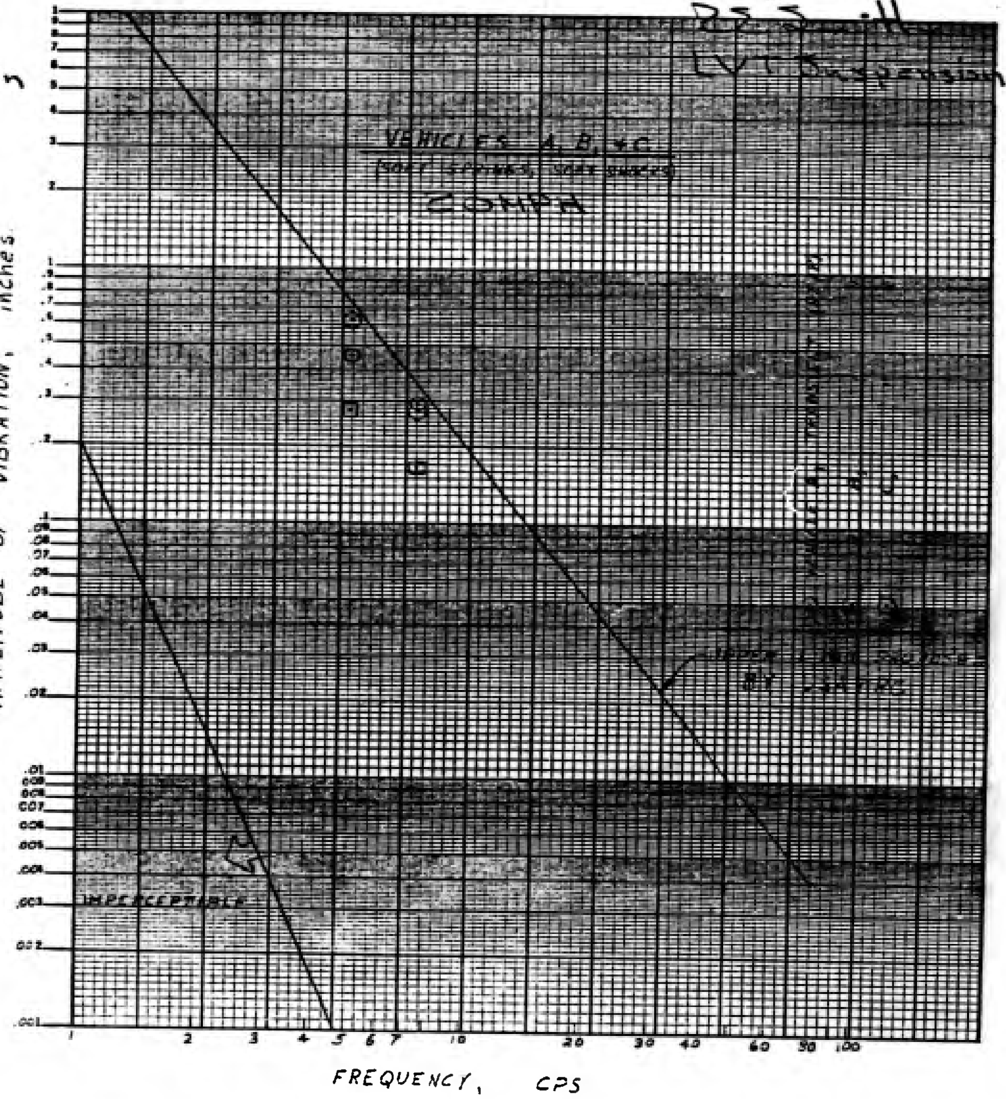
LVT Suspension



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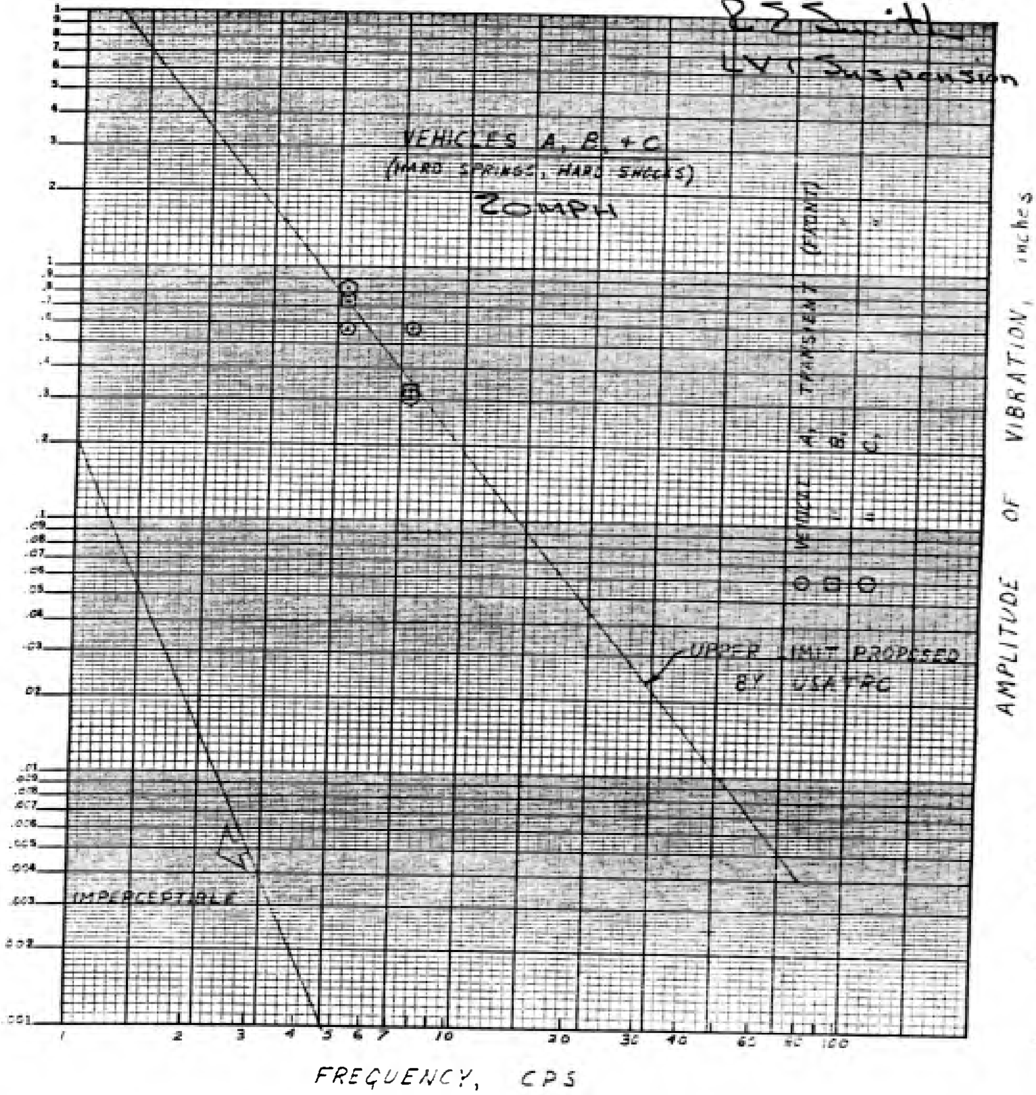

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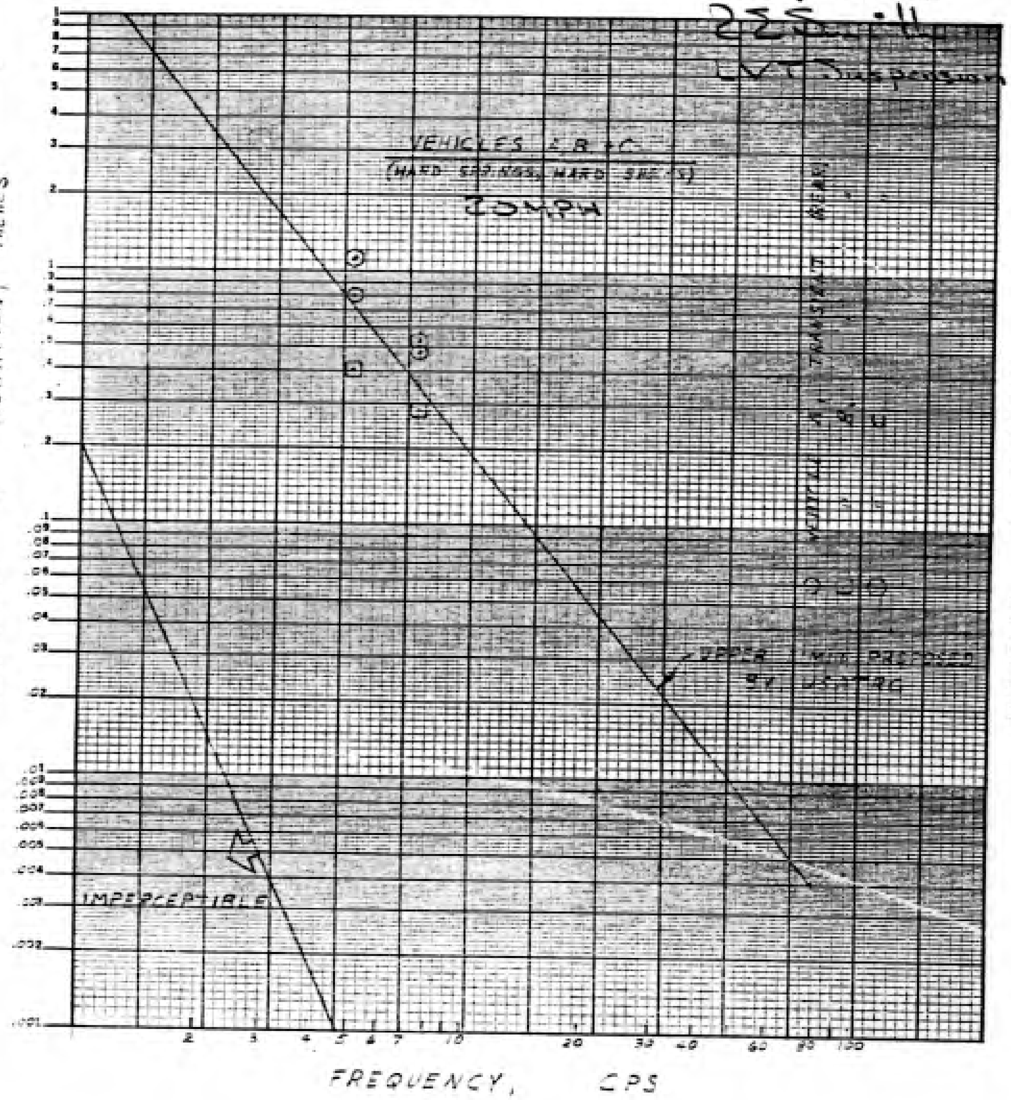

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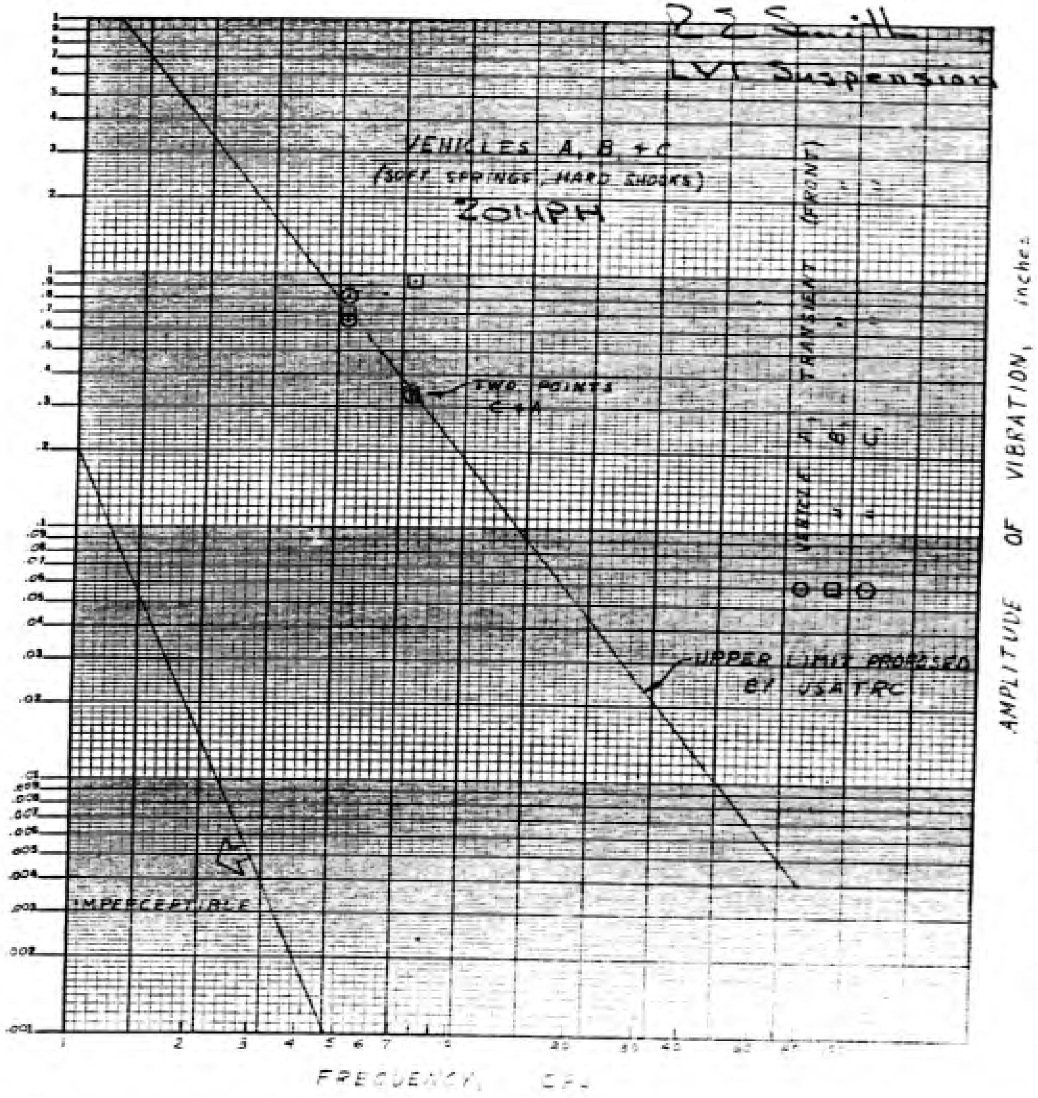
R E Smith
LVT Suspension



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R E Smith
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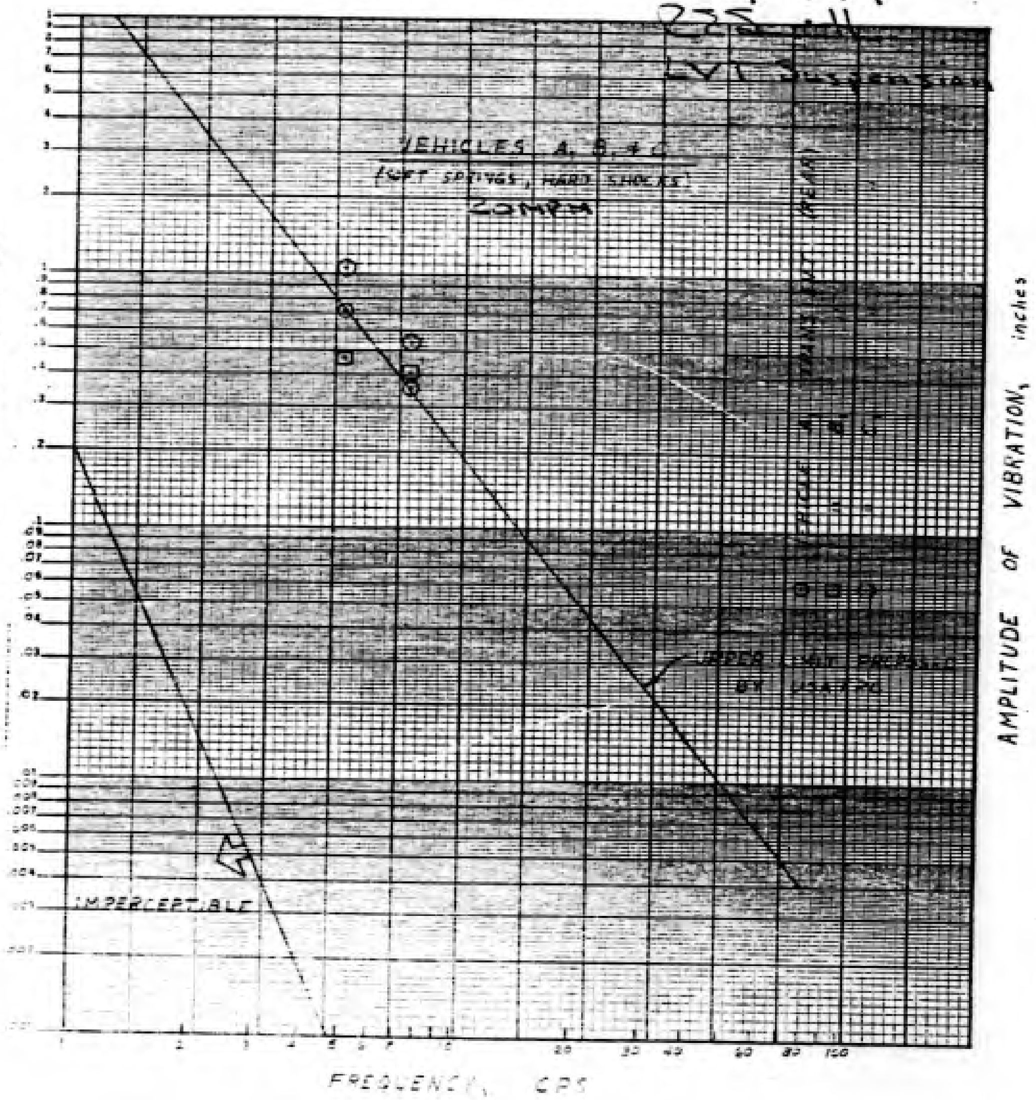

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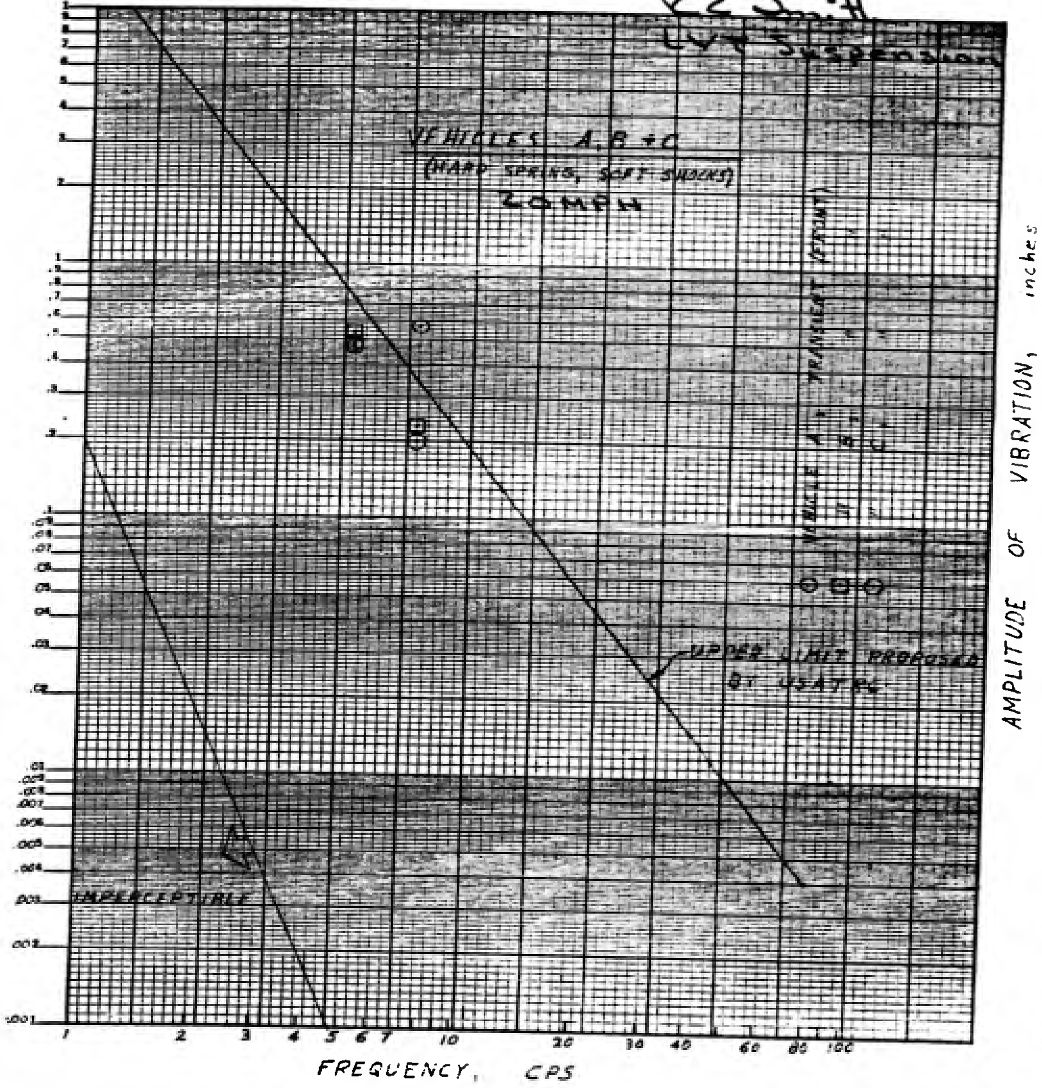
ZZ Smith
LVT Suspension



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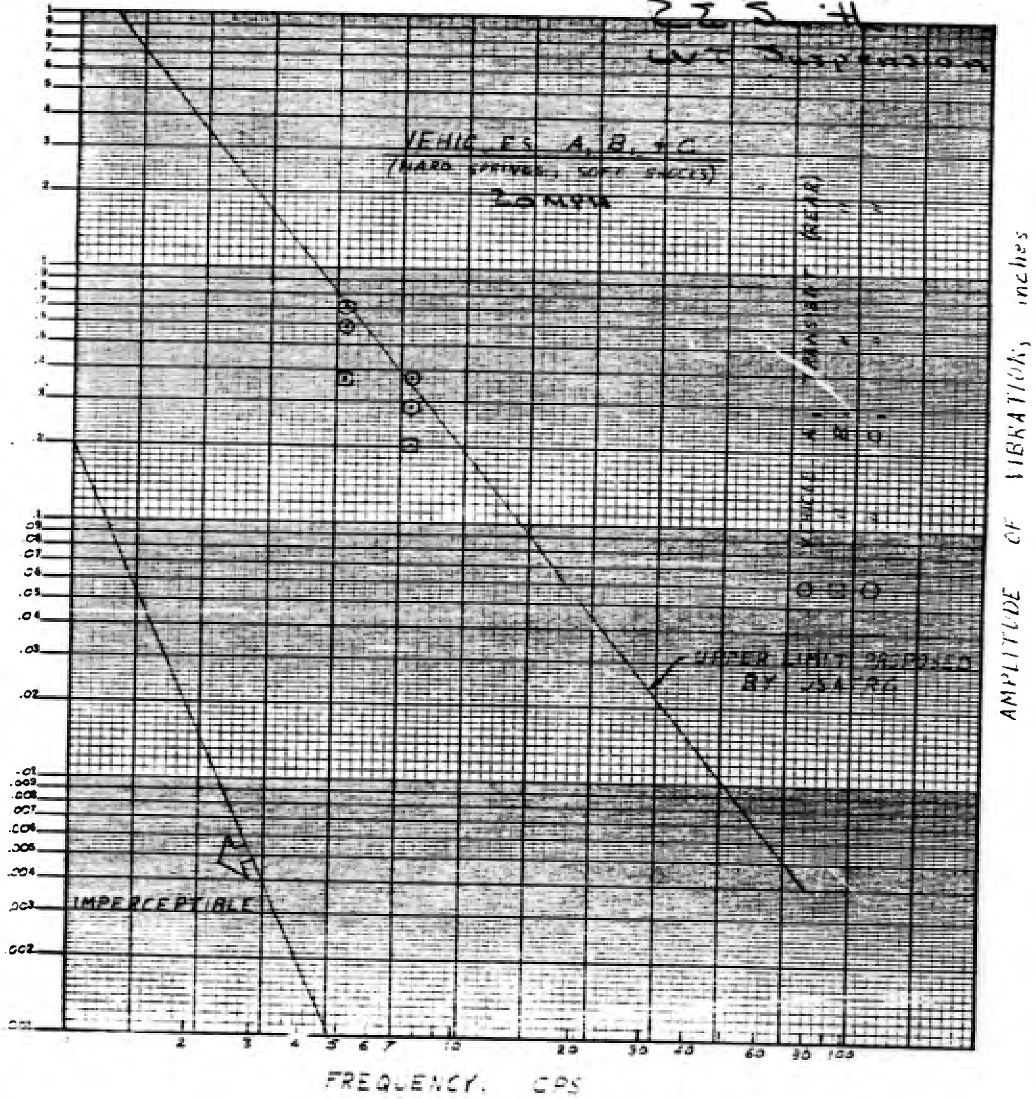

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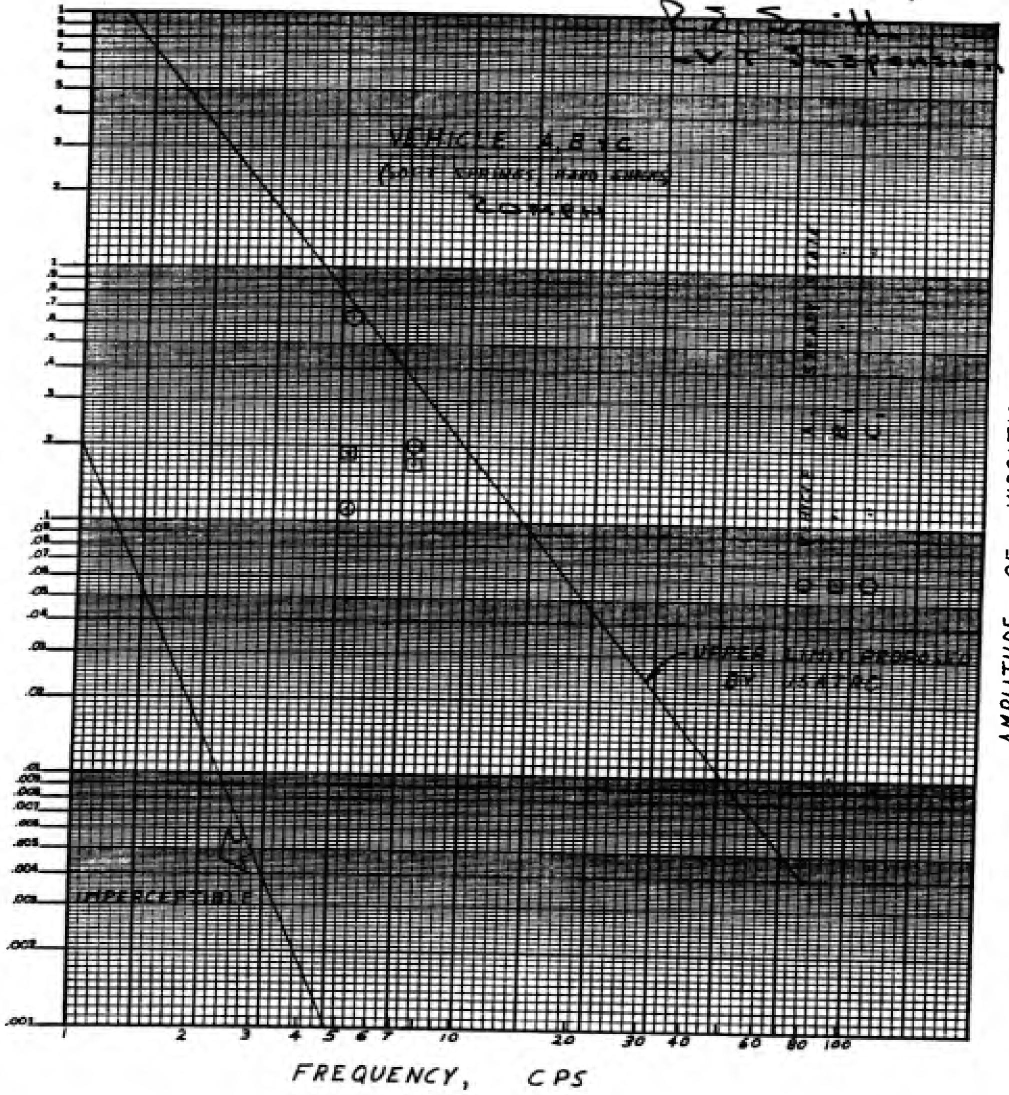

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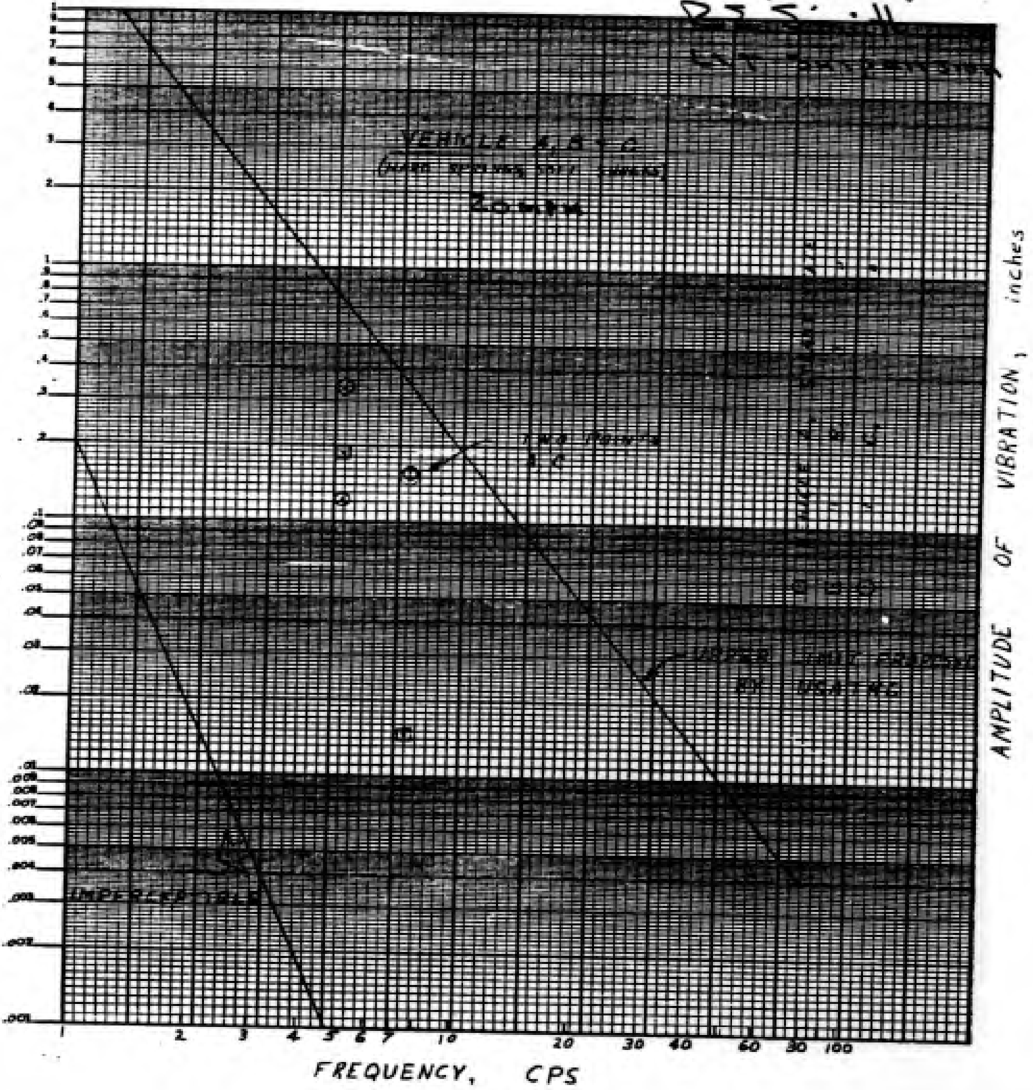

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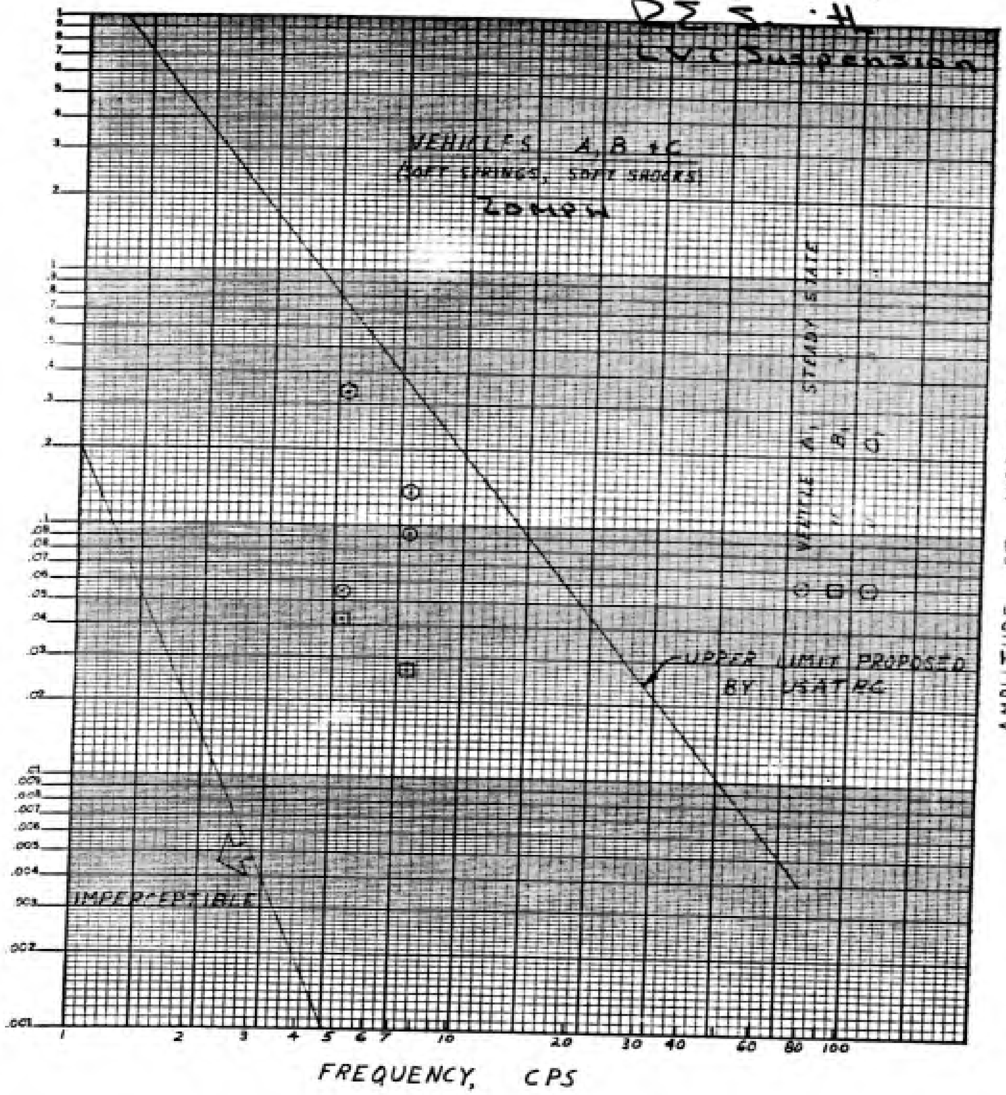
DZ Smith
LVC Suspension



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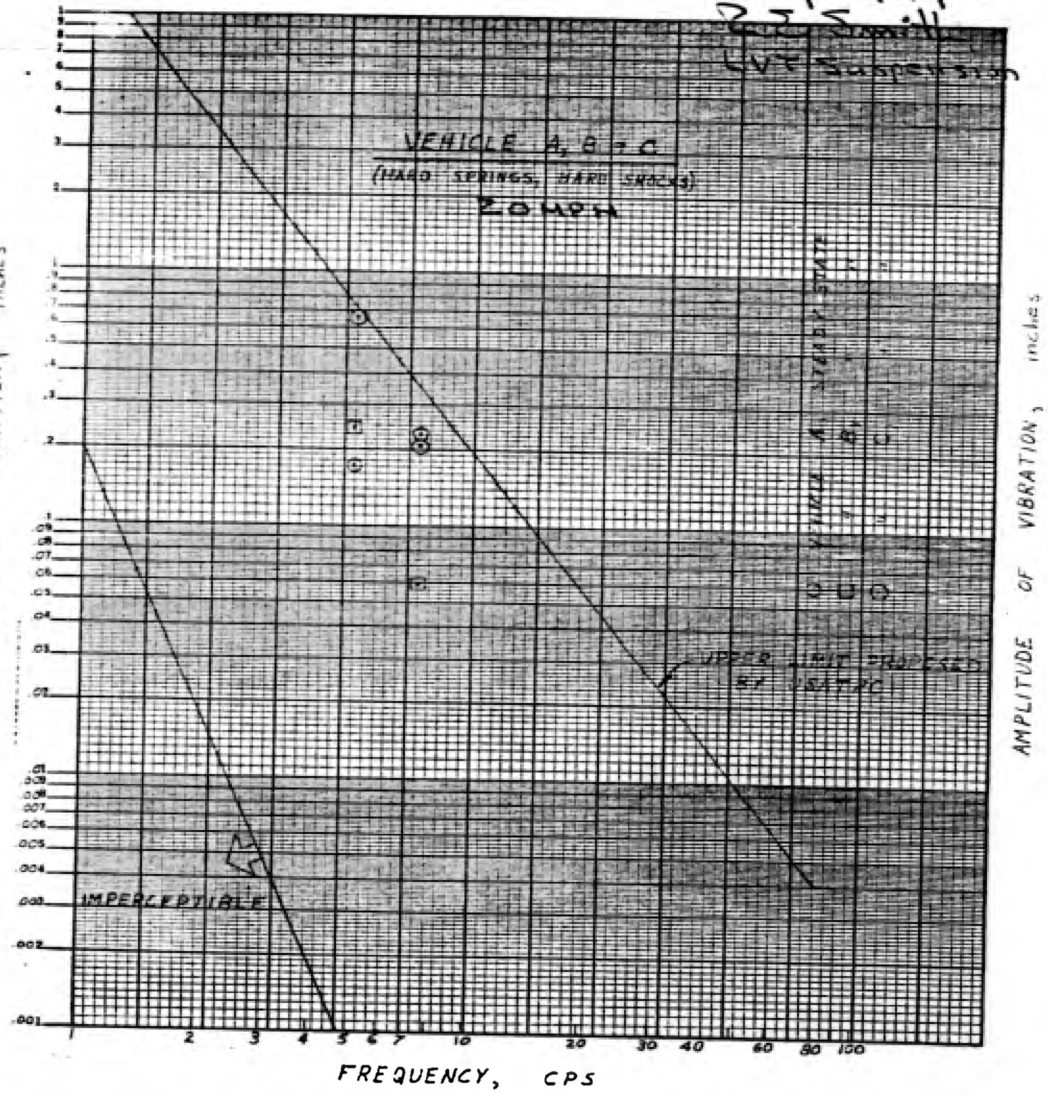
DZ Smith
LVT Suspension



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PREPARED BY MK		**WEIGHT AND CENTER OF GRAVITY DATA**			ORIG DATE OF ISSUE 10/24/61			
END ITEM LVTPX11 (MAX ARMOR)		GROUP SUMMARY SHEET MAXIMUM ARMOR VEHICLE (29000 LB. LIGHT WT.)	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
PART NO.	REV	NOMENCLATURE				STA	WL	BL
1		HULL (ARMOR)			12923	152.5	57.0	—
2		HULL (OTHER THAN ARMOR)			1721	149.0	64.3	9.9R
3		POWER TRAIN			3891	248.7	40.2	2.2R
4		ELECTRICAL			340	205.8	53.1	18.1R
5		FUEL SYSTEM			981	236.0	57.6	49.0L
6		SUSPENSION			6616	157.1	22.1	—
7		CREW			440	64.0	70.0	—
8		MISC.			886	118.6	49.1	3.6R
9		O.V.E.			1108	123.2	65.0	15.0R
10								
11								
12								
13								
14								
15								
16								
17								
18					28906	166.2	47.3	.3R

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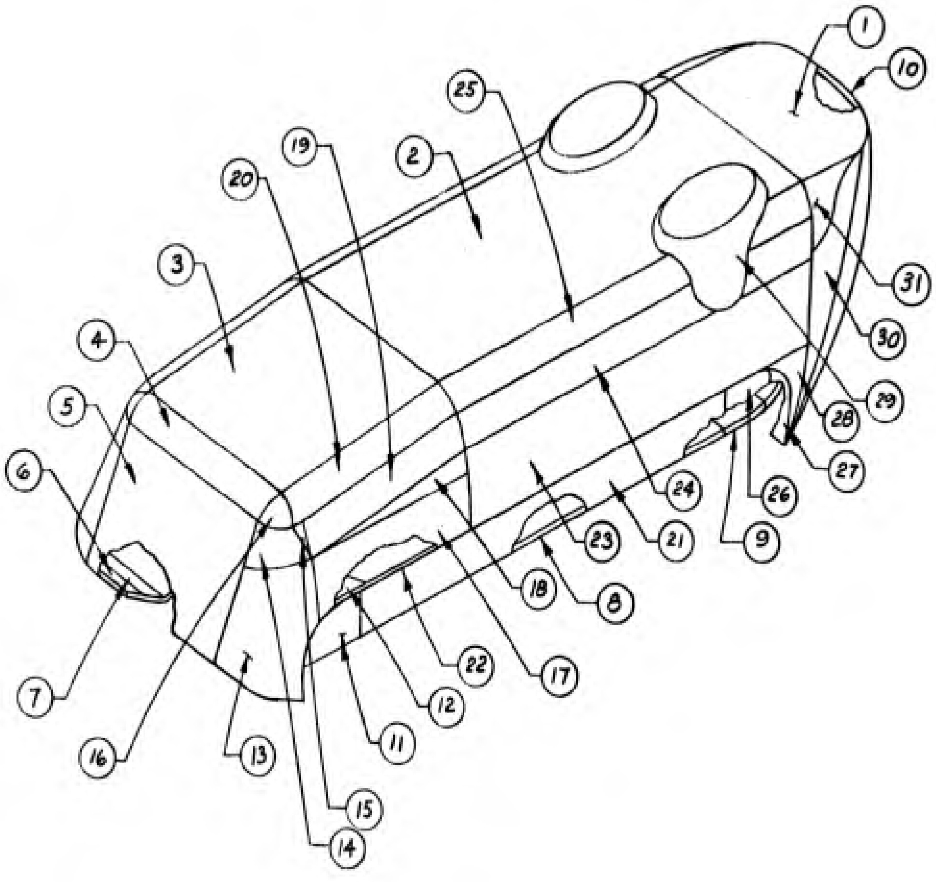

[illegible] OF VEHICLE = STA 7.5

Sheet 2

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PREPARED BY OMR	**WEIGHT AND CENTER OF GRAVITY DATA**	ORIG DATE OF ISSUE 10/24/61
END ITEM LVTPX11 (MAX ARMOR)	GROUP HULL (ARMOR)	

PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
1		PLATE - TOP BOW		1	499	25.5	79.5	-
2		PLATE - TOP FORWARD		1	2085	126	85	-
3		PLATE - TOP AFT		1	844	240	80	-
4		PLATE - TOP STERN CORNER		1	102	277	75	-
5		PLATE - STERN		1	589	284	49.5	-
6		PLATE - BOTTOM STERN CORNER		1	69	287	26	-
7		PLATE - BOTTOM AFT		1	139	280	22	-
8		PLATE - BOTTOM INT.		1	1460	172	18	-
9		PLATE - BOTTOM FWD		1	333	57	25	-
10		PLATE - BOW		1	732	27	55.5	-
11		PLATE - SIDE BOTTOM AFT		2	60	279	32	-
12		PLATE - SPONSON BOTTOM AFT		2	54	281	37.5	-
13		PLATE - CORNER AFT BOTTOM		2	186	280	45	-
14		PLATE - CORNER AFT INT.		2	93	276	62	-
15		PLATE - CORNER FILLER		2	27	264	66	-
16		PLATE - CORNER AFT TOP		2	17	276	74	-
17		PLATE - AFT SIDE BOTTOM		2	159	231	50	-
18		PLATE - AFT SIDE INT.		2	48	222	57	-

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PREPARED BY OMR	**WEIGHT AND CENTER OF GRAVITY DATA**	ORIG DATE OF ISSUE 10/24/61
END ITEM LVTPX11 (MAX. ARMOR)	GROUP HULL (ARMOR) (CONT.)	

PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
19		PLATE - AFT SIDE INT.		2	288	233	66	—
20		PLATE - AFT TOP CORNER		2	249	240	88.5	—
21		PLATE - SIDE BOTTOM INT.		2	1542	172	31.5	—
22		PLATE - SPONSON BOTTOM INT.		2	434	172	45	—
23		PLATE - SIDE INT.		2	762	124	53	—
24		PLATE - CORNER TOP INT.		2	831	125.5	70	—
25		PLATE - CORNER TOP		2	609	126	82.5	—
26		PLATE - SIDE BOTTOM FORWARD		2	160	60	33	—
27		PLATE - FRONT SPONSON		2	46	51	40	—
28		PLATE - SIDE BOTTOM FWD		2	15	47	42	—
29		PLATE - TURRET		2	257	64	87	—
30		PLATE - SIDE BOW		2	111	35.5	56	—
31		PLATE - BOW CORNER		2	123	36	79	—
		TOTAL ARMOR (INCLUDES PREVIOUS SHEET)			12923	152.5	57.0	—

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END ITEM LVTPXII (MAX. ARMOR)

GROUP HULL (OTHER THAN ARMOR)

PART NO.	REV	NOMENCLATURE		UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	WL	BL
		FLOOR PLATES		150	1	150	126	26	
		ENG. COMPT. BULKHEAD		125	1	125	207	58	
		RAMP FRAMING		200	1	200	30	50	
		AIR HOODS	INTAKE	249*	1	249	245	80	41R
			EXHAUST	195*	1	195	240	80	6.5L
		LIFTING EYES		8	4	32	150	77	
		MISC. WELD		50	1	50	150	57	
		MOORING BITS & HAND RAILS		50	1	50	150	77	
		TRACK SHROUDS W/ENDS		100	2	200	150	32	
		MISC. BRACKETS & FASTENERS		35	1	35	150	50	
		DRIVERS HATCH		20*	1	20	64	94	37L
		TOW HITCHES		25	2	50	150	30	
		MG. TURRET		250*	1	250	64	94	37R
		CARGO HATCH		100*	1	100	149	87	
		FUEL CAP & TELESCOPING FILLER		15*	1	15	205	85	30L
		TOTALS				1721	149.0	64.3	9.9R

* NOTE: WEIGHT SHOWN IS TOTAL WEIGHT (INCLUDING OVERLAP & HARDWARE) MINUS WEIGHT OF PLATE WHICH COVERS OPENING SINCE TOP HULL PLATE HAS BEEN CONSIDERED ONE SOLID PLATE TO SIMPLIFY ARMOR TRADEOFF CALCULATIONS.

FOOD MACHINERY AND CHEMICAL CORPORATION
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END ITEM LVTPXII (MAX. ARMOR)

GROUP POWER TRAIN

PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	WL	BL
		ENGINE - CUMMINS V8 300	1471*	1	1471	230	40	
		XTG TRANSMISSION (WET)	1260	1	1260	268	36	
		FINAL DRIVES	190	2	380	270	32	
		AIR CLEANER	30	1	30	211	65	25L
		HEAT EXCHANGER - TRANS.	35	1	35	254	30	16R
		"U" JOINTS & SHAFTS	100	1	100	270	38	
		MOUNTS	35	1	35	230	35	
		MISC. (HOSE, HARNESS, PIPE, ETC.)	80	1	80	230	35	
		RADIATOR AIR DUCTING	25	1	25	244	60	38R
		MUFFLER & PIPING	50	1	50	254	65	23L
		RADIATOR	120	1	120	244	60	30R
		COOLING WATER	100	1	100	235	50	15R
		CONTACT COOLER & PIPING	120	1	120	244	46	45R
		FAN & GEAR BOX ASSEMBLY	85	1	85	227	78	20L
		*WT. IS LESS ALTERNATOR WHICH IS INCLUDED IN ELECTRICAL						
		TOTALS			3891	248.7	40.2	2.2R

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END ITEM LVTPXII (MAX ARMOR)

GROUP ELECTRICAL

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	WL	BL
1			4 BATTERIES WITH BOX	–	–	162	281	50	38R
2			REGULATOR	12	1	12	238	36	
3			ALTERNATOR	40	1	40	238	36	
4			IR. POWER PACK	10	1	10	82	79	
5			HEADLIGHTS - FWD	3.5	2	7	30	83	
6			TAILLIGHTS - REAR	2.5	2	5	285	70	
7			I.R. LIGHTS	3.5	2	7	30	83	
8			B.O. MARKERS	1.5	2	3	45	81	
9			HORN	3	1	3	30	83	
10			JUNCTION BOX	4	1	4	80	80	
11			INST. PANEL	11	1	11	40	75	
12			WIRE HARNESS	50	1	50	140	45	
13			DOME LIGHTS	2	3	6	80	80	
14			MISC. (FASTENERS & CLIPS)	20	1	20	50	70	
15									
16									
17									
18			TOTALS			340	205.8	53.1	18.1R

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END ITEM LVTPXII (MAX ARMOR)

GROUP FUEL SYSTEM

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	WL	BL
1			FUEL CELL	30	1	30	236	58	44L
2			FUEL LINES & FITTINGS	15	1	15	236	40	44L
3			FUEL PUMP - AUX.	5	1	5	236	40	44L
4			FUEL CELL STRUCTURE	100	1	100	236	58	44L
5			FUEL 125 GAL @ 6.65 #/GAL	831	1	831	236	58	44L
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18			TOTALS			981	236	57.6	44L

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END ITEM LVTPX11 (MAX ARMOR)

GROUP SUSPENSION

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
							STA	WL	BL
1			SPROCKET ASSY.	150	2	300	270.7	29	
2			IDLER ASSY. W/COMP.	100	2	200	61.5	29	
3			TRACK SECTION	134	22	2948	165.5	22	
4			ANCHOR	5.5	12	66	147.5	23	
5			RETURN ROLLER ASSEMBLY	55	2	110	106	35.5	
6			IDLER WHEELS	45	4	180	61.5	29	
7			ROAD WHEELS	43	20	860	179.5	15	
8			ROAD WHEELS	43	4	172	88.5	15	
9			RETURN ROLLER ASSY.	55	4	220	106	35.5	
10			TORSION BAR	46	12	552	147.5	23	
11			SUPPORT ASSY - FRONT	89	2	178	81.5	19	
12			SUPPORT ASSY - INT.	65	8	520	152.5	19	
13			SUPPORT ASSY - REAR	89	2	178	222.5	19	
14			SHOCK ABSORBER	30	4	120	166.5	28	
15			BUMP STOP	6	2	12	166.5	24	
16									
17									
18			TOTALS						

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WEIGHT AND CENTER OF GRAVITY DATA

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END ITEM LVTPX11 (MAX. ARMOR)

GROUP CREW

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
							STA	WL	BL
1			CREW (WITH EQUIPMENT)	220	2	440	64	70	
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18			TOTALS			440	64	70	

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ORD-ENG-8M

PREPARED BY OMK

WEIGHT AND CENTER OF GRAVITY DATA

ORIG DATE OF ISSUE 10/24/61

END ITEM LVT PX II (MIN ARMOR)

GROUP MISCELLANEOUS

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
1			FIXED FIRE EXT. 10# BOTTLE	35	1	35	270	60	48R
2			SEATS, RESTS, & CUSHIONS	150	1	150	130	45	
3			BILGE PUMPS ELECTRIC MOTORS	30	2	60	150	30	
4			PUMPS - CENT.	14.5	4	58	150	24	
5			HYD. MOTORS	12	2	24	150	30	
6			HYD. PUMP & RESERVOIR	40	1	40	205	70	
7			HYD LINES	10	1	10	150	25	
8			ELECT. LINES	5	1	5	150	25	
9			DRIVER'S SEAT	45	1	45	64	55	
10			COMMANDER'S SEAT	45	1	45	64	55	
11			PAINT	40	1	40	150	55	
12			CONTROL BRACKETS	60	1	60	45	45	
13			SEAT BELTS	1	29	29	125	40	
14			BRAKE & STEER MECH.	75	1	75	45	60	
15			SHIFT CONTROLS	15	1	15	45	50	
16			RAMP CONTROL & LIFT MECH.	120	1	120	70	25	
17			THROTTLE & CHOKE CONTROLS	25	1	25	140	45	
18			PERSONNEL AIR INTAKE	50	1	50	203	70	30R
			TOTALS			886	118.6	44.1	3.6R

FOOD MACHINERY AND CHEMICAL CORPORATION
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DWG NO. ________
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PREPARED BY OMK

WEIGHT AND CENTER OF GRAVITY DATA

ORIG DATE OF ISSUE 10/24/61

END ITEM LVTPX II (MAX ARMOR)

GROUP O.V.E. - SHEET 1

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
1			BAG - PAMPHLET	1	1	1	60	70	
2			CABLE - TOW	35	2	70	141	45	
3			FIRE EXT. - PORTABLE	17	1	17	30	72	
4			FIXTURE - TRACK CONN.	28	2	56	130	50	48R
5			TOOLS AND BOX	45	2	90	230	50	55R
6			CAN - WATER	50	1	50	215	56	44R
7			PERISCOPE - M17	7	8	56	64	95	52.5R
8			" - M19	12	1	12	64	95	40L
9			" - M17 SPARE	7	1	7	71	77	40L
10			" - M19 SPARE HD.	3	1	3	75	77	54L
11			CROW BAR	10	1	10	204	86	54L
12			SLEDGE	7	1	7	204	86	
13			MATTOCK	5	1	5	204	86	
14			AXE	4	1	4	204	86	
15			SHOVEL	5	1	5	150	86	
16			ANTENNA	8	2	16	164	52	56R
17			RADIO	55	1	55	83	60	48L
18			SEE O.V.E SHEET 3 FOR TOTALS						

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WEIGHT AND CENTER OF GRAVITY DATA

ORIG DATE OF ISSUE 10/24/61

END ITEM LVT PX11 (MAX ARMOR)

GROUP O.V.E. SHEET 2

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
							STA	WL	BL
1			7.62 mm MACH. GUN	33	1	33	54	95	38R
2			SPARE BARREL	29	1	29	94	56	57R
3			TRIPOD	20	1	20	88	50	52R
4			COLLECTOR PROTECTOR (CBR)	40	1	40	80	73	39L
5			MISC. (PADLOCK, CANVAS PAIL, FLEXIBLE SPOUTS, ETC.)	50	1	50	140	55	
6			AMMUNITION 1000 ROUNDS	110	1	110	53	53	54R
7			SEARCH LIGHT - SIGNAL	10	1	10	30	74	59R
8			SPARE SHACKLE	20	1	20	18	73	39L
9			LANTERN	15	1	15	88	49	55L
10			COMPASS	5	1	5	43	70	52L
11			FIRST AID KIT	1	1	1	77	79	44L
12			BOAT HOOK	4	2	8	150	86	
13			GREASE GUN	5	1	5	242	47	31R
14			OIL CAN	3	1	3	226	47	31R
15			HYDRAULIC JACK	20	1	20	106	50	54L
16			ROPE - PAINTER	20	1	20	200	70	10R
17			SLAVE CABLE	10	1	10	200	70	10R
18			SEE O.V.E SHEET 3 FOR TOTALS						

FOOD MACHINERY AND CHEMICAL CORPORATION
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WEIGHT AND CENTER OF GRAVITY DATA

ORIG DATE OF ISSUE 10/24/61

END ITEM LVTPX11 (MAX. ARMOR)

GROUP O.V.E. SHEET 3

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
							STA	WL	BL
1			SPARE BAND TRACK SECTION	134	1	134	75	87	
2			PYROTECHNICS BOX	15	1	15	49	72	
3			CAN - GASOLINE MILITARY 5 GAL.	46	2	92	236	56	52.5R
4			FLASHLIGHT	1	1	1	64	65	
5			EXTENSION LIGHT	3	1	3	210	70	
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18			TOTALS (INCLUDES O.V.E SHEETS 1, 2, & 3)			1108	123.2	65.0	15.0R

FOOD MACHINERY AND CHEMICAL CORPORATION
ORDNANCE DIVISION, SAN JOSE, CALIFORNIA

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PREPARED BY CNK		**WEIGHT AND CENTER OF GRAVITY DATA**				ORIG DATE OF ISSUE 10/24/61		
END ITEM LVTPX11 (MAX ARMOR)		GROUP SUMMARY SHEET TROOP LOADING (35000# G.V.W)	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
PART NO.	REV	NOMENCLATURE				STA	WL	BL
1		VEHICLE EMPTY			28906	166.2	47.3	.3R
2		TROOPS	220	6	1320	150	56	
3		TROOPS	220	14	3080	132.5	56	
4		TROOPS	220	7	1540	140.5	56	
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18		TOTALS			34846	161.5	48.8	.2R

FOOD MACHINERY AND CHEMICAL CORPORATION
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PREPARED BY CNK		**WEIGHT AND CENTER OF GRAVITY DATA**				ORIG DATE OF ISSUE 10/24/61		
END ITEM LVTPX11 (MAX ARMOR)		GROUP SUMMARY SHEET 6000 # CARGO @ CARGO HATCH (35000# GVW)	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
PART NO.	REV	NOMENCLATURE				STA	WL	BL
1		VEHICLE EMPTY			28906	166.2	47.3	.3R
2		CARGO			6000	149	45	
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18		TOTALS			34906	163.2	46.9	.2R

FOOD MACHINERY AND CHEMICAL CORPORATION
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ORD-ENG 646

PREPARED BY OMR		**WEIGHT AND CENTER OF GRAVITY DATA**			ORIG DATE OF ISSUE 10/25/61			
END ITEM LVTPXII (MAX. WATER PERF.)		GROUP SUMMARY SHEET MAX. WATER PERF. VEHICLE (29000 LB. LIGHT	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
PART NO.	REV	NOMENCLATURE				STA	WL	BL
		HULL (ARMOR)			11978	152.6	57.3	
		HULL (OTHER THAN ARMOR)			1573	190.2	62.8	8.9R
		POWER TRAIN			5391	265.8	45.2	1.6R
*		ELECTRICAL			390	205.8	53.1	18.1R
*		FUEL SYSTEN			981	236.0	57.6	49.0L
		SUSPENSION			6286	156.7	22.1	—
*		CREW			490	64.0	70.0	—
*		MISC.			886	118.6	49.1	3.6R
		O.V.E.			1093	123.9	64.7	15.2R
* SEE WEIGHT & CENTER OF GRAVITY DATA FOR MAXIMUM								
ARMOR VEHICLE FOR DETAILED BREAKDOWN OF THESE ITEMS								
		TOTALS			28968	173.8	47.7	.2R

FOOD MACHINERY AND CHEMICAL CORPORATION
ORDNANCE DIVISION, SAN JOSE, CALIFORNIA

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PREPARED BY OMK		**WEIGHT AND CENTER OF GRAVITY DATA**			ORIG DATE OF ISSUE 10/25/61			
END ITEM LVTPXII (MAX. WATER PERF.)		GROUP HULL (ARMOR)	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY		
PART NO.	REV	NOMENCLATURE				STA	WL	BL
1		PLATE - TOP BOW		1	549	24	81	
2		PLATE - TOP FORWARD		1	2134	126	85	
3		PLATE - TOP AFT		1	373	231	83	
4		PLATE - STERN TOP		1	568	286	78	
5		PLATE - STERN BOTTOM		1	805	284	37	
6		PLATE - BOTTOM		1	1220	157	19	
7		PLATE - FWD SPONSON		1	803	33	45	
8		PLATE - STERN CORNER		2	563	258	70	
9		PLATE - CORNER INT.		2	1295	126	74	
10		PLATE - SIDE AFT		2	191	275	51	
11		PLATE - SIDE INT.		2	1085	144	53	
12		PLATE - BOW SIDE		2	247	28	58	
13		PLATE - BOW CORNER		2	231	34	77	
14		PLATE - SPONSON BOTTOM		2	574	166	43	
15		PLATE - LOWER SIDE		2	1340	167	28	
					11978	152.6	51.3	

FOOD MACHINERY AND CHEMICAL CORPORATION
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PREPARED BY GMR	**WEIGHT AND CENTER OF GRAVITY DATA**				ORIG DATE OF ISSUE 10/25/61	
END ITEM LVTPX11 (MAX WATER PERF.)	GROUP HULL (OTHER THAN ARMOR)					

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	WL	BL
1			NOTE: SAME WTS & C.G.s WERE USED FOR MAX WATER WATER PERFORMANCE						
2			VEHICLE AS WERE USED FOR MAXIMUM ARMOR VEHICLE WITH THE EXCEPTION						
3			OF THE AIR HOODS. THE TABULATION BELOW SHOWS THE						
4			ALLOWANCE MADE BECAUSE OF THE DIFFERENCE IN THICKNESS OF						
5			THE TOP PLATE						
6									
7			HULL (OTHER THAN ARMOR)(FROM MAX ARMOR VEH.)			1721	199.0	64.3	9.9R
8	MINUS →		INTAKE AIR HOOD (MAX ARMOR VEH.)			-249*	245	80.	41R
9	MINUS →		EXHAUST AIR HOOD (MAX ARMOR VEH.)			-195*	240	80	6.5L
10			INTAKE AIR HOOD			166*	245	80	41R
11			EXHAUST AIR HOOD			130*	240	80	6.5L
12									
13									
14									
15	* NOTE: WEIGHT SHOWN IS TOTAL WEIGHT (INCLUDING OVERLAP & HARDWARE)								
16	MINUS WEIGHT OF PLATE WHICH COVERS OPENING SINCE TOP HULL								
17	PLATE HAS BEEN CONSIDERED ONE SOLID PLATE TO SIMPLIFY ARMOR TRADEOFF CALCULATIONS.								
18			TOTALS			1573	190.2	62.8	8.9R

FOOD MACHINERY AND CHEMICAL CORPORATION
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PREPARED BY GMR	**WEIGHT AND CENTER OF GRAVITY DATA**				ORIG DATE OF ISSUE 10/25/61	
END ITEM LVTPX11 (MAX WATER PERF.)	GROUP POWER TRAIN					

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	WL	BL
1	*		POWER TRAIN (OTHER THAN WATER PROP. EQUIP)			3891	248.7	40.2	2.2R
2			PROPELLER ASSY, DRIVE TRAIN, GEAR BOXES, ETC.			1500	310	58	–
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14	* SEE WEIGHT & CENTER OF GRAVITY DATA FOR MAXIMUM								
15	ARMOR VEHICLE FOR DETAILED BREAKDOWN								
16									
17									
18			TOTALS			5391	265.8	45.2	1.6R

FOOD MACHINERY AND CHEMICAL CORPORATION
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REV DATE ________

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PREPARED BY MK

WEIGHT AND CENTER OF GRAVITY DATA

ORIG DATE OF ISSUE 10/25/61

END ITEM LVTPXII (MAX WATER PERF.)

GROUP SUSPENSION

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
1			NOTE : SAME WTS & C.G.; WERE USED FOR MAX WATER PERFORMANCE						
2			VEHICLE AS WERE USED FOR MAXIMUM ARMOR VEHICLE WITH THE EXCEPTION						
3			OF THE TRACK SECTIONS. THE TABULATION BELOW TAKES						
4			THIS DIFFERENCE INTO ACCOUNT.						
5									
6			SUSPENSION (MAX. ARMOR VEHICLE)			6616	157.1	22.1	
7	MINUS →		TRACK SECTION (MAX ARMOR VEHICLE)			-2948	165.5	22	
8			TRACK SECTION	119	22	2618	165.5	22	
9									
10									
11									
12									
13									
14									
15									
16									
17									
18			TOTALS			6286	156.7	22.1	

FOOD MACHINERY AND CHEMICAL CORPORATION
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WEIGHT AND CENTER OF GRAVITY DATA

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END ITEM LVT PXII (MAX WATER PERF.)

GROUP O.V.E.

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
1			NOTE: SAME WTS AND C.G.; WERE USED FOR MAX WATER PERFORMANCE						
2			VEHICLE AS WERE USED FOR MAXIMUM ARMOR VEHICLE WITH THE EXCEPTION						
3			OF THE SPARE TRACK SECTION. THE TABULATION BELOW TAKES THIS						
4			DIFFERENCE INTO ACCOUNT.						
5									
6			O.V.E. (MAX. ARMOR VEHICLE)			1108	123.2	65.0	15.0R
7	MINUS →		SPARE BAND TRACK SECTION (MAX ARMOR VEHICLE)			-134	75	87	
8			SPARE BAND TRACK SECTION			119	75	87	
9									
10									
11									
12									
13									
14									
15									
16									
17									
18			TOTALS			1093	123.9	64.7	15.2R

FOOD MACHINERY AND CHEMICAL CORPORATION
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PREPARED BY OMK

WEIGHT AND CENTER OF GRAVITY DATA

ORIG DATE OF ISSUE 10/25/61

END ITEM LVT PX 11 (MAX WATER PERF.)

GROUP SUMMARY SHEET LOADED WITH TROOPS (35000# GVW)

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
1			VEHICLE EMPTY			28968	173.8	47.7	.2R
2			TROOPS	220	6	1320	148	56	
3			TROOPS	220	14	3080	130	56	
4			TROOPS	220	7	1540	148	56	
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18			TOTALS			34908	167.8	49.1	.2R

FOOD MACHINERY AND CHEMICAL CORPORATION
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END ITEM LVTPX11 (MAX WATER PERF.)

GROUP SUMMARY SHEET 6000# CARGO @ CARGO HATCH (35000# G.V.W.)

	PART NO.	REV	NOMENCLATURE	UNIT WEIGHT	QTY PER END ITEM	WEIGHT PER END ITEM	CENTER OF GRAVITY STA	CENTER OF GRAVITY WL	CENTER OF GRAVITY BL
1			VEHICLE EMPTY			28968	173.8	47.7	.2R
2			CARGO			6000	144.5	45.0	
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18			TOTALS			34968	168.8	47.2	.2R

FOOD MACHINERY AND CHEMICAL CORPORATION
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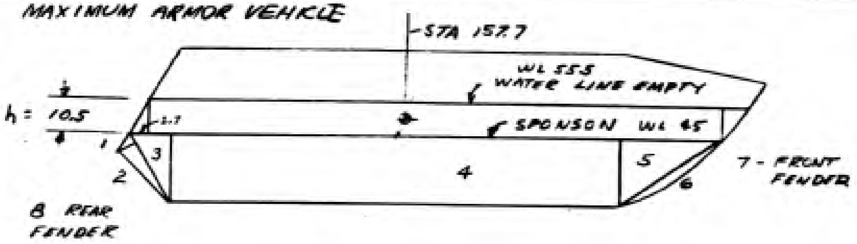
Load and stress analysis of:
Prepared by R. Sandell Date ______ Page No. 25
Checked by ______ Dwg. No. ______ Project No. ______

MAXIMUM ARMOR VEHICLE



SECTION		VOL	STA	MOMENT
1		5550	285	1,581,750
2		5180	281	1 455 000
3		12000	278	3 336 000
4		400 000	171	68 400 000
5		34,600	58	2 006 000
6		6 500	51.5	334 700
7		6 050	44	266 200
8		3520	285	1 003 000
		473,400		78 382 650

BUCYANCY CALCULATION

$\left[\frac{(10.5)}{2}(2.7) + (10.5)(248) + \frac{(10)}{2}(10.5)\right]116 = 309801$ STA 157.7 48 856 000

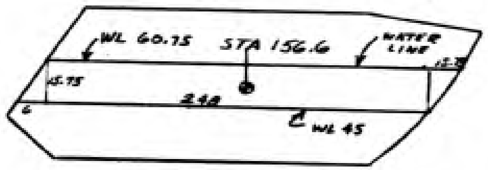
FROM TABLE ABOVE 473,400 78,382,000

783,201 127 238 000

$CB_{EMPTY} = \frac{127,238\,000}{783,201}$ = STA. 162.4

Load and stress analysis of:
Prepared by ______ Date ______ Page No. 26
Checked by ______ Dwg. No. ______ Project No. ______

ASSUME h = 15.75 FOR 35,000# LOAD



SIDE AREA = $\frac{6}{2}(15.75) + 248(15.75) + \frac{15.75^2}{2}$

= 4077 SQ IN

VOL = 4077 × 116 = 472,900 CU. IN.

MOMENT = 472,900 × 156.5 = 74,008,000
FROM TABLE 473,400 78 382 000
946,300 152,390,000

$CB_{LOADED} = \frac{152,390,000}{946,300}$ = STA 161.0

CHECK ON TOTAL 35000# WEIGHT

FROM ABOVE $\frac{946\,300}{1728}$ 64 = 35046#

CHECK OK SINCE 35046 ≃ 35000

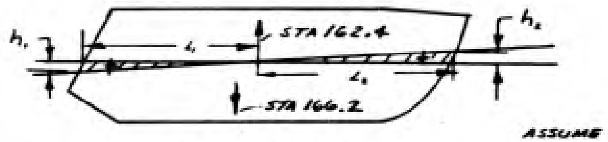
NOTE: THE DISPLACEMENT OF THE SUSPENSION HAS BEEN NOT BEEN CONSIDERED IN THE ABOVE CALC.

Load and stress analysis of:

Prepared by ______ Date ______ Page No. 27

Checked by ______ Dwg. No. ______ Project No. ______

TRIM CALCULATIONS - EMPTY



ASSUME $h_1 = h_2$
$l_1 = l_2$

$l_1 = 126.5$
$l_2 = 126.5$

EQUATING MOMENTS

$$(CG - CB)(VEH\ WEIGHT) = \frac{1}{2}\frac{(116)}{(1728)}(2)(64)(.44)l^2 h$$

$$= 2.863\, l^2 h$$

OR

$$(166.2 - 162.4)(28906) = 2.863\ (L)^2 h$$

$$3.8(28906) = 45{,}800\ h$$

$h = 2.4$ INCH

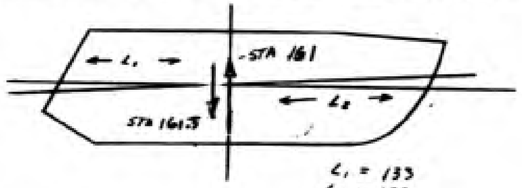
VEHICLE TRIM WILL BE UP 2.4
IN. AT THE BOW
AND DOWN 2.4 IN AT
THE STERN

Load and stress analysis of:

Prepared by ______ Date ______ Page No. 28

Checked by ______ Dwg. No. ______ Project No. ______

TRIM CALCULATIONS - LOADED - TROOPS



$l_1 = 133$
$l_2 = 133$

SUBSTITUTION

$$(161.5 - 161)\ 34896 = 2.863\ L^2\ h$$

$$17423 = 50643\ h$$

$h = .3$ INCH

VEHICLE WILL TRIM LOADED .3
IN. UP AT THE BOW
AND DOWN .3 IN. AT THE STERN

LOADED WITH 6000# CARGO AT CARGO HATCH

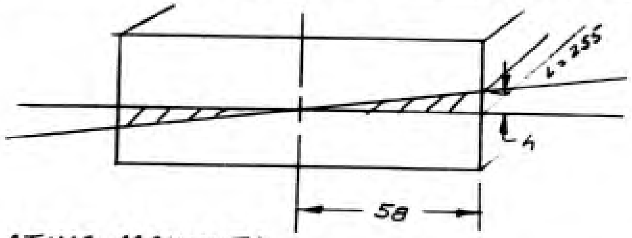
$$(163.2 - 161.0)\ 34906 = 50643\ \ell$$

$$\ell = \frac{76793}{50643} = 1.5$$

VEHICLE WILL TRIM 1.5 UP AT THE BOW
AND 1.5 IN DOWN AT THE STERN

Load and stress analysis of:
Prepared by R. Sandell Date Page No. 29
Checked by Dwg. No. Project No.

TRIM - SIDE TO SIDE - FULL FUEL CELL



EQUATING MOMENTS

UNBALANCE MOMENT FROM WEIGHT TABLE = WEIGHT OF SEGMENTS
8672R

OR

$$8672 = 2\left(\frac{1}{2}\right)\frac{58\,h\,(255)\,(.66)\,(58)\,64}{1728}$$

$$8672 = 20968\,h$$

$$h = .4 \text{ INCHES}$$

TRIM UP .6 IN. LEFT
DOWN .6 IN. RIGHT

TRIM - SIDE TO SIDE - EMPTY FUEL CELL

MOMENT TO RIGHT = 8672 IN#
PLUS GASOLINE MOMENT 35564 = 45236
IN#(RIG

Load and stress analysis of:
Prepared by R. Sandell Date Page No. 30
Checked by Dwg. No. Project No.

SUBSTITUTING

$$45236 = 2\left(\frac{1}{2}\right)\frac{58\,h\,(255)\,(.666)\,(58)\,64}{1728}$$

$$45236 = 20968\,h$$

$$h = 2.2 \text{ INCH}$$

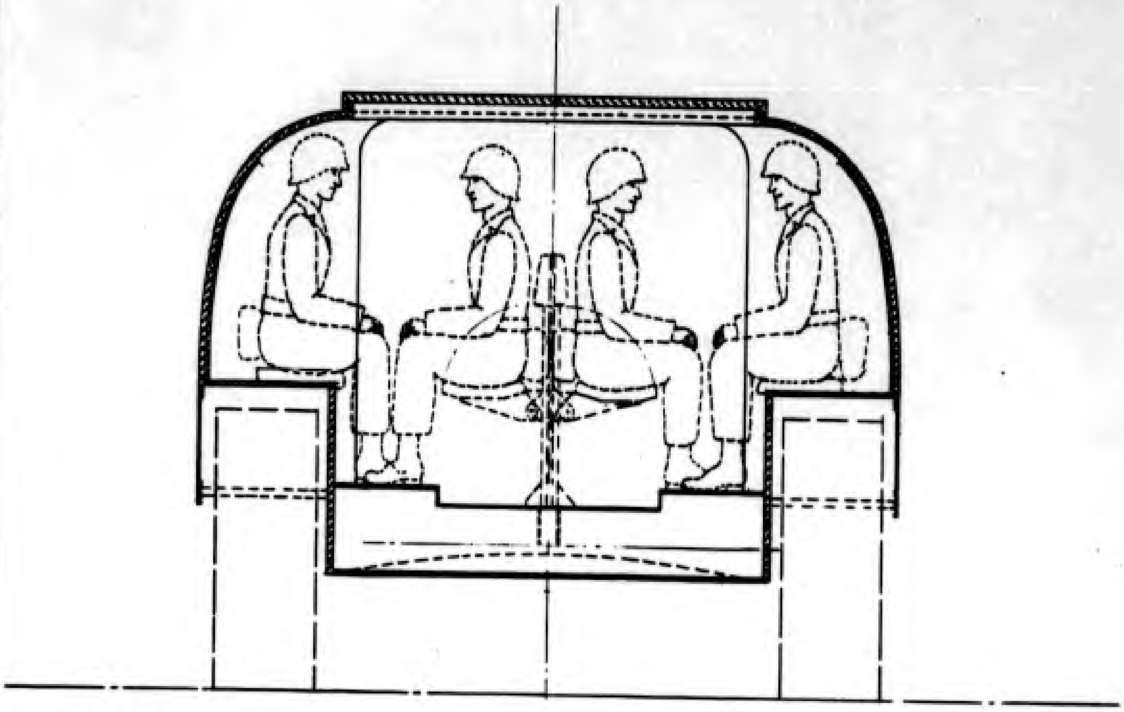
TRIM DOWN 2.2 RIGHT
UP 2.2 LEFT

APPENDIX C

ADDITIONAL CONCEPTS

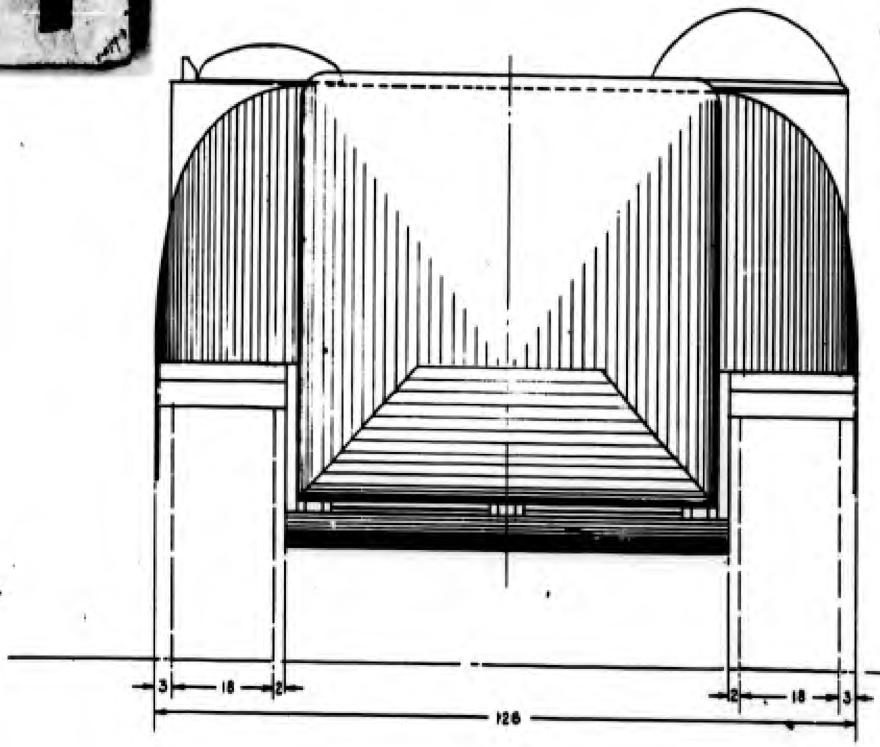
Rear Ramp LVT

Figure C-1.1 is a concept of an LVT with a rear ramp which uses tracks for water propulsion. It is similar to the "Maximum Armored Vehicle" shown in this report except that the ramp is at the stern and the engine compartment is near the bow. The vehicle has the advantage of a front sprocket drive plus short control linkage from the driver to the engine compartment. However, this vehicle, with a 35,000 pound GVW and a 10,000 pound cargo capacity, has the disadvantage of trimming down at the bow when unloaded. Also, if the engine compartment were fully developed, the passageways left for the driver and the gunner would become very small. This concept was set aside primarily because an LVT is undesirable if it trims down at the bow under any load condition.

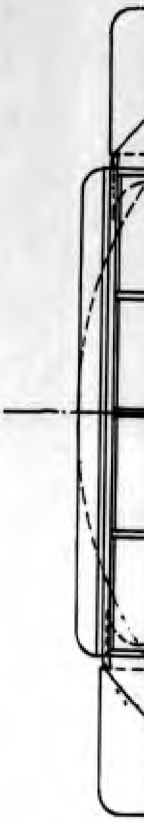


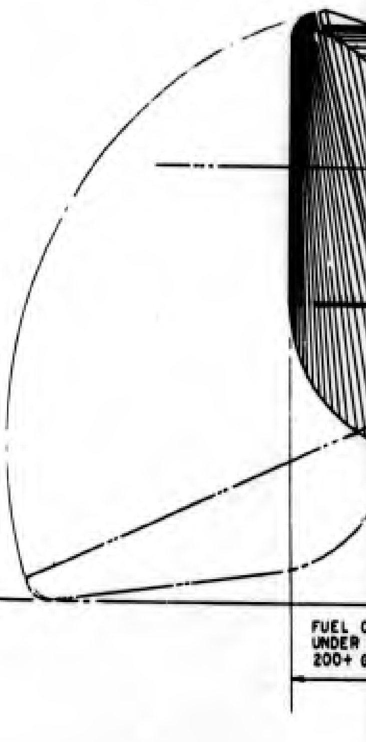
SECTION X-X

1

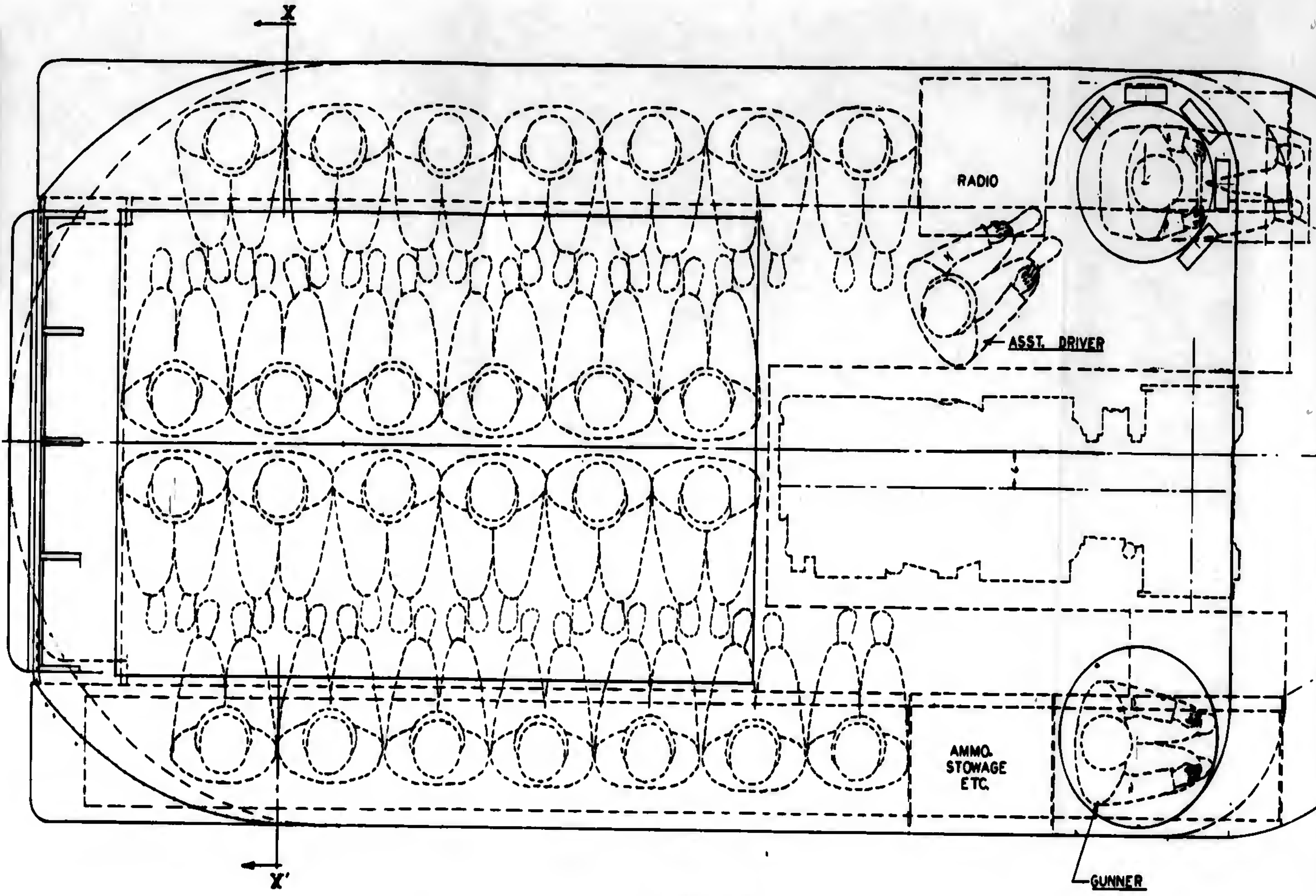


STERN VIEW

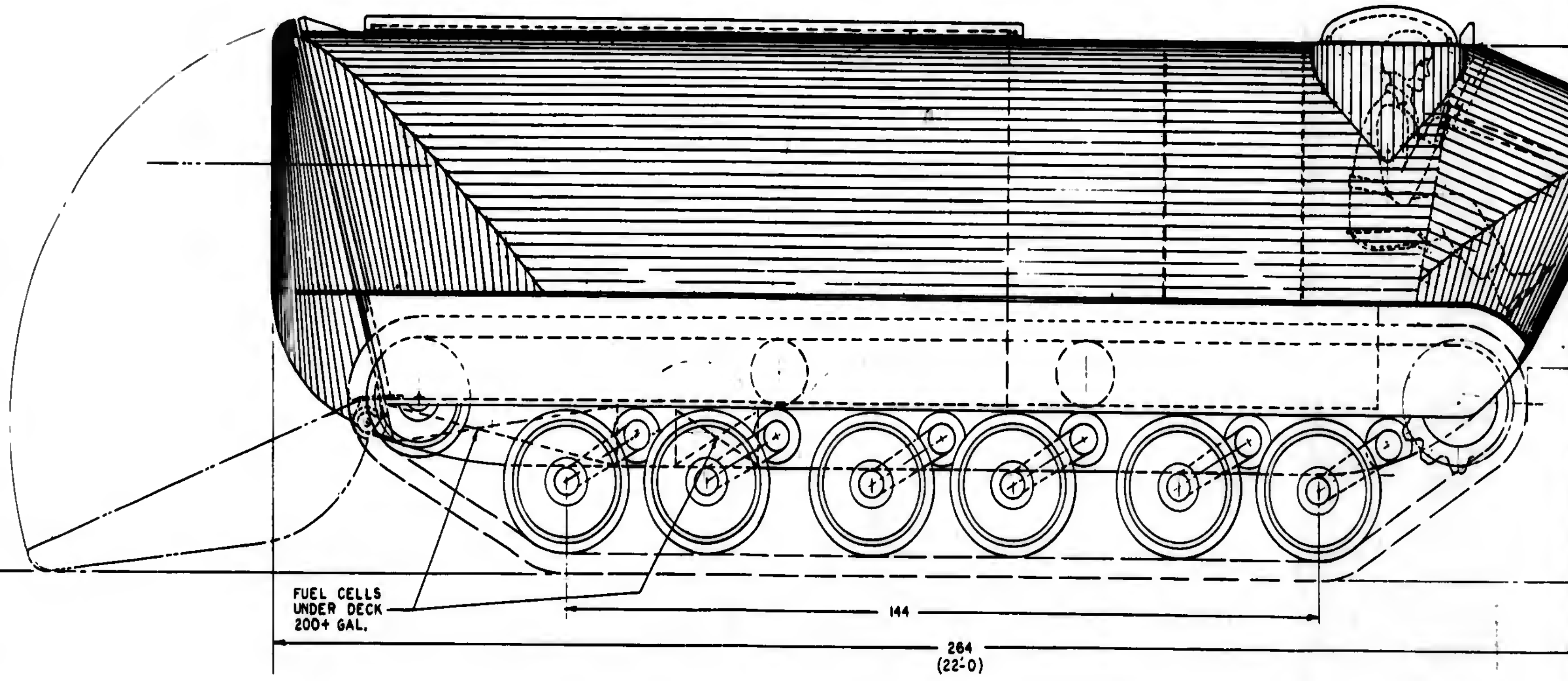




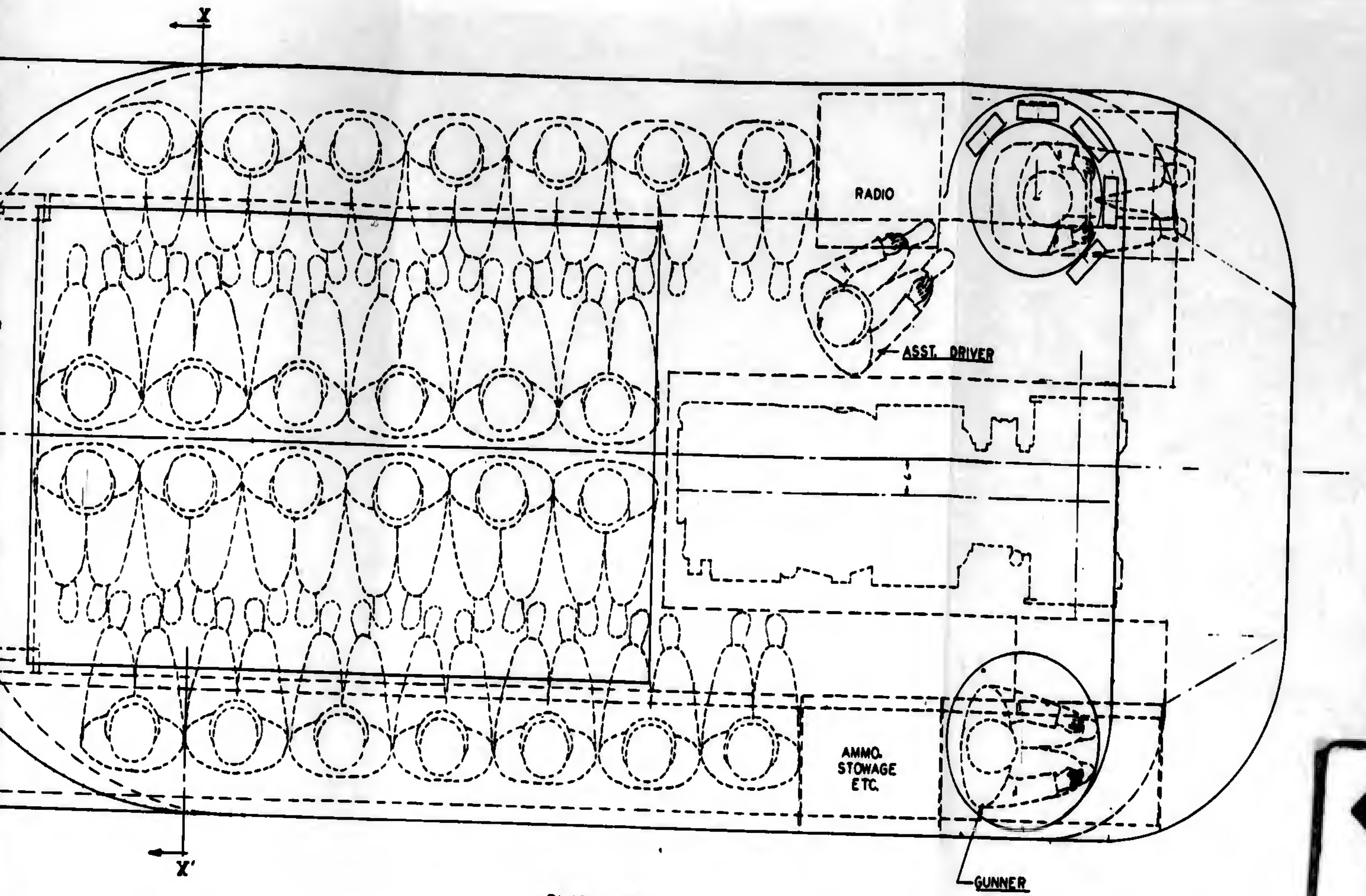
2



PLAN VIEW

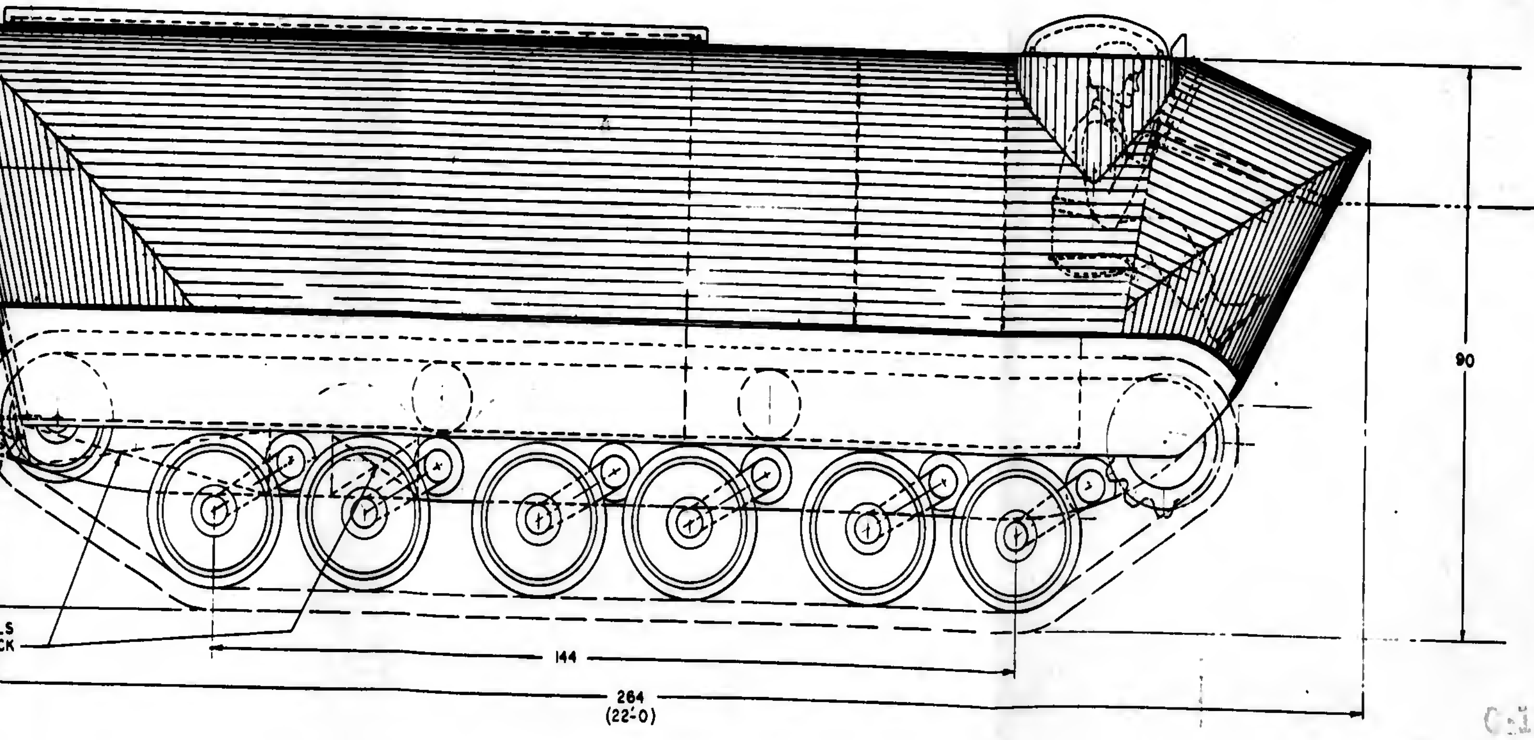


SIDE VIEW



PLAN VIEW

3



SIDE VIEW

C.1.1

Preliminary Design,Engineering
FOOD MACHINERY AND CHEMICAL CORPORATION
ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

PERSONNEL & CARGO
CARRIER (L.V.T.)
REAR RAMP TYPE

P.A. NO. 449
DWG. NO. K-1077302

APPENDIX C

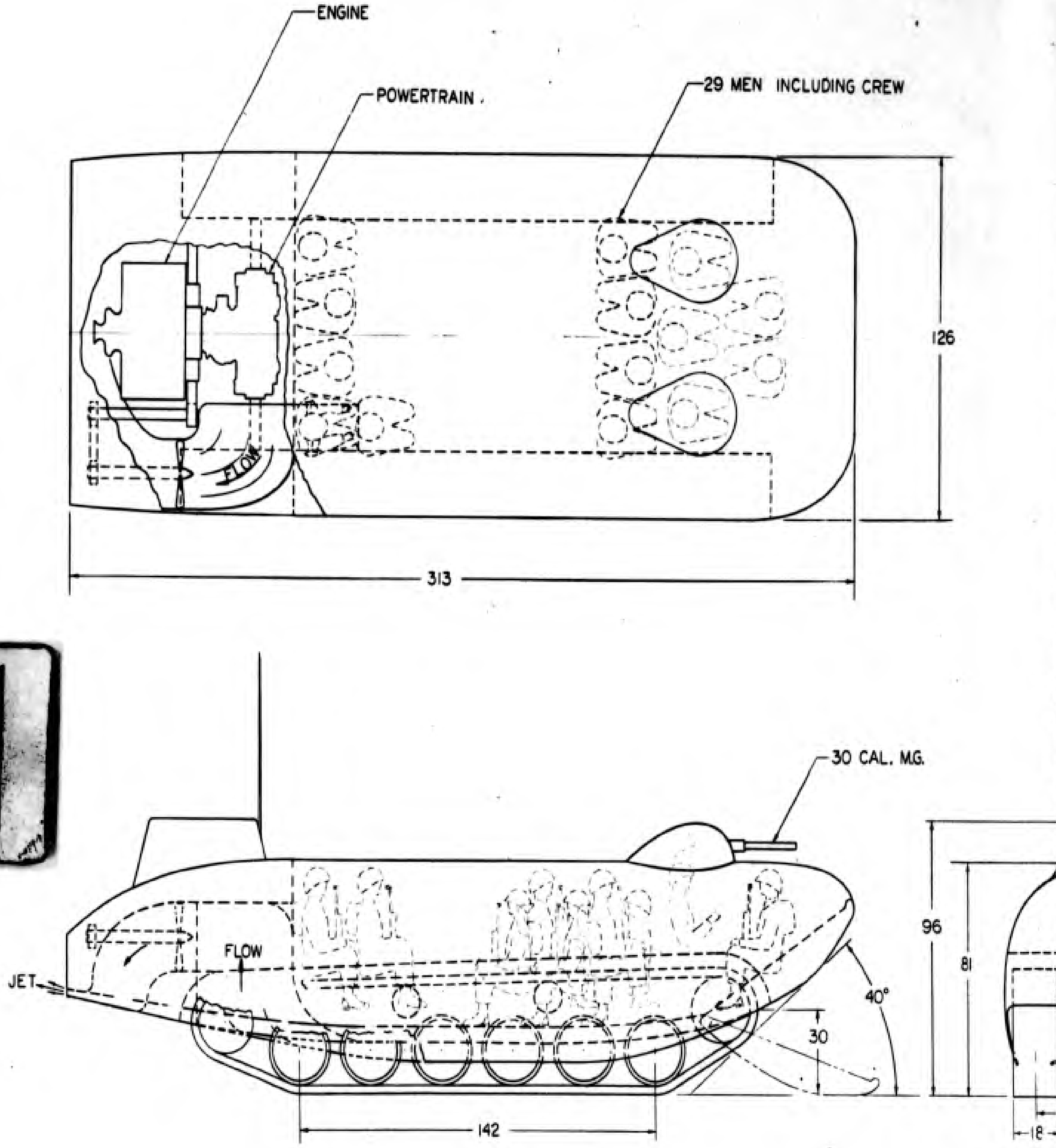
ADDITIONAL CONCEPTS (Continued)

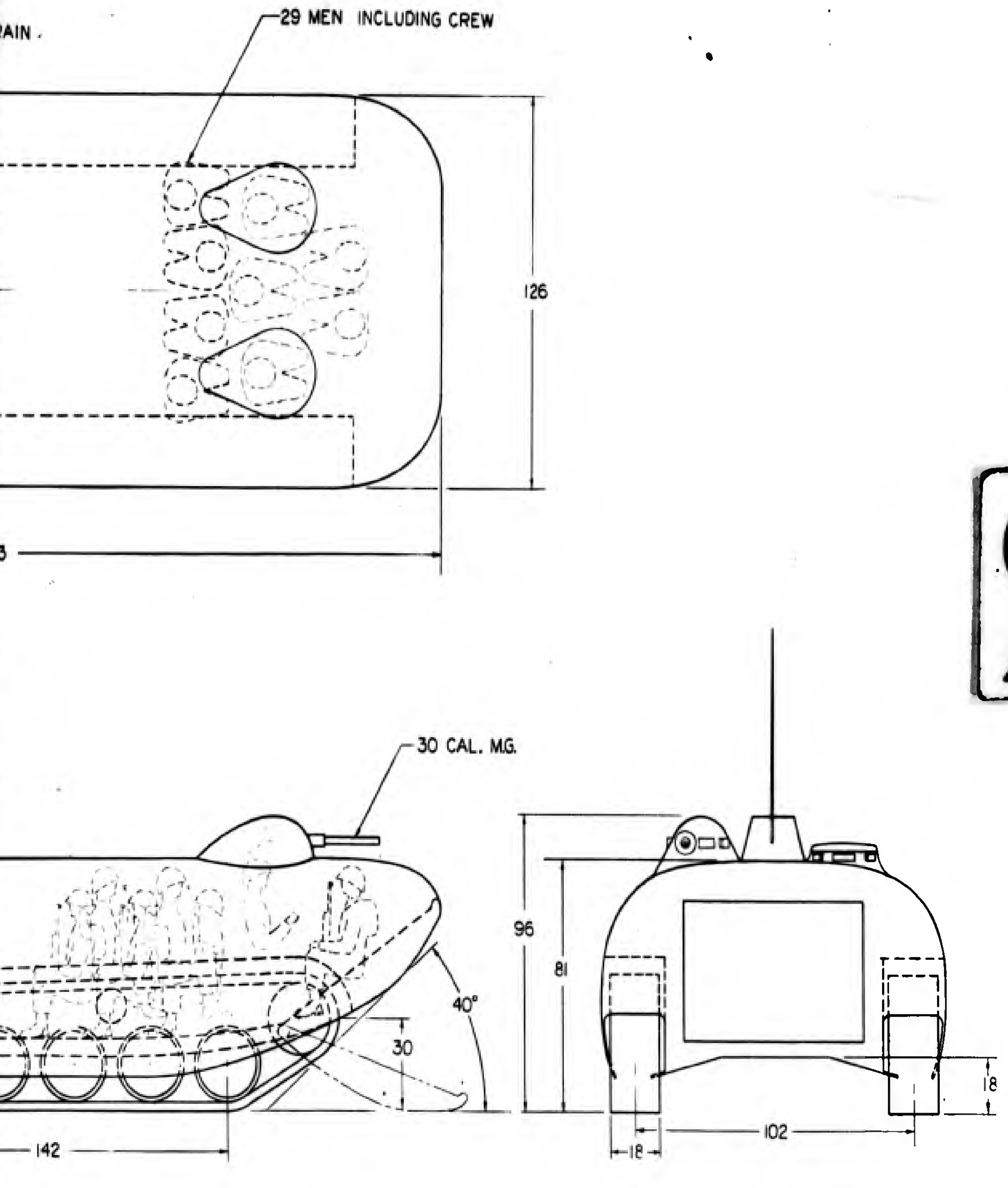
Stern Jet LVT - Front Ramp

Figure C-1.2 is a concept drawing of the stern jet LVT described in Section 3.9 of this report. This concept was discarded for the following reasons:

- Propeller in a tunnel is not as efficient as a propeller in open water.
- Based on model testing, the horizontal curtain of water ejected at the stern jet does not reduce the hull resistance a measurable amount.
- Large water ducts use up too much of hull space.
- Troops are crowded and two are seated on the front ramp.
- Vehicle has a very poor departure angle.

1


ENGINE
POWERTRAIN
29 MEN INCLUDING CREW
FLOW
126
313
30 CAL. M.G.
JET
FLOW
40°
30
142
96
81
18



2

SCALE: 3/4"=1'-0"
0 1 2 3 4 5 6 7 8 9 10 FEET

Preliminary Design Engineering
FOOD MACHINERY AND CHEMICAL CORPORATION
ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

DATE 5-4-61
DRAFTSMAN RS
ENGINEER R Sandell
APPROVED G.M. Snyder
SCALE 1/16 SIZE

STERN JET LVT,
FRONT RAMP

P.A. NO 449
DWG. NO 1077317
SHEET 1 OF

C-1.2

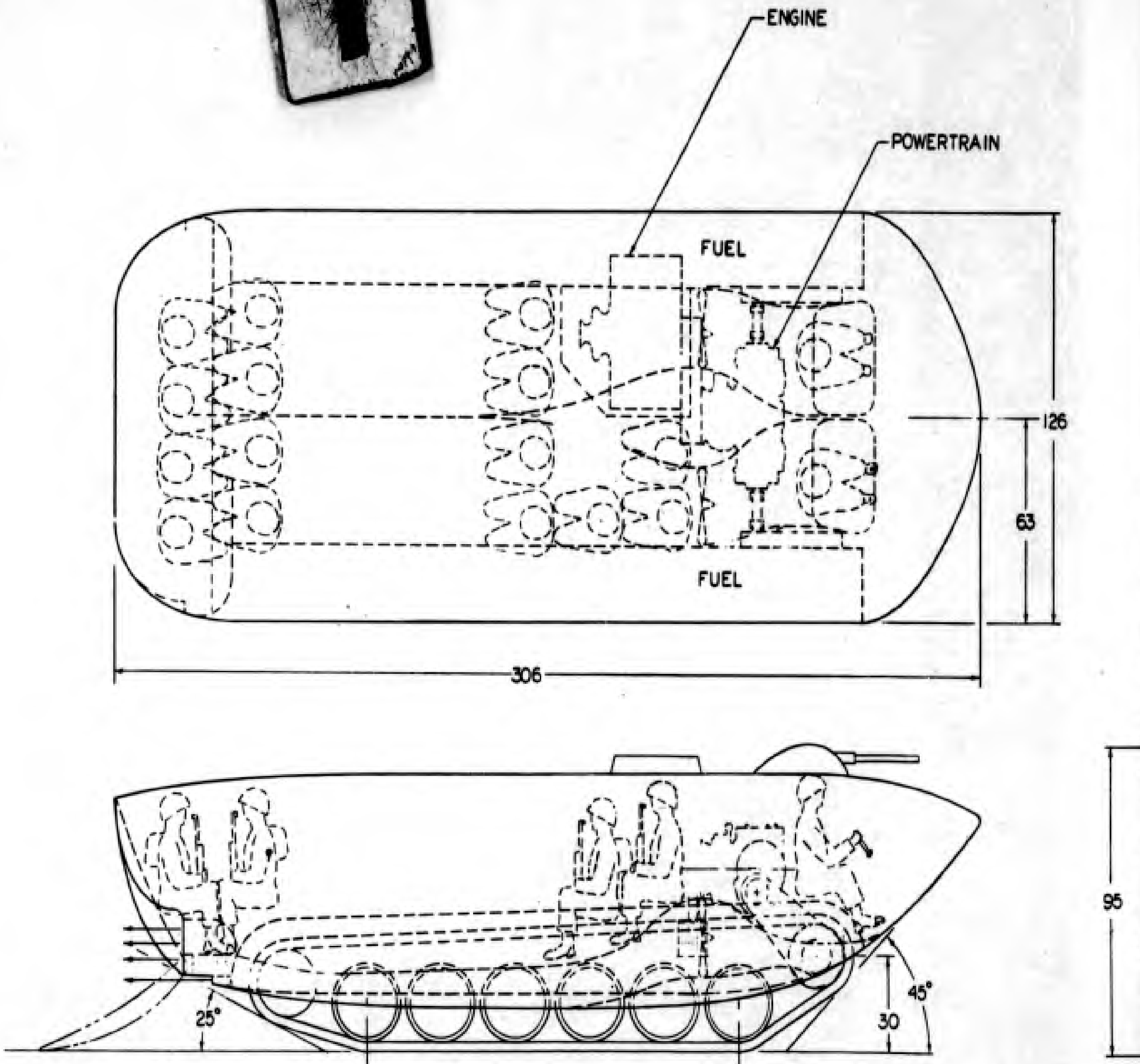
ADDITIONAL CONCEPTS (Continued)

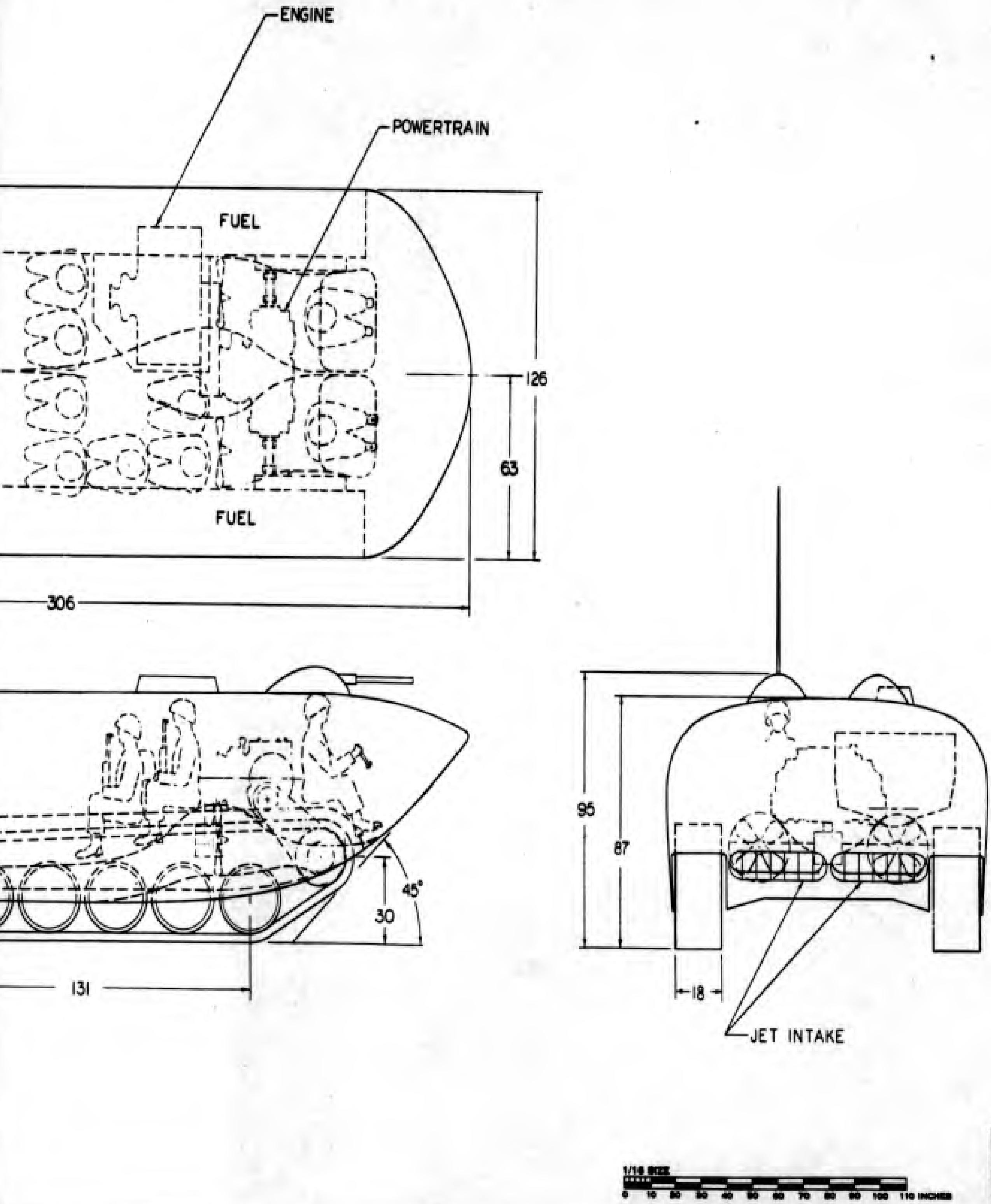
Stern Jet LVT - Rear Ramp

Figure C-1.3 is a concept drawing of another stern jet LVT, this time with a rear ramp. The purpose of the water inlet at the bow was to reduce the bow wave. This concept was set aside for the following reasons:

- Propeller in a tunnel is not as efficient as a propeller in open water.
- Based on model testing, the horizontal curtain of water ejected at the stern jet does not reduce the hull resistance a measurable amount.
- Large water ducts use up too much of hull space and represent large energy losses.
- Troops are crowded and 4 men are seated on rear ramp.
- Vehicle will trim down at bow when unloaded.

1





2

Preliminary Design Engineering
FOOD MACHINERY AND CHEMICAL CORPORATION
ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

STERN JET LVT,
REAR RAMP

P.A. NO. 449
DWG NO.
1077318
SHEET 1 OF

SCALE 1/16

C-1.3

ADDITIONAL CONCEPTS (Continued)

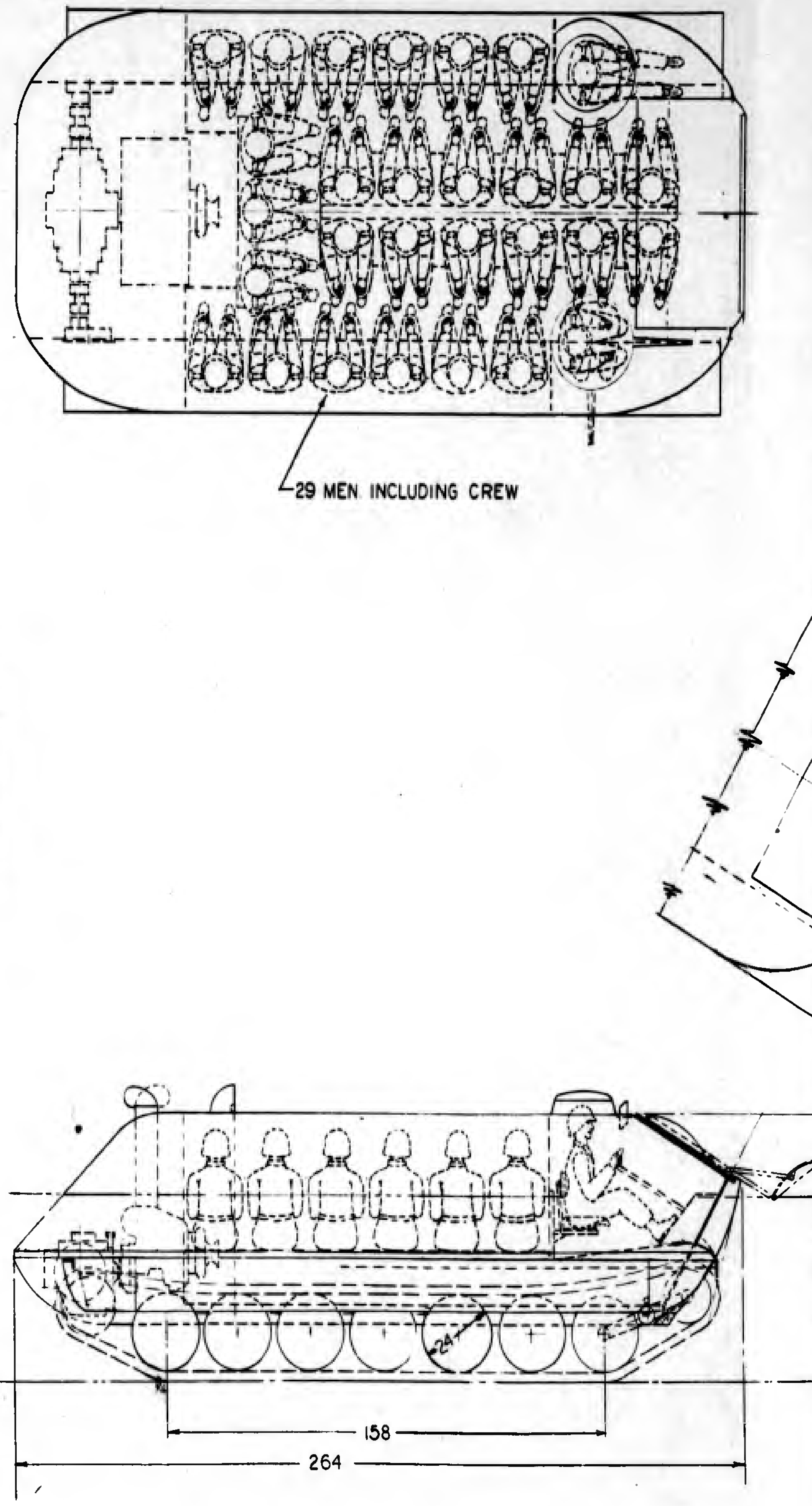
Bow Vane LVT

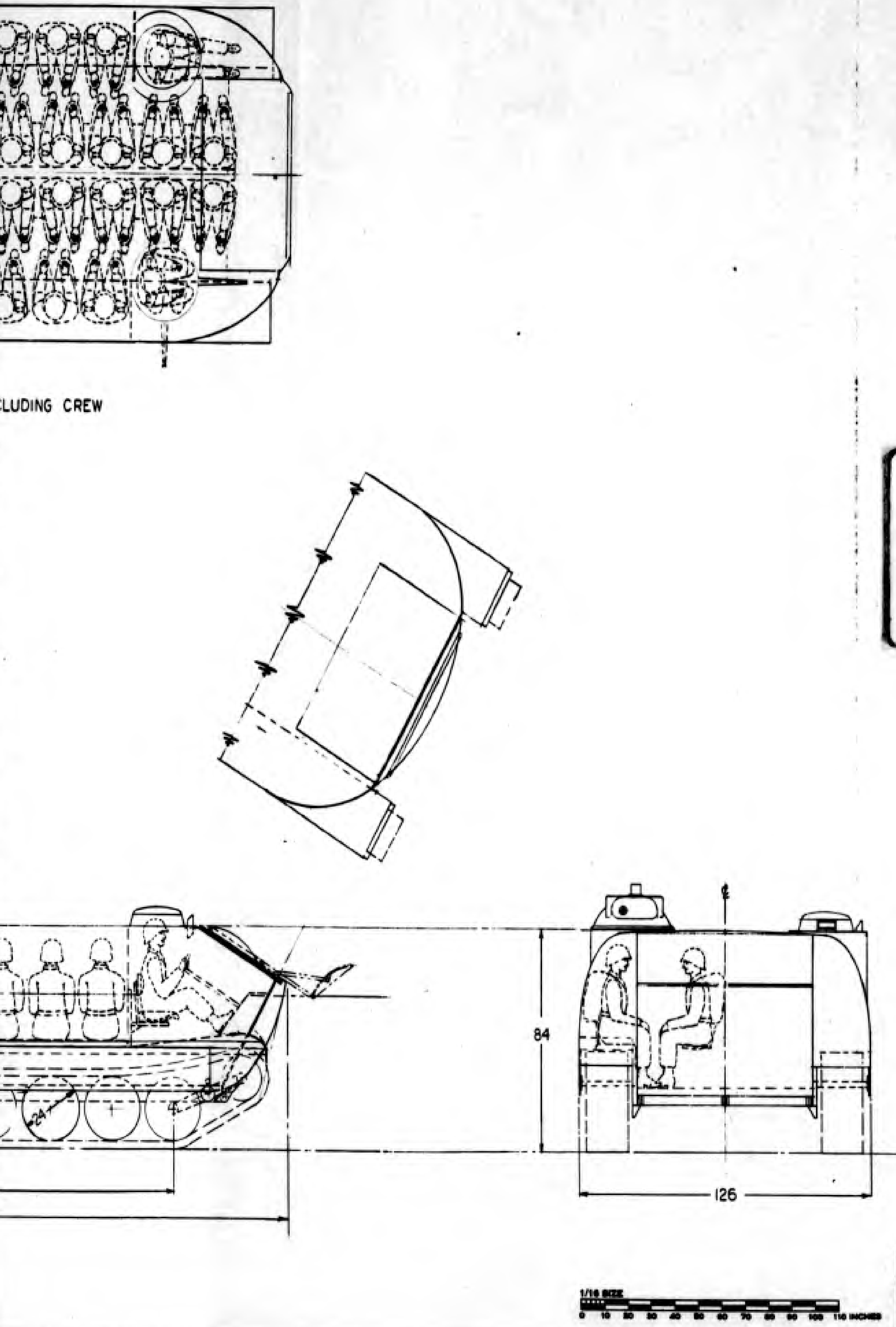
Figure C-1.4 is a concept of an LVT with a front ramp, designed to provide optimum visibility for the driver during land operation. A retractable bow vane is provided which can be extended as shown during water operation to keep the bow from submerging at maximum forward speed in the water. In order to provide reasonable access into the vehicle at the front, the upper deck would have to be designed to pivot upward when the ramp was opened.

Figure C-1.5 is another bow vane concept for providing more driver visibility on land, except the ramp is located at the stern. This vehicle would have the disadvantage of trimming bow down in the water when unloaded.

Neither of these bow vane concepts were carried further, because a bow vane is not considered desirable in high surf due to the extreme loads that could be applied. Also, it is contrary to the "Development Characteristic" philosophy of not having special water operation devices.

1

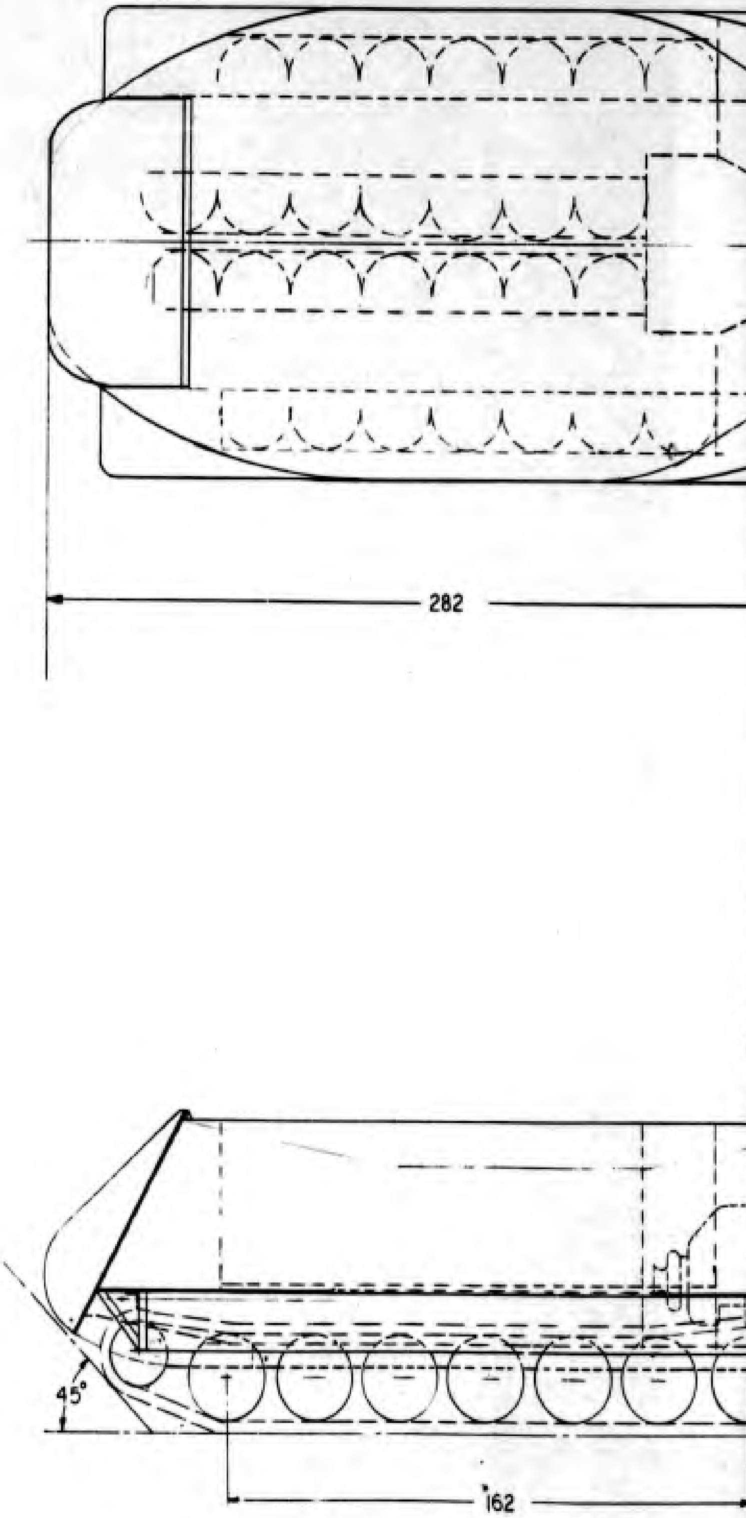




2

Preliminary Design Engineering
FOOD MACHINERY AND CHEMICAL CORPORATION
ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

DATE 6-?-61 DRAWN	BOW VANE LVT FRONT RAMP	P.A. NO. 449
CHECKED		DWG. NO 1077319
APPROVED		
SCALE 1/16		SHEET 1 OF



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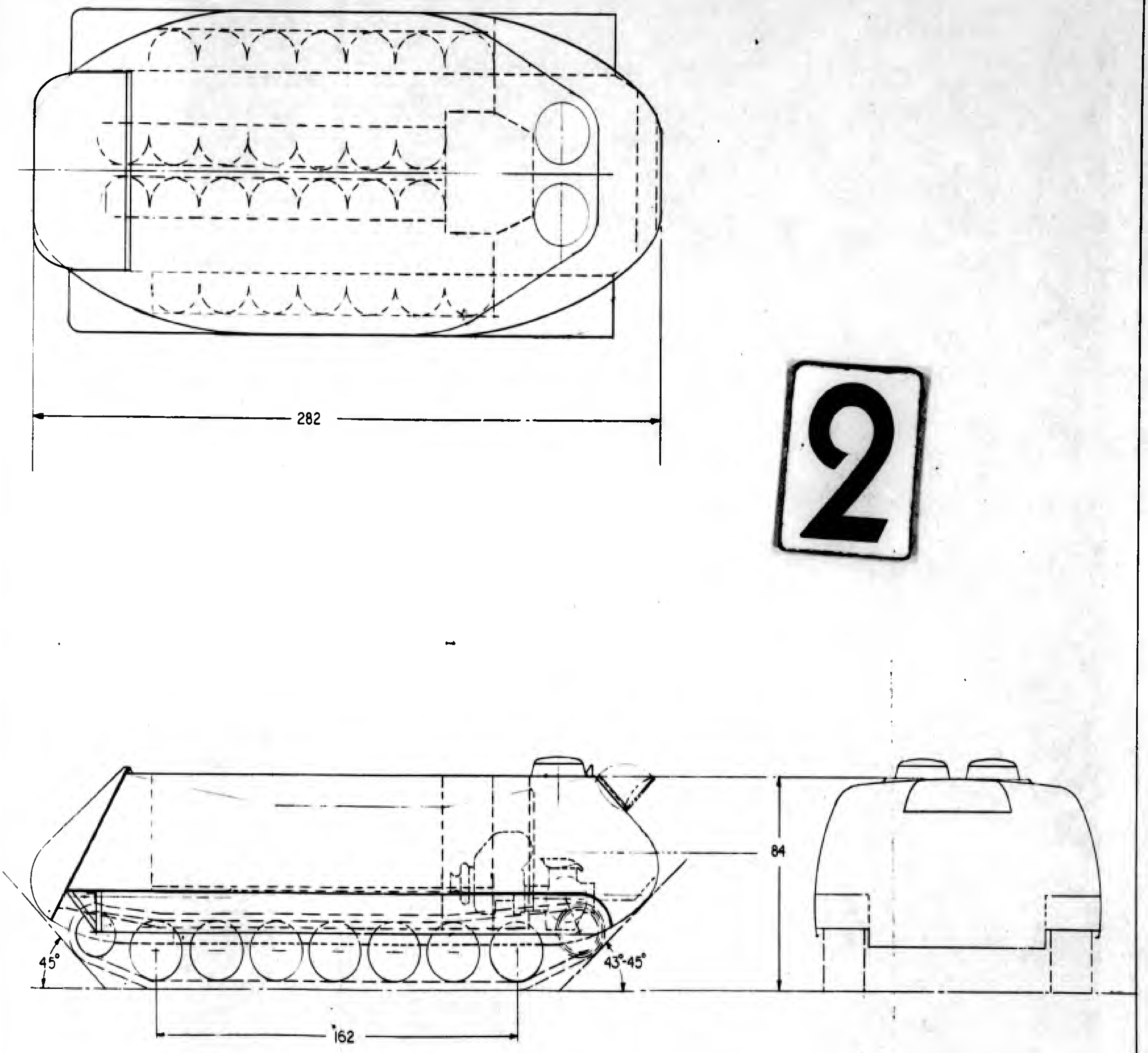


Preliminary Design Engineering
FOOD MACHINERY AND CHEMICAL CORPORATION

ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

BOW VANE LVT, REAR RAMP

P.A. NO. 449

DWG. NO. 1077320

SHEET 1 of

BOW VANE LVT, REAR RAMP

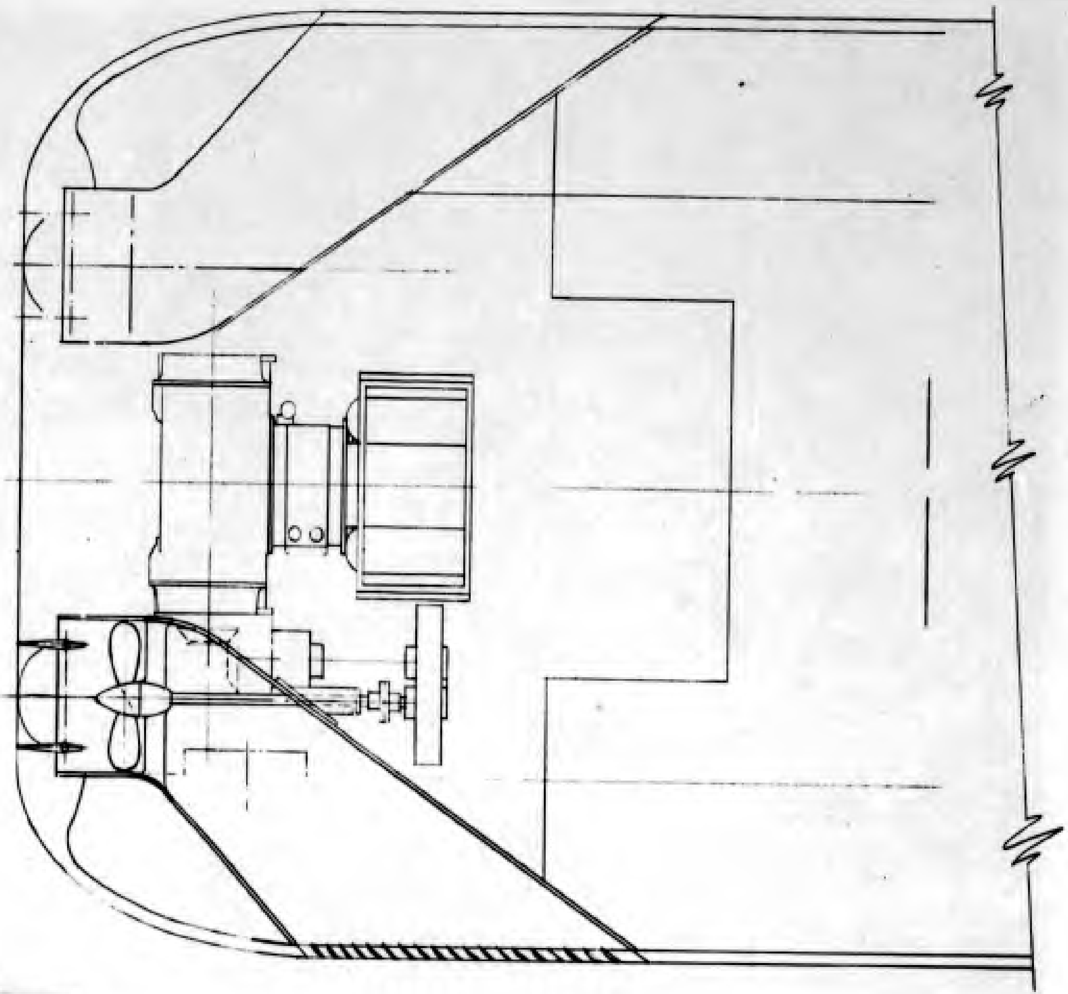
CM1.5

ADDITIONAL CONCEPTS (Continued)

Ducted Propellers - Dual Installation

Figure C-1.6 is a concept showing how dual ducted propellers could be adapted to a rear-drive LVT. Although this type of installation is less vulnerable than a propeller, such as shown on the "Maximum Water Performance Vehicle" (see Figure 3.3.1 of report), it has the following disadvantages:

- Propulsive efficiency is less than a propeller in open water.
- Intakes are close to the water surface, leading to inefficient operation.
- Loss of buoyancy due to water ducts may cause LVT to trim too low at stern.



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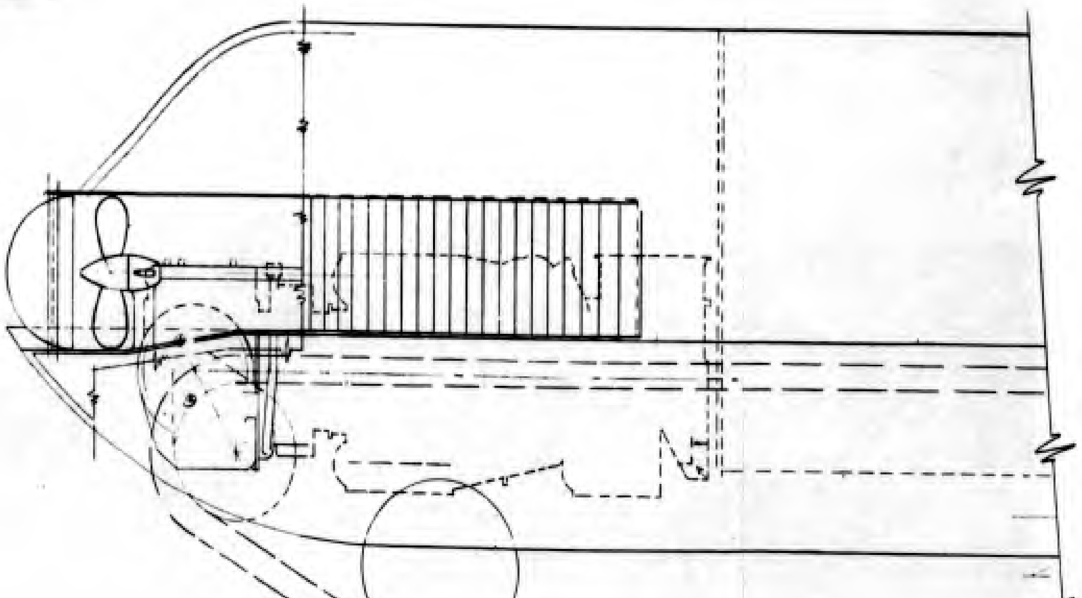
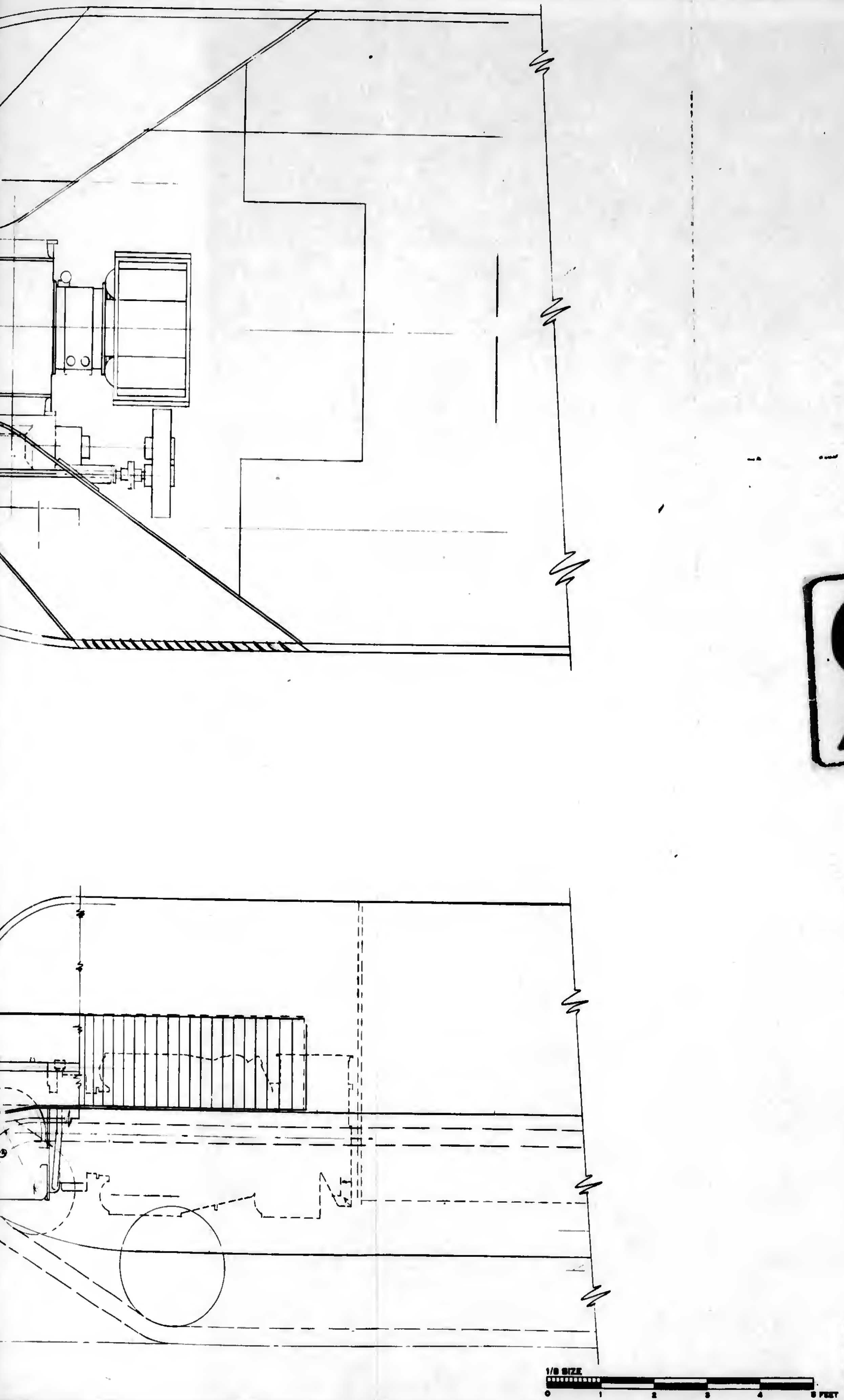


1/8 SIZE

0 1



2

Preliminary Design Engineering
FOOD MACHINERY AND CHEMICAL CORPORATION

ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

DATE
DRAFTSMAN
CHECKED
APPROVED
SCALE 1/8

DUCTED PROPELLER
TWIN
LVT

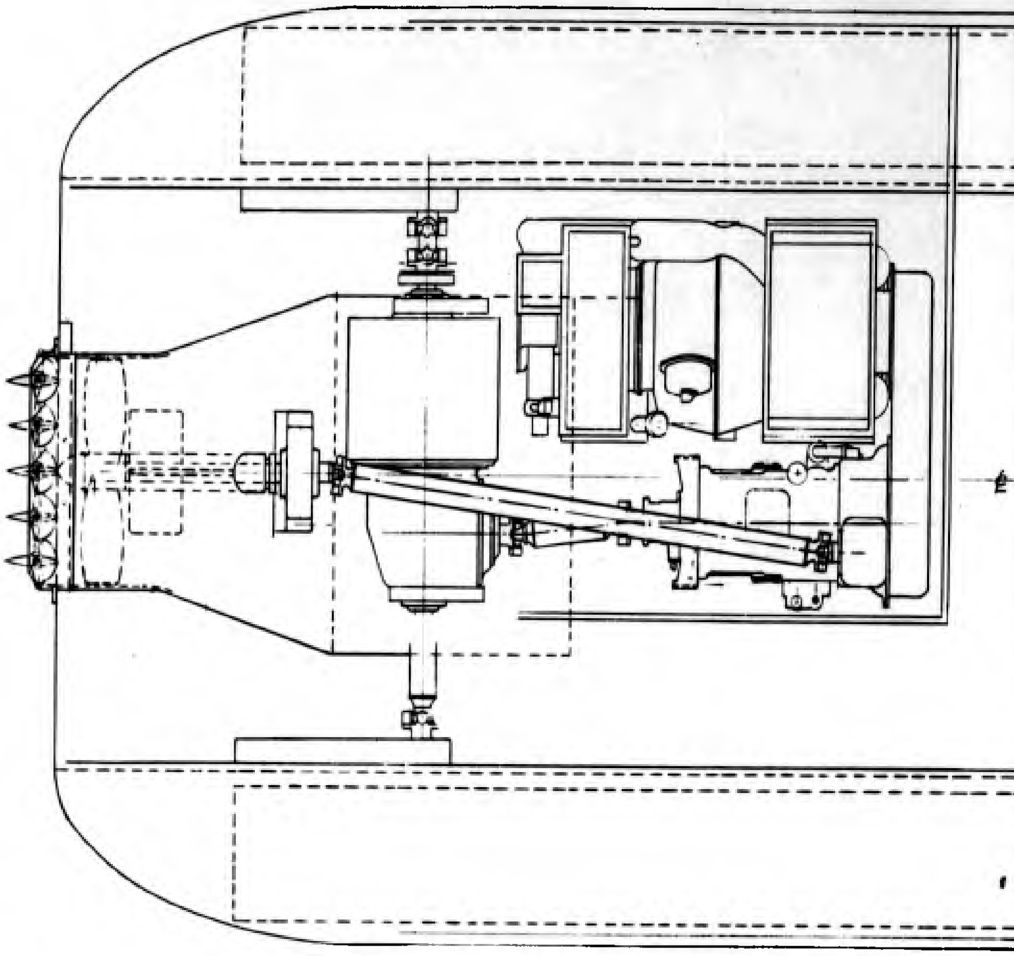
P.A. NO. 449
DWG. NO. 1077322
SHEET 1 OF

ADDITIONAL CONCEPTS (Continued)

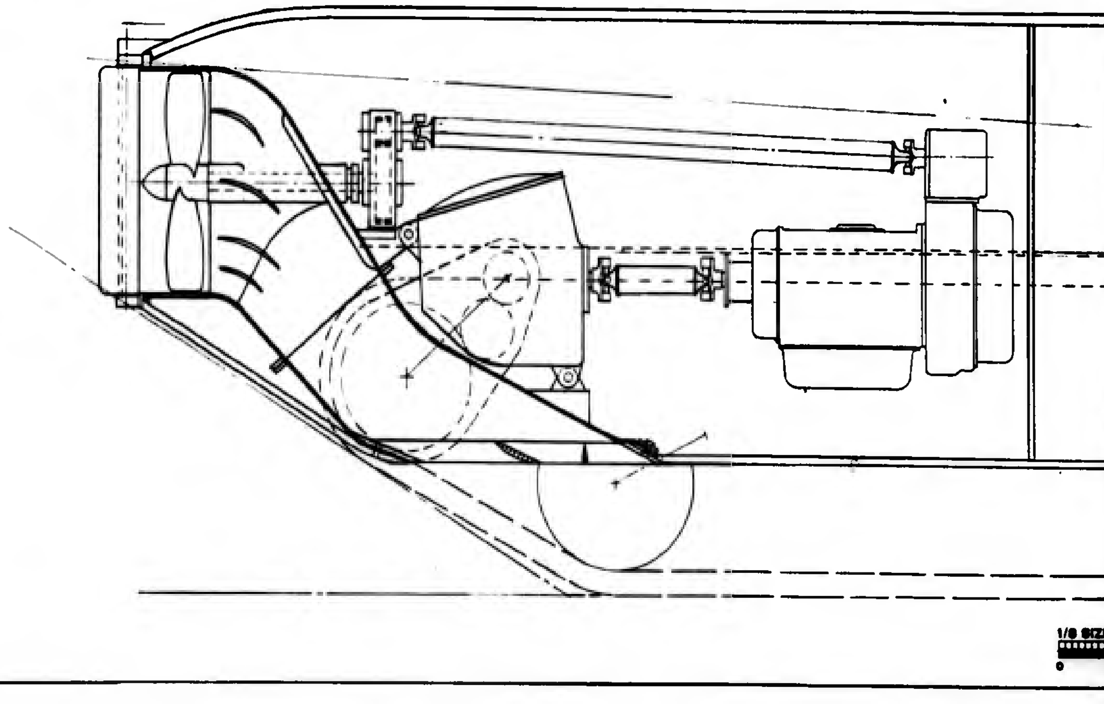
Ducted Propeller - Single Installation

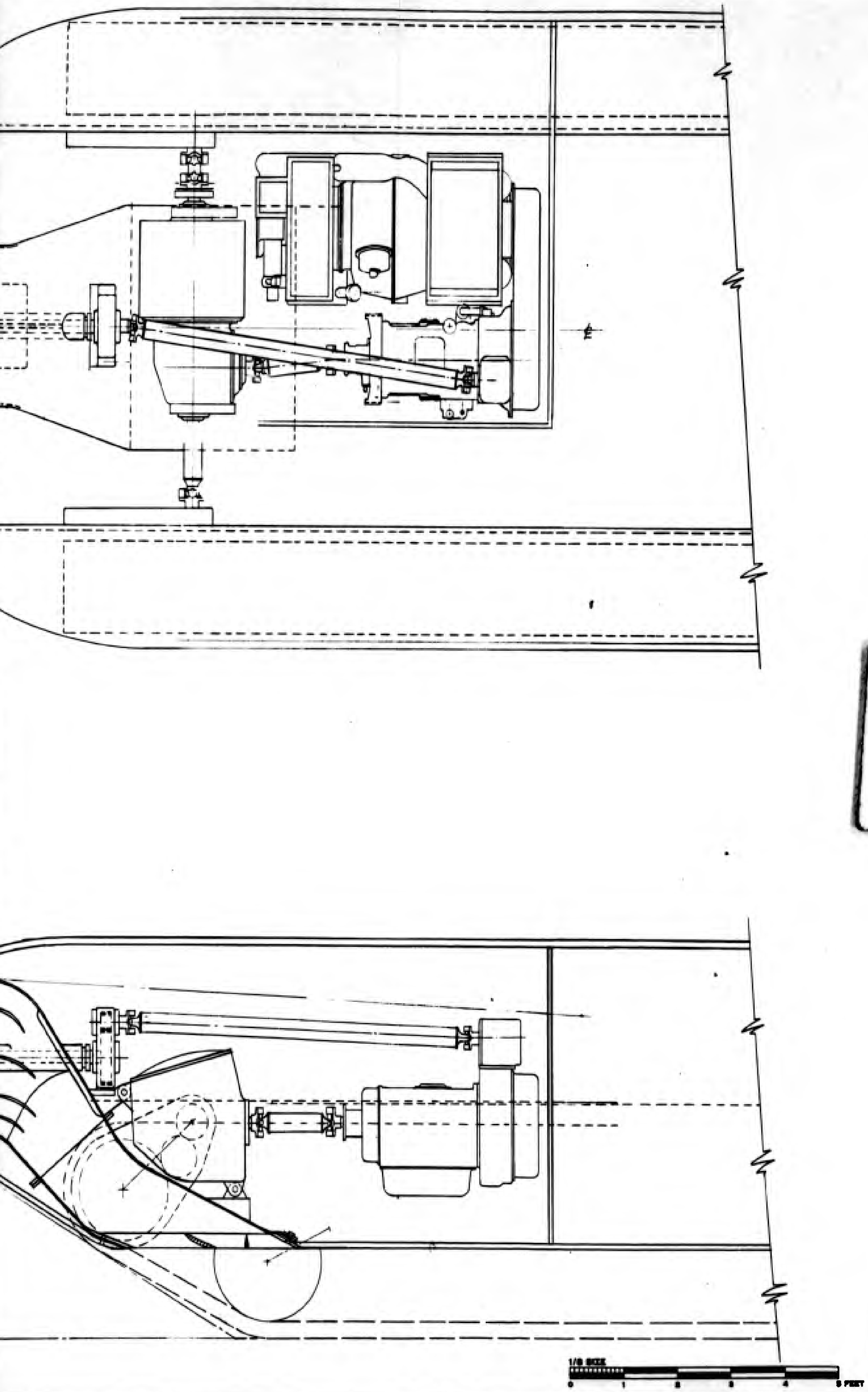
Figure C-1.7 is a concept showing how a single ducted propeller could be adapted to a rear-drive LVT. Here again, it has the advantage of being less vulnerable than an outside propeller at the stern. However, it has the following disadvantages:

- Propulsive efficiency is less than a propeller in open water.
- Stern of hull has been unduly extended to provide proper ducting. Troops would have to be crowded in order to maintain the 26-foot, 1-inch over-all requirement specified in the "Development Characteristics".



1





2

Preliminary Design Engineering
FOOD MACHINERY AND CHEMICAL CORPORATION

ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

DATE 4-15-61
DRAFTSMAN A.B.I.
CHECKED A.W. Ryder
APPROVED
SCALE 1/8 SIZE

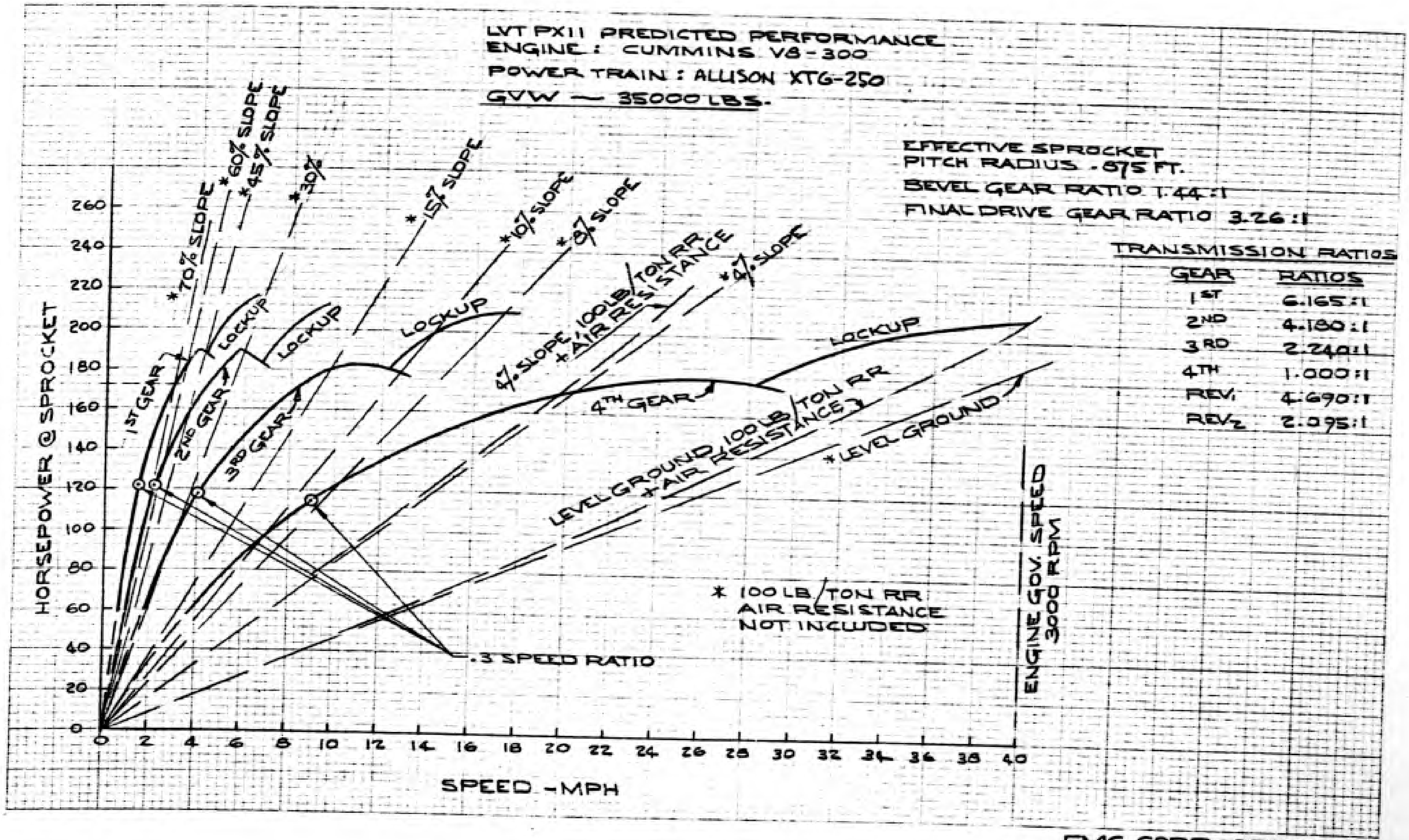
DUCTED PROPELLER,
SINGLE
LVT

P.A. NO. 449
DWG. NO. 1077321
SHEET 1 OF

C-1.7

APPENDIX D-1

CUMMINS V8-300 AND ALLISON XTG-250



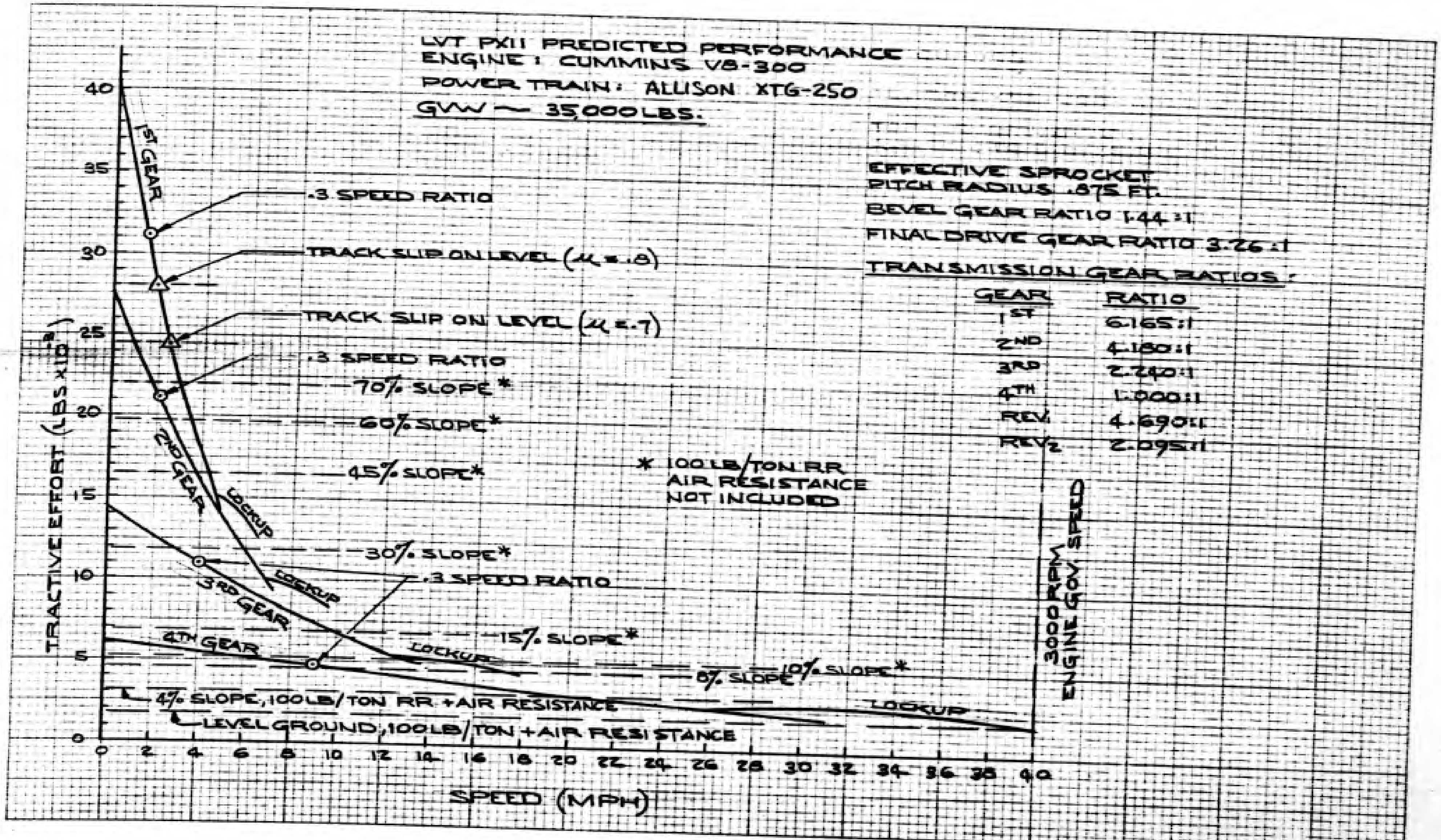
LVT PX11 PREDICTED PERFORMANCE
ENGINE : CUMMINS V8-300
POWER TRAIN : ALLISON XTG-250
GVW — 35000 LBS.

EFFECTIVE SPROCKET PITCH RADIUS .875 FT.
BEVEL GEAR RATIO 1.44:1
FINAL DRIVE GEAR RATIO 3.26:1

TRANSMISSION RATIOS

GEAR	RATIOS
1ST	6.165:1
2ND	4.180:1
3RD	2.240:1
4TH	1.000:1
REV1	4.690:1
REV2	2.095:1

FMC CORP. ORD. DIV.
BY RPM DATE 11-9-61



FMC CORP. ORD. DIV.
BY E.P.M. DATE 11-9-61

Subject: LVT PXII PERDICTED PERFORMANCE
ENGINE: COMMINS V8-300
TRANSMISSION, ALLISON XTG-250 & TG 370 CONV.
Prepared by R R MURPHEY Date 11-2-61 Code No.
Checked by Dwg. No. Project No. 918

TRANSMISSION GEAR RATIO 6.165:1 (1st GEAR)
BEVEL GEAR RATIO 1.440:1
FINAL DRIVE GEAR RATIO 3.260:1
OVERALL GEAR RATIO 28.8:1
POWER TRAIN EFF. (INCL. F.D.) INFO. ALLISON
EFFECTIVE SPROCKET PITCH RAD. [illegible] FT
GVW 35000 LBS

NET ENGINE OUTPUT		CONV. INPUT (a)	CONVERTER RATIO (b)		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2170	516		STALL	2.60	0	1340	0	0	0	40,500
2250	513		.30	2.00	676	1026	132	1.46	121	31700
2300	510		.40	1.79	920	913	159	1.98	144	27,600
2350	507		.54	1.50	1270	760	184	2.76	168	23000
2400	505		.61	1.38	1460	697	194	3.16	177	21,000
2500	495		.71	1.22	1780	604	205	3.86	190	18200
2600	487		.76	1.12	1980	545	206	4.30	188	16500
2800	465		COUPLING .83	.96	2320	446	197	5.03	179	13400
LOCKUP										
1800	525	510	1	1	1800	510	175	3.90	160	1550
2400	505	490	1	1	2400	490	224	5.20	205	14,800
3000	437	422	1	1	3000	422	241	6.50	217	12600

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE TC-6400)
(b) CALCULATED FROM ALLISON CURVES TC-6400 SHTS. 1 & 2

Subject: LVT PXII PERDICTED PERFORMANCE
ENGINE: COMMINS V8-300
TRANSMISSION, ALLISON XTG-250 & TC-370

Prepared by R R MURPHEY Date 11-2-61 Code No. CONV.

Checked by ________ Dwg. No. ________ Project No. 948

TRANSMISSION GEAR RATIO 4.180:1 (2ND GEAR)
BEVEL GEAR RATIO 1.440:1
FINAL DRIVE GEAR RATIO 3.260:1
OVERALL GEAR RATIO 19.65:1
POWER TRAIN EFF. (INCL. F.D.) INFO. ALLISON
EFFECTIVE SPROCKET PITCH RAD. .875 FT
GVW 35000 LBS

NET ENGINE OUTPUT		CONV. INPUT (a)	CONVERTER RATIO (b)		CONVERTER OUTPUT			ROAD SPEED MPH	HP @ [illegible]	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2170	516		STALL	2.60	0	1340	0	0	0	27600
2250	513		.30	2.00	676	1026	132	2.16	121	21200
2300	510		.40	1.79	912	912	153	2.92	144	18800
2350	507		.54	1.50	1270	760	184	4.07	168	15600
2400	505		.61	1.38	1460	697	194	4.70	177	14300
2500	495		.71	1.22	1780	604	205	5.70	190	12500
2600	487		.76	1.12	1980	545	206	6.33	186	11100
2800	465		coupling .83	.96	2320	446	197	7.40	178	9070
LOCKUP										
1800	525	510	1	1	1800	510	175	5.76	155	10200
2400	505	490	1	1	2400	490	224	7.70	198	9760
3000	437	422	1	1	3000	422	241	9.62	213	8400

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE TC-6400)
(b) CALCULATED FROM ALLISON CURVES TC-6400 SHTS. 1 & 2

FMC CORPORATION — ORDNANCE DIVISION
SAN JOSE, CALIFORNIA.

Subject: LVT PXII PERDICTED PERFORMANCE
ENGINE : COMMINS V8-300
TRANSMISSION , ALLISON XTG-250 & TG 310 CONV.

Prepared by [illegible] Date 11-9-61 Code No. CONV.

Checked by ________ Dwg. No. ________ Project No. 948

TRANSMISSION GEAR RATIO 2.240:1 (3RD GEAR)
BEVEL GEAR RATIO 1.430:1
FINAL DRIVE GEAR RATIO 3.260:1
OVERALL GEAR RATIO 10.50:1
POWER TRAIN EFF. (INCL. F.D.) INFO. ALLISON
EFFECTIVE SPROCKET PITCH RAD. [illegible] FT
GVW 35000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	(b) CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2170	516		STALL	2.60	0	1340	0	0	0	14500
2250	513		.30	2.00	676	1026	132	4.04	118	11000
2300	510		.40	1.79	912	912	155	5.46	141	9800
2350	507		.54	1.50	1270	760	184	7.64	165	8200
2400	505		.61	1.38	1460	697	194	8.75	174	7500
2500	495		.71	1.22	1780	604	205	10.70	183	6500
2600	487		.76	1.12	1980	545	206	11.80	183	5820
2800	465		coupling .83	.96	2320	446	197	13.90	176	4740
LOCKUP										
1800	525	510	1	1	1800	510	175	10.80	157	5530
2400	505	490	1	1	2400	490	224	14.30	200	5250
3000	437	422	1	1	3000	422	241	17.90	210	4470

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE TC-6400)
(b) CALCULATED FROM ALLISON CURVES TC-6400 SHTS. 1 & 2

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Ord-Eng-694

Subject: LVT PXII PERDICTED PERFORMANCE
ENGINE: COMMINS V8-300
TRANSMISSION, ALLISON XTG-250 & TG 370
Prepared by R P MURPHY Date 11-9-61 Code No. CONV.
Checked by ____ Dwg. No. ____ Project No. 948

TRANSMISSION GEAR RATIO 1.000:1 (4TH GEAR)
BEVEL GEAR RATIO 1.440:1
FINAL DRIVE GEAR RATIO 3.260:1
OVERALL GEAR RATIO 4.680:1
POWER TRAIN EFF. (INCL. F.D.) INFO. AL[illegible]
EFFECTIVE SPROCKET PITCH RAD. .875 FT
GVW 35000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	(b) CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2170	516		STALL	2.60	0	1340	0	0	0	6240
2250	513		.30	2.00	676	1026	132	9.02	115	4780
2300	510		.40	1.79	912	913	15[illegible]	12.2	137	4260
2350	507		.54	1.50	1270	760	184	16.9	160	3530
2400	505		.61	1.38	1460	697	194	19.5	169	3240
2500	495		.71	1.22	1780	604	205	23.8	177	2800
2600	487		.76	1.12	1980	545	206	26.4	178	2520
2800	465		coupling .83	.96	2320	446	197	31.0	169	2050
LOCKUP										
1800	525	510	1	1	1800	510	175	24.0	152	2380
2400	505	490	1	1	2400	490	2[illegible]	32.0	195	2280
3000	437	422	1	1	3000	422	241	40.0	204	1910

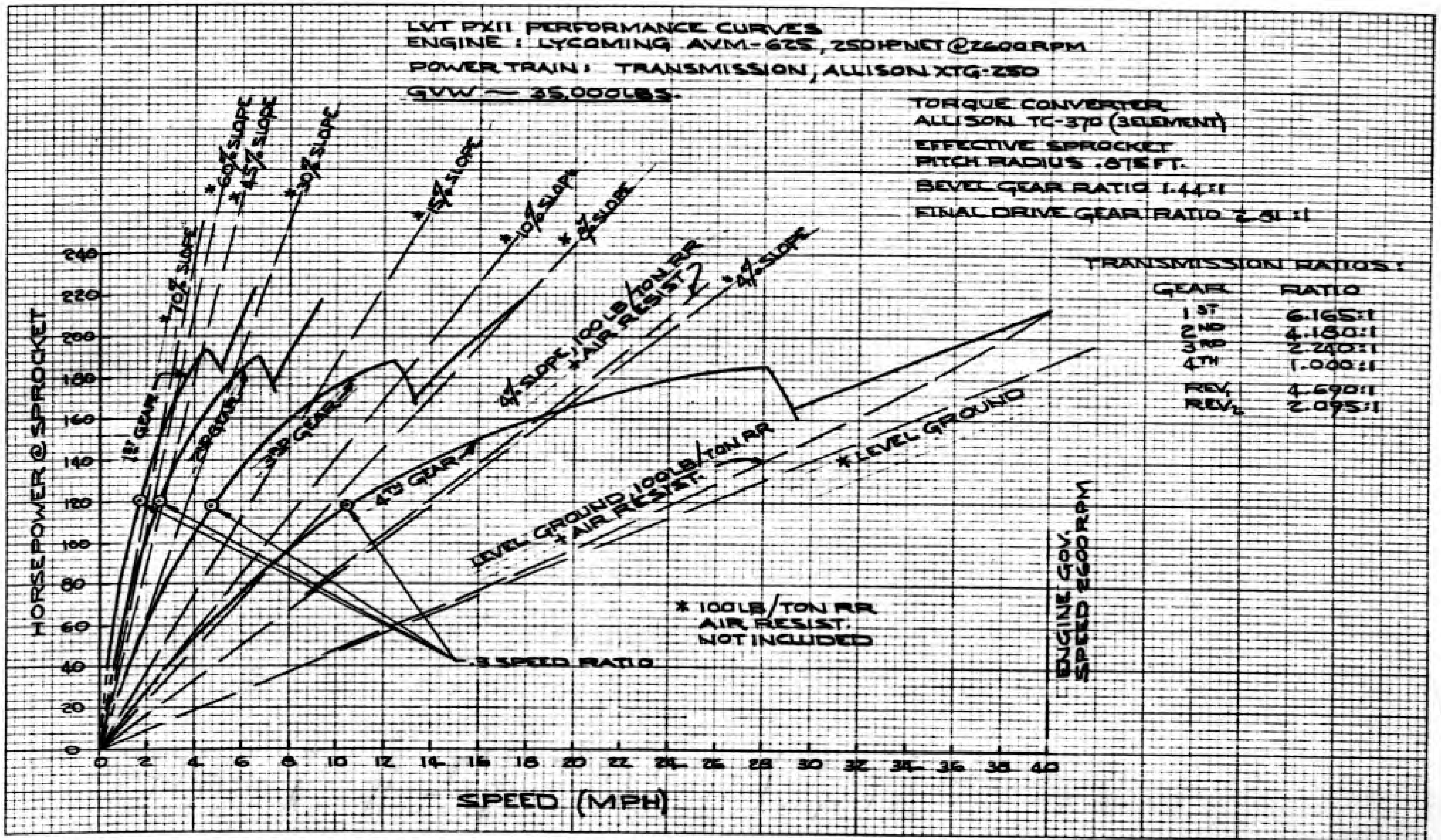
(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE TC-6400)
(b) CALCULATED FROM ALLISON CURVES TC-6400 SHTS. 1 & 2

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Ord-Eng-694

APPENDIX D-2

LYCOMING AVM-625 AND ALLISON XTG-250


LVT PX11 PERFORMANCE CURVES
ENGINE : LYCOMING AVM-625, 250 HP NET @ 2600 RPM
POWER TRAIN : TRANSMISSION, ALLISON XTG-250
GVW — 35,000 LBS.

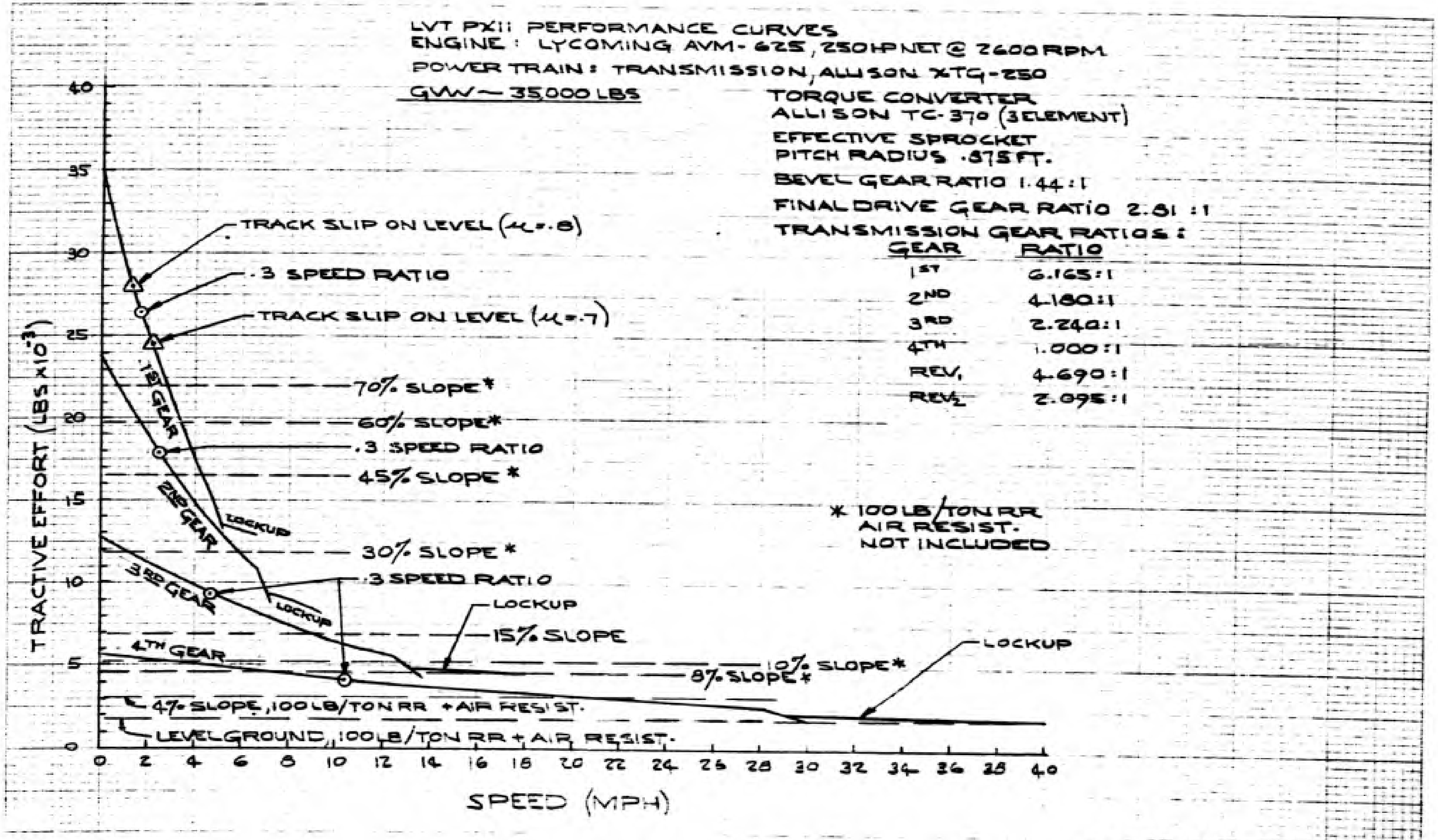
TORQUE CONVERTER
ALLISON TC-370 (3 ELEMENT)
EFFECTIVE SPROCKET
PITCH RADIUS .875 FT.
BEVEL GEAR RATIO 1.44:1
FINAL DRIVE GEAR RATIO 2.81:1

TRANSMISSION RATIOS :

GEAR	RATIO
1ST	6.165:1
2ND	4.180:1
3RD	2.240:1
4TH	1.000:1
REV.1	4.690:1
REV.2	2.095:1

* 100 LB/TON RR
AIR RESIST.
NOT INCLUDED

FMC CORP., ORD. DIV.
BY R.P.M. DATE 11-7-61



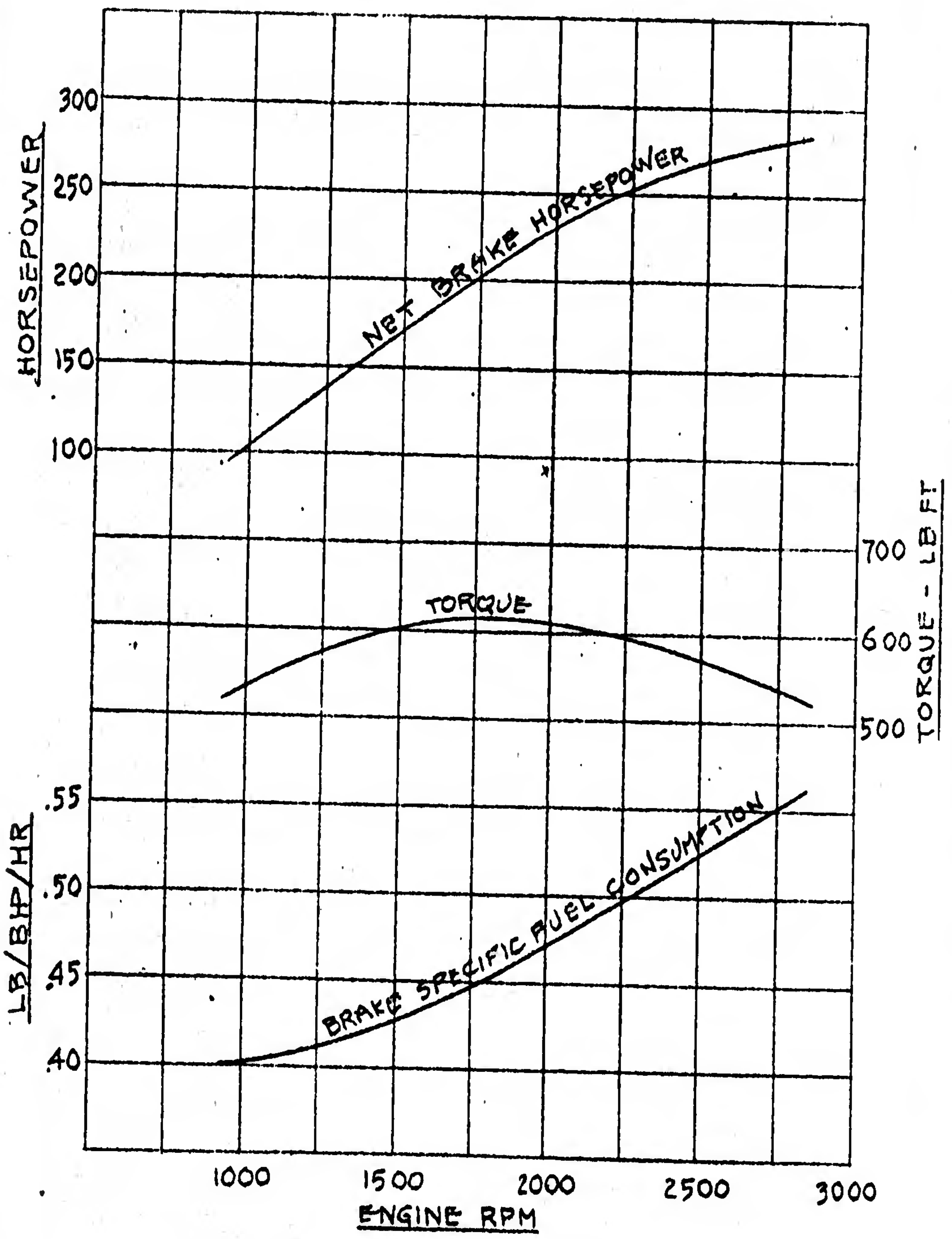
LVT PXII PERFORMANCE CURVES
ENGINE : LYCOMING AVM-625, 250HP NET @ 2600 RPM
POWER TRAIN : TRANSMISSION, ALLISON XTG-250
GVW ~ 35,000 LBS

TORQUE CONVERTER
ALLISON TC-370 (3 ELEMENT)
EFFECTIVE SPROCKET
PITCH RADIUS .875 FT.
BEVEL GEAR RATIO 1.44:1
FINAL DRIVE GEAR RATIO 2.81:1
TRANSMISSION GEAR RATIOS :

GEAR	RATIO
1ST	6.165:1
2ND	4.180:1
3RD	2.240:1
4TH	1.000:1
REV1	4.690:1
REV2	2.095:1

* 100 LB/TON RR
AIR RESIST.
NOT INCLUDED

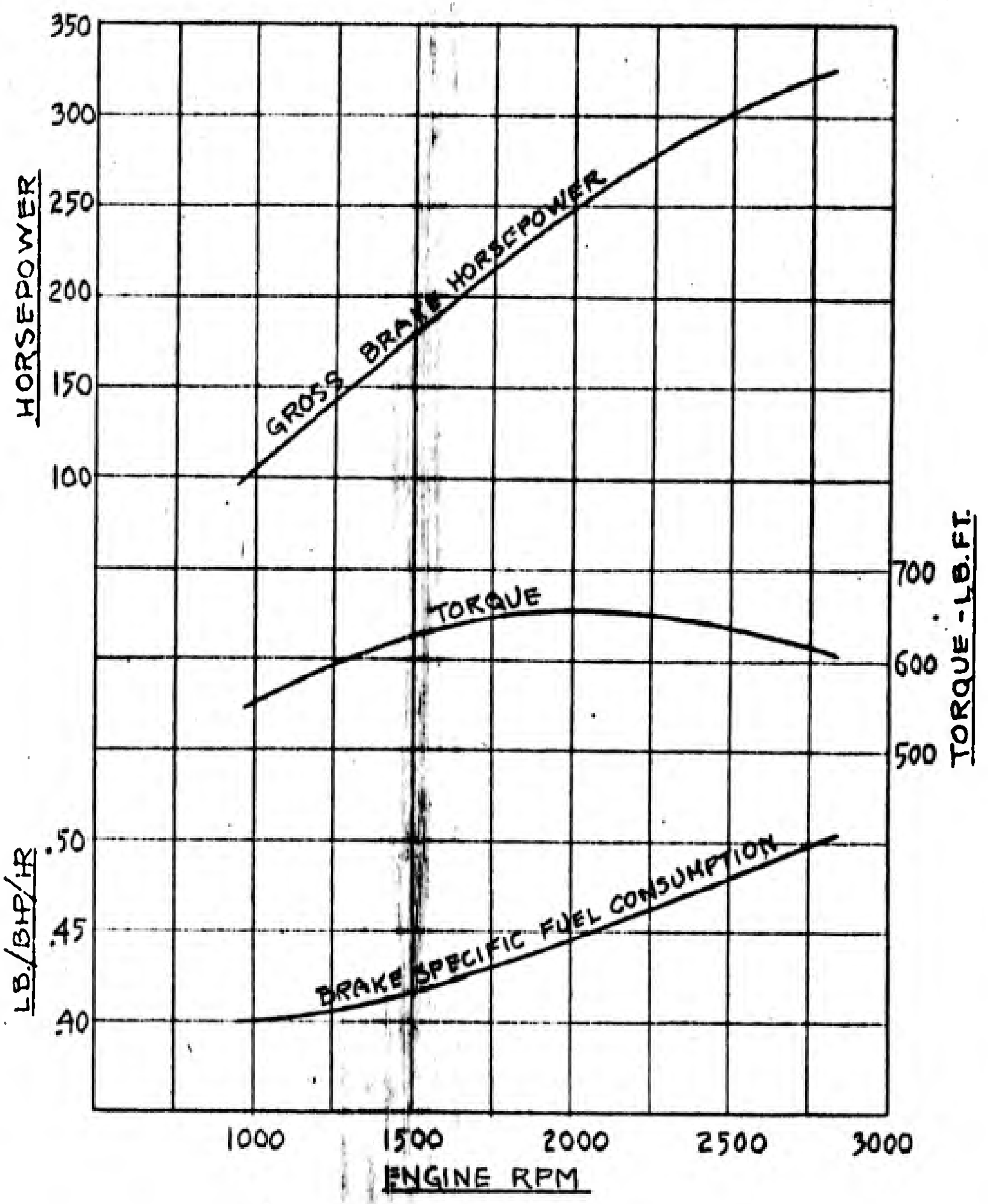
FMC CORP., ORD. DIV.
BY RPM DATE 11-8-61



ESTIMATED PERFORMANCE
AVM-625, 8 CYL. ENGINE

10-6-61

AVM-625



ESTIMATED PERFORMANCE
AVM-625, 8 CYL. ENGINE

8-16-61

Subject: LVT PX11 PERFORMANCE
ENGINE : (SEE TELECON 25 SEPT 61)
POWER TRAIN : ALLISON XTG 250 (w/o F.D.)
Prepared by B.R. MURPHEY Date 10-5-61 Code No.
Checked by Dwg. No. Project No. 449

TRANS. BEVEL GEAR RATIO	1.44:1
TRANSMISSION GEAR RATIO	6.165:1 (1ST RANGE)
FINAL DRIVE GEAR RATIO	2.82:1
OVERALL GEAR RATIO	25.00:1
POWER TRAIN EFF. (INCL. F.D.)	SEE CURVES
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.

GVW — 35000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	H.P. @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2215	518	501	STALL	2.53	0	1269	0	0	0	36,200
2270	516	499	.2	2.15	454	1072	93	1.14	85.4	28200
2300	515	498	.3	1.90	690	946	124	1.73	114	24800
2345	513	497	.4	1.73	938	860	154	2.34	141	22400
2435	509	494	.6	1.37	1479	676	190	3.70	172	17500
2600	505	491	.7	1.18	1846	580	204	4.62	186	15100
2800	469	457	.8	1.00	2240	457	195	5.60	175	13000
LOCKUP										
2000	525	507	1	1	2000	507	193	5.00	175	13100
2600	505	491	1	1	2600	491	244	6.50	222	12800
2800	469	457	1	1	2800	457	244	7.00	218	13000

(a) NET ENGINE TORQUE INTO CONVERTER REDUCED BECAUSE OF OIL PUMP LOSSES.

FMC CORPORATION — ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Ord-Eng-694

Subject: LVT PX11 PERFORMANCE
ENGINE : (SEE TELECON 15 SEPT 61)
POWER TRAIN : ALLISON XTG 250 (w/o F.D.)
Prepared by [illegible] Date 10-17-61 Code No.
Checked by Dwg. No. Project No. 449

TRANS. BEVEL GEAR RATIO 1.44:1
TRANSMISSION GEAR RATIO 4.18:1 (2ND RANGE)
FINAL DRIVE GEAR RATIO 2.82:1
OVERALL GEAR RATIO 17.00:1
POWER TRAIN EFF. (INCL. F.D.) SEE CURVES
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW — 35000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	H.P. @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2215	518	501	STALL	2.53	0	1269	0	0	0	24800
2270	516	499	.2	2.15	454	1072	93	1.68	85.5	19200
2300	515	498	.3	1.90	690	946	124	2.55	113	16800
2345	513	497	.4	1.73	938	860	154	3.48	142	15400
2465	509	494	.6	1.37	1479	676	190	5.48	175	12100
2600	505	491	.7	1.18	1846	580	204	6.83	185	10200
2800	469	457	.8	1.00	2240	457	195	8.30	172	7870
LOCKUP										
2000	525	507	1	1	2000	507	193	7.40	177	9100
2600	505	491	1	1	2600	491	244	9.62	222	8660
2800	469	457	1	1	2800	457	244	10.4	216	7870

(a) NET ENGINE TORQUE INTO CONVERTER REDUCED BECAUSE OF OIL PUMP LOSSES.

FMC CORPORATION — ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Ord-Eng-694

Subject: LVT PX11 PERFORMANCE
ENGINE : (SEE TELECON 25 SEPT 61)
POWER TRAIN : ALLISON XTG 250 (w/o F.D.)
Prepared by R.P. MURPHEY Date 10-5-61 Code No.
Checked by Dwg. No. Project No. 449

TRANS. BEVEL GEAR RATIO 1.44:1
TRANSMISSION GEAR RATIO 2.24:1 (3RD RANGE)
FINAL DRIVE GEAR RATIO 2.82:1
OVERALL GEAR RATIO 9.10:1
POWER TRAIN EFF. (INCL. F.D.) SEE CURVES
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW — 35000 LBS.

NET ENGINE OUTPUT		CONV. INPUT (a)	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	H.P. @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2215	518	501	STALL	2.53	0	1269	0	0	0	13200
2270	516	499	.2	2.15	454	1072	93	3.14	83.3	10,000
2300	515	493	.3	1.90	690	946	124	4.75	111	8,800
2345	513	497	.4	1.73	938	860	154	6.48	138	8000
2465	509	494	.6	1.37	1479	676	190	10.20	169	6260
2600	505	491	.7	1.18	1846	580	204	12.70	180	5335
2800	469	457	.8	1.00	2240	457	195	15.45	170	4140
LOCKUP										
2000	525	507	1	1	2000	507	193	13.80	174	4750
2600	505	491	1	1	2600	491	244	17.90	214	4500
2800	469	457	1	1	2800	457	244	19.30	212	4140

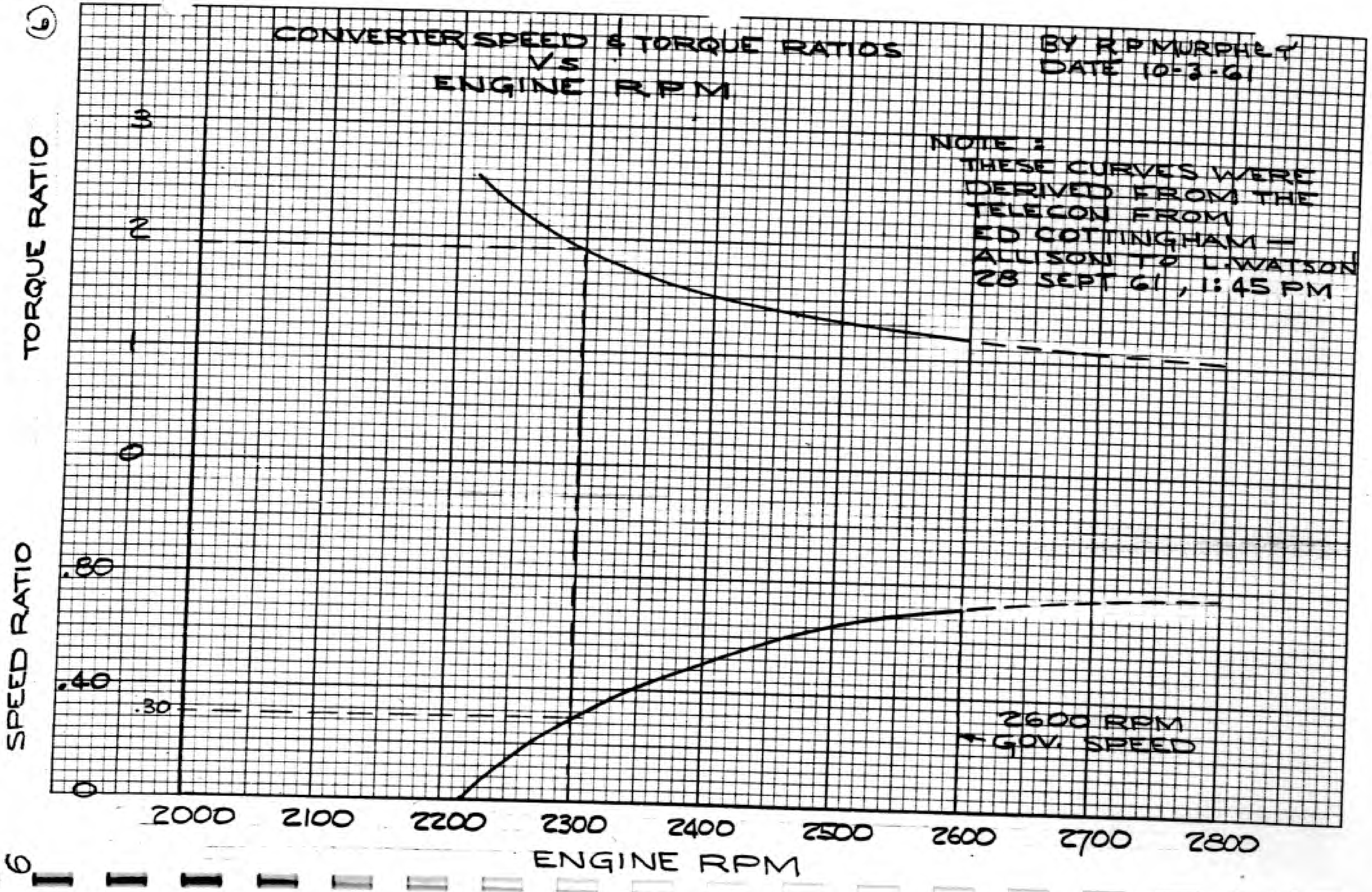
(a) NET ENGINE TORQUE INTO CONVERTER REDUCED BECAUSE OF OIL PUMP LOSSES.

Subject: LVT PXII PERFORMANCE
ENGINE : (SEE TELECON 25 SEPT 61)
POWER TRAIN : ALLISON XTG 250 (w/o F.D.)
Prepared by R. D. MURPHY Date 10-5-61 Code No.
Checked by Dwg. No. Project No. 449

TRANS. BEVEL GEAR RATIO 1.44:1
TRANSMISSION GEAR RATIO 1:00:1 (4TH RANGE)
FINAL DRIVE GEAR RATIO 2.82:1
OVERALL GEAR RATIO 4.06:1
POWER TRAIN EFF. (INCL. F.D.) SEE CURVE
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW — 35000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED M.P.H.	H.P. @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2215	518	501	STALL	2.53	0	1269	0	0	0	5870
2270	516	499	.2	2.15	454	1072	93	7.0	81	4330
2300	515	498	.3	1.90	690	946	124	10.6	108	3810
2345	513	497	.4	1.73	933	860	154	14.5	134	3460
2465	509	494	.6	1.37	1479	676	190	22.8	165	2720
2600	505	491	.7	1.18	1846	580	204	28.4	175	2310
2800	469	457	.8	1.00	2240	457	195	34.5	163	1768
LOCKUP										
2000	525	507	1	1	2000	507	193	30.8	168	2040
2600	505	491	1	1	2600	491	244	40.0	209	1950
2800	469	457	1	1	2800	457	244	43.1	204	1768

(a) NET ENGINE TORQUE INTO CONVERTER REDUCED BECAUSE OF OIL PUMP LOSSES.



CONVERTER SPEED & TORQUE RATIOS
VS
ENGINE RPM

BY R P MURPHEY
DATE 10-3-61

NOTE:
THESE CURVES WERE DERIVED FROM THE TELECON FROM ED COTTINGHAM — ALLISON TO L. WATSON 28 SEPT 61, 1:45 PM

fmc CORPORATION

Subject: LUTPx11 STUDY — Fuel Consumption

Prepared by: A J Samuel Date 12 OCT 61 Code No.

Checked by Dwg. No. Project No. 449

Calculate predicted fuel consumption for Lycoming AVM-625 MultiFuel Engine and Allison XTG-250 Powertrain for 250 mile range @ 25 mph from performance curve Page 1. and engine curve Page 3.

a) Based on <u>level ground</u> 100#/ton RR w/ air resistance.

From performance curve HP @ sprocket = 124

At this part load condition transmission in 4th lockup and engine RPM = $\frac{25}{40} \times 2600 = 1630$ RPM

HP into transmission = $\frac{\text{HP @ sprocket}}{\text{Powertrain Eff}} = \frac{124}{.87} = 143$

{Note: max net HP available to transmission at 1630 RPM = 175 ∴ 143 HP is part load condition

From engine curve Page 3 fuel consumption equals 64#/hr for 143 HP & 1630 RPM.

For $\frac{250 \text{ mi}}{25 \text{ mph}} = 10$ hr

∴ Total fuel req'd = $\frac{64 \times 10}{6.65} = \boxed{\text{97 gal diesel fuel}}$

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

⑫

fmc CORPORATION

Subject: LVTPX11 STUDY — Fuel Consumption

Prepared by: A J Samuel Date 12 Oct 61 Code No. _____

Checked by: _____ Dwg. No. _____ Project No. 449

b) Same as a) except @ max power at 25 mph.
(Note this corresponds to approx 2% slope + 100#/Ton RR + Air Res)
Refering to performance curve Fig 1
transmission is in 4th gear converter.

Converter slip ratio = $\frac{25}{40}$ = .625

From Page 9 – engine RPM = 2480 RPM

From Page 10 . HP to transmission = 240 @ 2480 RPM

From engine curve Page 3 . fuel consumption equals 125 #/hr for 240 HP & 2480 RPM

∴ Total fuel req'd = $\frac{125 \times 10}{6.65}$ = $\boxed{\text{188 gal diesel fuel}}$

c) As a compromise between a) & b) Suggest Consider 150 gal fuel capacity to meet Land Performance Spec requirement of 250 mi @ 25 mph.

Calculate predicted fuel consumption for 50 mi range in water, using tracks as means of propulsion.

Refering to Page 13 – water speed equals 7 mph at track speed 16 mph. Transmission in 3rd lockup.

Refering to Page 13, Engine RPM = $\frac{16}{18}$ x 2600 = 2300

Subject: LVTPX11 Study — Fuel Consumption
Prepared by: A J Samuel Date: 12 Oct 61 Code No.:
Checked by: Dwg. No.: Project No.: 449

From Page 13, HP equals 195 @ sprocket @ 7 mph water speed

HP into transmission = $\frac{\text{HP @ sprocket}}{\text{Powertrain eff}} = \frac{195}{.895} = 218$

From engine curve Page 3, fuel consumption equals 108 #/HR

For $\frac{50 \text{ mi}}{7 \text{ mph}} = 7.15$ hrs

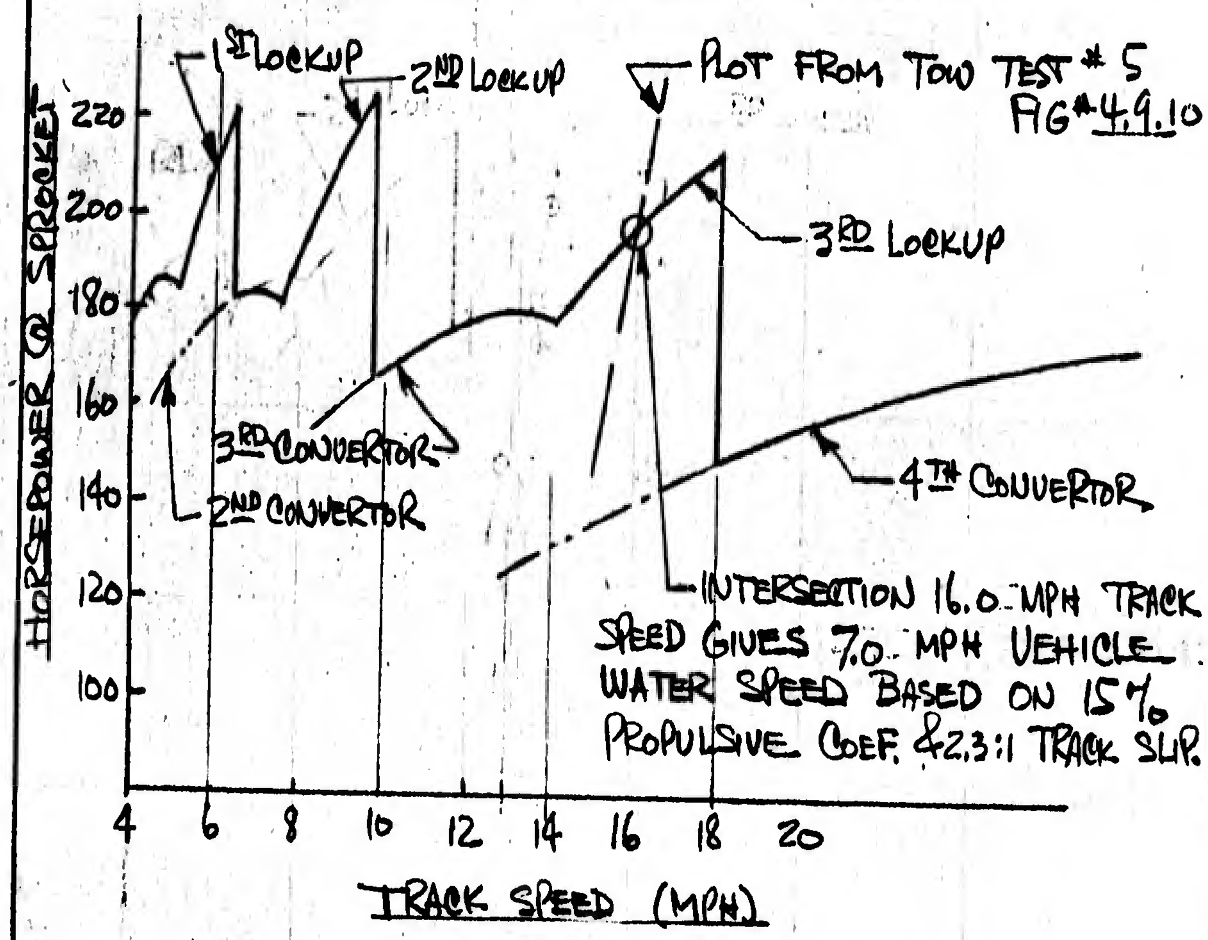
∴ Total fuel req'd = $\frac{108 \times 7.15}{6.65} = \boxed{116 \text{ gal diesel fuel}}$

Note: This requirement is easily met with the 150 gal vehicle fuel capacity suggested in C) to meet land requirements.

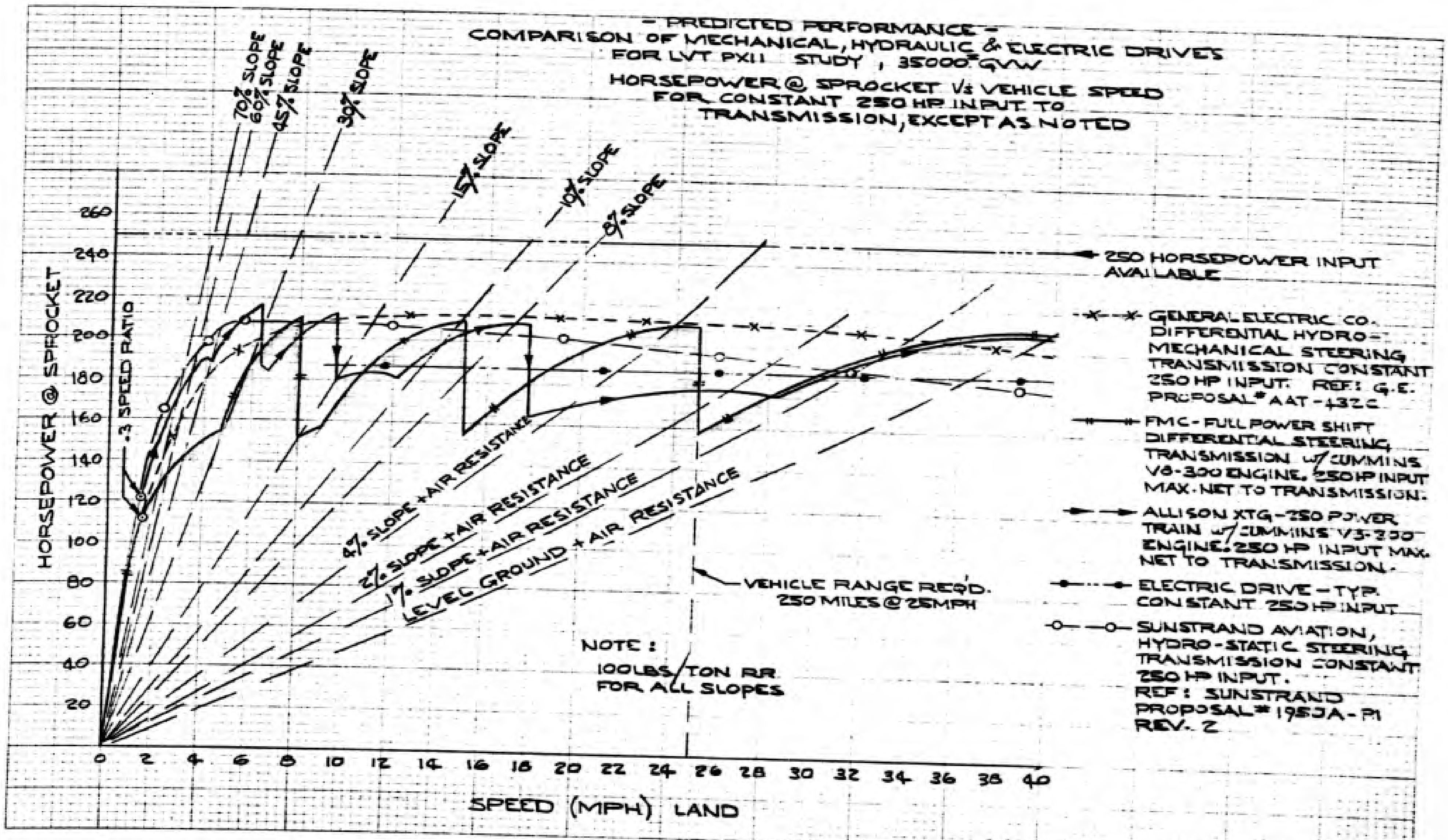
(10)

Subject: LUTPx II STUDY
Prepared by: a J Samuel Date: 1 OCT 61 Code No.
Checked by: Dwg. No. Project No. 449

DETERMINATION OF VEHICLE WATER SPEED DUE TO TRACK PROPULSION, BASED ON TOW TEST # 5 (FIG 4.9.10) & MAX TORQUE TO ALLISON XTG-250 POWERTRAIN (REF. FIG)



INTERSECTION 16.0 MPH TRACK SPEED GIVES 7.0 MPH VEHICLE WATER SPEED BASED ON 15% PROPULSIVE COEF. & 2.3:1 TRACK SLIP.



– PREDICTED PERFORMANCE –
COMPARISON OF MECHANICAL, HYDRAULIC & ELECTRIC DRIVES
FOR LVT PXII STUDY, 35000# GVW

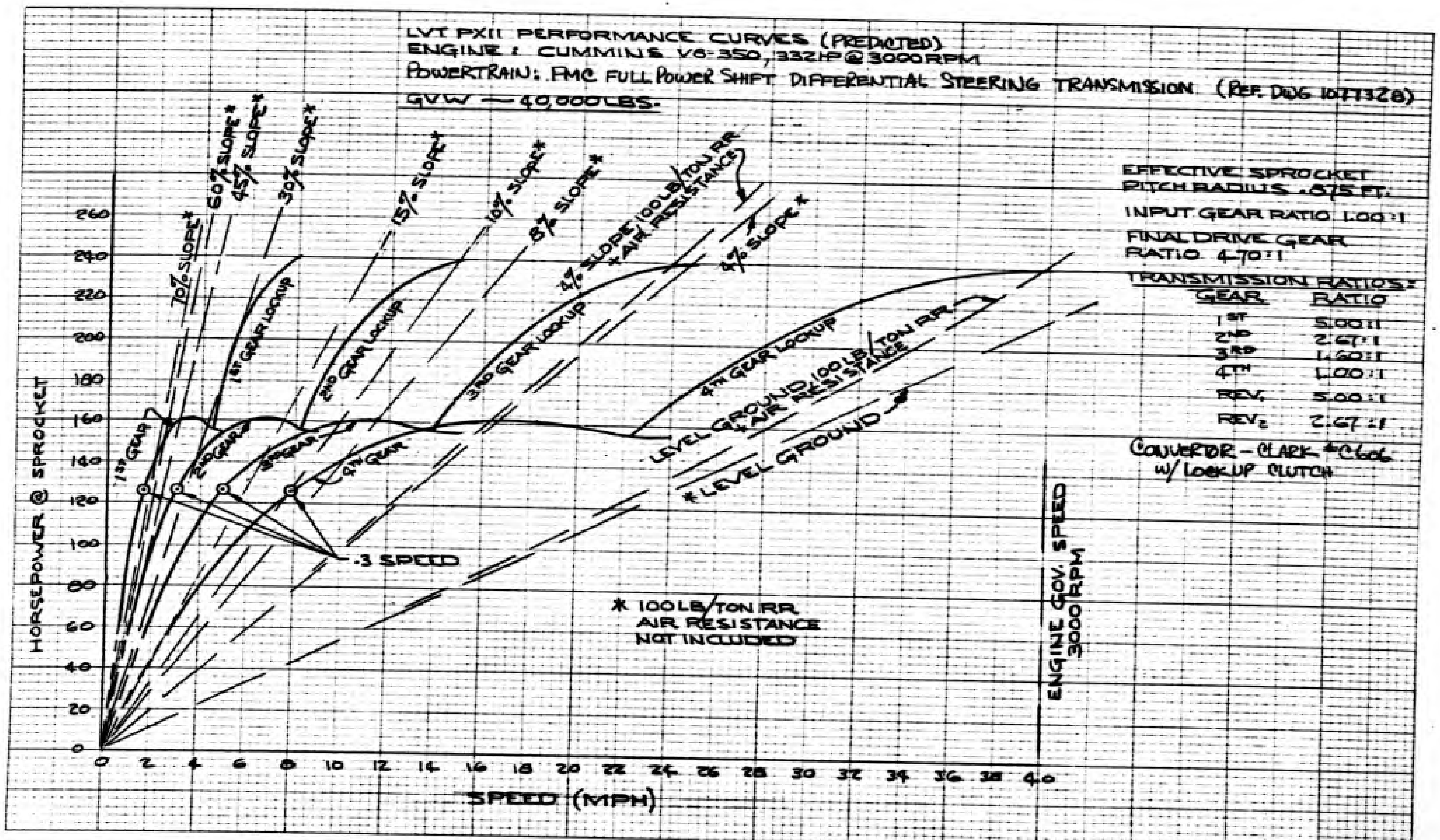
HORSEPOWER @ SPROCKET Vs VEHICLE SPEED
FOR CONSTANT 250 HP INPUT TO
TRANSMISSION, EXCEPT AS NOTED

FMC CORP. ORD. DIV.
BY RPH DATE 11-1-61

APPENDIX D-3

LAND PERFORMANCE
CUMMINS V8-350 AND FMC POWER TRAIN

LVT PXII PERFORMANCE CURVES (PREDICTED)
ENGINE: CUMMINS V6-350, 332HP @ 3000RPM
POWERTRAIN: FMC FULL POWER SHIFT DIFFERENTIAL STEERING TRANSMISSION (REF. DWG 1077328)
GVW — 40,000 LBS.



* 100 LB/TON RR
AIR RESISTANCE
NOT INCLUDED

EFFECTIVE SPROCKET PITCH RADIUS .875 FT.

INPUT GEAR RATIO 1.00:1

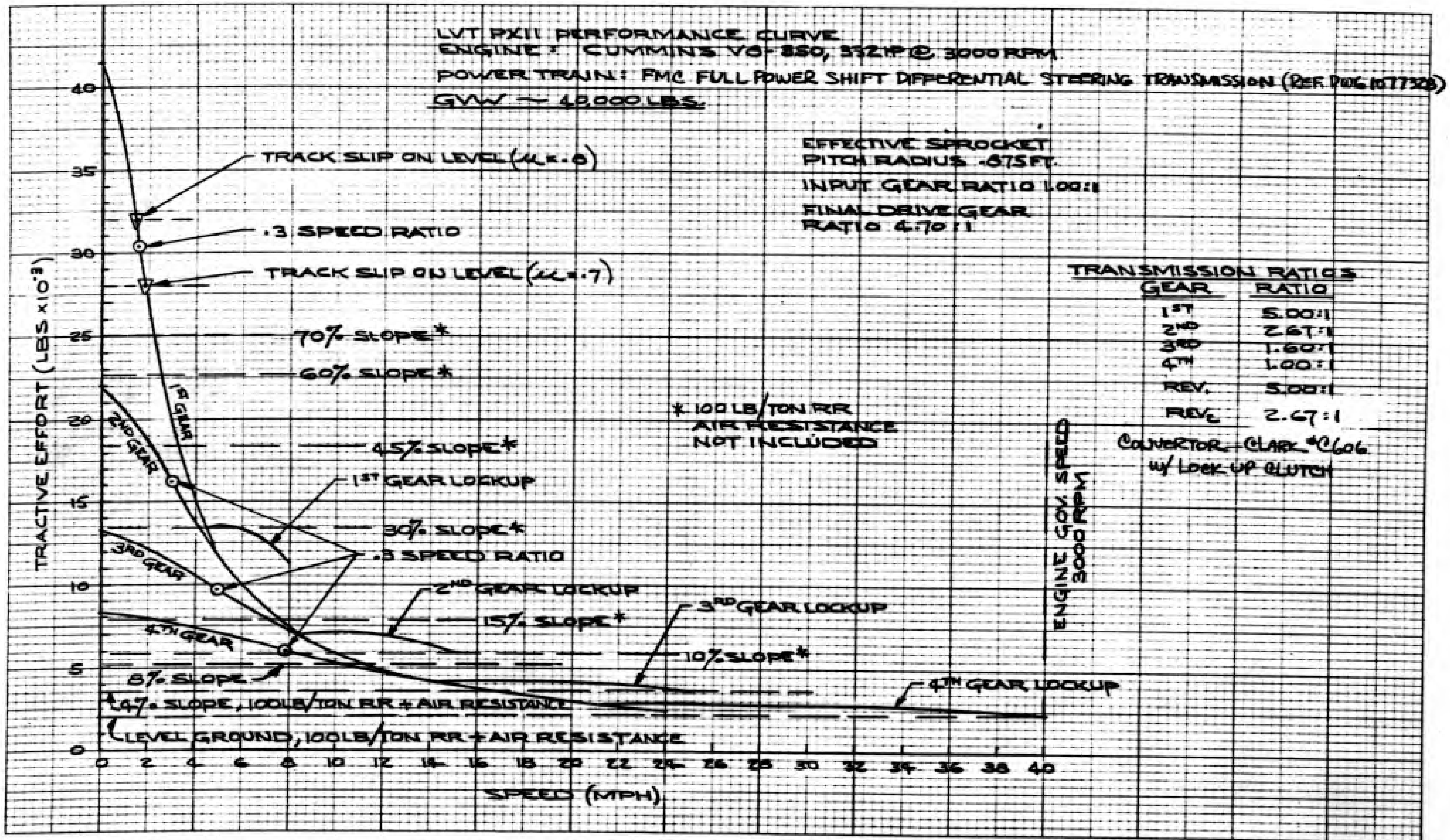
FINAL DRIVE GEAR RATIO 4.70:1

TRANSMISSION RATIOS:

GEAR	RATIO
1ST	5.00:1
2ND	2.67:1
3RD	1.60:1
4TH	1.00:1
REV.1	5.00:1
REV.2	2.67:1

CONVERTOR – CLARK #C606 w/ LOCKUP CLUTCH

FMC CORP., ORD. DIV.
BY RFM DATE 11-4-61



FMC CORP., ORD. DIV.
BY RPM. DATE 11-4-61

FMC CORPORATION

LVT PXII PERFORMANCE

Subject: ENGINE : CUMMINS V8-350, 332 HP @ 3000 RPM
FMC TRANSMISSION & CLARK #16 (C-606) CONV.

Prepared by R. P. MURPHY Date 11-4-61 Code No.

Checked by Dwg. No. Project No. 948

TRANSMISSION GEAR RATIO 5.00:1 (1st GEAR)
INPUT GEAR RATIO 1.00:1
FINAL DRIVE GEAR RATIO 4.70:1
OVERALL GEAR RATIO 23.50:1
POWER TRAIN EFF. (INCL. F.D.) 85%
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW ~ 40,000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	(b) CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2087	595		STALL	3.02	0	1800	0	0	0	41500
2045	597		.10	2.815	204.5	1680	65.5	.55	56	38800
2000	598		.20	2.519	400	1510	115	1.06	99	35000
1970	598		.30	2.197	591	1315	148	1.57	127	30,400
1945	597		.40	1.882	776	1120	166	2.08	143	26000
1970	596		.70	1.210	1379	720	189	3.68	162	16600
2045	597		.785	1.000	1610	597	183	4.30	157	13800
2185	592		.825	.892	1800	527	180	4.80	155	12200
LOCKUP										
1600	569	557	1	1	1600	557	170	4.26	146	12900
2400	580	568	1	1	2400	568	260	6.40	224	13100
3000	500	488	1	1	3000	488	280	8.00	240	11300

(a) NET ENGINE TORQUE REDUCED BY 12 LB FT. FOR TRANSMISSION OIL PUMP LOSSES.
(b) CALCULATED FROM "CLARK" CONV. CURVE PA-16-8

LVT PXII PERFORMANCE

Subject: ENGINE : CUMMINS V8-350, 332 HP @ 3000 RPM
FMC TRANSMISSION & CLARK #16 (C-606) CONV.

Prepared by R. P. MURPHY **Date** 11-4-61 **Code No.**

Checked by **Dwg. No.** **Project No.** 948

TRANSMISSION GEAR RATIO 2.67:1 (2ND GEAR)
INPUT GEAR RATIO 1.00:1
FINAL DRIVE GEAR RATIO 4.70:1
OVERALL GEAR RATIO 12.55:1
POWER TRAIN EFF. (INCL. F.D.) 86%
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW ~ 40,000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	(b) CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2087	595		STALL	3.02	0	1800	0	0	0	22000
2045	597		.10	2.815	204.5	1680	65.5	1.02	56	20,600
2000	598		.20	2.519	400	1510	115	2.00	99	18600
1970	598		.30	2.197	591	1315	148	2.94	127	16200
1945	597		.40	1.882	776	1120	166	3.88	143	13750
1970	598		.70	1.210	1379	720	189	6.87	162	8850
2045	597		.785	1.000	1610	597	183	8.02	157	7350
2185	592		.825	.892	1800	527	180	8.96	155	6480
LOCKUP										
1600	569	557	1	1	1600	557	170	8.00	146	6850
2400	580	568	1	1	2400	568	260	12.00	224	7000
3000	500	488	1	1	3000	488	280	15.00	240	6000

(a) NET ENGINE TORQUE REDUCED BY 12 LB FT. FOR TRANSMISSION OIL PUMP LOSSES.
(b) CALCULATED FROM "CLARK" CONV. CURVE PA-16-8

FMC CORPORATION

Subject: LVT PXII PERFORMANCE
ENGINE : CUMMINS V8-350, 322 HP @ 3000 RPM
FMC TRANSMISSION & CLARK #16 (C-606) CONV.

Prepared by R.P. MURPHEY Date 11-4-61 Code No.

Checked by Dwg. No. Project No. 948

TRANSMISSION GEAR RATIO 1.60:1 (3RD GEAR)
INPUT GEAR RATIO 1.00:1
FINAL DRIVE GEAR RATIO 4.70:1
OVERALL GEAR RATIO 7.52:1
POWER TRAIN EFF. (INCL. F.D.) 85%
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW ~ 40,000 LBS

NET ENGINE OUTPUT		CONV. INPUT (a)	CONVERTER RATIO (b)		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	H.P.			
2087	595		STALL	3.02	0	1800	0	0	0	13300
2045	597		.10	2.815	204.5	1680	65.5	1.70	56	12440
2000	598		.20	2.519	400	1510	115	3.3	99	11200
1970	598		.30	2.197	591	1315	148	4.9	127	9730
1945	597		.40	1.882	776	1120	166	6.47	143	8270
1970	596		.70	1.210	1379	720	189	11.5	162	5340
2045	597		.785	1.000	1610	597	183	13.4	157	4420
2185	592		.825	.892	1800	527	180	15.00	155	3900
LOCKUP										
1600	569	557	1	1	1600	557	170	13.3	14.6	4120
2400	580	568	1	1	2400	568	260	20.0	229	4200
3000	500	488	1	1	3000	488	280	25.0	240	3600

(a) NET ENGINE TORQUE REDUCED BY 12 LB FT. FOR TRANSMISSION OIL PUMP LOSSES.
(b) CALCULATED FROM "CLARK" CONV. CURVE PA-16-8

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Ord-Eng-694

Subject: LVT PXII PERFORMANCE
ENGINE : CUMMINS V8-350, 332 HP @ 3000 RPM
FMC TRANSMISSION & CLARK #16 (C-606) CONV.
Prepared by R.P. MURPHEY Date 11-4-61 Code No. ____
Checked by ____ Dwg. No. ____ Project No. 943

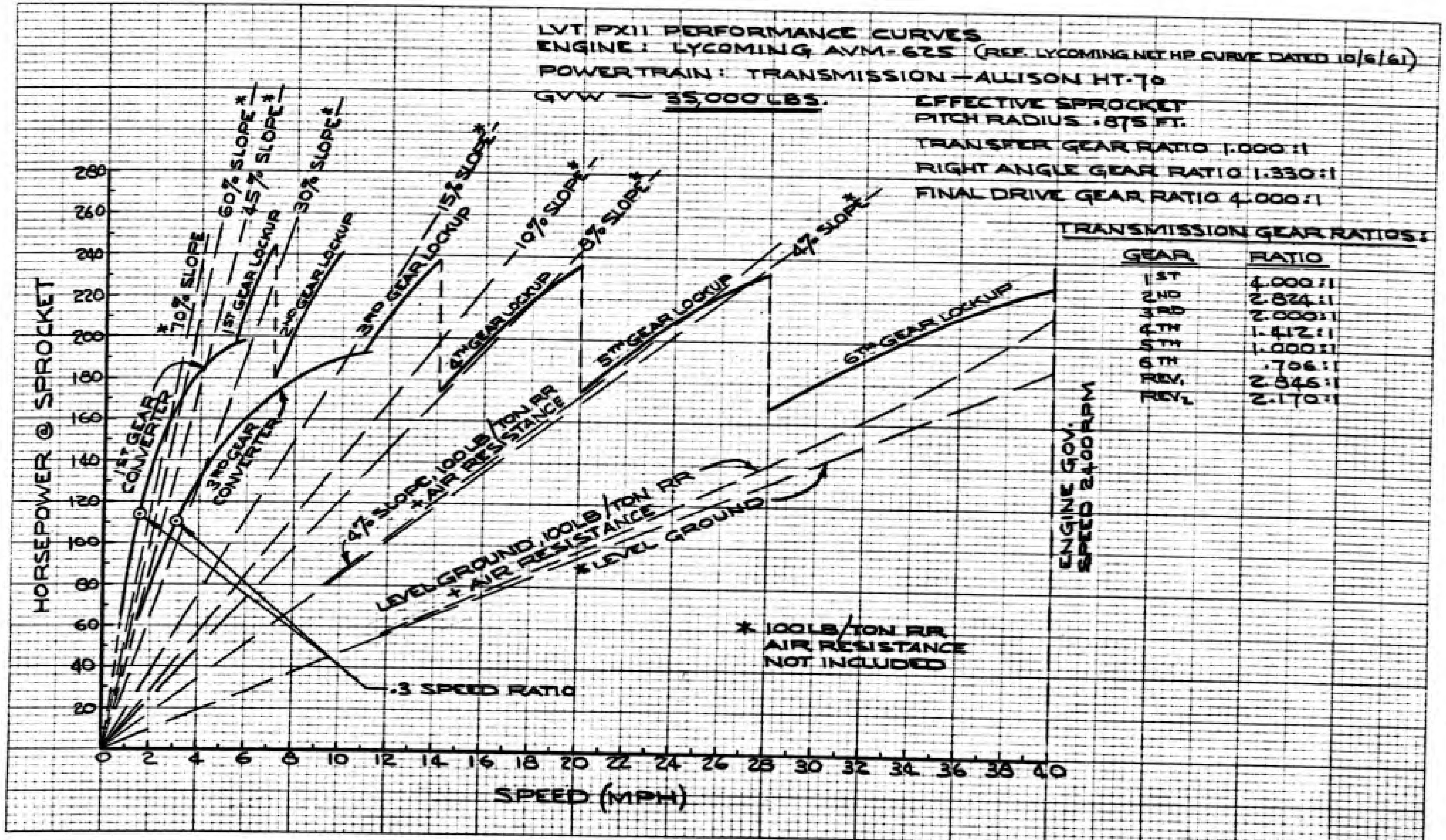
TRANSMISSION GEAR RATIO 1.00:1 (4TH GEAR)
INPUT GEAR RATIO 1.00:1
FINAL DRIVE GEAR RATIO 4.70:1
OVERALL GEAR RATIO 4.70:1
POWER TRAIN EFF. (INCL. F.D.) 85%
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW ~ 40,000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	(b) CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
2087	595		STALL	3.02	0	1800	0	0	0	8320
2045	597		.10	2.815	204.5	1680	65.5	2.72	56	7760
2000	598		.20	2.519	400	1510	115	5.32	99	7000
1970	598		.30	2.197	591	1315	148	7.85	127	6050
1945	597		.40	1.882	778	1120	166	10.3	143	5170
1970	596		.70	1.210	1379	720	189	18.3	162	3320
2045	597		.785	1.000	1610	597	183	21.4	157	2760
2185	592		.825	.892	1800	527	180	24.0	155	2440
LOCKUP										
1600	569	557	1	1	1600	557	170	21.3	146	2570
2400	580	568	1	1	2400	568	260	32.0	224	2620
3000	500	488	1	1	3000	488	280	40.0	240	2260

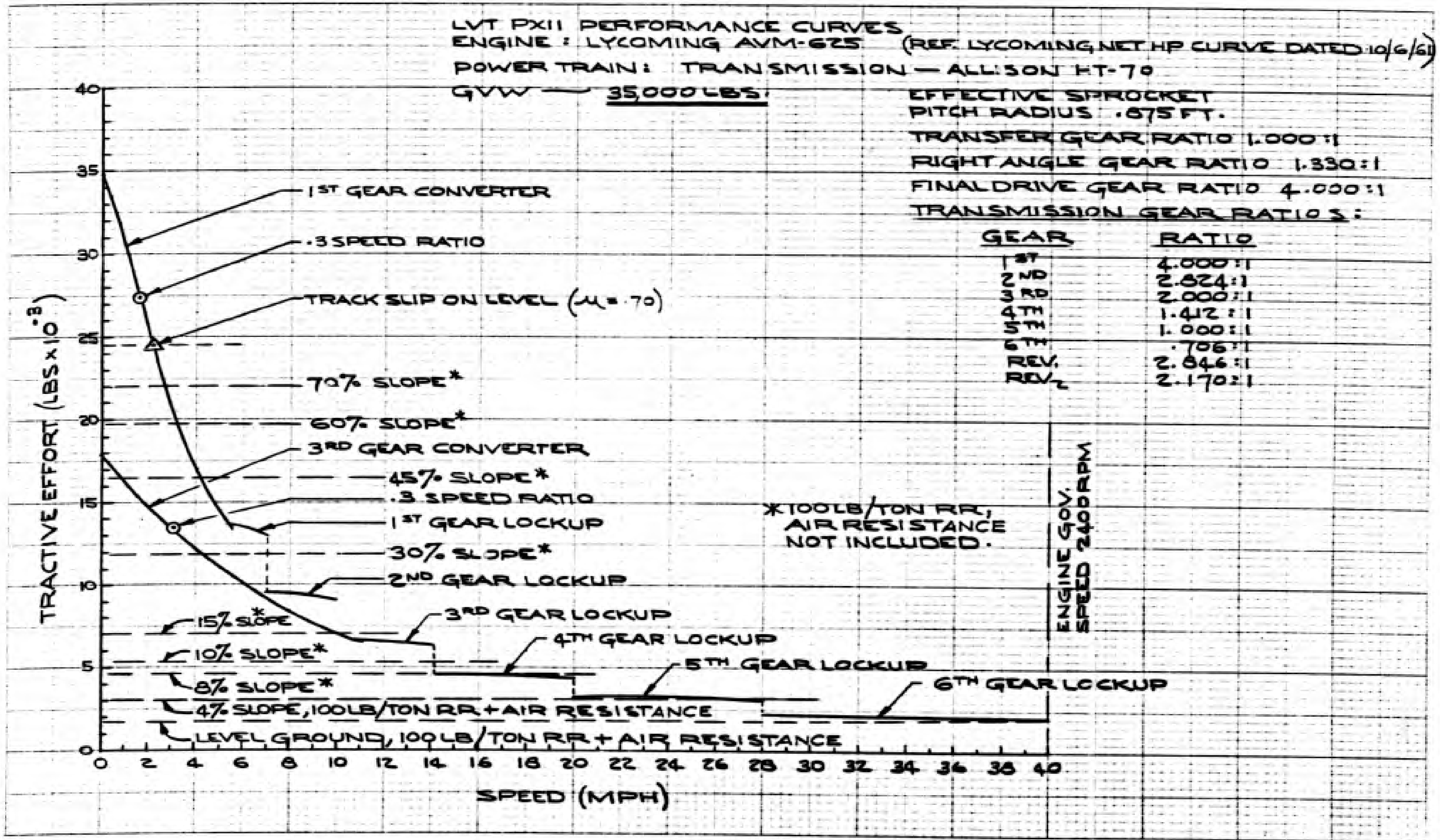
(a) NET ENGINE TORQUE REDUCED BY 12 LB FT. FOR TRANSMISSION OIL PUMP LOSSES.
(b) CALCULATED FROM "CLARK" CONV. CURVE PA-16-8

APPENDIX D-4

LAND PERFORMANCE
LYCOMING AVM-625 AND ALLISON HT-70



FMC CORP., ORD. DIV.
BY R.P.H. DATE 10-13-61



LVT PXII PERFORMANCE CURVES
ENGINE : LYCOMING AVM-625 (REF. LYCOMING NET HP CURVE DATED 10/6/61)
POWER TRAIN : TRANSMISSION — ALLISON HT-70
GVW — 35,000 LBS.

EFFECTIVE SPROCKET PITCH RADIUS .875 FT.
TRANSFER GEAR RATIO 1.000:1
RIGHT ANGLE GEAR RATIO 1.330:1
FINAL DRIVE GEAR RATIO 4.000:1
TRANSMISSION GEAR RATIOS:

GEAR	RATIO
1ST	4.000:1
2ND	2.824:1
3RD	2.000:1
4TH	1.412:1
5TH	1.000:1
6TH	.706:1
REV.$_1$	2.846:1
REV.$_2$	2.170:1

* 100 LB/TON RR, AIR RESISTANCE NOT INCLUDED.

FMC CORP, ORD. DIV.
BY RPM DATE 10-16-61

Subject: LVT PXII PERFORMANCE
ENGINE : LYCOMING AVM-625 (REF. LYCOMING NET HP CURVE DATED 10-6-61
POWER TRAIN : ALLISON HT-70
Prepared by E. P. MURPHEY Date 10-16-61 Code No.
Checked by Dwg. No. Project No. 410

TRANSMISSION GEAR RATIO 4.000:1 (1ST RANGE)
RIGHT ANGLE GEAR RATIO 1.330:1
TRANSFER GEAR RATIO 1.000:1
FINAL DRIVE GEAR RATIO 4.000:1
OVERALL GEAR RATIO 21.30:1
POWER TRAIN EFF. (INCL. F.D.) 94%
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW 35,000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	(b) CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
1695	610	595	STALL	2.55	0	1520	0	0	0	34800
1725	610½	595½	.15	2.33	258	1388	68.2	.76	64	31,800
1760	611	596	.30	2.02	528	1200	121	1.55	114	27,400
1850	610½	595½	.52	1.56	963	930	171	2.83	161	21,300
2000	608	593	.70	1.25	1400	742	198	4.11	186	17000
2300	590	575	.865	.97	1990	557	211	5.85	198	12800
		LOCKUP								
1800	610½	595½	1	1	1800	595½	204	5.30	192	13650
2000	608	593	1	1	2000	593	226	5.88	212	13600
2400	581	566	1	1	2400	566	257	7.05	244	13000

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE Tc 6741)
(b) CALCULATED FROM ALLISON CURVES Tc 6741 SHTS. 1 & 2

Subject: LVT PXII PERFORMANCE
ENGINE: LYCOMING AVM-625 (REF. LYCOMING NET HP CURVE DATED 10-6-61)
POWERTRAIN: ALLISON HT-70

Prepared by R.P. MURPHEY Date 10-16-61 Code No. ____

Checked by ____ Dwg. No. ____ Project No. 440

TRANSMISSION GEAR RATIO	2.824:1 (2ND RANGE)
RIGHT ANGLE GEAR RATIO	1.330:1
TRANSFER GEAR RATIO	1.000:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	15.00:1
POWERTRAIN EFF. (INCL. F.D.)	93%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.
GVW	35000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
		LOCKUP								
1800	610½	595½	1	1	1800	595½	204	7.50	190	9560
2000	608	593	1	1	2000	593	226	8.34	210	9520
2400	581	566	1	1	2400	566	259	10.00	241	9080

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP OPERATION.
(REF. ALLISON CURVE № Tc 6741 SHT. 1)

Subject: LVT PXII PERFORMANCE
ENGINE : LYCOMING AVM-625 (REF. LYCOMING NET HP CURVE DATED 10-6-61
POWER TRAIN : ALLISON HT-70
Prepared by D. P. MURPHEY Date 10-16-61 Code No.
Checked by Dwg. No. Project No. 449

TRANSMISSION GEAR RATIO 2.000:1 (3RD RANGE)
RIGHT ANGLE GEAR RATIO 1.330:1
TRANSFER GEAR RATIO 1.000:1
FINAL DRIVE GEAR RATIO 4.000:1
OVERALL GEAR RATIO 10.62:1
POWER TRAIN EFF. (INCL. F.D.) 92%
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW 35,000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	(b) CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED M.P.H.	H.P. @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
1695	610	595	STALL	2.55	0	1520	0	0	0	16900
1725	610½	595½	.15	2.33	258	1388	68.7	1.51	62.6	15400
1760	611	596	.30	2.02	528	1200	121	3.11	111	13400
1850	610½	595½	.52	1.56	963	930	171	5.66	157	10400
2000	608	593	.70	1.25	1400	742	198	8.23	182	8260
2300	590	575	.865	.97	1990	557	211	11.70	194	6220
LOCKUP										
1800	610½	595½	1	1	1800	595½	204	10.6	188	6640
2000	608	593	1	1	2000	593	226	11.8	208	6600
2400	581	566	1	1	2400	566	259	14.1	238	6300

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE Tc 6741)
(b) CALCULATED FROM ALLISON CURVES Tc 6741 SHTS. 1 & 2

Subject: LVT PXII PERFORMANCE
ENGINE: LYCOMING AVM-625 (REF. LYCOMING NET HP CURVE DATED 10-6-61)
POWERTRAIN: ALLISON HT-70
Prepared by R.P. MURPHEY Date 10-16-61 Code No. ______
Checked by ______ Dwg. No. ______ Project No. 449

TRANSMISSION GEAR RATIO	1.412:1 (4TH RANGE)
RIGHT ANGLE GEAR RATIO	1.330:1
TRANSFER GEAR RATIO	1.000:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	7.50:1
POWERTRAIN EFF. (INCL. F.D.)	91%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.
GVW	35000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
		LOCKUP								
1800	610½	595½	1	1	1800	595½	204	15.0	186	4650
2000	608	593	1	1	2000	593	226	16.7	206	4630
2400	581	566	1	1	2400	566	259	20.0	236	4420

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP OPERATION.
(REF. ALLISON CURVE № Tc 6741 SHT. 1)

Subject: LVT PXII PERFORMANCE
ENGINE : LYCOMING AVM-625 (REF. LYCOMING NET HP CURVE DATED 10-6-61)
POWERTRAIN : ALLISON HT-70
Prepared by R.P. MURPHEY Date 10-16-61 Code No. ______
Checked by ______ Dwg. No. ______ Project No. 449

TRANSMISSION GEAR RATIO 1.000:1 (5TH RANGE)
RIGHT ANGLE GEAR RATIO 1.330:1
TRANSFER GEAR RATIO 1.000:1
FINAL DRIVE GEAR RATIO 4.000:1
OVERALL GEAR RATIO 5.32:1
POWER TRAIN EFF. (INCL. F.D.) 90%
EFFECTIVE SPROCKET PITCH RAD. .875 FT.
GVW 35000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
		LOCKUP								
1800	610½	595½	1	1	1800	595½	204	21.0	183	3270
2000	608	593	1	1	2000	593	226	23.4	204	3260
2400	581	566	1	1	2400	566	259	28.0	233	3100

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP OPERATION.
(REF. ALLISON CURVE № Tc 6741 SHT. 1)

Subject: LVT PXII PERFORMANCE
ENGINE : LYCOMING AVM-625 (REF. LYCOMING NET HP CURVE DATED 10-6-61)
POWERTRAIN : ALLISON HT-70
Prepared by R.P. MURPHEY Date 10-16-61 Code No. ______
Checked by ______ Dwg. No. ______ Project No. 449

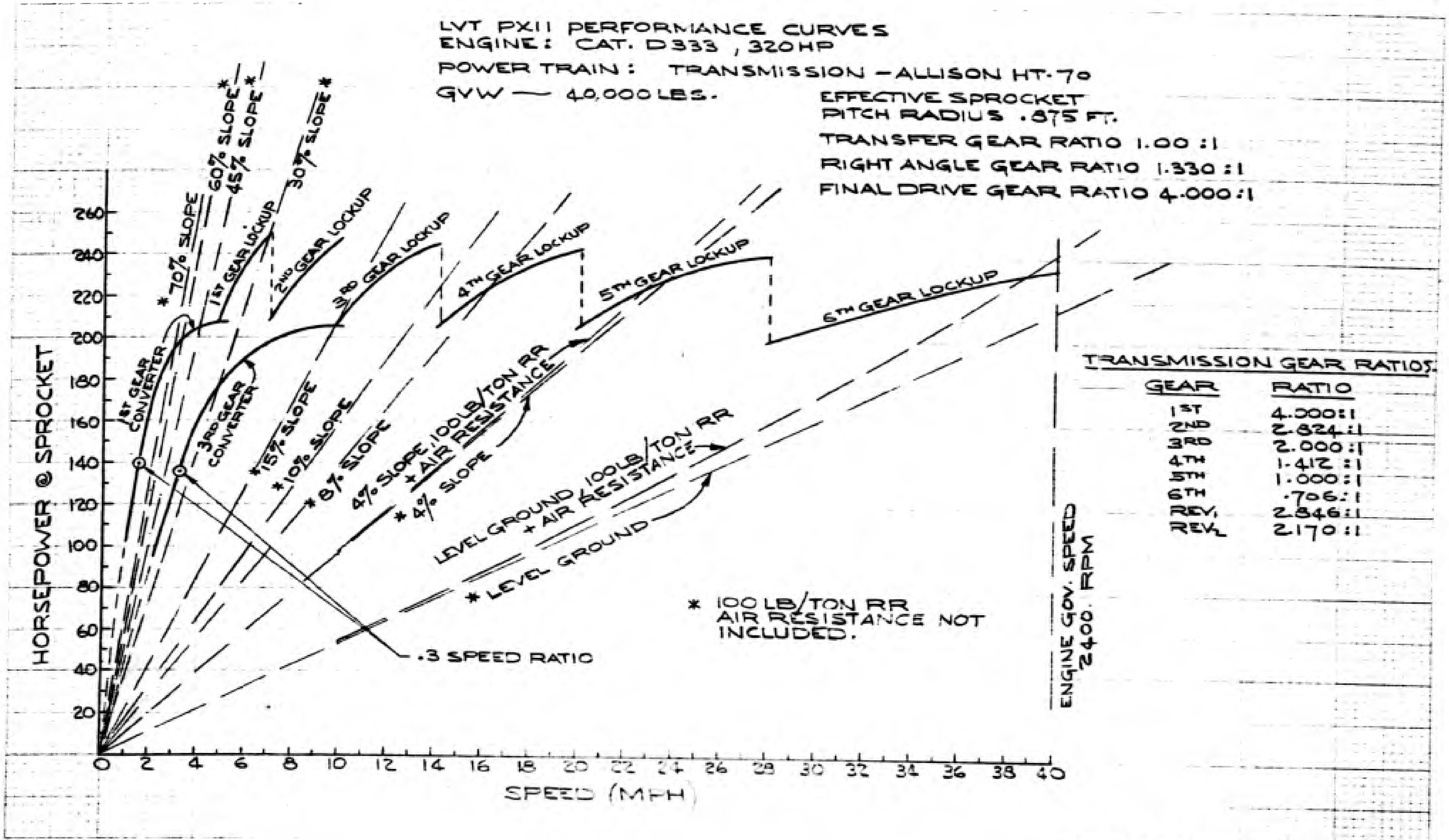
TRANSMISSION GEAR RATIO	.706:1 (6TH RANGE)
RIGHT ANGLE GEAR RATIO	1.330:1
TRANSFER GEAR RATIO	1.000:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	3.750:1
POWER TRAIN EFF. (INCL. F.D.)	88%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.
GVW	35000 LBS

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
		LOCKUP								
1800	610½	595½	1	1	1800	595½	204	30.0	180	2250
2000	608	593	1	1	2000	593	226	33.4	199	2240
2400	581	566	1	1	2400	566	259	40.0	228	2140

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP OPERATION.
(REF. ALLISON CURVE № Tc 6741 SHT. 1)

APPENDIX D-5

LAND PERFORMANCE
CATERPILLAR D-333 AND ALLISON HT-70



LVT PXII PERFORMANCE CURVES
ENGINE: CAT. D333, 320HP
POWER TRAIN: TRANSMISSION – ALLISON HT-70
GVW — 40,000 LBS.

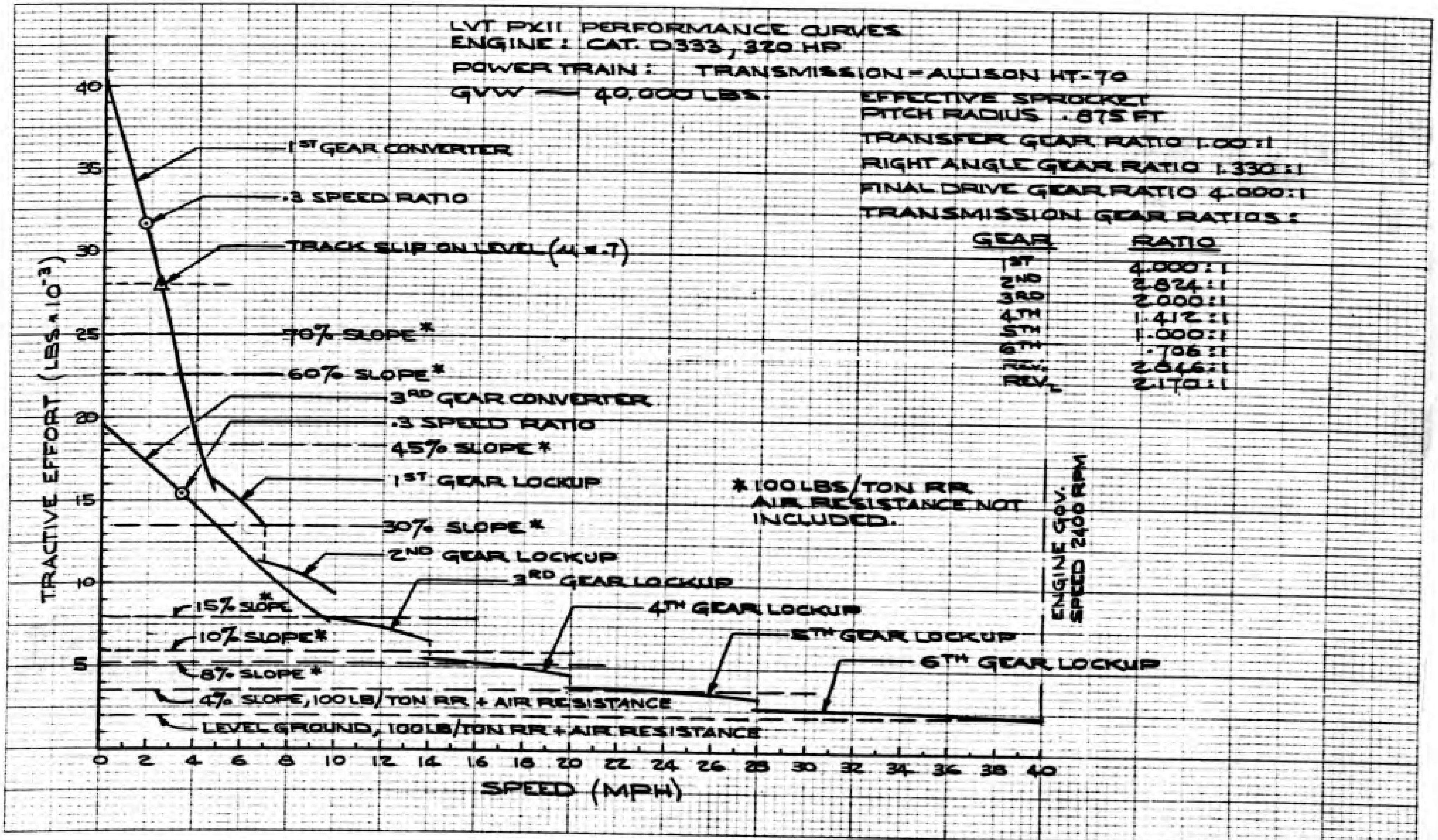
EFFECTIVE SPROCKET PITCH RADIUS .875 FT.
TRANSFER GEAR RATIO 1.00 :1
RIGHT ANGLE GEAR RATIO 1.330 :1
FINAL DRIVE GEAR RATIO 4.000 :1

TRANSMISSION GEAR RATIOS

GEAR	RATIO
1ST	4.000:1
2ND	2.824:1
3RD	2.000:1
4TH	1.412:1
5TH	1.000:1
6TH	.706:1
REV.1	2.846:1
REV.2	2.170:1

* 100 LB/TON RR AIR RESISTANCE NOT INCLUDED.

FMC CORP., ORD. DIV.
BY R.P.H. DATE 10-11-61



FMC CORP., ORD. DIV.
BY R.P.M DATE 10-11-61

Subject: LVT PXII PERFORMANCE
ENGINE: CAT. D333, 320 HP
POWER PLANT: ALLISON HT-70 (w/o F.D.)
Prepared by R.P. MURPHEY Date 10-9-61 Code No.
Checked by Dwg. No. Project No. 449

TRANSMISSION GEAR RATIO	4.000:1 (1ST RANGE)
TRANSFER GEAR RATIO	1.000:1
RIGHT ANGLE GEAR RATIO	1.330:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	21.30:1
POWER TRAIN EFF. (INCL. F.D.)	94%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT
GVW	40,000 LBS.

NET ENGINE OUTPUT (a)		CONV. INPUT (b)	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
1825	707	692	STALL	2.55	0	1760	0	0	0	40,300
1860	702	687	.20	2.24	372	1540	109	1.09	103	35,200
1885	698	683	.30	2.02	565	1380	148	1.66	139	31,600
2000	682	667	.58	1.46	1160	974	215	3.41	202	22,300
2300	625	610	.85	.97	1960	592	221	5.76	208	13,550
2400	600	585	.89	.97	2140	568	232	6.28	218	13,000
LOCKUP										
1600	728	713	1	1	1600	713	218	4.70	205	16,300
1700	720	705	1	1	1700	705	228	5.00	214	16,100
2400	600	585	1	1	2400	585	267	7.06	251	13,400

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE Tc 6741)
(b) CALCULATED FROM ALLISON CURVES Tc 6741 SHTS. 1 & 2

Subject: LVT PXII PERFORMANCE
ENGINE : CAT. D333 , 320 HP
POWER PLANT : ALLISON HT-70 (w/o F.D.)
Prepared by R.P. MURPHEY Date 10-9-61 Code No. ____
Checked by ____ Dwg. No. ____ Project No. 44-9

TRANSMISSION GEAR RATIO	2.824:1 (2ND RANGE)
TRANSFER GEAR RATIO	1.000:1
RIGHT ANGLE GEAR RATIO	1.330:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	15.00:1
POWER TRAIN EFF. (INCL. F.D.)	93%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.
GVW	40,000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
LOCKUP										
1600	728	713	1	1	1600	713	218	6.66	202	11,400
1700	720	705	1	1	1700	705	228	7.08	212	11,300
2400	600	585	1	1	2400	585	267	10.00	248	9,360

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT. FOR TRANSMISSION OIL PUMP LOSSES (REF. ALLISON CURVE № Tc 6741 SHT. 1)

Subject: LVT PXII PERFORMANCE
ENGINE: CAT. D333, 320 HP
POWER PLANT: ALLISON HT-70 (w/o F.D.)
Prepared by R.P. MURPHEY Date 10-9-61 Code No.
Checked by Dwg. No. Project No. 449

TRANSMISSION GEAR RATIO	2.000:1 (3RD RANGE)
TRANSFER GEAR RATIO	1.000:1
RIGHT ANGLE GEAR RATIO	1.330:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	10.62:1
POWER TRAIN EFF. (INCL. F.D.)	92%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT
GVW	40,000 LBS.

(a) NET ENGINE OUTPUT		(b) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
1825	707	692	STALL	2.55	0	1760	0	0	0	19,700
1860	702	687	.20	2.24	372	1540	109	2.18	100	17,250
1885	698	683	.30	2.02	565	1380	148	3.32	136	15,450
2000	682	667	.58	1.46	1160	974	215	6.83	198	10,900
2300	625	610	.85	.97	1960	592	221	11.50	203	6,630
2400	600	585	.89	.97	2140	568	232	12.60	214	6,360
LOCKUP										
1600	728	713	1	1	1600	713	218	9.40	200	8,000
1700	720	705	1	1	1700	705	228	10.00	210	7,900
2400	600	585	1	1	2400	585	267	14.10	245	6,550

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT FOR TRANSMISSION OIL PUMP (REF. ALLISON CURVE Tc 6741)
(b) CALCULATED FROM ALLISON CURVES Tc 6741 SHTS. 1 & 2

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Ord-Eng-694

Subject: LVT PXII PERFORMANCE
ENGINE : CAT. D333, 320 HP
POWER PLANT : ALLISON HT-70 (w/o F.D.)
Prepared by R.P. MURPHEY Date 10-9-61 Code No.
Checked by Dwg. No. Project No. 449

TRANSMISSION GEAR RATIO	1.412:1 (4TH RANGE)
TRANSFER GEAR RATIO	1.000:1
RIGHT ANGLE GEAR RATIO	1.330:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	7.50:1
POWER TRAIN EFF. (INCL. F.D.)	91%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.
GVW	40,000 LBS.

NET ENGINE OUTPUT		CONV. INPUT (a)	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
		LOCKUP								
1600	728	713	1	1	1600	713	218	13.4	198	5550
1700	720	705	1	1	1700	705	228	14.2	208	5500
2400	600	585	1	1	2400	585	267	20.0	243	4560

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT. FOR TRANSMISSION OIL PUMP LOSSES (REF. ALLISON CURVE № Tc 6741 SHT. 1)

FMC CORPORATION – ORDNANCE DIVISION
SAN JOSE, CALIFORNIA

Subject: LVT PXII PERFORMANCE
ENGINE : CAT. D333, 320 HP
POWER PLANT : ALLISON HT-70 (w/o F.D.)
Prepared by R.P. MURPHEY Date 10-9-61 Code No.
Checked by Dwg. No. Project No. 449

TRANSMISSION GEAR RATIO	1.000:1 (5th RANGE)
TRANSFER GEAR RATIO	1.000:1
RIGHT ANGLE GEAR RATIO	1.330:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	5.32 :1
POWER TRAIN EFF. (INCL. F.D.)	90%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.
GVW	40,000 LBS.

NET ENGINE OUTPUT		(a) CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
		LOCKUP								
1600	728	713	1	1	1600	713	218	18.7	196	3910
1700	720	705	1	1	1700	705	228	19.8	205	3860
2400	600	585	1	1	2400	585	267	28.0	240	3200

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT. FOR TRANSMISSION OIL PUMP LOSSES (REF. ALLISON CURVE № Tc 6741 SHT. 1)

Subject: LVT PXII PERFORMANCE
ENGINE: CAT. D333, 320 HP
POWER PLANT: ALLISON HT-70 (W/o F.D.)
Prepared by E.P. MURPHEY Date 10-9-61 Code No.
Checked by Dwg. No. Project No. 449

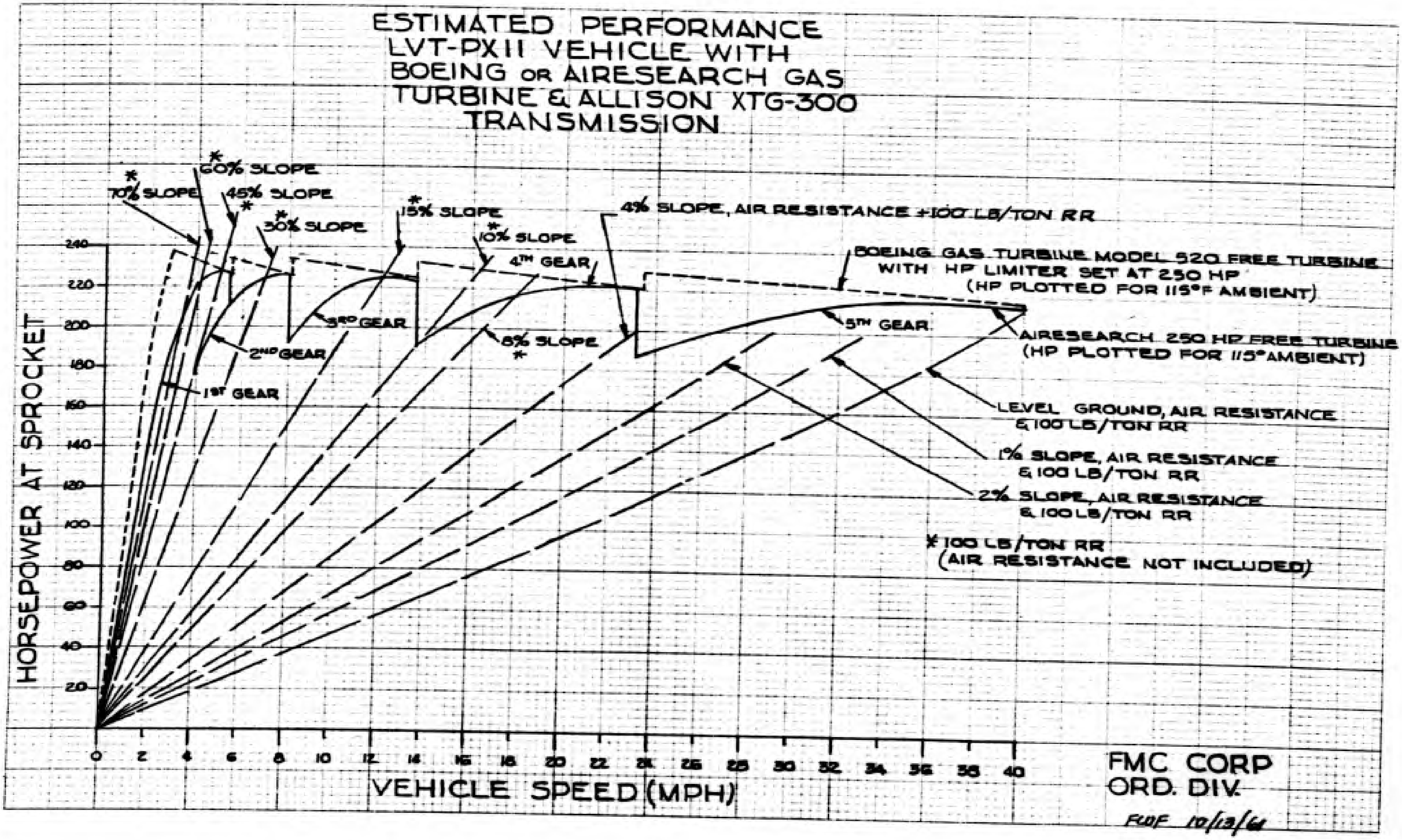
TRANSMISSION GEAR RATIO	.706:1 (6th RANGE)
TRANSFER GEAR RATIO	1.000:1
RIGHT ANGLE GEAR RATIO	1.330:1
FINAL DRIVE GEAR RATIO	4.000:1
OVERALL GEAR RATIO	3.750:1
POWER TRAIN EFF. (INCL. F.D.)	88%
EFFECTIVE SPROCKET PITCH RAD.	.875 FT.
GVW	40,000 LBS.

NET ENGINE OUTPUT	(a)	CONV. INPUT	CONVERTER RATIO		CONVERTER OUTPUT			ROAD SPEED MPH	HP @	TRACTION LBS.
RPM	TORQUE LB FT	TORQUE LB FT	SPEED RATIO	TORQUE RATIO	RPM	TORQUE LB FT	HP			
LOCKUP										
1600	728	713	1	1	1600	713	218	26.8	192	2700
1700	720	705	1	1	1700	705	228	28.4	202	2660
2400	600	585	1	1	2400	585	267	40.0	235	2210

(a) NET ENGINE TORQUE REDUCED BY 15 LB FT. FOR TRANSMISSION OIL PUMP LOSSES (REF. ALLISON CURVE Nº Tc 6741 SHT. 1)

APPENDIX D-6

PERFORMANCE TURBINE



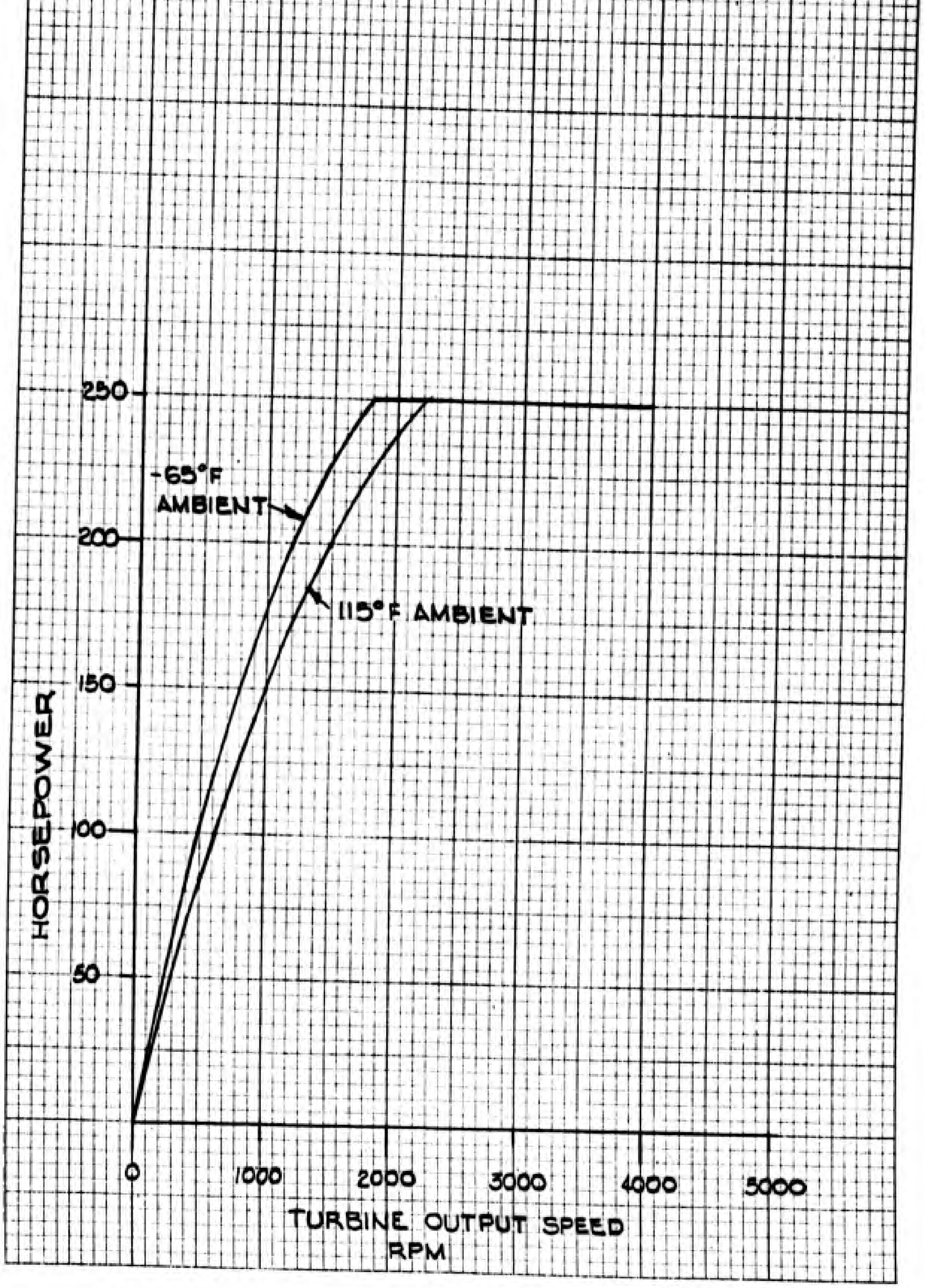
ESTIMATED PERFORMANCE
LVT-PXII VEHICLE WITH
BOEING OR AIRESEARCH GAS
TURBINE & ALLISON XTG-300
TRANSMISSION

FMC CORP
ORD. DIV.

FCOF 10/13/61

BOEING GAS TURBINE MODEL 520-3 NET POWER CURVE

115° F AMBIENT, TEMPERATURE COMPENSATED & EQUIPPED WITH HORSEPOWER LIMITER

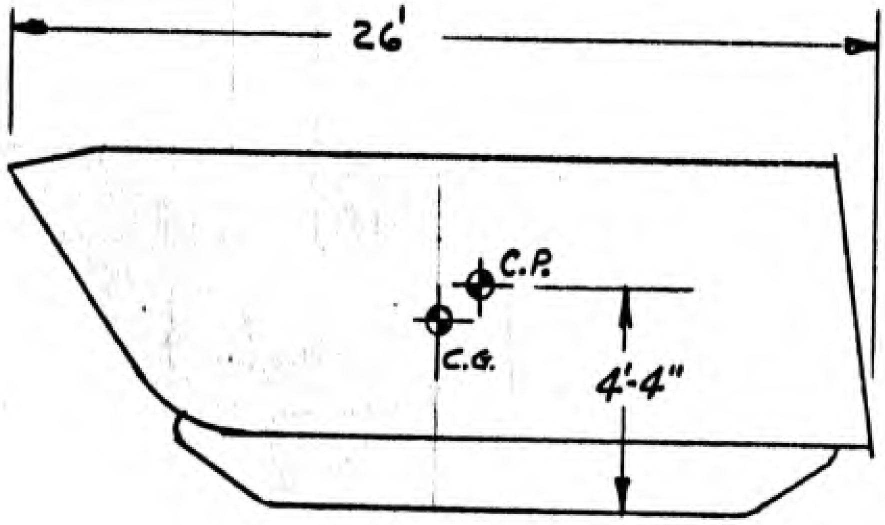


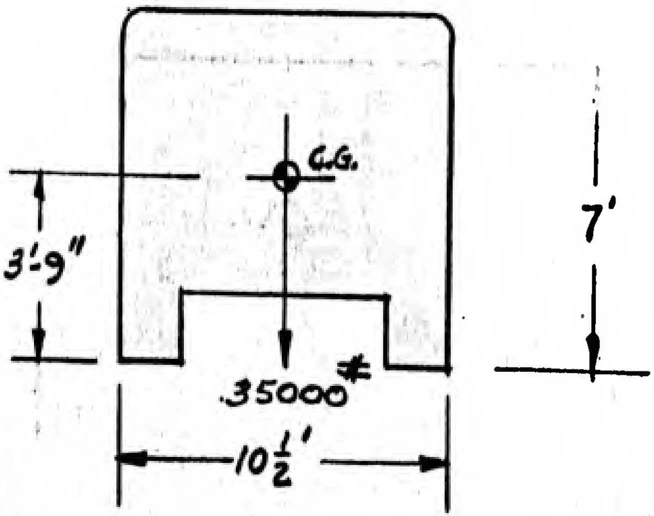
APPENDIX D-7

NUCLEAR BLAST DATA

Load and stress analysis of: LVT-PX11 -
Prepared by COLLIVER Date 9/23/61 Page No. 1
Checked by ______ Dwg. No. ______ Project No. 449

NUCLEAR BLAST OVERTURNING





Load and stress analysis of: LVT - PXT1
Prepared by COLLIVER Date 9/23/61 Page No. 2
Checked by ________ Dwg. No. ________ Project No. 449

ABREVIATIONS.

H = HEIGHT = 7.0'
W = TOTAL WT = 35,000 LB.
C_D = DRAG COEFFICIENT = 1.5
R_r = MOMENT ARM TO WT. = 5.25'
R_p = MOMENT ARM TO CENTER PRESSURE = 4.33'
R_g = RADIUS OF PERCUSSION = $\sqrt{R_r^2+R_p^2}$
A_p = AREA SUBJECTED TO PRESSURE = 132 □'
M_p = MOMENT DUE TO PRESSURE
q_s = STEADY DYNAMIC PRESSURE
q = PEAK DYNAMIC PRESSURE, TRANSIENT
t = TIME
ω = ANGULAR NATURAL FREQUENCY
P_r = REFLECTED PRESSURE
t_0 = POSITIVE PHASE DURATION OF TIME
J = MOMENTAL IMPULSE = $P_r A R_p \frac{t}{2}$
β = EXPONENTIAL DECAY CONSTANT = $4/t_0$
g = GRAVITATIONAL CONSTANT
M_s = STABILITY MOMENT
P = OVER PRESSURE
P_0 = ATMOSPHERIC PRESSURE

Load and stress analysis of: LVT. PX 11
Prepared by COLLIVER Date 9/23/61 Page No. 3
Checked by ______ Dwg. No. ______ Project No. 449

STABILITY MOMENT

$$M_s = W \times R_r$$

$$= 35000^{\#} \times 5.25'$$

$$M_s = 184,000'^{\#}$$

STEADY DYNAMIC PRESSURE TO OVERTURN

$$q_s = \frac{M_s}{A\,C_D\,R_p}$$

$$= \frac{184,000}{132 \times 144 \times 1.5 \times 4.33}$$

$$q_s = 1.49 \text{ psi}$$

RADIUS OF PERCUSSION

$$R_g = \sqrt{5.25^2 + 4.33^2}$$

$$R_g = 6.8'$$

Load and stress analysis of: LVT - PX11

Prepared by COLLIVER Date 9/23/61 Page No. 4

Checked by ________ Dwg. No. ________ Project No. 449

ANGULAR NATURAL FREQUENCY

$$\omega = \sqrt{\frac{g}{R_g}} = \sqrt{\frac{32.2}{6.8}}$$

$$\omega = 2.18/\text{SEC.}$$

TIME @ 12 PSI OVER PRESSURE ZONE

$$t = \frac{3}{2} \times \frac{H}{\text{SHOCK VEL}} = 1.5 \times \frac{7.0}{1500}$$

$$t = .0070 \text{ SEC.}$$

MOMENTAL IMPULSE

$$J = P_r A R_p \frac{t}{2}$$

$$= P_r \times 132 \times 144 \times 4.33 \times \frac{.0070}{2}$$

$$J = 288 P_r$$

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Load and stress analysis of: LVT · PX11
Prepared by COLLIVER Date 9/23/61 Page No. 5
Checked by ______ Dwg. No. ______ Project No. 449

ASSUME 15 PSI OVER PRESSURE ZONE

DISTANCE FROM GROUND O

FOR 1 KT BURST = .17 MILES.

FOR 100 KT BURST

$$D = .17 \times (100)^{\frac{1}{3}}$$

$$D = .79 \text{ MILES}$$

ARRIVAL TIME.

FOR 1 KT BURST = .25 SEC.

FOR 100 KT BURST

$$t_A = .25 \times (100)^{\frac{1}{3}}$$

$$t_A = 1.16 \text{ SEC.}$$

DURATION TIME

FOR 1 KT BURST = .22 SEC.

FOR 100 KT BURST

$$t_D = .22 \times (100)^{\frac{1}{3}}$$

$$t_D = 1.02 \text{ SEC.}$$

DYNAMIC PRESSURE

$$\frac{q}{q_s} = \left(1 + \frac{\beta}{\omega}\right)\left(1 - \frac{J\omega}{M_s}\right)$$

$$\beta = \frac{4}{t_D} = \frac{4}{1.02} = 3.92/\text{sec.}$$

$$1 + \frac{\beta}{\omega} = 1 + \frac{3.92}{2.18} = 2.8$$

$$\frac{J\omega}{M_s} = \frac{288\,P_r \times 2.18}{184{,}000} = .00341\,P_r$$

$$\frac{q}{q_s} = 2.8(1 - .00341\,P_r)$$

$$q_s = 1.49 \text{ psi}$$

$$q = 1.49 \times 2.8(1 - .00341\,P_r)$$

$$\underline{q = 4.17 - .0142\,P_r}$$

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Load and stress analysis of: LVT - PX 11

Prepared by COLLIVER Date 9/23/61 Page No. 7

Checked by ______ Dwg. No. ______ Project No. 449

REFLECTED AND PEAK DYNAMIC PRESSURES AT 13 PSI OVERPRESSURE ZONE.

$$P_r = 2P \frac{7P_o + 4P}{7P_o + P}$$

$$= 2 \times 13 \frac{(7 \times 14.7) + (4 \times 13)}{(7 \times 14.7) + 13}$$

$$\underline{\underline{P_r = 39.2}} \text{ psi}$$

$$q = 2.5 \frac{P^2}{7P_o + P}$$

$$= 2.5 \frac{13^2}{(7 \times 14.7) + 13}$$

$$\underline{\underline{q = 3.64 \text{ psi}}}$$

FROM. Pg. 6

$$q = 4.17 - .0142\, P_r$$

$$= 4.17 - .0142 \times 39.2$$

$$\underline{\underline{q = 3.61 \text{ psi}}}$$

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Load and stress analysis of: LVT-PX11

Prepared by: COLLIVER Date: 9/28/61 Page No.: 8

Checked by: ______ Dwg. No.: ______ Project No.: 449

NUCLEAR BLAST THERMAL RADIATION

AT THE 13 PSI OVERPRESSURE ZONE FOR A 100 KT BURST THE DISTANCE FROM GROUND ZERO IS .79 MILES

AT THIS DISTANCE, THE TOTAL ENERGY RECEIVED FROM A 1 KT BURST IS 1.5 CAL/SQ CM OF SURFACE.

FOR 100 KT

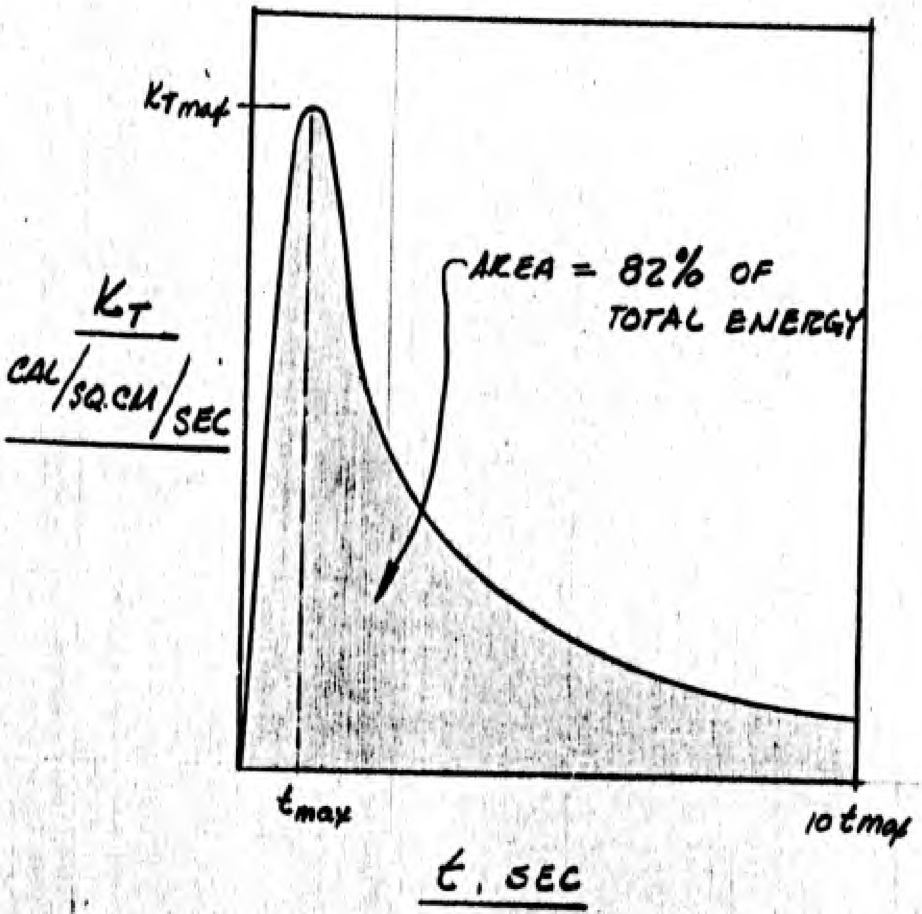
TOTAL ENERGY = 1.5 × 100 = 150 CAL/SQ CM.

THIS ENERGY BUILDS UP RAPIDLY AND THEN DECAYS SLOWLY AS INDICATED BY THE CURVE ON PAGE 9, WITH 82% OF THE ENERGY BEING RECEIVED WITHIN 10 TIMES THE TIME OF MAXIMUM RADIATION.

Load and stress analysis of: L VT-PX11

Prepared by COLLIVER Date 9/28/61 Page No. 9

Checked by ____ Dwg. No. ____ Project No. 449



Load and stress analysis of: LVT PX 11
Prepared by COLLIVER Date 9/28/61 Page No. 10
Checked by ______ Dwg. No. ______ Project No. 449

THERMAL ENERGY RECEIVED

AT 10 t_{max} TOTAL RECEIVED IS:

$150 \times .82 = 123$ CAL/SQ CM

TEMPERATURE RISE IN VEHICLE HULL

ASSUME AN ABSORPTION FACTOR OF 0.94 FOR THE DARK COLOR PAINT.

SPECIFIC HEAT OF ALUMINUM
.22 BTU/LB/°F

38.9 CAL/SQ CM = 1 BTU/SQ IN.

ASSUME 1" AL HULL PLATES
WT = .10 LB/SQ IN

$$\text{TEMP RISE} = \frac{123 \times .94}{38.9 \times .10 \times .22}$$

$$= \underline{\underline{135^{\circ}F}}$$

FOR 1.5" HULL PLATES

$$\underline{\text{TEMP RISE}} = 135^{\circ} \times \frac{1.0}{1.5} = \underline{\underline{90^{\circ}F}}$$

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Load and stress analysis of: TRACK PROPULSION

Prepared by MWK Date 10/10/61 Page No. 1

Checked by _____ Dwg. No. _____ Project No. 934

RELATIONSHIP BETWEEN TRACK SPEED AND VEHICLE SPEED

F = THRUST PRODUCED BY TRACKS (LB) = HULL RESISTANCE

V_1 = VEHICLE SPEED (FPS)

V_2 = SPEED OF TRACK (FPS)
ALSO ASSUMED TO BE VELOCITY OF JET OF WATER FROM TRACKS

$Q = V_2 A_2$ = FLOW RATE OF WATER FROM TRACKS IN DIRECTION OPPOSITE TO TRAVEL

A_2 = AREA OF JET OF WATER FROM TRACKS

JET THRUST

$$F = Q\rho(V_2 - V_1)$$

$$F = A_2 V_2 \rho (V_2 - V_1) \qquad (1)$$

HULL RESISTANCE

$$* \quad F = K_1 \rho V_1^2 \qquad (2)$$

WHERE K_1 IS A FUNCTION OF HULL RESISTANCE CHARACTERISTICS.

SETTING (1) = (2)

$$K_1 \rho V_1^2 = A_2 V_2 \rho (V_2 - V_1)$$

LET $\frac{A_2}{K_1} = K_2 \qquad (3)$

$$V_1^2 + K_2 V_1 V_2 - K_2 V_2^2$$

FOR POSITIVE ROOTS

$$V_1 = V_2 \left[\frac{-K_2 + \sqrt{K_2^2 + 4K_2}}{2} \right]$$

SUBSTITUTING K_3 FOR QUANTITY IN BRACKETS

$$V_1 = K_3 V_2 \qquad (4)$$

*NOTE: MOST HULL RESISTANCE CURVES DO NOT FOLLOW A PERFECT SQUARE. IN THIS CASE IT IS NECESSARY TO WORK WITH ACTUAL RESTANCE CURVES

Load and stress analysis of: TRACK PROPULSION

Prepared by OMR Date 10/10/61 Page No. 1

Checked by Dwg. No. Project No. 934

USING PERFORMANCE CURVES FOR LVTP6, DETERMINE PERFORMANCE THAT CAN BE EXPECTED OF #5 LVT HULL USING LVTP6 TRACK WITH 210 HP AVAILABLE AT TRACK SPROCKETS.

PROPULSIVE THRUST IS OBTAINED BY ACCELERATING WATER AND DISCHARGING AT SOME VELOCITY (V_2) BEHIND VEHICLE. ASSUMING THIS DISCHARGE SPEED EQUALS THE TRACK SPEED, DETERMINE HYPOTHETICAL AREA OF JET REQUIRED TO PRODUCE THE PROPULSIVE THRUST

DATA FROM LVTP6 SELF PROPELLED & TOWED TESTS:

MAX SPEED = V_1 5.7 MPH = 8.35 FPS

CORRESPONDING TRACK SPEED = 14.3 MPH = 21.0 FPS

P = 281 HP @ SPROCKET (REF ATB'S MEMO DATED 8/15/61)

F = DRAWBAR PULL (TRACKS MOVING AT VEHICLE SPEED) = 2275 LB.

$$F = A_2 V_2 \rho (V_2 - V_1)$$

$$A_2 = \frac{2275}{20.9 \times 1.99 \underbrace{(21.0 - 8.3)}_{12.7}} = 4.40 \text{ FT}^2$$

THE TABLE FOLLOWING ON THE NEXT PAGE GIVES COMPUTED AREAS (A₂ FOR VARIOUS VEHICLE SPEEDS TO DETERMINE CONSISTANCY OVER RANGE OF VEHICLE OPERATION

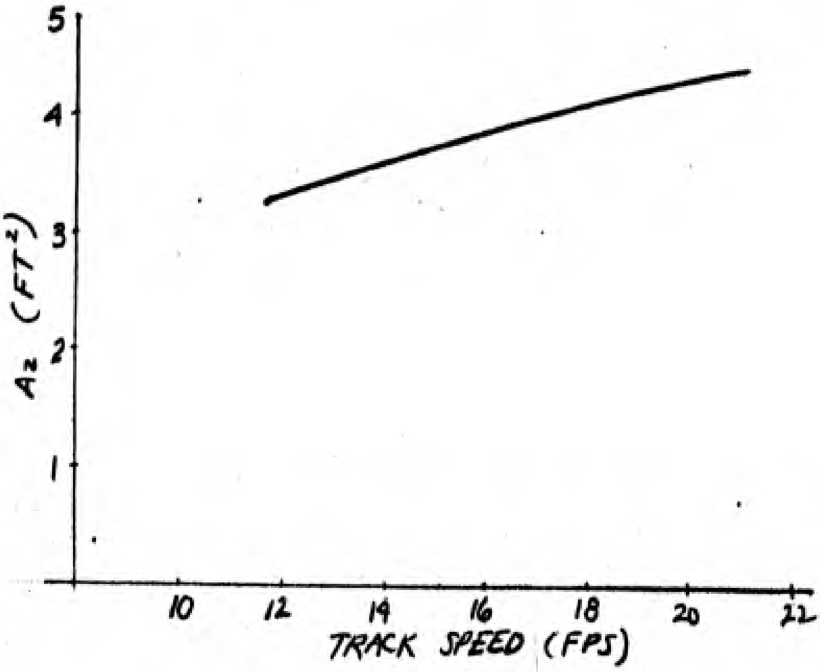
fmc CORPORATION

Load and stress analysis of: TRACK PROPULSION

Prepared by OWK Date 10/10/61 Page No. 3

Checked by ______ Dwg. No. ______ Project No. 934

①	②	③	④	⑤	A_2
F (LB)	V_1 (FPS)	V_2 (FPS)	③ - ②	③×④ × e	①/⑤ (FT^2)
500	4.90	11.7	6.8	154	3.25
750	5.64	13.6	8.0	211	3.55
1000	6.22	15.2	9.0	265	3.77
1250	6.74	16.5	9.8	314	3.98
1500	7.18	17.9	10.7	371	4.04
1750	7.61	19.0	11.4	420	4.16
2000	7.98	20.1	12.1	471	4.24
2275	8.35	20.9	12.5	507	4.49



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Load and stress analysis of: TRACK PROPULSION

Prepared by OMK Date 10/10/61 Page No. 4

Checked by ____ Dwg. No. ____ Project No. 934

IF TRACK SPEED ON LVTP6 IS 20.7 FPS WITH 281 HP, IT WILL BE LESS WITH 210 HP @ SPROCKET ON NEW LVT APPLICATION.

$$\frac{207}{280} = \frac{V_2^3}{(20.7)^3}$$

$$V_2 = \left(\frac{207}{280}\right)^{\frac{1}{3}} \times 20.7 = 18.7 \text{ FPS}$$

THIS COMPUTED TRACK SPEED WILL ACTUALLY BE SLIGHTLY LOW BECAUSE WITH THE HS HULL A GREATER VEHICLE SPEED WILL RESULT (COMPARED TO LVTP6) WITH A CONSEQUENT REDUCTION IN POWER REQUIRED FOR A GIVEN TRACK SPEED. SPARKMAN & STEPHENS REPORT NO. 500 SHOWS THAT POWER REQUIRED TO MAINTAIN A GIVEN TRACK SPEED DECREASES AS THE VEHICLE SPEED INCREASES. (FROM TOWED MODEL TESTS WITH TRACK MOVING)

USING $A_2 = 4.5 \text{ FT}^2$, WRITE RELATIONSHIP BETWEEN TRACK PROPULSIVE FORCE AND VEHICLE SPEED ASSUMING CONSTANT TRACK SPEED OF 18.7 FPS

$$F = A_2 V_2 \rho (V_2 - V_1)$$

$$F = 4.5 \times 18.7 \times 1.94 (18.7 - V_1)$$

$$F = 3050 - 163 V_1$$

FOR LVTP6

$$F = 4.5 \times 20.7 \times 1.94 (20.7 - V_1)$$

$$F = 3740 - 181 V_1$$

Load and stress analysis of: TRACK

Prepared by OMK Date 10/10/61 Page No. 5

Checked by Dwg. No. Project No.

USING COMPARATIVE DATA FROM 1/4 SIZE MODEL TESTS TRACK PROPULSIVE FORCE IS AS FOLLOWS (ASSUMING CONSTANT TRACK SPEED)

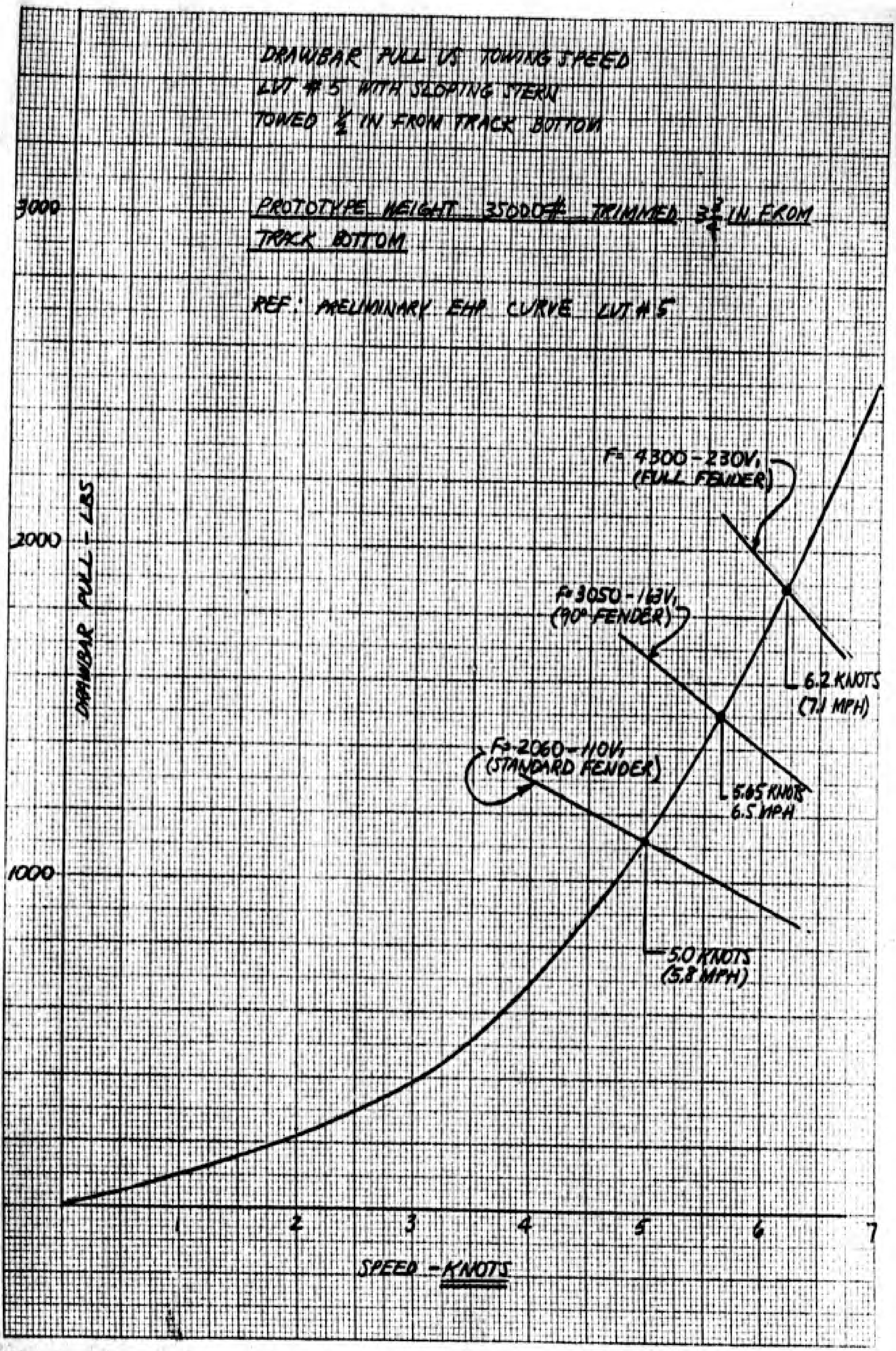
$F = 2060 - 110V_1$ (STANDARD FRONT FENDER)

$F = 3050 - 163V_1$ (90° FRONT FENDER)

$F = 4300 - 230V_1$ (FULL FRONT FENDER)

THE INTERSECTIONS OF THESE LINES WITH THE #5 LVT DRAWBAR PULL CURVE GIVES THE FOLLOWING PREDICTED SPEEDS AND PROPULSIVE EFFICIENCIES :

VEHICLE EQUIPMENT	PREDICTED SPEED	PROPULSIVE EFF.
STANDARD FRONT FENDER	5.8 MPH	8.4%
90° FRONT FENDER	6.5 MPH	12.4%
FULL FRONT FENDER	7.1 MPH	17.2%

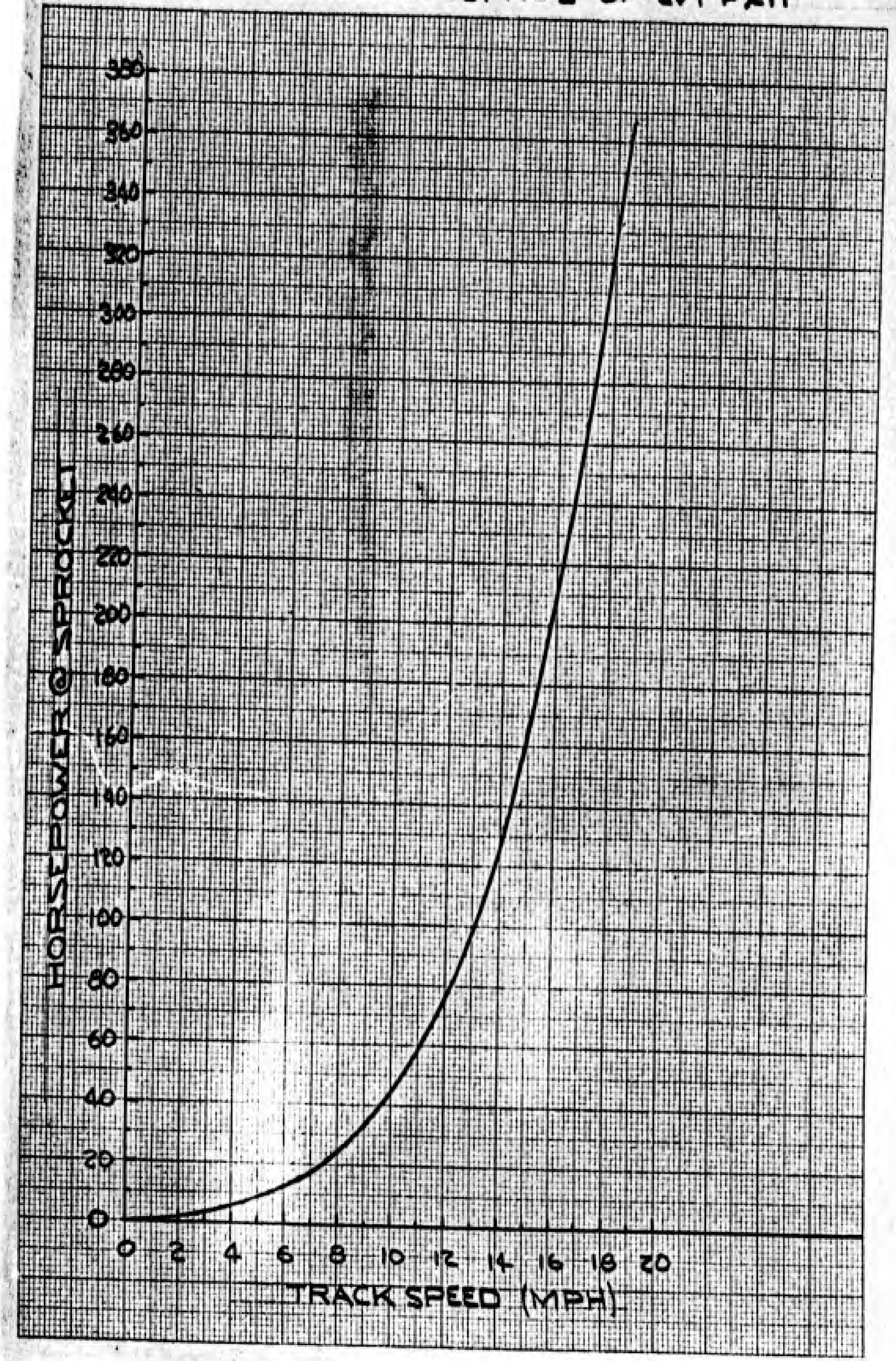


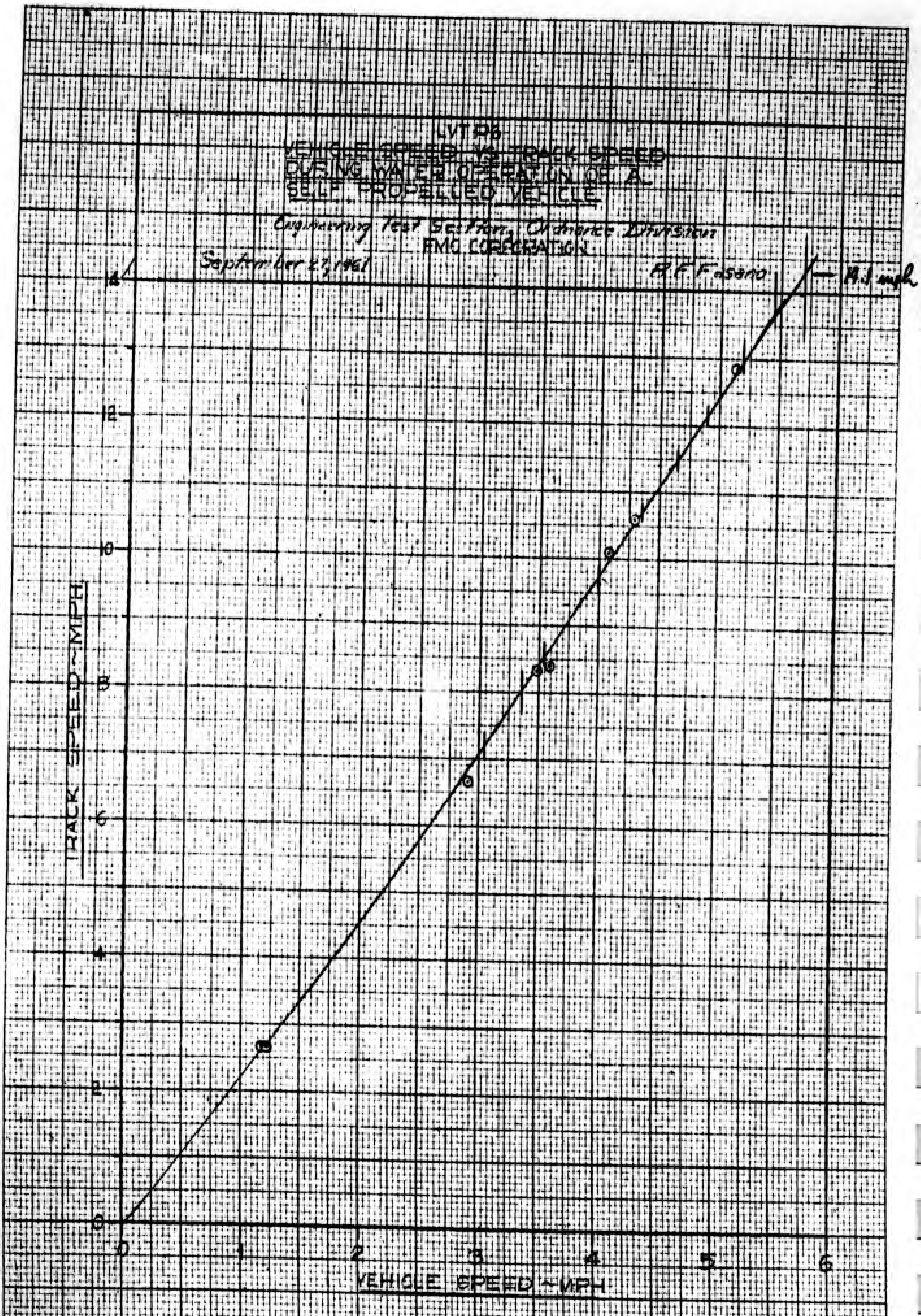
DRAWBAR PULL VS TOWING SPEED
LVT #5 WITH SLOPING STERN
TOWED $\frac{1}{2}$ IN FROM TRACK BOTTOM

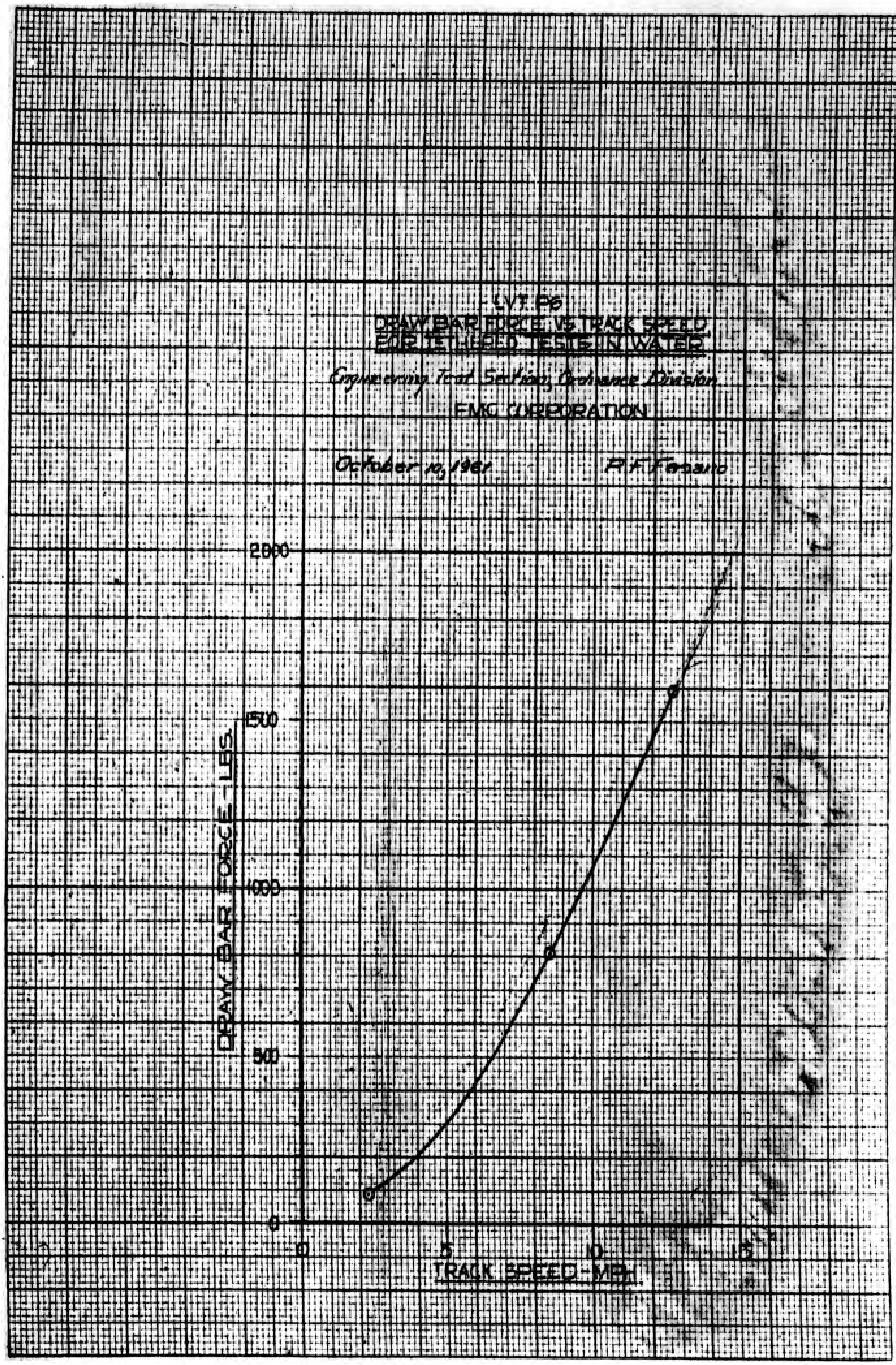
PROTOTYPE WEIGHT 35000# TRIMMED $3\frac{3}{4}$ IN FROM TRACK BOTTOM

REF: PRELIMINARY EHP CURVE LVT #5

SPROCKET HP Vs TRACK SPEED FOR 15% PROPULSION EFF. & 2.31 :1 TRACK SLIP, USING DATA FROM MODEL TEST No 5 OF LVT PX11



LVTP6
VEHICLE SPEED VS TRACK SPEED
DURING WATER OPERATION OF A
SELF PROPELLED VEHICLE
Engineering Test Section, Ordnance Division
FMC CORPORATION
September 27, 1961
R. F. Fasano
14.1 mph
TRACK SPEED ~ MPH
0
2
4
6
8
10
12
14
VEHICLE SPEED ~ MPH
0
1
2
3
4
5
6

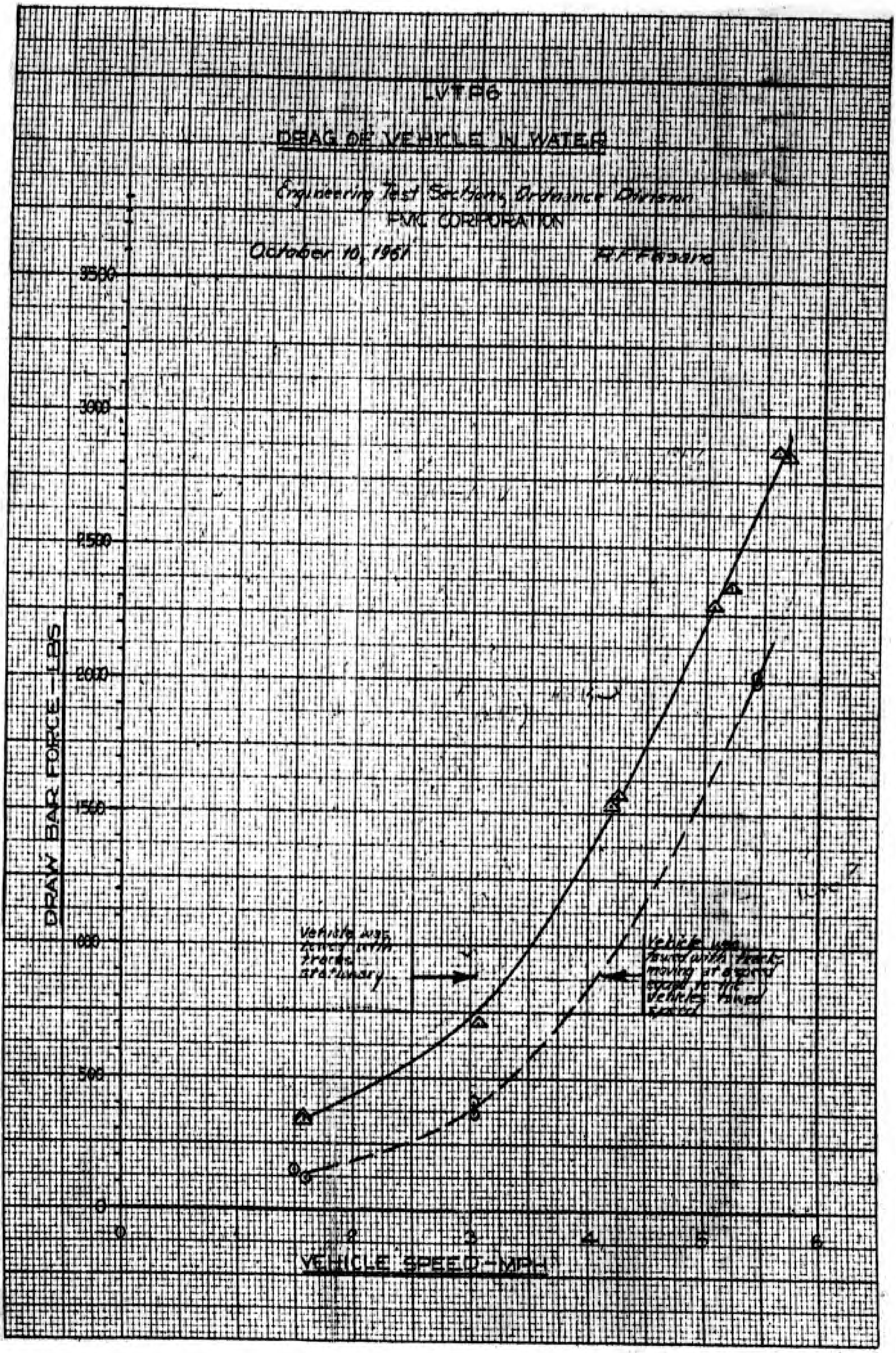


LVT P6
DRAW BAR FORCE VS TRACK SPEED
FOR TETHERED TESTS IN WATER

Engineering Test Section, Ordnance Division
FMC CORPORATION

October 10, 1961
R F Ferrario

this revised sheet rec'd 10/10



LVTP6

DRAG OF VEHICLE IN WATER

Engineering Test Sections, Ordnance Division
FMC CORPORATION

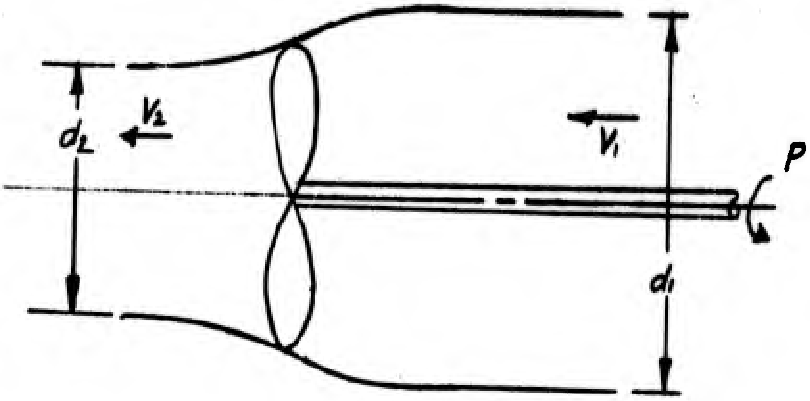
October 10, 1961 R. F. Fasano

This revised sheet rec'd 10/10

Load and stress analysis of: WATER PROPULSION DEVICES

Prepared by: MK Date: Page No.:

Checked by: Dwg. No.: Project No.: 449



SYMBOL	DESCRIPTION	UNITS
F	PROPULSIVE FORCE	LBS.
Q	FLOW RATE	CFS
A_1	INTAKE AREA	$FT.^2$
d_1	INTAKE DIAMETER	FT.
A_2	OUTLET AREA	$FT.^2$
d_2	NOZZLE (DISCHARGE) DIAMETER	FT.
ρ	DENSITY OF FLUID	$\frac{LB. SEC^2}{FT.^4}$
η	PUMP EFFICIENCY	—
P	INPUT POWER AT SHAFT	FT LBS/SEC (OR HP WITH CONV. FACTOR)

η_I = IDEAL EFFICIENCY

Load and stress analysis of: WATER PROPULSION DEVICES

Prepared by ____ Date ____ Page No. ____

Checked by ____ Dwg. No. ____ Project No. ____

BASIC EQUATIONS

REF. VENNARD - ELEMENTARY FLUID MECHANICS
& ROUSE - ELEMENTARY MECHANICS OF FLUIDS

PROPULSIVE FORCE

$$F = Q\rho\,(V_2 - V_1) \qquad (1)$$

$$Q = A_2 V_2 = A_1 V_1$$

$$F = A_2 V_2 \rho\,(V_2 - V_1) \qquad (2)$$

POWER REQUIRED

$$\eta P = \frac{Q\rho}{2}\,(V_2^2 - V_1^2) \qquad (3)$$

$$\eta P = \frac{A_2 V_2 \rho}{2}\,(V_2^2 - V_1^2) \qquad (4)$$

DIVIDING (1) BY (3) OR (2) BY (4)

$$F = \frac{2\eta P}{V_2 + V_1} \qquad (5)$$

IDEAL EFFICIENCY

$$\eta_I = \frac{2V_1}{V_2 + V_1}$$

η_p = PROPULSIVE EFFICIENCY = $\eta \cdot \eta_I = \frac{EHP}{REQ.\ H.P.}$

fmc CORPORATION

Load and stress analysis of: HYDROJET PROPULSION

Prepared by OMK Date 9/22/61 Page No. 1

Checked by ______ Dwg. No. ______ Project No. 934

HYDROJET REQUIREMENTS FOR LVT

GIVEN:

$V_1 = 9.5$ MPH $= 13.9$ FPS (REQUIRED VEHICLE SPEED)

$F = 4150$ LB (HULL DRAG AND REQUIRED HYDROJET THRUST)

$P = 210$ HP (AVAILABLE POWER AT HYDROJET SHAFT)

$\eta = .8$ (PUMP EFFICIENCY)

$\rho = 2.0 \frac{LB\ SEC^2}{FT^4}$ (SEA WATER)

DETERMINE NOZZLE SIZE REQUIRED

$$F = \frac{2\eta P}{V_2 + V_1}$$

$$V_2 = \overset{44.5}{\frac{2 \times .8 \times 210 \times 550}{4150}} - 13.9 = 30.6 \text{ FPS}$$

$$F = A_2 V_2 \rho (V_2 - V_1)$$

$$A_2 = \frac{4150}{30.6 \times 2.0 \underset{16.7}{(30.6 - 13.9)}} = 4.06 \text{ FT}^2$$

NOZZLE DIA:

FOR SINGLE HYDROJET

$$d_2 = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 4.06}{\pi}} = \underline{\underline{2.28 \text{ FT}}}$$

FOR TWO HYDROJETS

$$d_2 = \sqrt{\frac{4 \times 2.03}{\pi}} = \underline{\underline{1.61 \text{ FT}}}$$

fmc CORPORATION

Load and stress analysis of: HYDROJET PROPULSION

Prepared by OMK Date 9/22/61 Page No. 2

Checked by ______ Dwg. No. ______ Project No. 934

FOR THREE HYDROJETS

$$d_2 = \sqrt{\frac{4 \times 1.35}{\pi}} = \underline{\underline{1.35 \text{ FT}}}$$

FOR FOUR HYDROJETS

$$d_2 = \sqrt{\frac{4 \times 1.02}{\pi}} = \underline{\underline{1.17 \text{ FT.}}}$$

DETERMINE MINIMUM INLET AREA

$$Q = A_2 V_2 = A_1 V_1$$

$$A_1 = \frac{4.06 \times 30.6}{13.9} = 8.94 \text{ FT}^2$$

IF INLET AREA IS CIRCULAR

$$d_1 = \sqrt{\frac{4 \times 8.94}{\pi}} = 3.38 \text{ FT (MIN.)}$$

IDEAL EFFICIENCY

$$\eta_I = \frac{2V_1}{V_2 + V_1} = \frac{2 \times 13.9}{30.6 + 13.9} = .624$$

PROPULSIVE EFFICIENCY

$$\eta_T = .8 \times .624 = .49$$

CHECK:

$$\eta_T = \frac{4150 \times 13.9}{210 \times 550} = .49$$

NOTE: PROPULSIVE EFF. BASED ON POWER AT HYDROJET SHAFT. IN THIS CALC.

INDIANA GEAR WORKS
A DIVISION OF
THE BUEHLER CORPORATION
9000 PRECISION DRIVE • PHONE FLEETWOOD 9-9501
INDIANAPOLIS 26, INDIANA

August 23, 1961

Food Machinery and Chemical Corporation
Ordnance Division
P. O. Box 367
San Jose 3, California

Attention: Mr. Grant C. Colliver
Preliminary Design Engineering

Subject: Buehler Turbopower Water Jet Propulsion Information

Reference: Food Machinery's Letter of August 11, 1961
Ser. 481-61-PA 934

Gentlemen:

The following is submitted in reply to your recent request for information regarding our Turbopower water jet propulsion units:

The thrust horsepower requirements for your new LVT vehicle can not be met by any of our existing jet units, and a new design would be required. A brief preliminary study indicates that a unit of the following size and characteristics would be required to provide 4000 lbs. of thrust at 15 miles and hour and 280 HP input -

Approximate Diameter - 26 in.

Number of Stages - 2

Approximate Weight - 1200 lbs.

Maximum Unit RPM - 1000 RPM

Development Time - 12 mos.

• POWER GEARING FOR AIRCRAFT & MISSILES
• FINE PITCH GEARING AND AVIONICS

The following estimated costs are also submitted for your evaluation:

(2) Units	$15,000.00 ea.
(6) Units	9,000.00 ea.

The above prices can only be considered as preliminary estimates and do not include any tooling charges.

The configuration of the units proposed would be similar to the enclosed drawings of our Model 75 (7.5 in. dia.), Model 100 (10 in. dia.), and Model 120 (12 in. dia.) units. Performance curves for each of these units have also been enclosed for your evaluation.

It is anticipated that directional control and reverse thrust would be accomplished in the same manner provided on the current models described in the enclosed drawings; however, we shall be glad to consider any special mounting or control requirements dictated by the LVT installation.

The development of the unit to meet your specific requirements is entirely feasible, and we would be interested in providing you with more detailed information when time permits as well as meeting with representatives of the Food Machinery and Ehemical Corporation for further discussion of such a program.

Very truly yours,

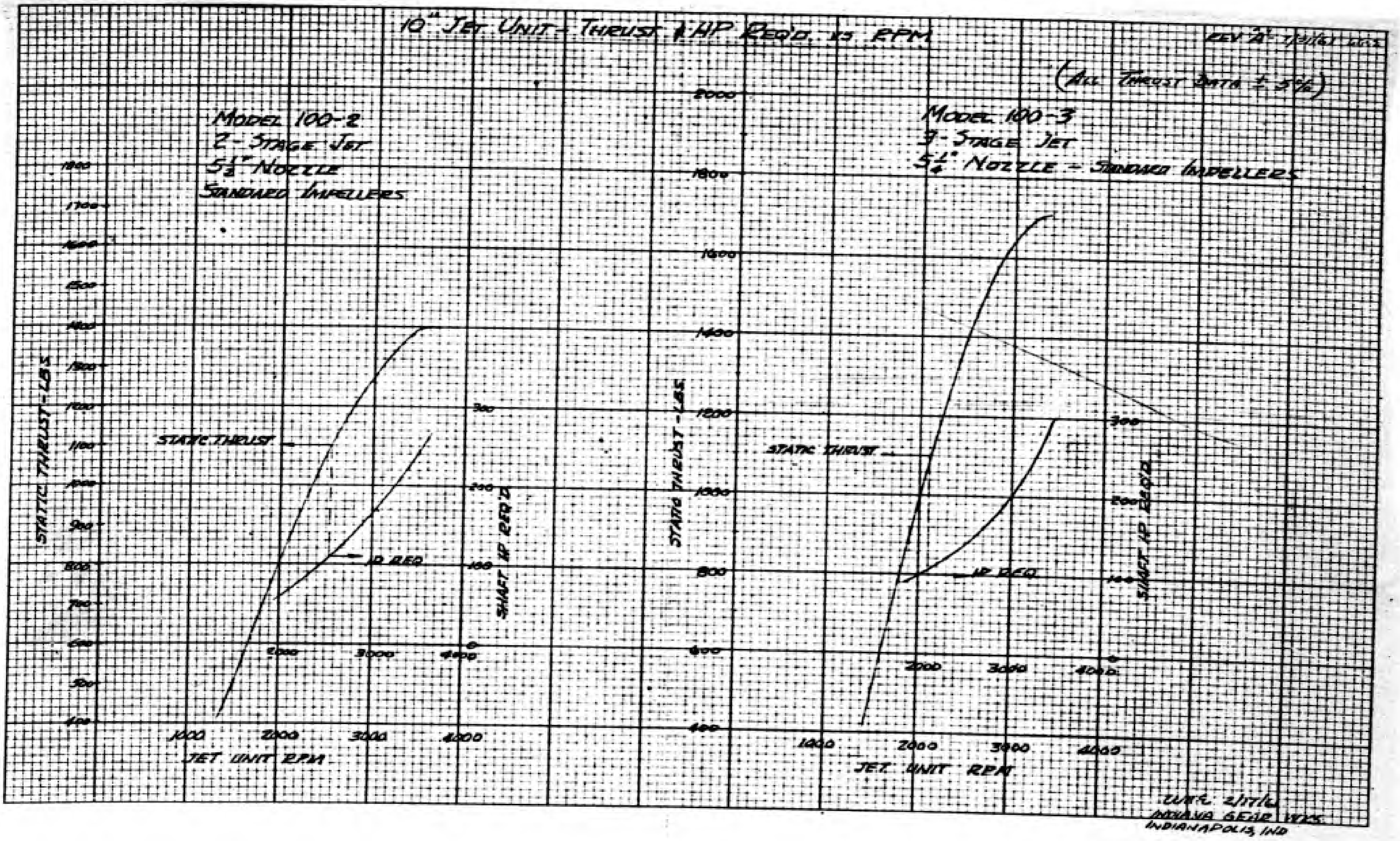
INDIANA GEAR WORKS
a division of
THE BUEHLER CORPORATION

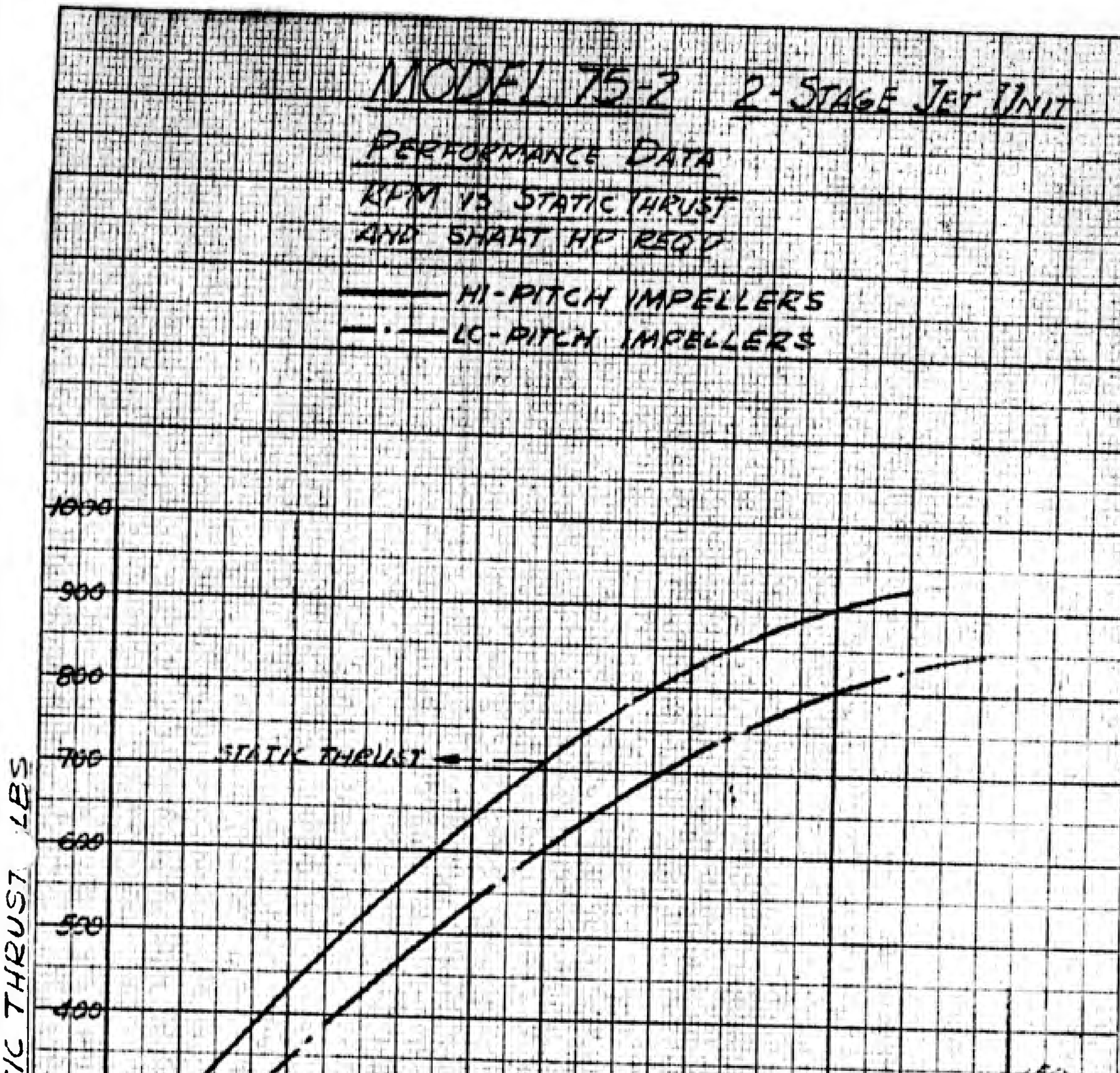
G. R. Shields

G. R. Shields
Marketing Manager

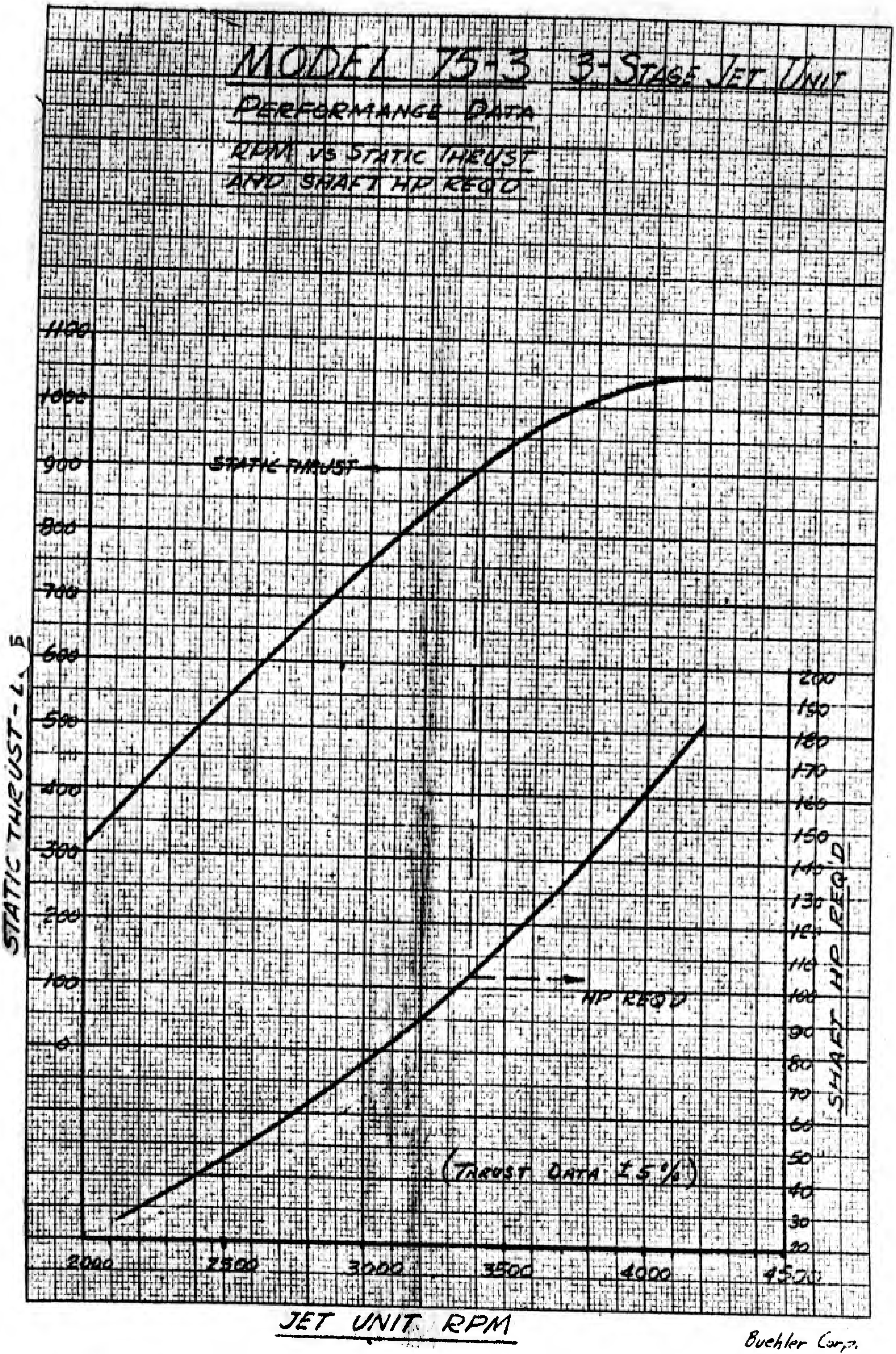
GRS:k
Enclosures

cc: Mr. Lawrence W. Werner, Jr.

10" JET UNIT - THRUST & HP REQ'D. vs RPM
REV "A" 7/31/61
(ALL THRUST DATA ± 5%)
MODEL 100-2
2 - STAGE JET
5½" NOZZLE
STANDARD IMPELLERS
MODEL 100-3
3 - STAGE JET
5¼" NOZZLE - STANDARD IMPELLERS
STATIC THRUST - LBS
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
STATIC THRUST
HP REQ
SHAFT HP REQ'D
300
200
100
0
2000
3000
4000
1000
2000
3000
4000
JET UNIT RPM
STATIC THRUST - LBS
2000
1800
1600
1400
1200
1000
800
600
400
STATIC THRUST
HP REQ
SHAFT HP REQ'D
300
200
100
0
2000
3000
4000
1000
2000
3000
4000
JET UNIT RPM
2/17/61
INDIANA GEAR WKS.
INDIANAPOLIS, IND



Buehler Corp
6/16/61 WHS



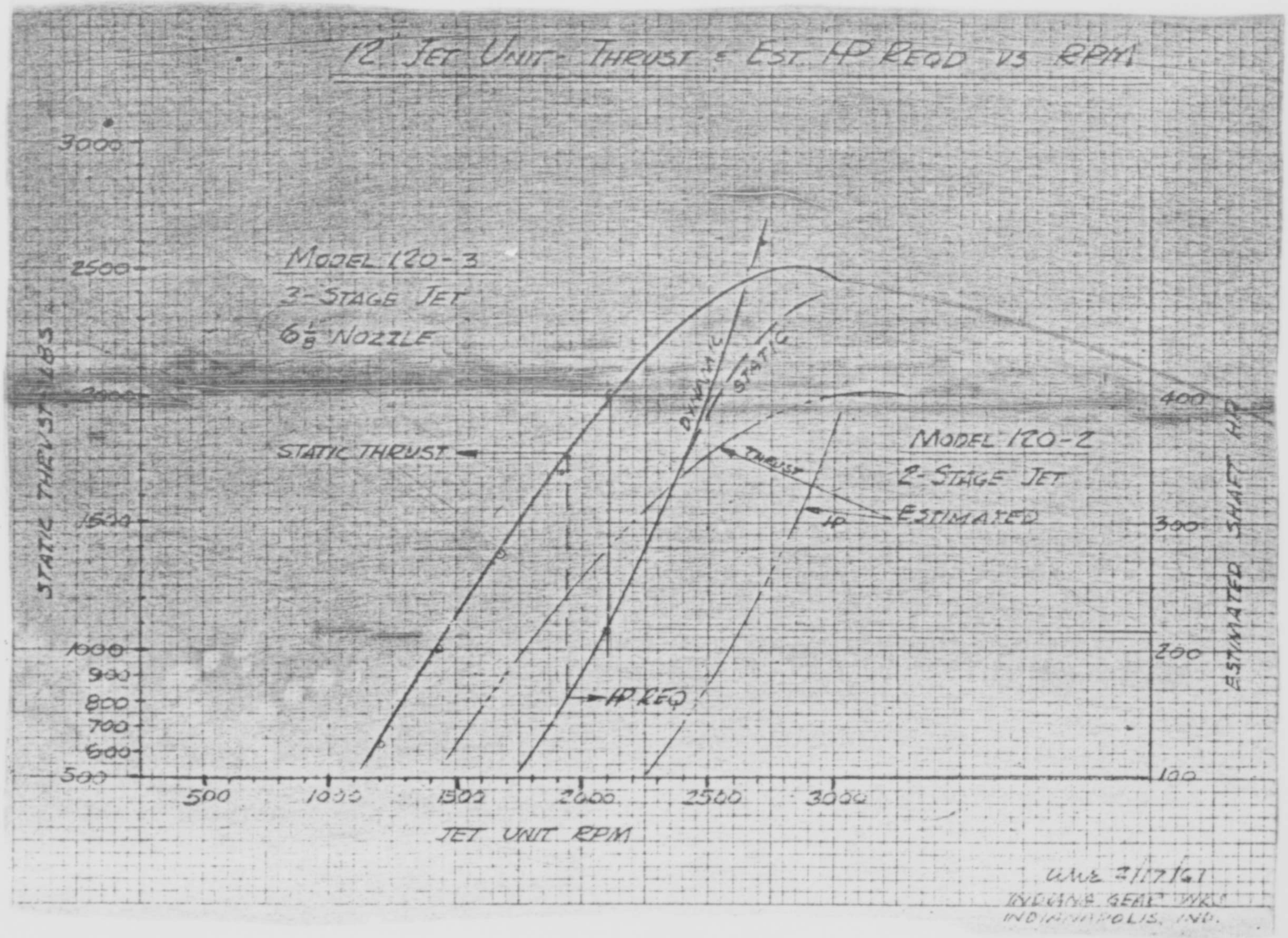
MODEL 75-3 3-STAGE JET UNIT

PERFORMANCE DATA

RPM VS STATIC THRUST AND SHAFT HP REQ'D

(THRUST DATA ± 5%)

Buehler Corp.
6/16/61 [illegible]


12" JET UNIT - THRUST & EST. HP REQD VS RPM
MODEL 120-3
3-STAGE JET
$6\frac{1}{8}$ NOZZLE
STATIC THRUST
DYNAMIC
STATIC
THRUST
HP
HP REQ
MODEL 120-2
2-STAGE JET
ESTIMATED
STATIC THRUST - LBS
3000
2500
2000
1500
1000
900
800
700
600
500
ESTIMATED SHAFT HP
400
300
200
100
500
1000
1500
2000
2500
3000
JET UNIT RPM
UME 2/17/61
INDIANA GEAR WKS
INDIANAPOLIS, IND.

CABLE "MASCON"

MACHINERY CONSULTANTS, inc.

machine tools *engineering* *fabrication*

6101 VERMONT STREET • DETROIT 8, MICHIGAN • TYLER 8-9617

October 6, 1961

Food Machinery & Chemical Corporation
P. O. Box 367
San Jose 3, California

Attention Mr. Grant C. Colliver

Dear Mr. Colliver:

We are herewith, enclosing for your consideration information on our Water Jet System which you requested.

Possibly in the very near future, we will have more data available for you, however, at the moment we are unable to submit more data on our unit.

Thank you for your interest.

Very sincerely,

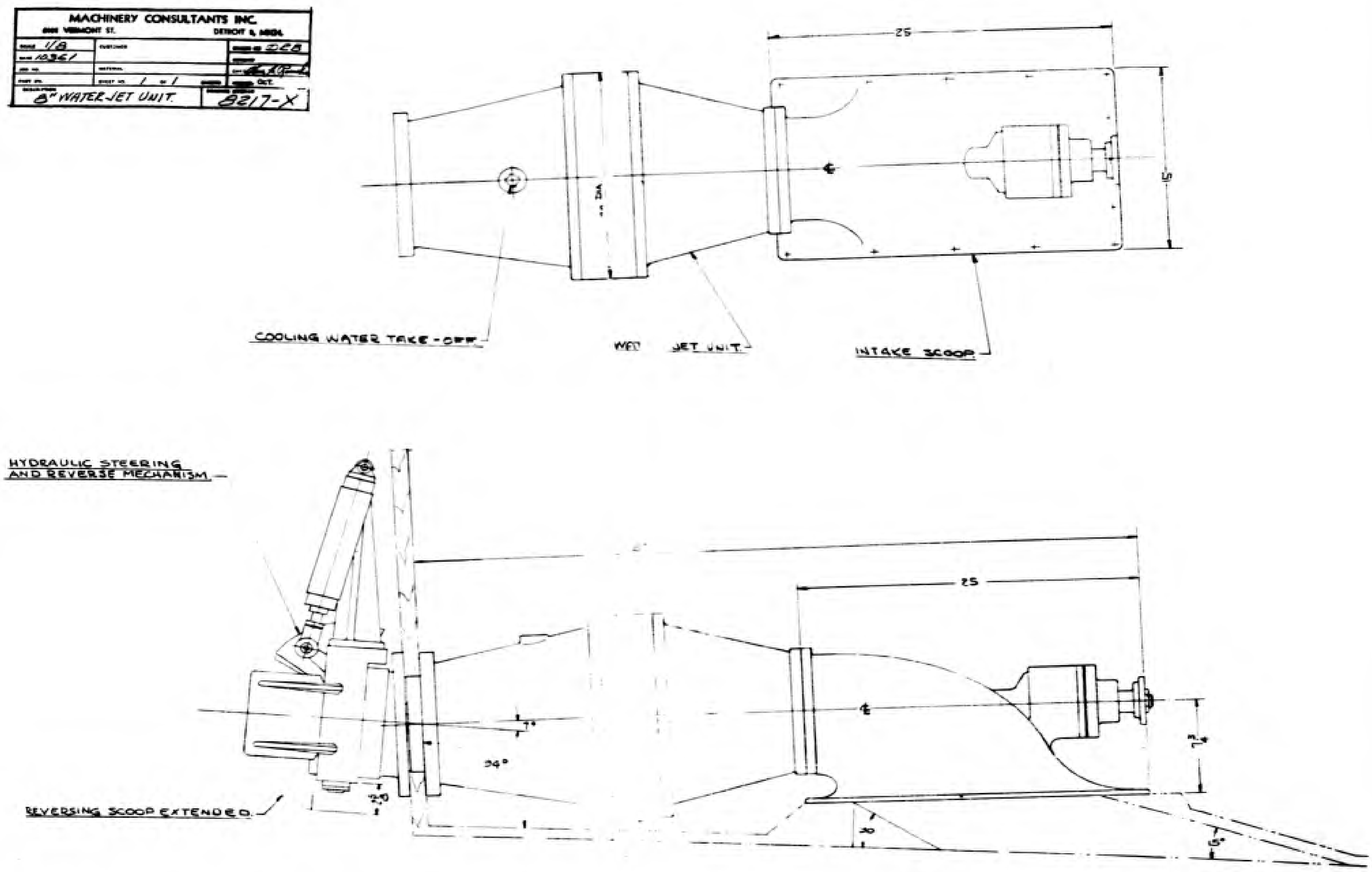
MACHINERY CONSULTANTS, INC.

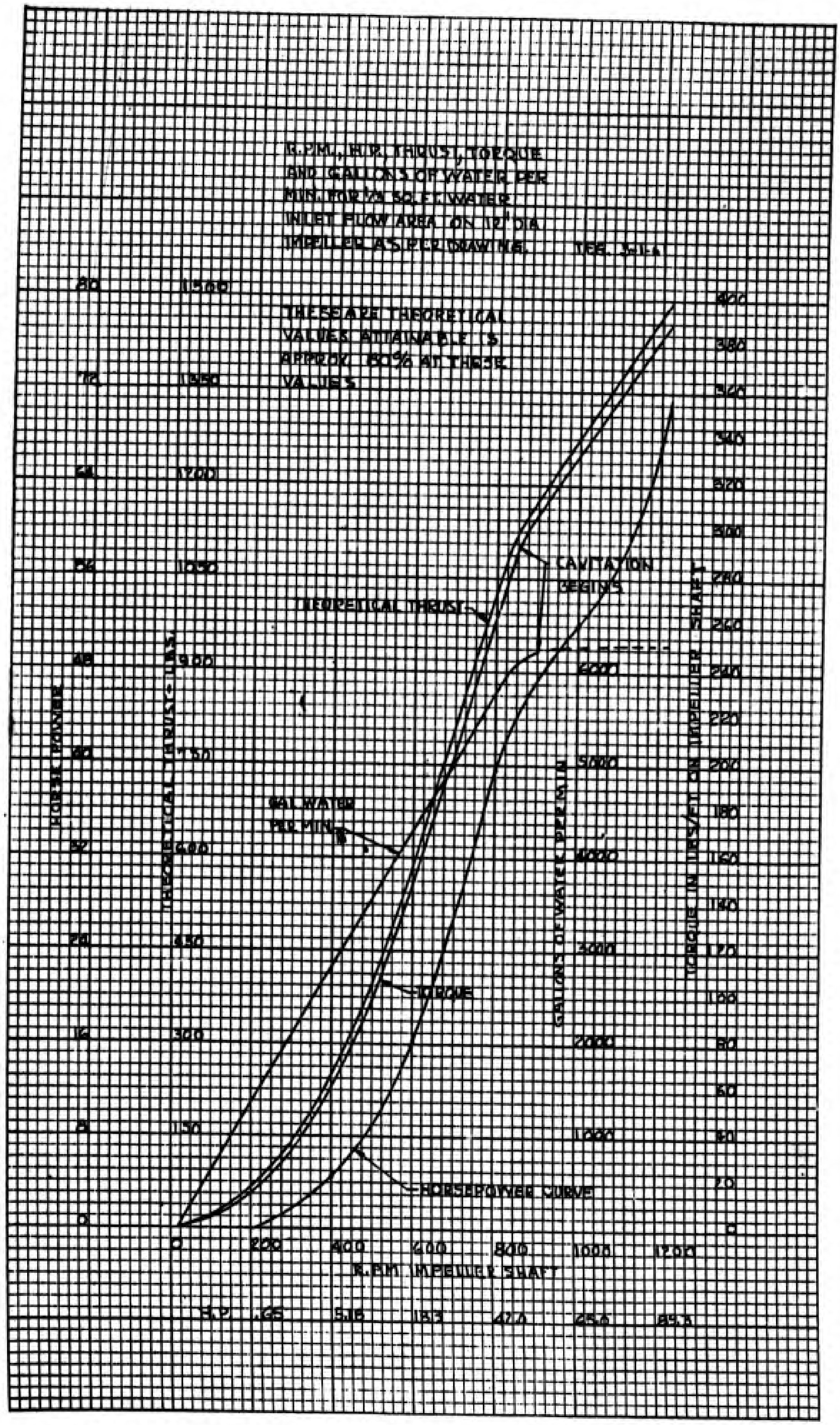
Fred E Parsons

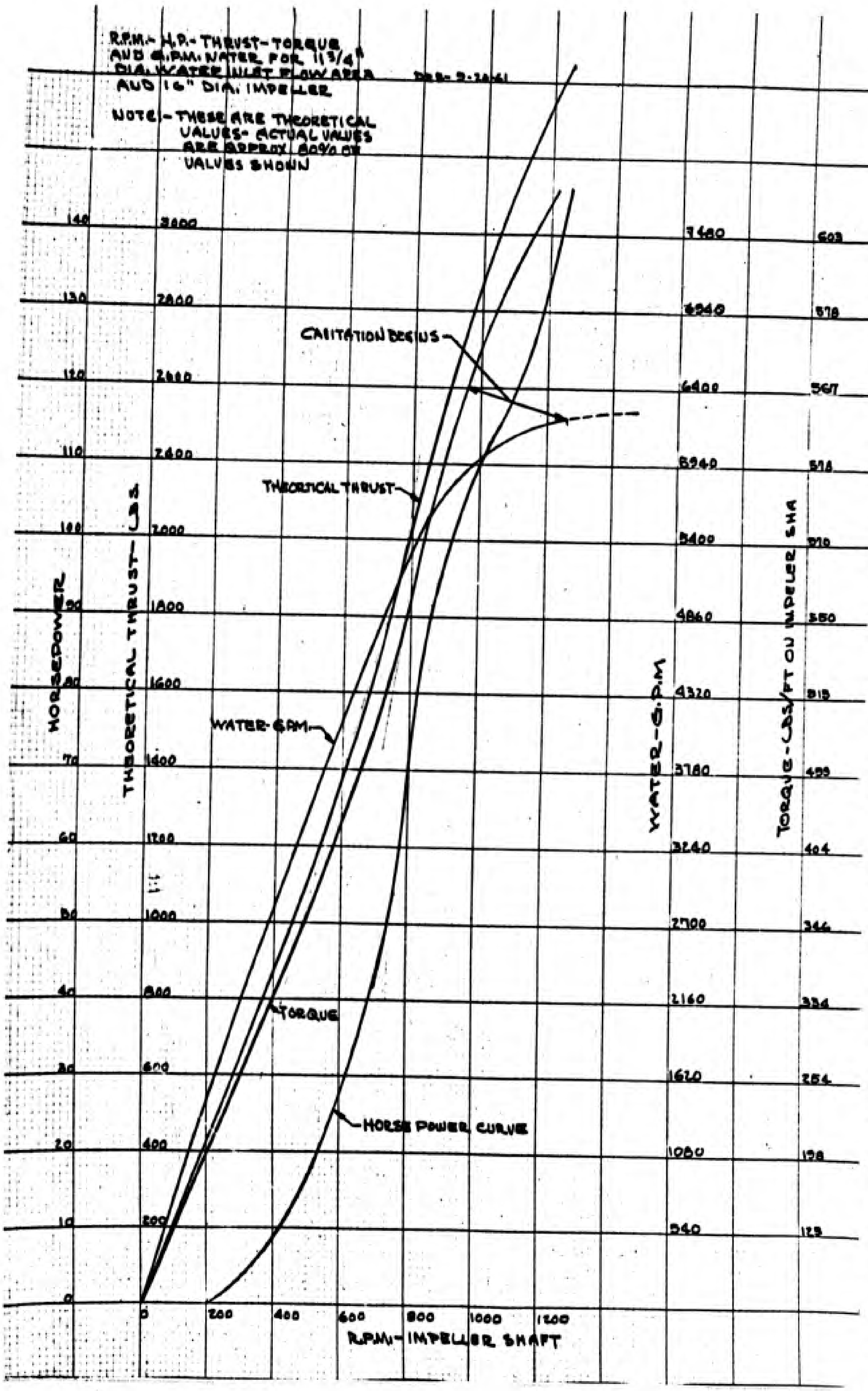
Fred E. Parsons

FEP:ma

Enclosures


MACHINERY CONSULTANTS INC.
VERMONT ST.
DETROIT, MICH.
1/8
10361
DCB
1 of 1
8" WATER-JET UNIT.
8217-X
25
15
DIA
COOLING WATER TAKE-OFF
WET JET UNIT
INTAKE SCOOP
HYDRAULIC STEERING AND REVERSE MECHANISM
REVERSING SCOOP EXTENDED.
25
7°
34°
2.0
30
15°


R.P.M., H.P., THRUST, TORQUE
AND GALLONS OF WATER PER
MIN. FOR 1/3 SQ. FT. WATER
INLET FLOW AREA ON 12" DIA
IMPELLER AS PER DRAWING.
FIG. 3-1-A
THESE ARE THEORETICAL
VALUES ATTAINABLE IS
APPROX. 80% AT THESE
VALUES
HORSE POWER
80
72
64
56
48
40
32
24
16
8
0
THEORETICAL THRUST - LBS.
1500
1350
1200
1050
900
750
600
450
300
150
0
CAVITATION
BEGINS
THEORETICAL THRUST
GAL. WATER
PER MIN.
TORQUE
HORSEPOWER CURVE
GALLONS OF WATER PER MIN.
6000
5000
4000
3000
2000
1000
TORQUE IN LBS/FT. ON IMPELLER SHAFT
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
200
400
600
800
1000
1200
R.P.M. IMPELLER SHAFT
H.P.
.65
5.16
18.3
47.4
45.6
85.3



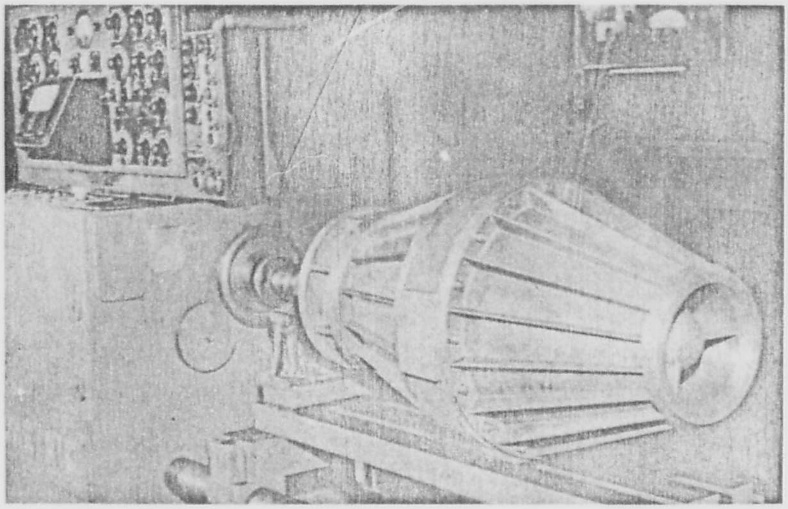
R.P.M.- H.P.- THRUST- TORQUE AND G.P.M. WATER FOR 11 3/4" DIA. WATER INLET FLOW AREA AND 16" DIA. IMPELLER

NOTE - THESE ARE THEORETICAL VALUES- ACTUAL VALUES ARE APPROX 80% OF VALUES SHOWN

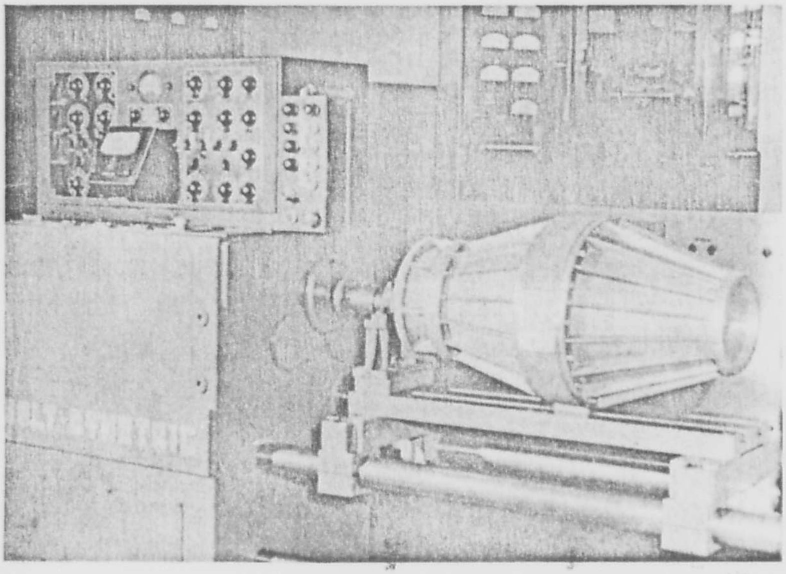
MACHINERY CONSULTANTS INC.

6101 VERMONT STREET • DETROIT 8, MICH.

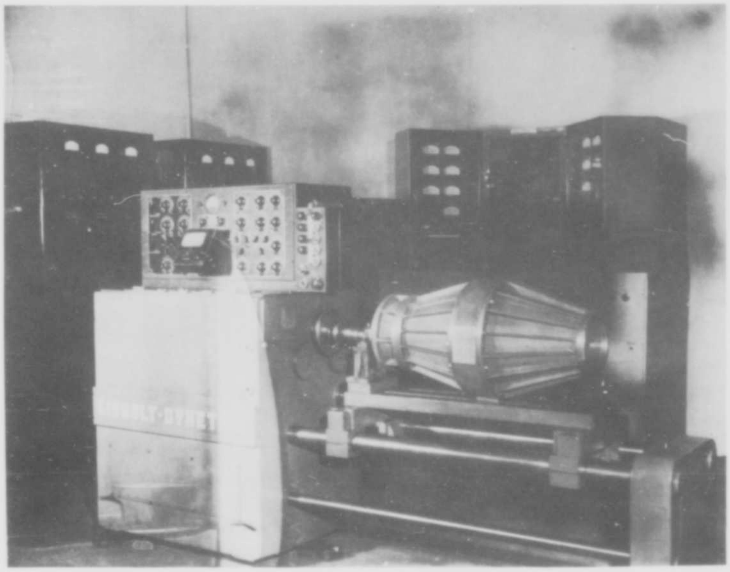
WATER-JET PROPULSION SYSTEM

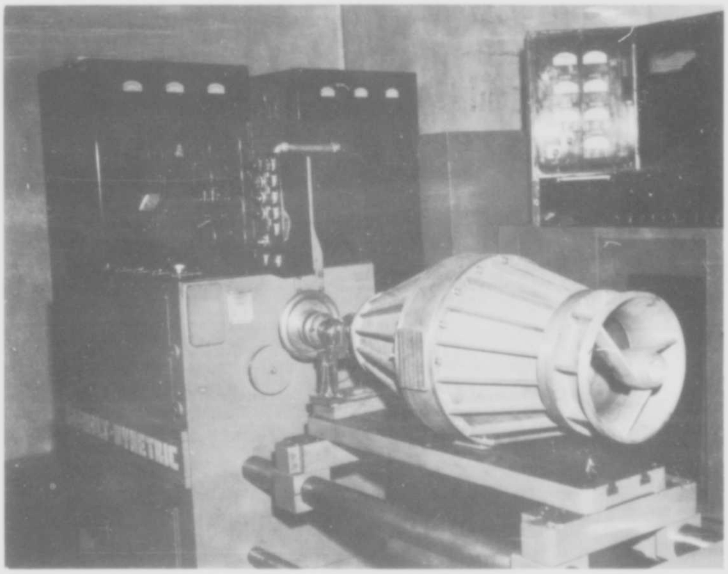


8"-DIA. INLET AREA. 1/3 SQUARE FOOT.



TEST STAND DYNAMIC BALANCER


DYNET


DYNETRIC

CURTISS-WRIGHT CORPORATION
RESEARCH DIVISION
QUEHANNA, PENNSYLVANIA
AMHERST 3-4711

October 12, 1961

Mr. A. M. Rider, Project Engineer
Food Machinery and Chemical Corporation
Ordnance Division
1105 Coleman Avenue, P. O. Box 367
San Jose, California

Dear Mr. Rider,

Herewith please find a brief discussion on propulsion systems for amphibious vehicles and a set of the figures previously posted. Also included are figures illustrating the Model 185 Aquajet we discussed with you. Should there be any question, or if we can be of any service to you, please do not hesitate to call me.

Very truly yours,

George H. Pedersen

mlb

PROPULSION - AMPHIBIOUS VEHICLES

Performance capabilities of an LVTP in the water are a function of vehicle weight, body hydrodynamic drag, installed power and the method of propulsion. The prime contractor has studied all these design criteria and selected the system which is believed superior in view of the basic requirements of the vehicle. Late in the subject study, Curtiss-Wright visited the prime contractor to discuss propulsion systems, namely the use of a water jet for propulsion on the water. In view of Curtiss-Wright's demonstrated accomplishments, the prime contractor requested information concerning the system and how it could be applied to the LVTPX under study.

Recognizing the amphibious vehicle, LVTPX under study has a duty cycle of 80% land operation and 20% water operation, the initial reaction could be to insure flotation of the vehicle and not thoroughly investigate the means of propulsion and the hydrodynamic drag characteristics of the body shape. Actually, due to the state of the art in vehicle design, the attainment of satisfactory performance on water is the major problem, performance on land is quite acceptable now. Satisfactory performance on the water presents a multitude of problems yet to be solved and herein lies a major development program.

The propulsion of an amphibious on the water may be accomplished by the use of special tracks, a propeller or a water jet. These are the major methods of propulsion and some general comments on each method are as follows:

Tracks appear the easiest system to use because, even though they are unique for the application, they are relatively simple and the control of the vehicle is handled in the same manner be it for land or water operation.

In terms of vehicle readiness, maintenance and reliability, it would appear this method of propulsion is quite satisfactory. Substantial research has been done on track design to arrive at configurations which can result in propulsion system efficiencies of 10 - 14%. It is thus reasonably safe to say that, although there is room for improvement, the meaningful gains in performance from here on will probably be small and if a substantial increase in speed is to occur it will not be the result of track design. Believing substantial gains in speed over the water are of appreciable importance, other systems must be analyzed which can provide the desired speed and yet not sacrifice, to an appreciable degree, the current basic simplicity, reliability and general operational capability of the vehicle on both land and water.

The conventional method of propelling a vehicle over water is by a propeller and such a system can provide propulsion efficiencies of 20 to 60% depending upon the propeller selected. Propeller size and weight limitations serve to necessitate operation at the low end of the potential efficiency area. The efficiency of the propeller itself can be in the 50 to 65% range. For the type of vehicle under study, a "shoe box," matching a propeller to the system is, at best, a difficult task because for optimum performance the propeller diameter would be prohibitively large. Installation of a propeller poses several problems in that it must be well protected to avoid damage during land operation, be capable of shedding weeds and withstanding damage due to sand, rocks and debris in addition to which it must be placed in the water at a location where it can get a good "bite" on the water it pumps. To do all this the basic external vehicle design must be altered to allow installation of the propeller.

Considering the aforementioned there is little doubt the propeller can provide an increased propulsive efficiency (twice that of tracks should be easily attainable) but the basic drag of the hull can be changed little to help the overall system. Thus the propeller has numerous operational problems in addition to offering little help in reducing the base drag of the vehicle. One can thus conclude a gain in speed can readily be realized using a propeller for over the water propulsion, but at an appreciable sacrifice to overall vehicle combat condition capability.

Before going to the next propulsion system, let us define some efficiencies used to date:

$$\text{Propulsive Efficiency} = \frac{\text{Net Thrust x Vehicle Velocity}}{\text{Shaft Horsepower x 550}}$$

$$\text{Propeller Efficiency} = \frac{\text{Mass Flow x } \Delta V *}{\text{Shaft Horsepower x 550}}$$

* ΔV represents the actual change in the energy level of the mass flow due to passing through the propeller.

The use of a water jet for propulsion can be traced back several hundreds of years, a propeller can be considered one "free form" so to speak, shrouding a propeller one obtains a Kort nozzle. Going one step farther, the pump jet evolved wherein the complete system was still external of the basic hull and the propeller had many blades followed by straightening vanes and perhaps two or more sets of these which are called stages. Next, and the system herein recommended for study, is an Aquajet or water jet wherein the water is taken on board at some desirable location, fed into an impeller and thence discharged overboard. All this is done below the water line of the vehicle although the discharge of water may be to the atmosphere if so desired.

The Curtiss-Wright Aquajet was installed in a 23 ft. Penn Yan lapstroke hull with a Graymarine 188 HV8 engine. Initial tests showed the performance at high speed close to that of the same boat using the same engine with a propeller installed.

A schematic, Figure I, of the Model 185 Aquajet illustrates the basic system and its attendant controls for piloting as well as making headway or sternway. An installation drawing, Figure II, shows the overall configuration, and Figure III shows the actual assembly of the unit.

Based upon the data obtained, further gains in performance are available when the Aquajet is tailored or matched to the boat. What does all this mean? It means that an Aquajet can be made to match or possibly exceed the performance of a propeller in the same hull using the same engine. Admittedly this was at high speed, but upon examination of what it takes to accomplish this, a high efficiency impeller is mandatory. The measured efficiency attainable with the impeller used during the aforementioned tests is 92%. Adding the turning vane losses, the efficiency becomes 85%. This efficiency can be related to propeller efficiency where 65% is a very acceptable value.

The propulsion efficiency of a system is directly related to the change in water velocity, entrance to exit, with respect to the speed of the vehicle. Water must leave the propulsive device at a speed greater than that of the vehicle. Analysis of the system and its attendant losses allows the selection of an exit velocity which will provide the highest propulsive efficiency. This is for "shoe box" vehicles, ships, hydrofoils, speed boats and actually for any water or airborne vehicle. For any given amount of vehicle installed horsepower, having the drag characteristics of the vehicle, the optimum water jet system may be selected based upon known component efficiencies. These component efficiencies consist of inlet recovery or inlet duct losses, impeller efficiency, turning vane efficiency, exhaust duct losses and nozzle losses. These may appear as substantial by quantity but by quality, namely a 92% impeller efficiency, the losses can be held to reasonably low values which can show system performance comparable to that of a propeller.

Selection of the most desirable system for a given vehicle requires consideration of many factors and, as is the usual case, the final installation is the result of numerous compromises. A less than optimum system is always the case no matter what propulsive system is used. Size, weight, speed, power available, vehicle drag characteristics, wide range of operation, general operating requirements and vehicle design commensurate with the missions to be accomplished all effect the end result, the vehicle to be manufactured. In terms of the subject vehicle track, propeller and water jet propulsion systems should be examined in terms of what overall system performance each can provide and their attendant disadvantages, as regards the vehicle requirements. The short time available to do this using a Curtiss-Wright Aquajet prohibits a complete study but in terms of general characteristics and performance capabilities a set of curves were prepared.

In terms of performance potential, Figure IV shows the thrust produced at various vehicle speeds for the horsepower considered for this vehicle. Also shown is the relationship between the impelled diameter and engine rpm. As in the case of propellers, the larger the unit the greater the thrust which relates to propulsion efficiency. Taking a track propulsion efficiency of 10 - 14%, twice this is readily attainable using an Aquajet.

Weight is also of concern and Figure V shows the estimated weight of an Aquajet as a function of impeller diameter. For this weight estimate the impeller and exit vanes were of Ni resist and the casings, etc., were of aluminum. It is believed this selection will more than satisfy the duty cycle imposed upon the Aquajet unit and afford a rugged unit capable of injesting appreciable debris of all kinds.

A major item for consideration when considering the use of water jet is, in addition to the attractive propulsion efficiency potential, can the system be used to decrease the drag of the vehicle in water. Here an added potential exists, which Curtiss-Wright believes worthy of serious consideration. Past experience has shown that matching a propulsion system to the vehicle, be it airborne or waterborne, can result in substantial gains in overall performance. Time prohibits such an evaluation of this concept for this report but the basic possibilities appear worthy of future exploration.

The installation of an Aquajet poses problems in terms of internal volume consumed, controls and operational considerations. In terms of volume the gain in performance must be measured against the current volume utilization and what it would take to install the unit. In terms of controls it would appear the control system for the Aquajet could be integrated with the current vehicle controls. Actual maneuverability of the vehicle can be superior to that of a propeller or tracks depending upon the control system selected. For this application the system should be somewhat different than that used in the Model 185 Aquajet because of the difference in the vehicles.

The injestion of debris, namely "bag cabbage" or the like, poses a problem. Currently the inlet system of the Aquajet performs quite well for most all conditions but big, leafy weeds pose a problem. Several solutions to this problem appear promising. One is a circular saw type blade which can be rotated and moved across the inlet cutting weeds between it and the fingers currently incorporated in the Model 185 Aquajet. Another is a reciprocating sickle bar which could move across the inlet cutting weeds between it and the current fingers in the inlet.

It should also be noted the use of a water jet allows the elimination of a separate bilge pump system because the Aquajet can serve as such a pump.

SUMMATION:

The above discussion, admittedly, is not a complete detailed analysis of the problems, state of the art, and general capabilities of the three (3) major methods of propelling an amphibious vehicle. However, the Aquajet does offer superior performance potential and as such is worthy of serious consideration as the method of on the water propulsion for amphibious vehicles including the LVTPX II currently under study. Curtiss-Wright is interested in providing the on the water propulsion system as a member of the group charged with responsibility of providing an advanced type amphibious vehicle such as the LVTPX.

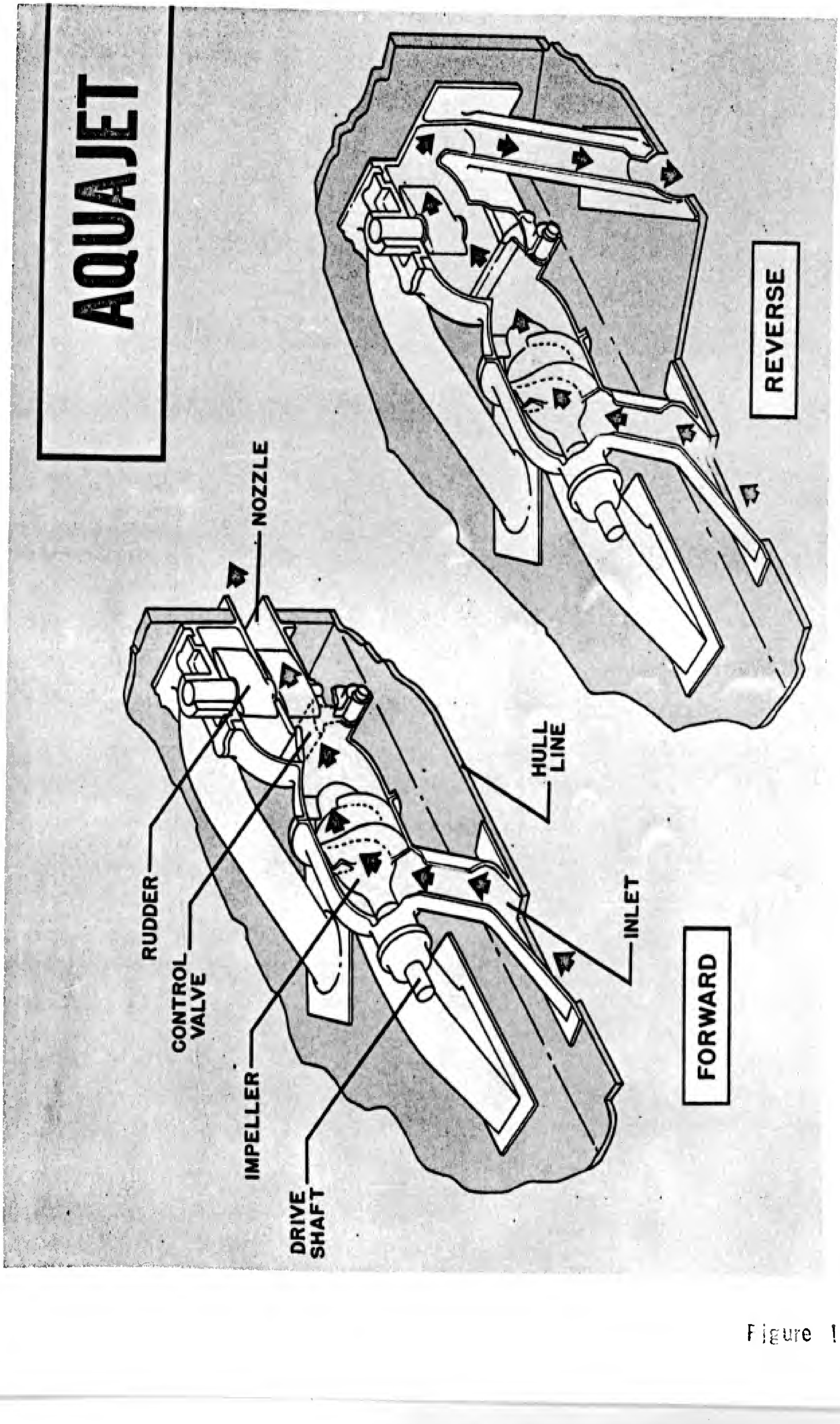
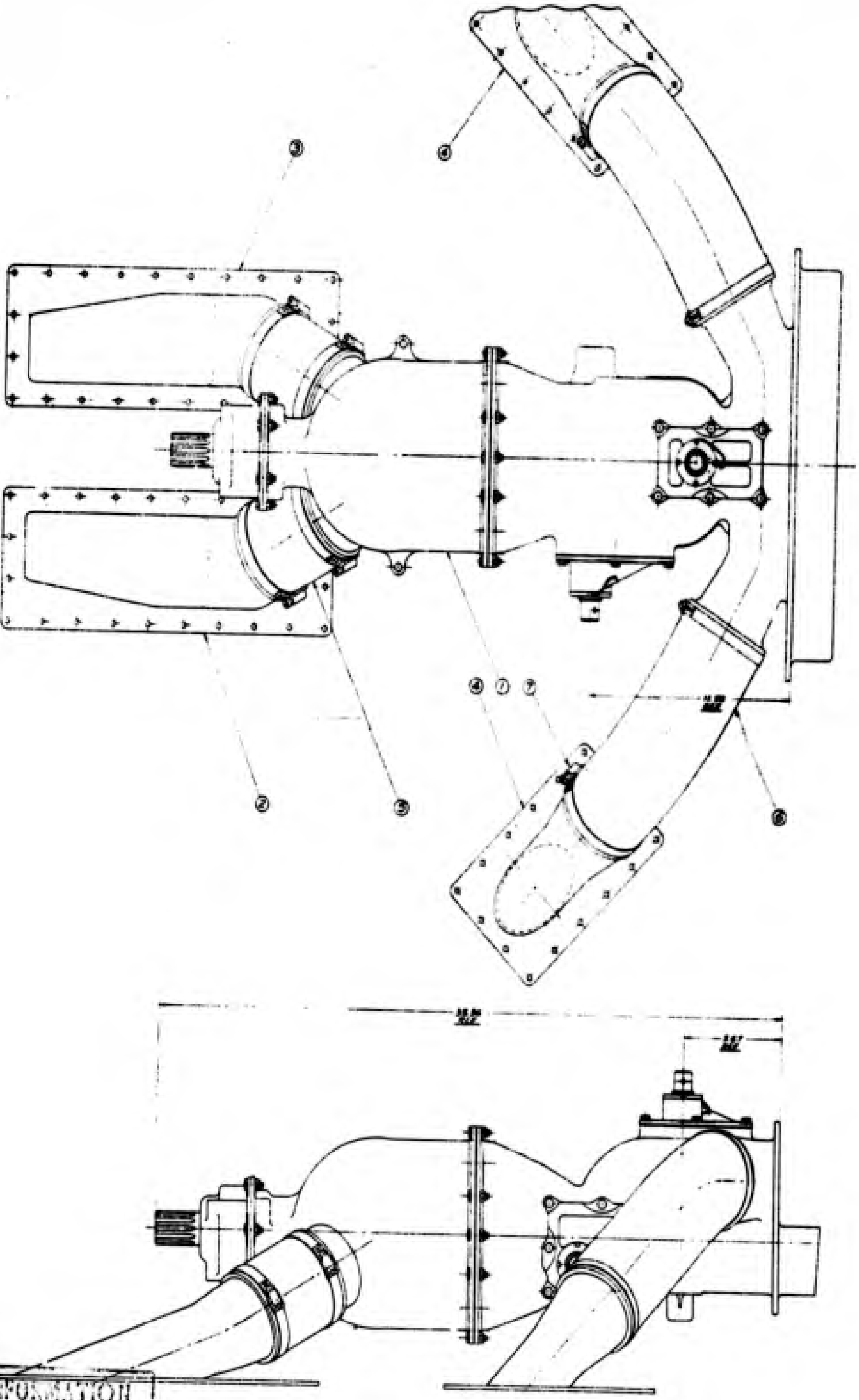

AQUAJET
RUDDER
CONTROL VALVE
IMPELLER
DRIVE SHAFT
NOZZLE
HULL LINE
INLET
FORWARD
REVERSE

Figure 1



7	[illegible]		CLAMP - HOSE
6	[illegible]		HOSE - OUTLET
5	[illegible]		HOSE - INLET
4	[illegible]		OUTLET
3	[illegible]		INLET - STARB
2	[illegible]		INLET - PORT
1	[illegible]		HYDROJET AS

1

Figure 11

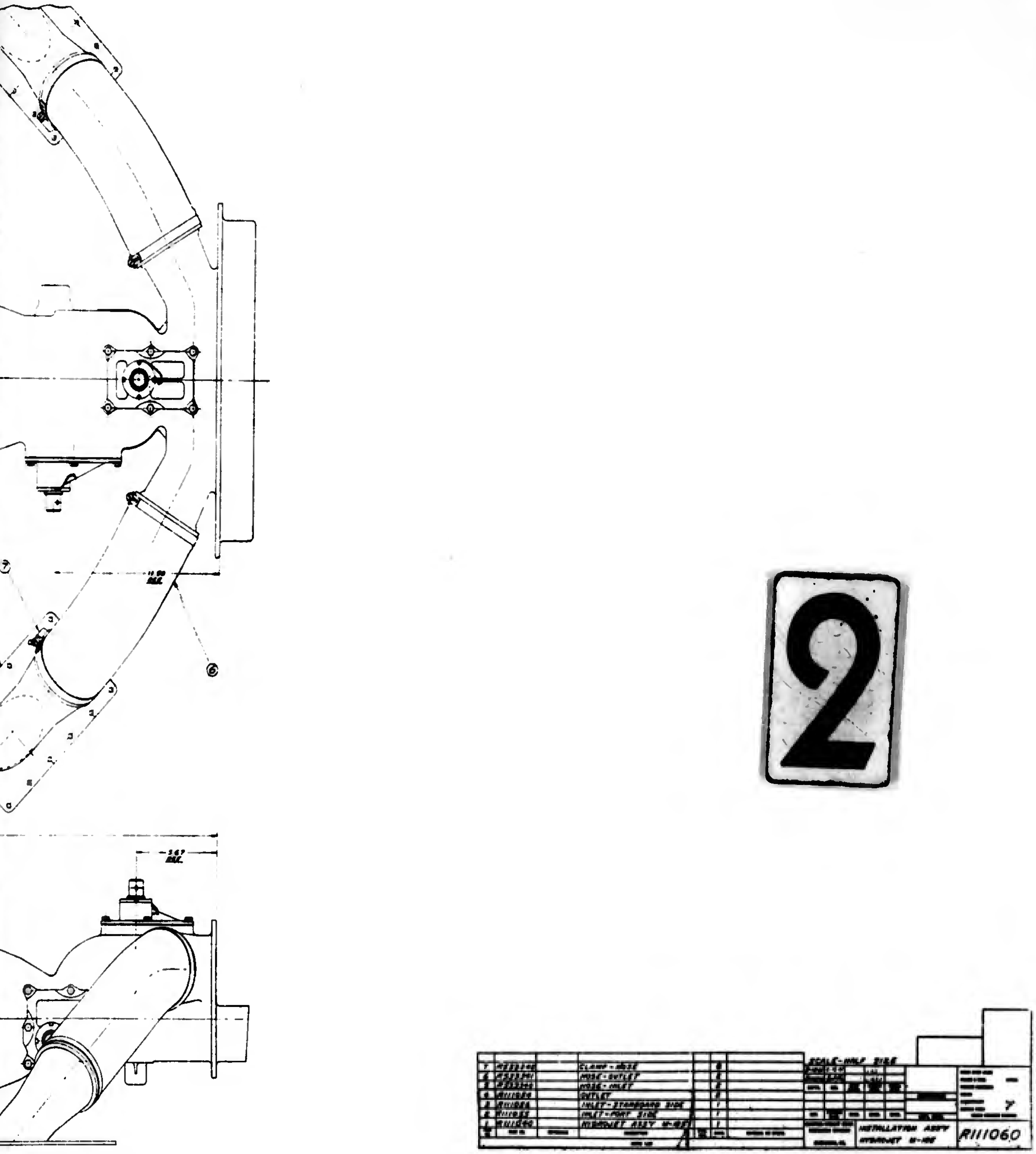

7
3
6
11.90 REF.
3.67 REF.
2
CLAMP-HOSE
HOSE-OUTLET
HOSE-INLET
OUTLET
INLET-STARBOARD SIDE
INLET-PORT SIDE
HYDROJET ASSY
SCALE-HALF SIZE
7
INSTALLATION ASSY
HYDROJET
R111060

Figure 11

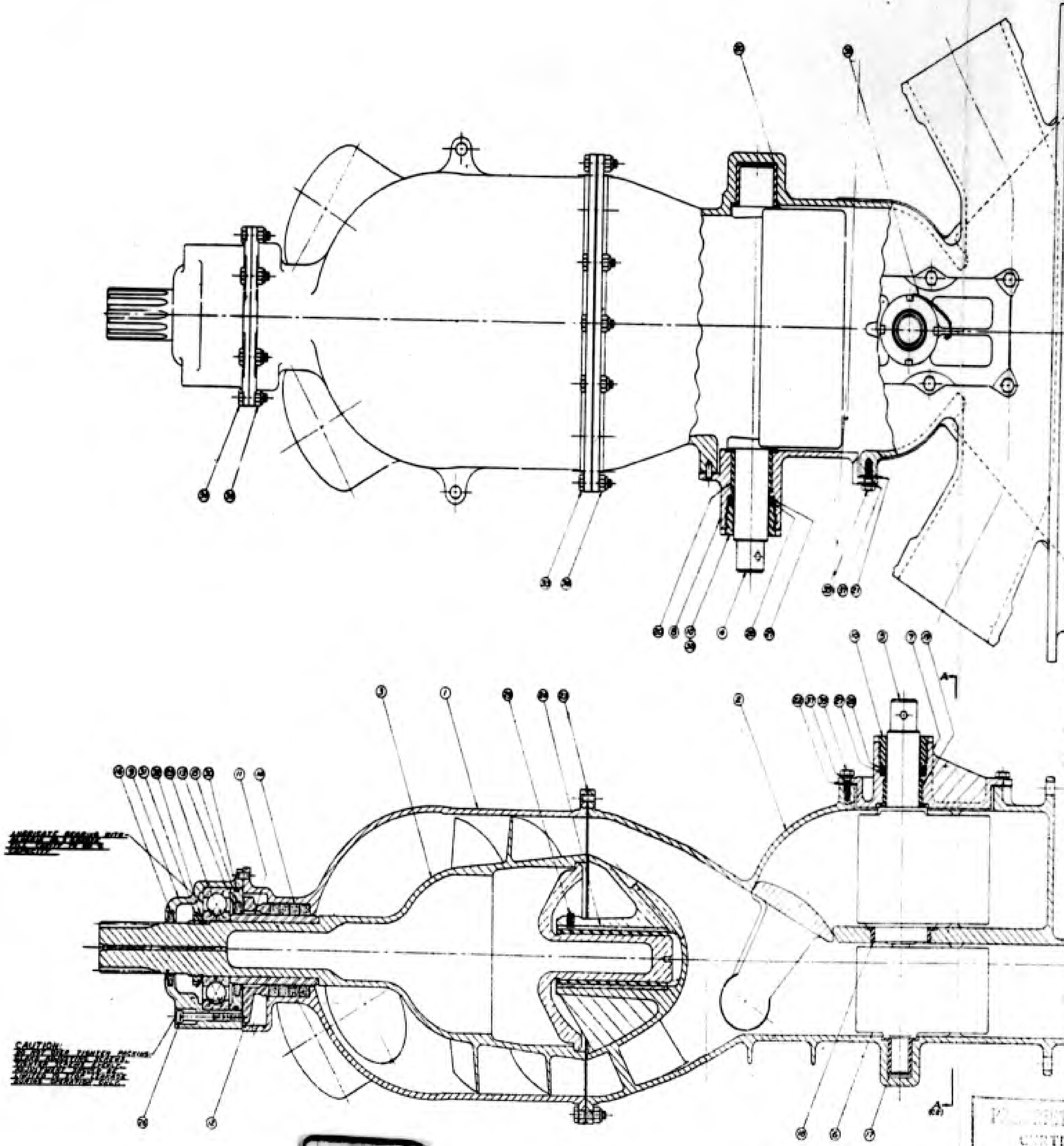
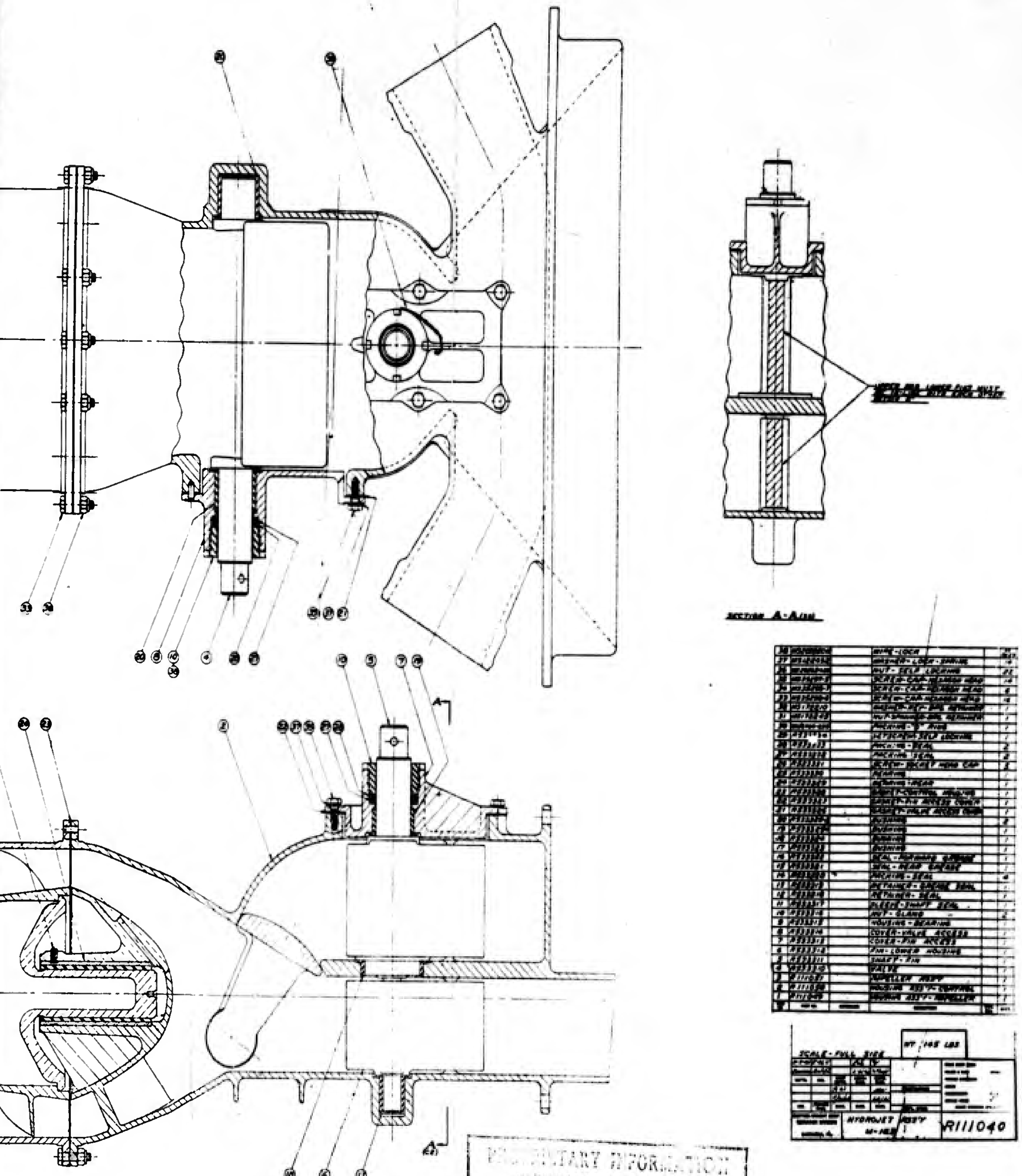


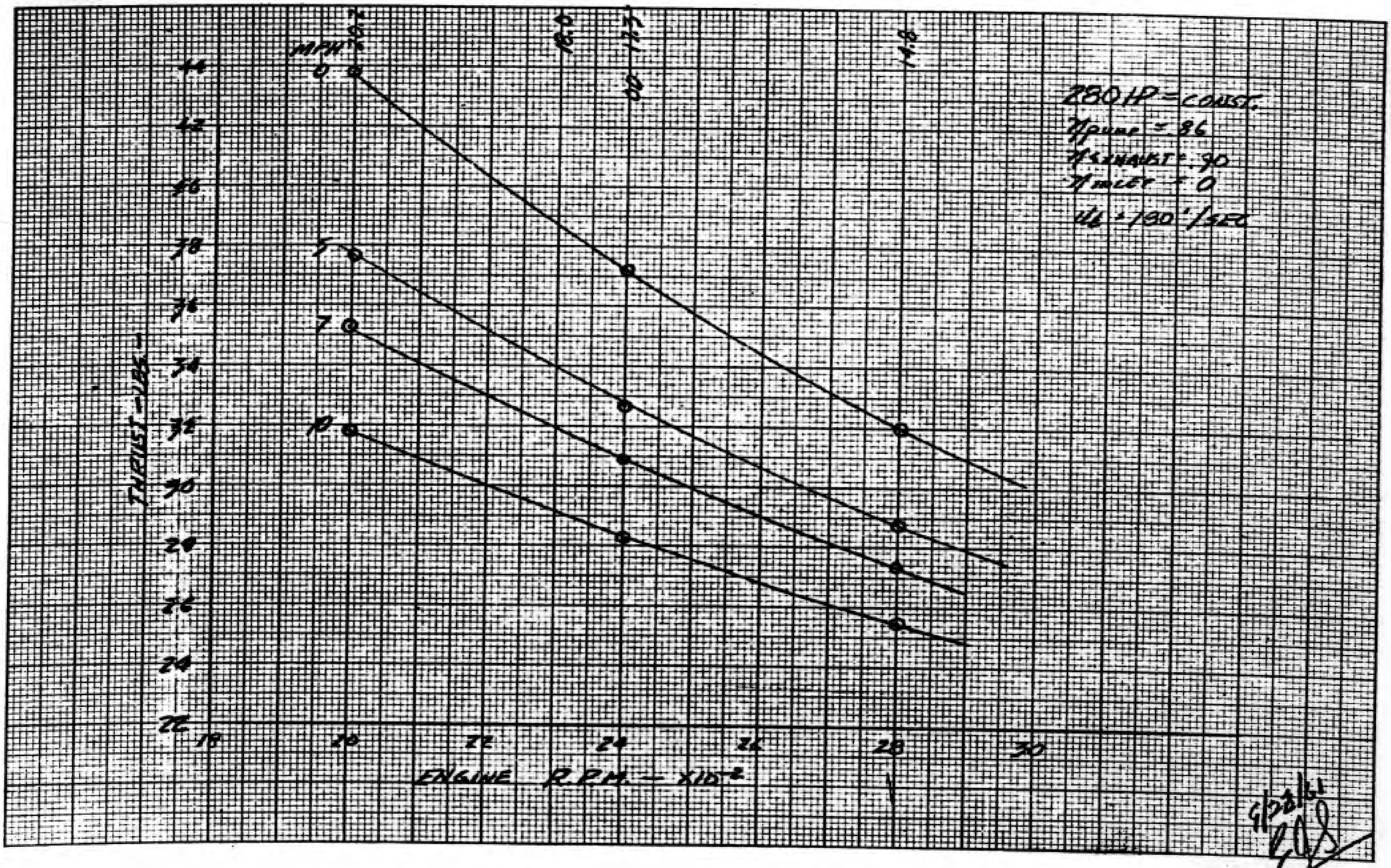
Figure III



PROPRIETARY INFORMATION
CURTISS-WRIGHT CORP.

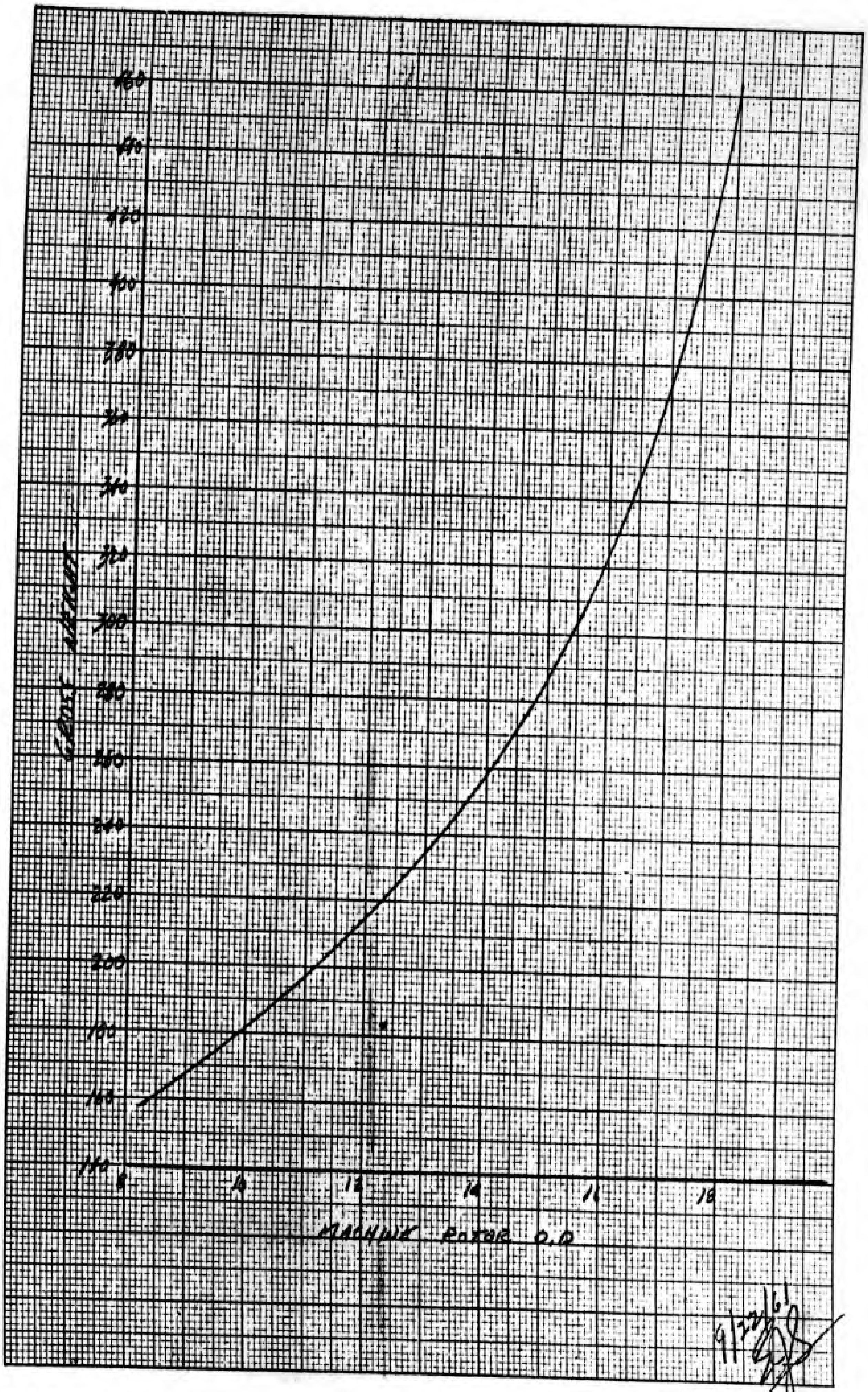
2

Figure III



6/28/61

Figure IV



9/22/61

Figure V

fmc CORPORATION

Load and stress analysis of: CURTISS WRIGHT HYDROJET UNITS

Prepared by MK Date 9/25/61 Page No. 1

Checked by Dwg. No. Project No.

THE FOLLOWING PERFORMANCE FIGURES WERE FURNISHED BY PHONE BY MR. GEORGE PEDERSON FOR SINGLE UNIT HYDROJETS. THE FIGURES ARE BASED ON A POWER OF 280 HP @ THE HYDROJET SHAFT.

IMPELLER DIA. (IN)	20.7	17.3	14.8
IMPELLER RPM	2000	2400	2800
SPEED (MPH)	THRUST (LB)		
0	4380	3790	3200
5	3780	3280	2880
7	3520	3090	2730
10	3180	2830	2550

	IMPELLER DIA (IN.)			
	18	17	15	12
WT. (LB.)	460	370	285	218

fmc CORPORATION

Load and stress analysis of: CURTISS-WRIGHT HYDROJET UNITS

Prepared by MK Date 9/25/61 Page No. 2

Checked by ____ Dwg. No. ____ Project No. ____

REF: HYDROJET INFO REC'D. FROM MR. GEORGE PEDERSON - CURTISS-WRIGHT BY TELEPHONE 9/25/61

DETERMINE RELATIONSHIP BETWEEN THRUST AND VEHICLE SPEED USING DATA GIVEN FOR 20.7" DIA UNIT

$$\frac{F-4380}{V_1-0} = \frac{3180-4380}{14.7-0}$$

NOTE: CURTISS WRIGHT USED $P = 280$ HP. THIS AMOUNT OF POWER IS NOT AVAILABLE ON VEHICLE

$$F = 4380 - 81.5V_1$$

DETERMINE JET VELOCITY

WHEN $V_1 = V_2$, $F = 0$

$$V_1 = V_2 = \frac{4380}{81.5} = 53.8 \text{ FPS}$$

DETERMINE Q

$$F = Q\rho(V_2 - V_1)$$

$4380 = Q \times 2.0 \times 53.8$ (STATIC CONDITION)

$Q = 41.0$ CFS

DETERMINE NOZZLE DIA

$$Q = A_2V_2$$

$$A_2 = \frac{41.0}{53.8} = .76 \text{ FT}^2$$

$$d_2 = \sqrt{\frac{4 \times .76}{\pi}} = .988 \text{ FT}$$

DETERMINE PUMP EFFICIENCY IN STATIC CONDITION

$$\eta = \frac{F(V_2+V_1)}{2P} = \frac{4380(53.8+0)}{2 \times 280 \times 550} = .76$$

fmc CORPORATION

Load and stress analysis of: CURTISS-WRIGHT HYDROJET UNITS

Prepared by MK Date 9/25/61 Page No. 3

Checked by ______ Dwg. No. ______ Project No. ______

STATIC THRUST (LB)	IMPELLER SIZE (IN)	* NOZZLE SIZE (IN)	* JET VELOCITY FPS	* PUMP EFF. @ $V_s = 0$	IMPELLER RPM	* Q CFS
4380	20.7	12	53.8	.76	2000	41
3790	17.3	10	58.0	.72	2400	32.6
3200	14.8	7.5	72.5	.75	2800	22.1

P = 280 HP @ HYDROJET SHAFT

* CALCULATED FROM INFO, FURNISHED BY C-W

PREDICTED PERFORMANCE
WITH 280 HP @ HYDROJET SHAFT
BASED ON #4 HULL (BARE HULL)

IMPELLER SIZE (IN.)	PREDICTED WATER SPEED (MPH)	PROPULSIVE EFFICIENCY %
20.7	8.8	27.8
17.3	8.5	23.4
14.8	8.2	20.0

fmc CORPORATION

Load and stress analysis of: CURTISS-WRIGHT HYDROJET UNITS

Prepared by OMK Date 10/2/61 Page No. 4

Checked by ______ Dwg. No. ______ Project No. ______

DETERMINE EXPECTED WATER SPEED WITH 225 HP
@ SHAFT OF 20.2" IMPELLER

n = 2000 RPM WITH 280 HP AVAILABLE
ASSUMING CONSTANT EFFICIENCY

$$\frac{280}{225} = \frac{(2000)^3}{n^3}$$

$$n = \overset{.931}{\left(\frac{225}{280}\right)^{\frac{1}{3}}} \times 2000 = 1860 \text{ RPM}$$

WITH 225 HP

$$V_2 = \frac{1860}{2000} \times 53.8 = 50.0 \text{ FPS}$$

$$F = Q\rho(V_2 - V_1)$$

$$F = 41.0 \times 2.0\,(50.0 - V_1)$$

$$F = 4100 - 82V_1$$

PREDICTED SPEED WITH 225 HP @ HYDROJET SHAFT
BASED ON #4 (BARE HULL

V_1 = $\underline{\text{8.6 MPH}}$
WITH 225 HP. (COMPARED TO 8.8 MPH WITH 280 HP)

COMPARISON OF INDIVIDUAL ARM AND WALKING BEAM SUSPENSIONS ON MODELS OF AN IMPROVED LVT

Report ORD 725

Project Authorization 449

September 25, 1961

Compiled by

ORDNANCE DIVISION
FMC CORPORATION
San Jose, California

Reported by: D. A. Luttrell
D. A. Luttrell
Test Engineer

Approved by:
E. H. Suhr, Supervisor
Engineering Test Section

PURPOSE

This report covers the results of a test run to compare the characteristics of two proposed LVT suspension systems, a conventional individual roadwheel arm system and a walking-beam system with oversize wheels and a softer spring rate.

Comparison was made by towing two 1/16 scale models along washboard and random bump courses while measuring vertical and angular acceleration.

This report closes out TWR 725.

RESULTS

Maximum and minimum acceleration and pitching experienced by the models towed over an identical washboard course were:

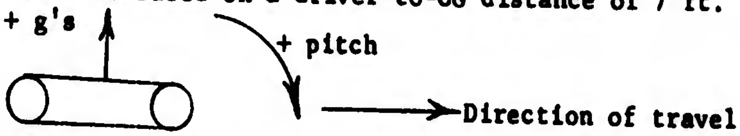
Table 1

Model and Prototype Speed	Vertical Acceleration g's	Angular Acceleration Radians/Sec^2	Apparent Vertical Acceleration at Driver, g's
5.9 MPH Individual Arms	+0.15 -0.15	-1.21 -2.18	+0.41 +0.32
5.9 MPH Walking Beam	+0.2 +0.3	+0.97 +0.48	-0.01 +0.21
16.8 MPH Individual Arms	-0.35 +0.5	+1.69 -1.45	-0.72 +0.82
16.7 MPH Walking Beam	-0.55 +0.4	+0.24 -3.41	-0.61 +1.15

NOTES: These accelerations are the maximum for each vehicle running the course at the indicated speed. They do not necessarily occur at the same part of the course or on the same part of the vehicle. See Table 3, Appendix I, for more complete data.

Acceleration at the driver is based on a driver-to-CG distance of 7 ft.

Sign Convention:



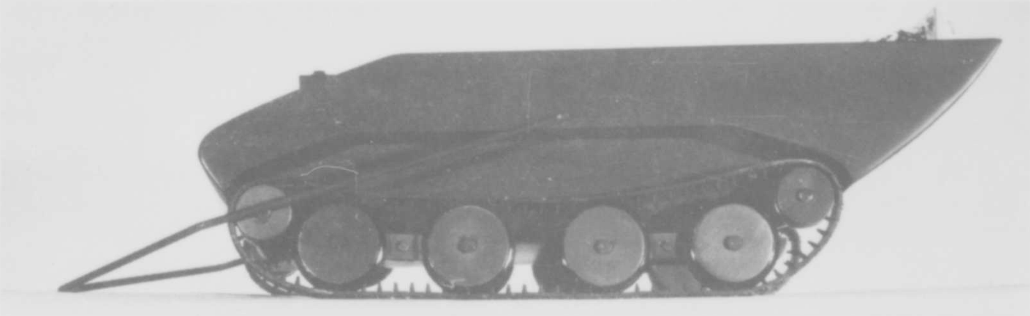
In general the individual arm model experiences maximum acceleration when the first roadwheel runs onto a bump and when the last roadwheel comes off the bump.

The walking beam vehicle takes the first bump well, but pitches heavily when the second walking beam assembly runs onto and off a bump.

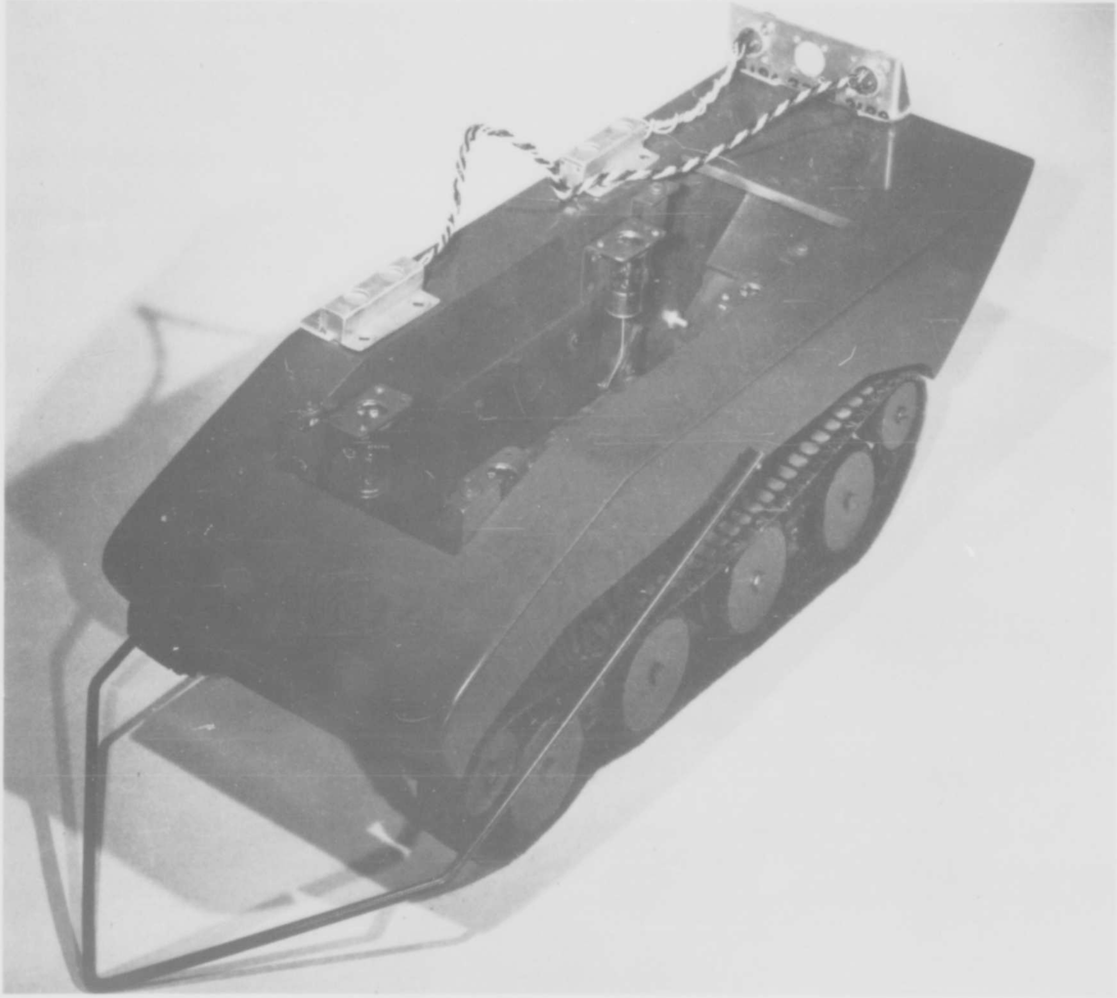
Since model forcing frequency was equal to prototype forcing frequency (one pitch of the washboard traversed in equal times for model and prototype) but model natural frequency was 4 times prototype natural frequency (see Appendix II, page 10) no check for resonances could be made. These tests were for comparison only, and should not be used to predict prototype behavior.

CONCLUSIONS

1. On the simulated Aberdeen severe washboard course, performance of the two models is about equal.
2. On irregular bumps, the walking beam suspension compares unfavorably with the individual arm suspension; the former gives a rougher overall ride and pitches easily when the leading arm assembly at the rear of the model encounters abrupt changes in slope. A walking beam type suspension in which all arms to the walking beams were trailing type might have shown up better on the irregular bump course.

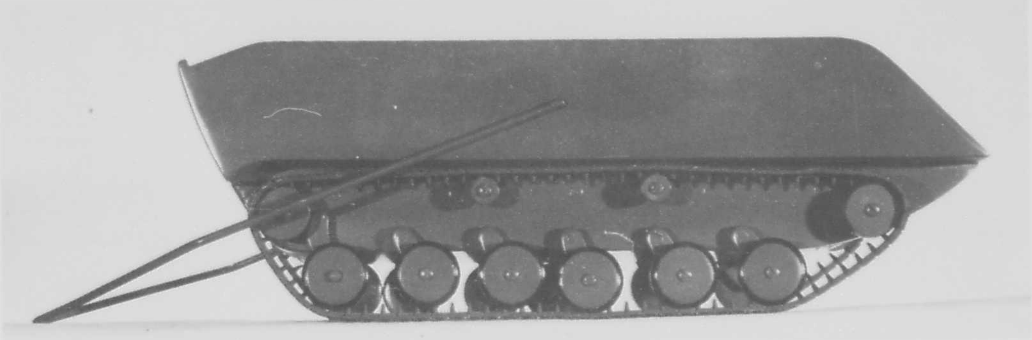


Side View

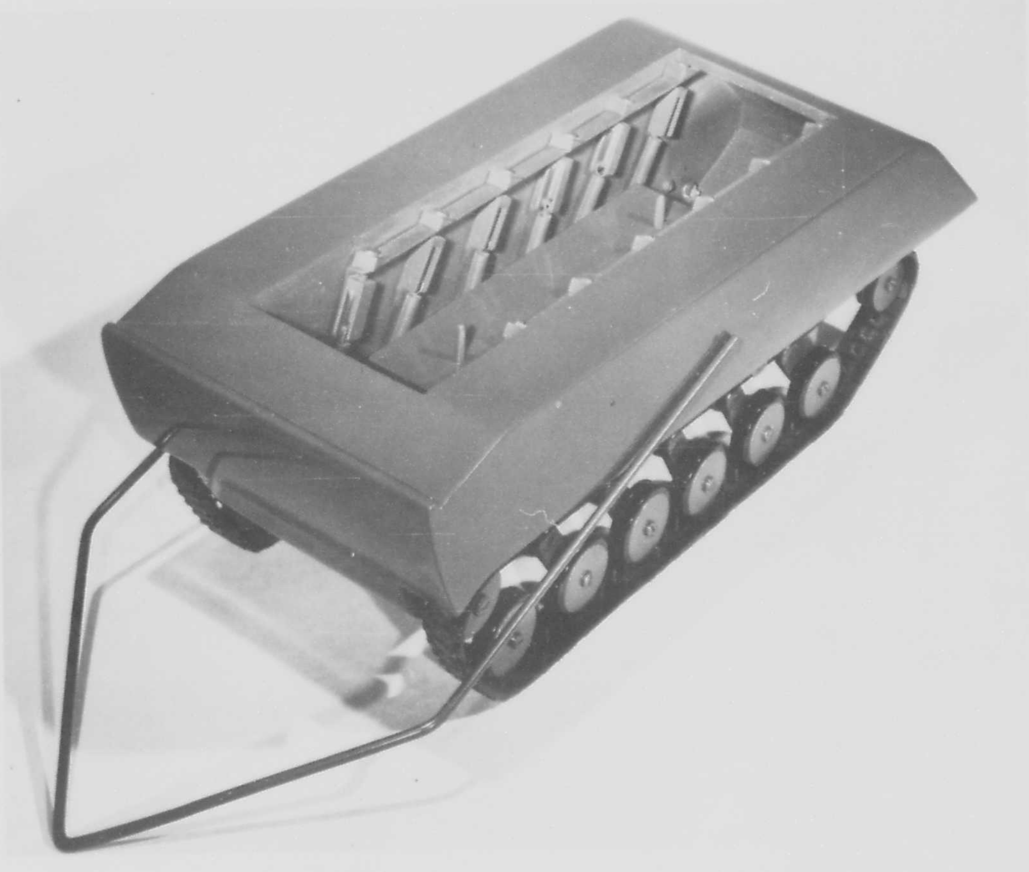


Spring and Shock Absorber Detail — Accelerometers Are In Place

FIGURE 1 WALKING-BEAM MODEL



Side View



Top View Showing Suspension Detail

FIGURE 2 INDIVIDUAL-ARM MODEL

DISCUSSION OF WORK

Figures 1 and 2 (Photographs 17173, 4 and 17175, 6) show the vehicle models tested.

Prototype Vehicle No. 1 has four 36" roadwheels per side, located on two walking beams. The front walking beam is supported by a trailing arm, the rear walking beam by a leading arm.

Prototype Vehicle No. 2 has six 18" roadwheels per side, individually sprung on trailing arms. The overall spring rate of this vehicle is twice the spring rate of the walking beam vehicle. Weight of both vehicles is 35,000 lb. Both models are 1/16 scale. Model data are given in Table 5, Appendix III, page 11.

Instrumentation consisted of 2 Statham ± 6 g accelerometers placed 10 inches apart on the vehicle. Accelerometers were oriented to be sensitive to vertical accelerations. Readout was with a 2-channel Mark II Brush Recorder. The 2 accelerometers can sense vertical acceleration and pitch as shown:

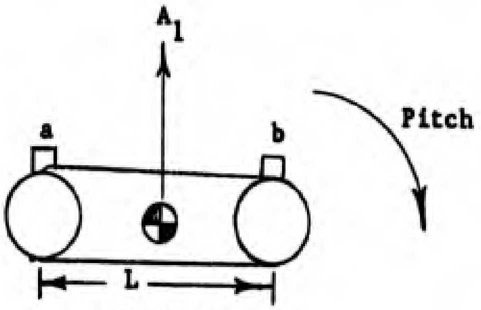


Figure 4

Consider the vehicle as a rigid body subjected to a vertical acceleration and pitch as shown. Accelerometers a and b are mounted a distance L apart.

Pure vertical forces produce equal acceleration readings, A_1, at a and b. Pure pitching moment produces readings ($\pm A_2$) at a and b which are equal in value and opposite in sign. The apparent acceleration at a and b is:

$$A_a = A_1 + A_2 \qquad A_b = A_1 - A_2$$

From the two accelerometer readings (in g's) we can calculate vertical and angular acceleration.

$$A \text{ (Vertical Acceleration)} = \frac{A_a + A_b}{2} \text{ g's}$$

$$\alpha \text{ (Angular Acceleration} = \frac{(A_a - A_b)}{L} \times 32.2 \text{ Radians/Sec}^2$$

To convert to prototype values:

$$A_{model} = A_{prototype} \quad \text{(Vertical Acceleration)}$$

$$\alpha_{model} = 16 \times \alpha_{prototype} \quad \text{(Angular Acceleration)}$$

(See Appendix II,page 10, for derivation)

Speed was measured by depressing a microswitch with the carriage (see Figure 3). The switch remains closed while the 24-inch long carriage is running over it. This switch operates one of the Event Marker Pens on the Brush Recorder.

Two test courses were used. One consisted of a series of 3/8" and 1/2" high half-round bumps arranged and spaced as shown in Figure 5, below.

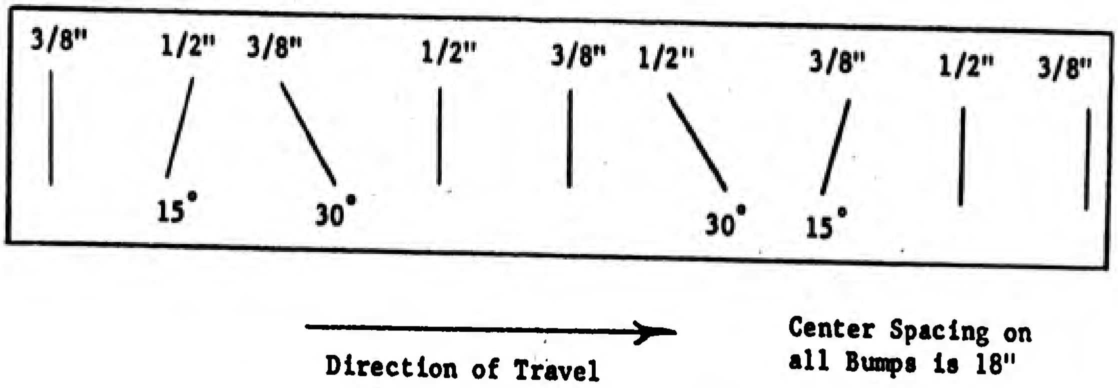


Figure 5
IRREGULAR BUMP COURSE

Models were towed over this course at speeds corresponding to prototype speeds of 15-30 MPH.

Although this course was eventually discarded as too severe, it allowed these comparisons between several vehicle configurations:

1. Wooden wheels are preferable to metal ones since metal wheels on a wooden model concentrate too high a portion of the model weight in the unsprung part of the suspension.
2. Non-stretchable fiber tracks will tie the roadwheels together without adding any additional springing, and thus they provide a better approximation of articulated vehicle track than rubber tracks.
3. A great reduction in pitching was achieved by concentrating as much weight as possible in the extreme forward and rearward parts of the walking beam vehicle. This high polar moment, however, does not really represent vehicle weight distribution.

Results of the irregular bump course runs are shown in Table 2, Appendix.I.

The other test course consisted of a washboard, 4-1/2" pitch and 3/8" from peak to valley. This washboard duplicates the 6" washboard on the Munson course at Aberdeen Proving Ground. The washboard was followed by two 3/8" high half-round bumps. Figure 6 shows the layout of the washboard course. (This is the course shown in Figure 3, Photograph 17185)

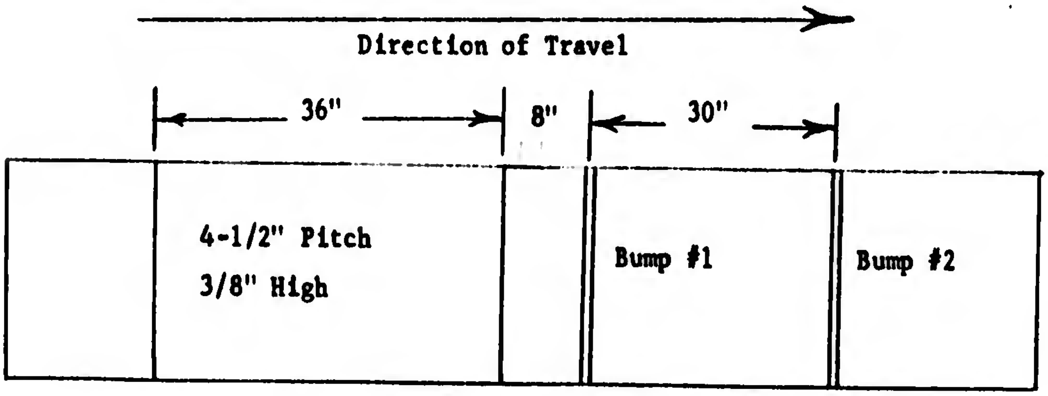


Figure 6

1/16 SCALE SEVERE
WASHBOARD AND BUMP COURSE

Models were towed over this course at speeds corresponding to 5-15 MPH. Results of these runs are shown in Table 3, Appendix. I.

In general, maximum shock in the Individual Arm Model occurred when the first roadwheel encountered a bump. This produces high accelerations at the front of the vehicle.

In the Walking Beam Model, maximum shock occurred when the #3 roadwheel (on the leading arm walking beam) hit a bump. Since the shock tends to be transmitted by a leading arm (see Figure 7), this produces high accelerations in the rear of the vehicle, and severe pitching. The trailing arm part of the walking beam suspension absorbs shock very well.

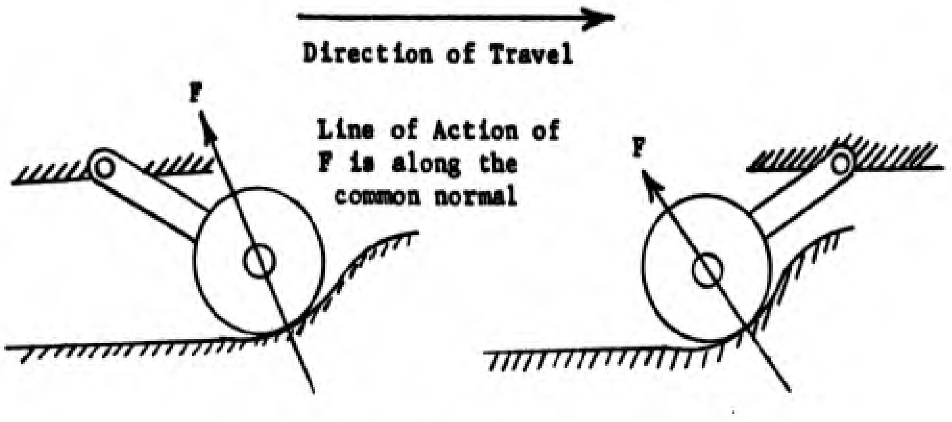


Figure 7
COMPARISON OF LEADING AND TRAILING ARMS

Throughout all the previously described runs, the only damping present was frictional damping in the model. Three runs were made with shock absorbers set to simulate prototype shock absorber settings at 508 and 1024 lb.-sec./ft., and a control run was made with the shock absorbers ineffective. Table 4, Appendix I, gives the results of the three runs. Frictional damping inherent in the models was great enough that the additional damping of the shock absorbers did not measurably affect the results.

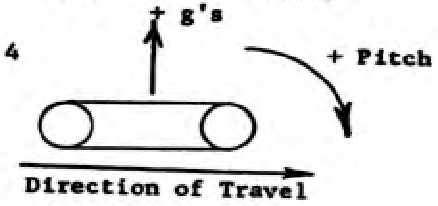
APPENDIX I

Table 2

MAXIMUM PROTOTYPE VERTICAL ACCELERATION AND PITCH IRREGULAR BUMP COURSE (FIGURE 5)

VEHICLE CONFIGURATION	8" High Bump 90° to Direction of Travel		8" High Bump 75° to Direction of Travel		8" High Bump 60° to Direction of Travel	
	Prototype Vertical Acceleration g's	Prototype Pitch Radians/Sec^2	Prototype Vertical Acceleration g's	Prototype Pitch Radians/Sec^2	Prototype Vertical Acceleration g's	Prototype Pitch Radians/Sec^2
PROTOTYPE SPEED 15-16 MPH						
1. Walking Beam - No Tracks	+0.45	+6.58	+0.6	+4.03	+0.65	+3.16
2. Walking Beam - Rubber Tracks	+1.05	+2.85	+0.55	+2.01	+0.15	+1.44
3. Walking Beam - Fiber Tracks	+1.35	+3.63	+1.05	+3.16	+0.35	+2.20
4. Same as 3, Wood Wheels	+0.9	+3.33	+0.7	+2.87	+0.3	+1.92
5. Same as 4, High Polar Moment	+1.85	+2.06	+0.6	+1.54	+0.65	+0.48
6. Individual Arm, No Tracks	-0.35	-2.53	+0.7	+2.59	+0.4	+1.89
7. Individual Arm, Rubber Tracks	+0.25	-1.81	-0.1	-1.41	- - -	- - -
8. Individual Arm, Fiber Track	+0.15	+1.14	-0.25	+0.605	+0.4	-1.21
PROTOTYPE SPEED 24-26 MPH						
1. Walking Beam - No Tracks	+0.40	+6.15	+0.95	+4.89	+0.75	+4.31
2. Walking Beam - Rubber Tracks	+1.1	+3.45	+0.6	+2.69	+0.2	+1.92
3. Walking Beam - Fiber Tracks	+0.95	+4.70	+1.0	+3.26	+0.4	+2.50
4. Same as 3, Wood Wheels	+1.0	+5.37	+1.0	+4.03	+0.35	+2.39
5. Same as 4, High Polar Moment	+0.85	+2.40	+0.6	+1.92	+0.3	+0.58
6. Individual Arm, No Tracks	-0.4	+2.60	-0.65	+4.59	-0.5	+2.13
7. Individual Arm. Rubber Tracks	+0.8	-1.38	-0.45	-1.07	- - -	- - -
8. Individual Arm, Fiber Tracks	+0.8	-0.45	-0.55	+0.85	-0.6	+1.45

NOTE: Model Data, Table 5
Model Relationships, Table 4



APPENDIX I
TABLE 3

MAXIMUM VERTICAL ACCELERATION AND PITCH
COMBINED 6" WASHBOARD AND 6" VERTICAL BUMP COURSE (FIGURE 6)

Vehicle and Prototype Speed	Conditions	Prototype Vertical Acceleration, g's	Prototype Pitch Radians/Sec^2	Vertical Acceleration at Driver, g's
Individual Arm 5.9 MPH				
	Maximum Washboard Shock	+0.15	-1.21	+0.41
	Front Wheel Hitting Bump #1	-0.05	-1.21	+0.21
	Hitting Bump #2	-0.15	-2.18	+0.32
Individual Arm 16.8 MPH				
	Maximum Washboard Shocks	+0.05	-1.70	+0.42
		-0.2	-1.45	+0.15
		+0.45	+0.25	+0.40
	#1 Wheel Hitting Bump #1	+0.45	+0.24	+0.40
	Rear Leaving Bump #1	-0.35	+1.69	-0.72 min.
	#1 Wheel Hitting Bump #2	+0.5	-1.45	+0.82 max.
Walking Beam 5.9 MPH				
	Maximum Washboard Shock	-0.3	-0.48	-0.20
	#3 Wheel Hitting Bump #1	+0.2	+0.97	-0.01
	Hitting Bump #2	+0.3	+0.48	+0.21
Walking Beam 16.7 MPH				
	Maximum Washboard Shocks	-0.45	+0.24	-0.50
		-0.4	0	-0.40
		-0.55	+0.24	-0.61 min.
	#3 Wheel Hitting Bump #1	+0.3	-3.41	+1.05
	Hitting Bump #2	+0.4	-3.41	+1.15 max.

NOTES: Vehicle Description - Walking Beam --- Low Polar Moment, Wood Wheels, Fiber Tracks
Individual Arm --- Fiber Tracks

Model Data - Table 5
Model Relationships - Table 4

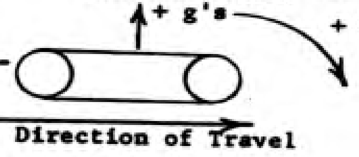


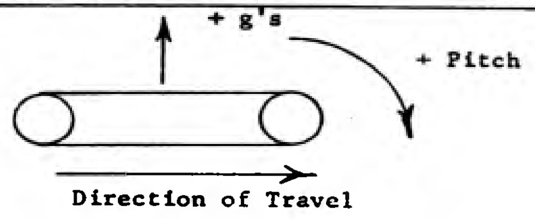
TABLE 4

MAXIMUM ACCELERATIONS WITH AND WITHOUT DAMPING

VEHICLE --- WALKING BEAM, WOOD WHEELS, FIBER TRACKS, LOW POLAR MOMENT

Test Course - Washboard and 2 Bumps as Shown in Figure 6
Test Speed - 14.75 MPH All Runs
All Values are Prototype

Condition		No Damping		Light Damping 508 lb.sec./ft.		Heavy Damping 1016 lb.sec./ft.	
		Vertical Acceleration g's	Pitch Radians/Sec^2	Vertical Acceleration g's	Pitch Radians/Sec^2	Vertical Acceleration g's	Pitch Radians/Sec^2
Last Washboard Bump	Hitting	-0.55	-2.18	-0.65	-1.65	-0.55	-2.42
	Leaving	+0.6	+1.45	+0.65	+1.21	+0.7	+1.70
Bump #1, #2 Road-wheel Hitting		-0.35	+1.70	-0.35	+1.70	-0.4	+1.93
Bump #1, #4 Road-wheel Leaving		-0.45	-1.21	-0.45	-1.21	-0.3	-1.21
Bump #2, #4 Road-wheel Leaving		-0.55	-1.70	-0.7	-1.97	-0.5	-1.93



NOTE: Model Weight - 8 lb. 9 oz., this test only

APPENDIX II

DERIVATION OF MODEL RELATIONSHIPS:

Length: $L_m/L_p = 1/16$

m = model

p = prototype

Weight: $W_m/W_p = 1/(16)^3$

Force: $F_m/F_p = 1/(16)^3$ Same units as Weight

Spring Constant:
$$\frac{K_m}{K_p} = \frac{\frac{F_m}{L_m}}{\frac{F_p}{L_p}} = \frac{16}{(16)^3} = \frac{1}{(16)^2}$$

Velocity:
$$\frac{V_m}{V_p} = \frac{L_m/t_m}{L_p/t_p} = \frac{1}{16}$$

t = time, invariant

Acceleration:
$$\frac{F_m}{F_p} = \frac{M_m}{M_p} \times \frac{A_m}{A_p} = \frac{W_m/G_m \times A_m}{W_p/G_p \times A_p}$$

m = mass

G - Acceleration of gravity, invariant

$$\frac{F_m}{F_p} = \frac{W_m}{W_p} \times \frac{A_m}{A_p}$$

$A_m = A_p$

Angular Acceleration:
$$\frac{\alpha_m}{\alpha_p} = \frac{A_m/L_m}{A_p/L_p} = 16$$

Natural Frequency:
$$\frac{f_m}{f_p} = \frac{\sqrt{\frac{K_m}{M_m}}}{\sqrt{\frac{K_p}{M_p}}} = \sqrt{16} = 4$$

Damping:
$$\frac{C_m}{C_p} = \frac{F_m\ t_m/L_m}{F_p\ t_p/L_p} = \frac{16}{(16)^3} = \frac{1}{(16)^2}$$

APPENDIX III

Table 5

Model Data:

Walking Beam

Weight: 8# 15 oz. for all runs except shock absorber runs.

8# 9 oz. for shock absorber runs.

Springs: 7# 12 oz. additional load produced 5/16 inch additional deflection.

K = 24.8 lb./inch

Shocks: Airpot air-damping dashpots

Settings: $2.6 \frac{\text{oz. - sec.}}{\text{in}}$ (soft)

$5.3 \frac{\text{oz. - sec.}}{\text{in}}$ (hard)

Accelerometers: Statham ± 6 g 2063 rear
2047 front
Spacing 10 inches

Individual Arm

Weight: 9# 4 oz.

Springs: 7# 12 oz. additional load gave 11/64 inch additional deflection.

K - 45.2 lb./in.

Accelerometers: Statham ± 6 g 2051 rear
2056 front
Spacing 10 inches

LVT
TOW BASIN EVALUATION OF SEVEN PROPOSED LVT HULLS

REPORT ORD 738

PROJECT AUTHORIZATION 449

October 27, 1961

Compiled by

ORDNANCE DIVISION
FMC CORPORATION
San Jose, California

Reported by W.H. Bauer
for J. E. Brewster
Test Engineer

Approved by
E. H. Suhr, Supervisor
Engineering Test Section

PURPOSE

A program has been introduced to design a new LVT. As a part of this program, tests have been performed on seven 1/16 scale models in FMC's tow basin to determine EHP required to overcome the hull resistance at various speeds.

Major test objective was to determine the effective HP required to overcome hull resistance through the proposed speed range with GVW of 25,000 and 35,000 pounds. A second objective was to find any undesirable stability or water flow characteristics within the proposed speed range of each hull. Desirable characteristics from the first four hulls could then be combined in two final hulls, one for track propulsion and the other for propeller propulsion.

Work was accomplished in the period August 2, 1961 through October 27, 1961 under project authorizations 449 and 934.

RESULTS AND CONCLUSIONS

Seven 1/16 scale models were tested in FMC's tow basin, the first four to provide design information for the two final hulls. One of the final hulls is to use track propulsion, while the other is to use propeller propulsion. No conclusions have been drawn from the data obtained for Hulls 1 through 4.

The track propelled vehicle, Hull 5, Figures 13 and 16, requires 42.5 EHP to reach its design speed of 6.5 knots with 35,000 pounds GVW. Stability and general dynamic characteristics are good to a speed of 7 knots where this hull shows a slight tendency to porpoise with the hull taking on occasional water.

Hull 6 was discarded due to general trim problems.

The propeller driven vehicle, Hull 7, Figures 14 and 17, requires 95 EHP to reach a design speed of 8.3 knots with GVW of 35,000 pounds. Stability was good to a terminal test speed of 9.1 knots where the hull shipped occasional water over the bow.

Hull 1E, Figures 8, 9, and 15 (Hull 1 with bow and stern each extended 50% of the basic vehicle length), requires 30% less EHP than the next best hull tested at a speed of 8 knots. Improved EHP versus speed characteristics are probably due to the improved length/width ratio. This configuration could not operate in normal land operations, due to the excessive overhang at both ends, unless the hull extensions could be removed or collapsed for land operation.

With an estimated 40 EHP available from track propulsion, Hull 5 would obtain 6.4 knots or 7.4 MPH with a G.V.W. of 35,000 pounds. EHP required throughout the speed range with various configurations is shown in Figure 6.

Hull 7 would reach a speed of 8.3 knots or 9.5 MPH with 95 EHP delivered to the water. EHP versus speed is shown in Figure 7.

At a speed of 6.5 knots and with G.V.W. of 25,000 and 35,000 pounds, the following EHP's are required:

Hull	Prototype Weight 25,000 lbs.	 35,000 lbs.	Comment
1	49	68	
1	-	50	V-shaped bow vane
1E	-	25	Bow and stern extension
2	44	51	
3	38	50	Tracks up
3	42	55	Tracks down
4	29	45	
4	-	39	Static trim is 4 inches high at bow (prototype)
5	30	45	
7	-	38	

This table includes only those hulls exhibiting undesirable water dynamics. Speeds below the noted points and hulls not mentioned have normal water operation characteristics.

TABLE 1

Hull	Weight Pound	Static Trim	Speed Knots	Water Dynamics of Model
1	35,000	Level	7	Water over front 2/3 of hull
2	35,000	Level	6	Water back 1 inch over bow*
3	35,000	Level	7	Fishtailing with tracks down
3	25,000	Level	8	Fishtailing with tracks up
5	35,000	Level	7	Slight porpoising**
5	35,000	Level	8	Bouncing**

*This condition corrected by trimming hull slightly up at the bow.
**Both conditions occurred above design speed of hull.

DISCUSSION

1. TEST MODELS AND INSTRUMENTATION

Seven hulls have been tested in FMC's tow basin as a part of the LVT improvement study. Tests were conducted to determine EHP required to overcome hull resistance at various speeds and to detect any dynamic instability of the hulls. Models were made to 1/16 scale in FMC's pattern shop.

The seven basic hulls tested were:

A. Hull 1:

Block-shaped model, shown in Figure 18, to serve as a standard for design improvement. The entire hull could be fabricated from flat plates.

B. Hull 2:

Moderately rounded hull, Figure 10, with blunt rounded bow and tracks extending well forward to provide a reasonable angle of approach for land operations.

C. Hull 3:

Reversible hull, Figure 11, to operate in one direction on land and the opposite direction in water. The reversible feature allows good visibility during land operation and a high bow for water operation.

D. Hull 4:

Streamlined hull, Figure 12, with fully rounded bow and stern. This hull would require simple and compound curved plates for most of the exterior.

E. Hull 5:

Optimum hull for track propulsion on land and in water, Figures 13 and 16, derived from the previous 4 hulls. Construction is largely flat plates with the corners being curved for ballistic protection and improved water performance.

F. Hull 7:

Compromise hull for track propulsion on land and propeller propulsion in water, Figures 14 and 17, similar to the previous hull but longer and with the stern modified to provide good water flow to a propeller.

Force measurements were made by using a strain-gaged plate mounted to the towing carriage and a towing arm mounted to the plate. Towing force acting at the towing attachment point on the tow arm induces a moment in the strain gage plate. Strain gages arranged as a wheatstone bridge to amplify the change in strain gage resistance, were read out on a model BL 320 Brush Amplifier and Recorder. Calibration was accomplished by weights and a pulley acting upon the towing point. Towing force is proportional to recorder pen deflection.

Speed measurements were made from a wheel of 6 inches circumference that rolls along the rail, with the carriage, and provides an electrical pulse to the recorder for each revolution. Elapsed time is the measured distance along the tape which runs at a pre-determined speed. Corresponding distance and time then determines velocity.

2. OPERATION DURING RUNS

All runs were made to determine model drag at pre-selected speeds. The following conditions were met during these runs.

A. Models were towed from a point 1/2 inch above the bottom of the tracks as an estimated thrust center for the track propulsion vehicles. The propeller driven vehicle was towed on a forward extension of the propeller center line.

B. Force measuring apparatus was zeroed before each run.

C. Models were unrestrained in conditions of attitude and trim. Directional stability was influenced by a V-shaped towing bridle.

D. Models were trimmed to the equivalent of 25,000 or 35,000 pounds with level water line or 1/4 or 1/2 inch higher at the bow than at the stern. Trim conditions are noted on the EHP curves.

E. Towing force was applied parallel to the bottom of the tracks.

Each run was repeated at least once to confirm results and minimize possible errors caused by equipment malfunction or operator error.

3. HULL STABILITY

Stability of all hulls was satisfactory below 7 knots (prototype speed) except Hull 1 with extended bow and stern. Towing arrangement of this hull with bridle attached at front of tracks resulted in a vehicle that either wandered or followed a straight course offset from the carriage towing arm. During the tests with bridle attached to the front of the tracks the hull was stable at approximately 6 to 7 knots but unstable above and below these speeds. Relocating the lowing bridle nearer the bow improved stability to the terminal test velocity of nine knots.

Hull 3, the reversible model, became unstable in roll and yaw at 7 to 8 knots (prototype speed) depending upon vehicle weight and track position. Observation at the start of instability indicated that when the model reached a small trim angle, it would fall off to one side; then the tow bridle action pulled the model back and past center to produce a combined rolling and yawing action. Without two bridle restraint the action could possibly have been poor directional stability, though there is also the possibility that a self-propelled model would not exhibit this instability.

Undesirable stability and water dynamic characteristics of the seven hulls are shown in Table 1. Only the undesirable characteristics are shown.

4. EFFECT OF TRACK PROPULSION

Track propelled vehicles derive a major part of their thrust from the change in momentum of the water in the front sprocket area. The net force is a resultant of lift and thrust vectors. (Observation of full-size LVT's shows that they trim up at the bow due to this action.) Trim angle in the model was not corrected for this condition.

5. CALCULATIONS

To obtain prototype speed in knots, the model velocity in ft./sec. was multiplied by 2.37.

V_m = model speed - ft./sec.
V_p = prototype speed - ft./sec.
V_k = prototype speed - knots
G_m & G_p = gravity relationship with model and prototype

L_m = typical dimension of model
L_p = typical dimension of prototype
S = scale factor = L_p/L_m

Froude number must be the same in model and prototype.

$$\frac{V_m^2}{G_m L_m} = \frac{V_p^2}{G_p L_p}$$

$$V = \frac{V_p}{\sqrt{S}} = \frac{V_p}{\sqrt{16}} = \frac{V_p}{4}$$

So that model speed is 1/4 the speed of the prototype. Then with 6080 FPH equal to 1 knot.

$$V_k = 4\,\frac{V_m \times 60 \times 60}{6080} = 2.37\ V_m$$

Horsepower values for fresh water are obtained by using the factor 29.8 multiplied by model speed in FPS times model drag in pounds.

F_m = model drag - pounds
F_p = prototype drag - pounds
HP_p = prototype horsepower
S^3 = model - prototype drag factor
$S^{\frac{1}{2}}$ = model - prototype speed factor

$$HP_p = \frac{V_m \times F_m \times S^3 \times S^{\frac{1}{2}}}{550}$$

$$= \frac{V_m \times F_m \times S^{7/2}}{550}$$

$$= \frac{V_m \times F_m \times 16^{7/2}}{550}$$

$$= 29.8\ V_m F_m$$

FIGURE 1

No. 1 LVT P.A. 449

PROTOTYPE EHP VS. PROTOTYPE WATER SPEED

Level Trim Line. Model Tow Points Noted.
EHP Is For Fresh Water

Engineering Test Section Ordnance Division
FMC CORPORATION
August 31, 1961 R. N. Bibbens

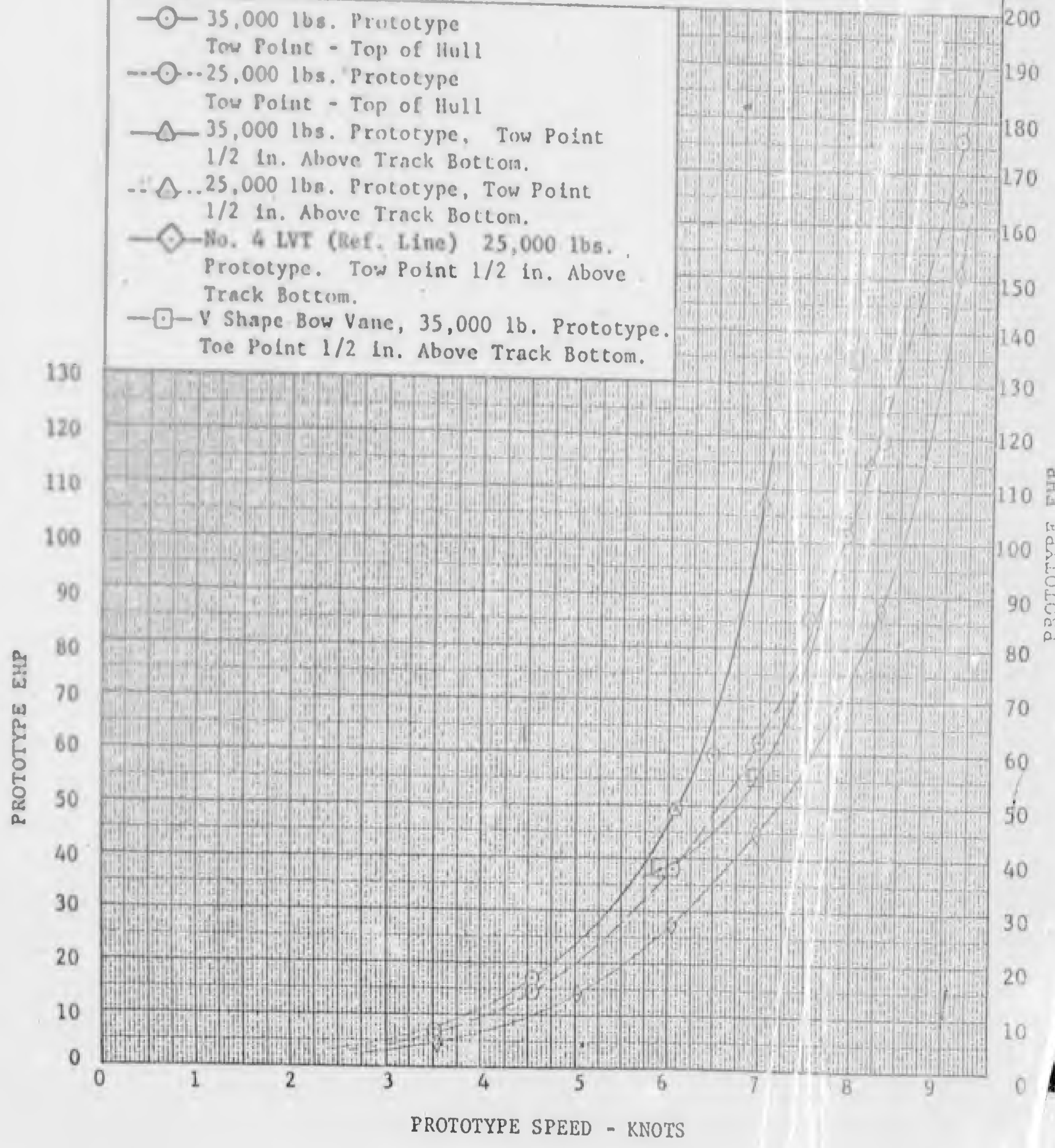
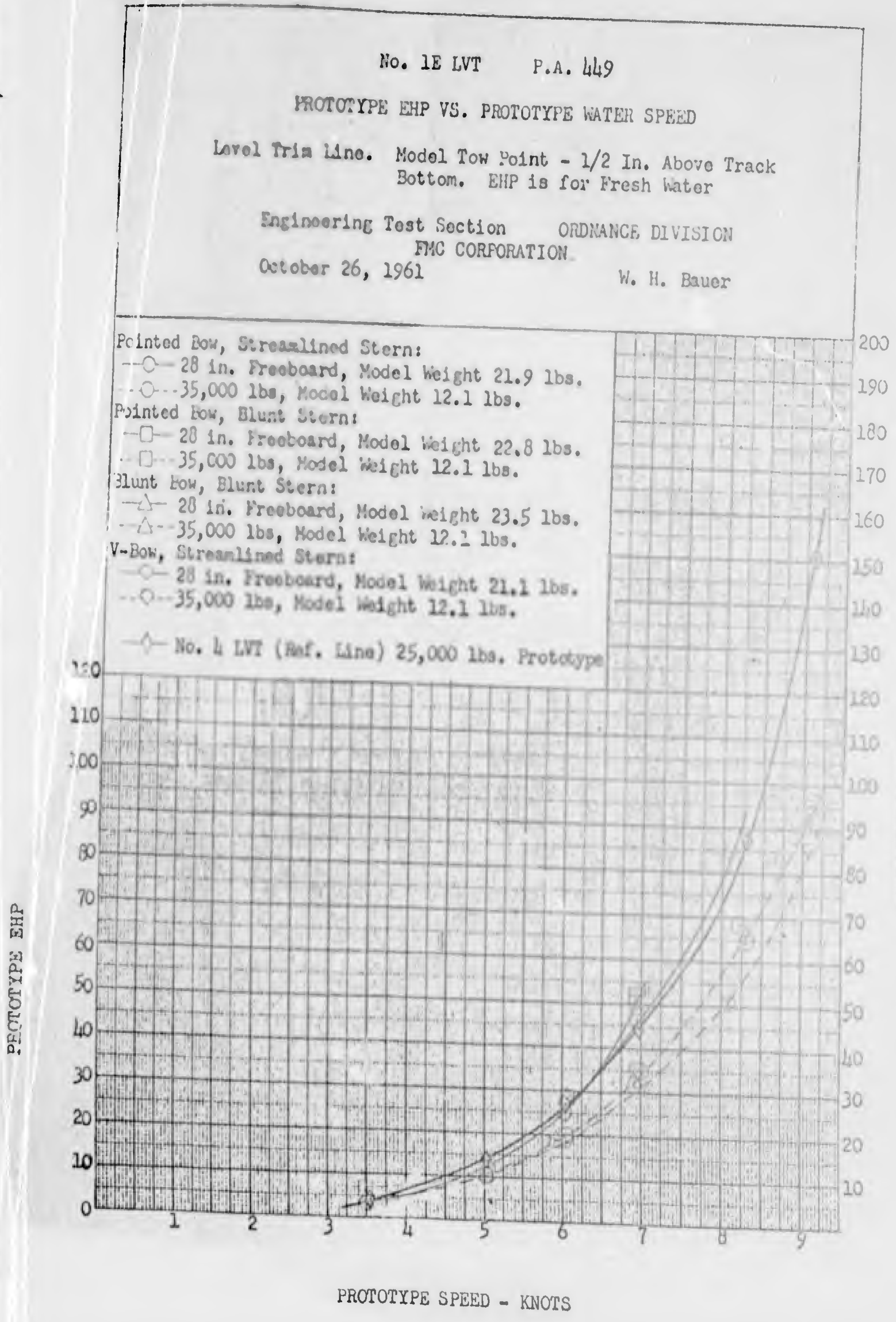


FIGURE 2



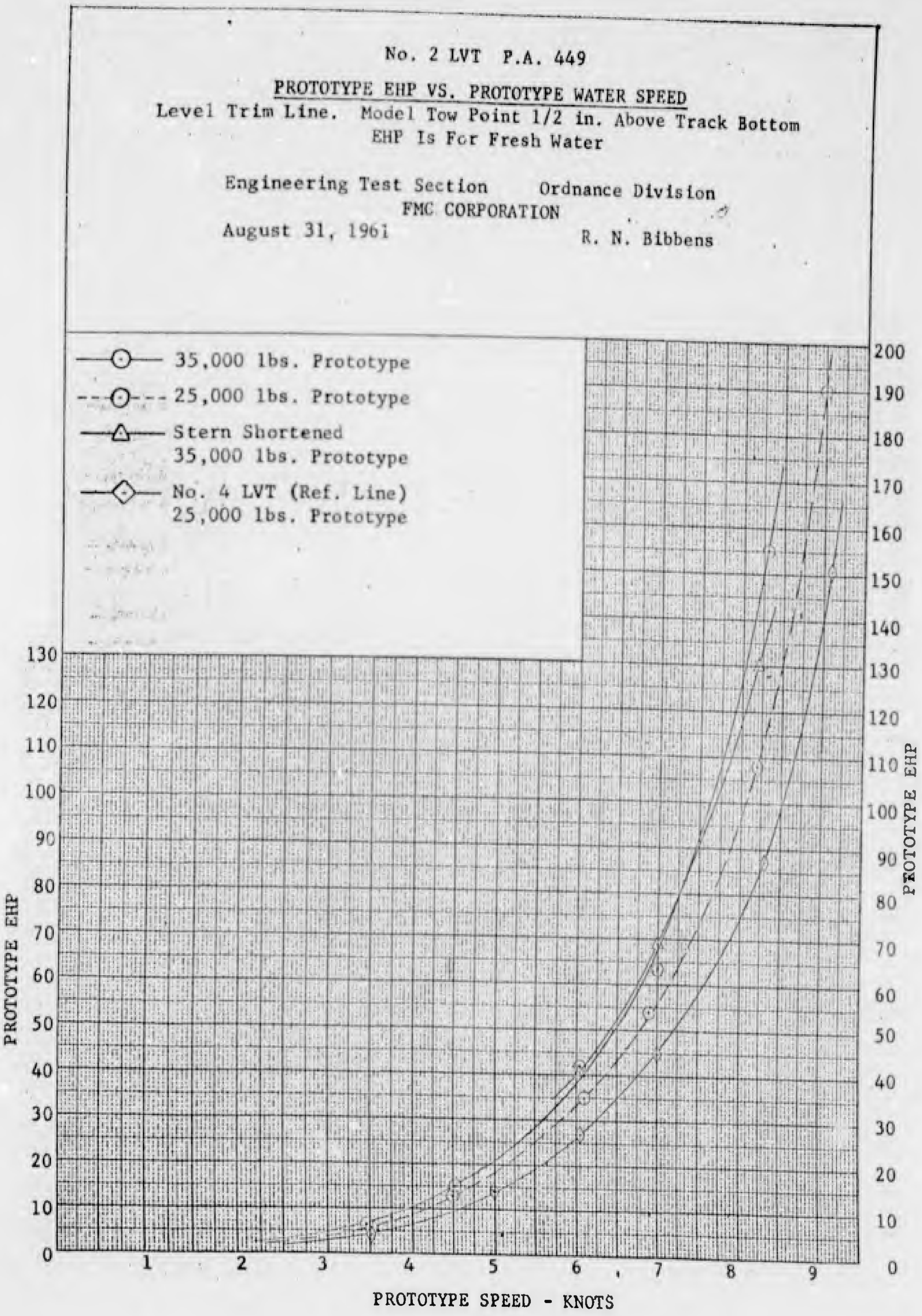
No. 1E LVT P.A. 449

PROTOTYPE EHP VS. PROTOTYPE WATER SPEED

Level Trim Line. Model Tow Point - 1/2 In. Above Track Bottom. EHP is for Fresh Water

Engineering Test Section ORDNANCE DIVISION
FMC CORPORATION
October 26, 1961 W. H. Bauer

FIGURE 3



No. 2 LVT P.A. 449

PROTOTYPE EHP VS. PROTOTYPE WATER SPEED

Level Trim Line. Model Tow Point 1/2 in. Above Track Bottom

EHP Is For Fresh Water

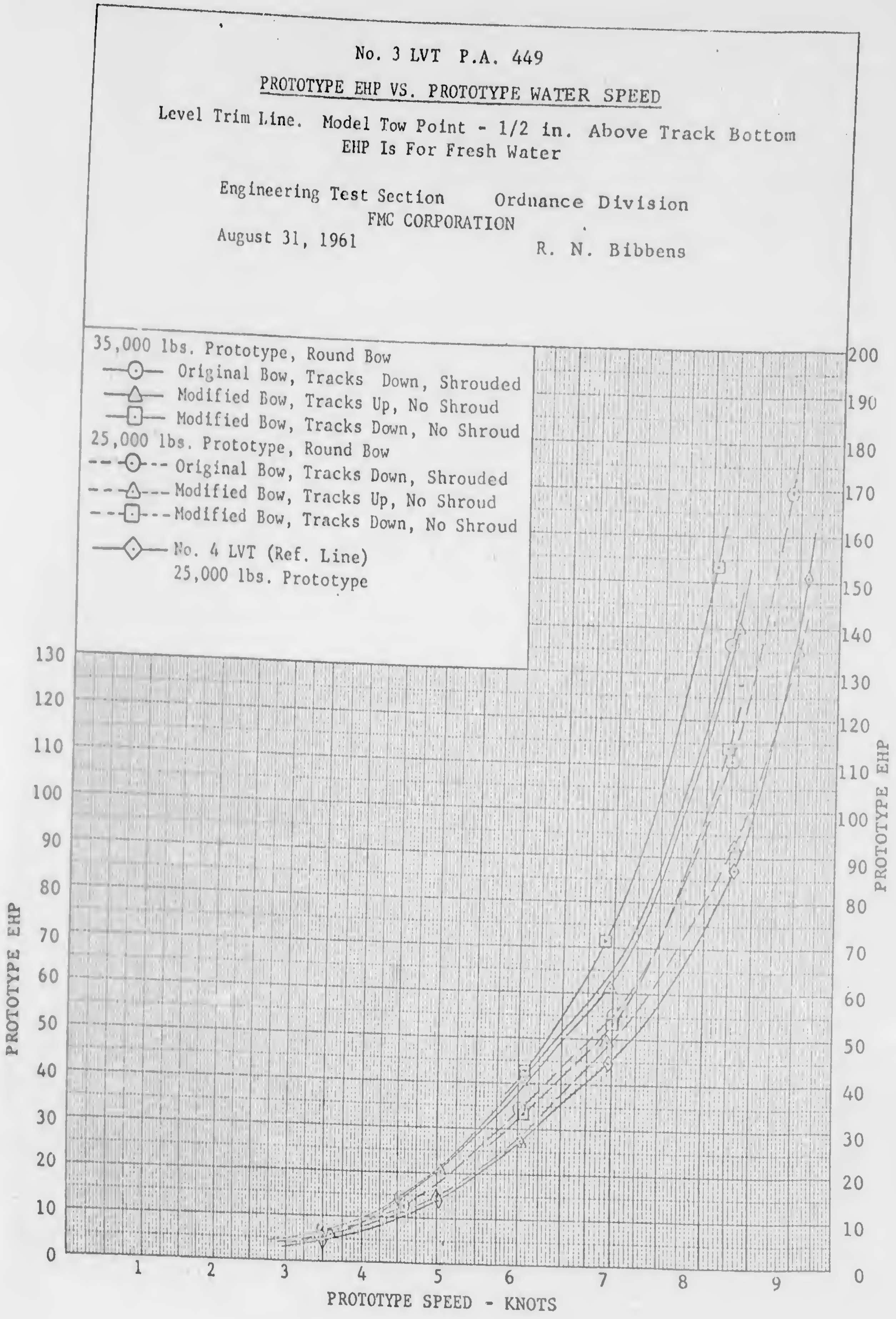
Engineering Test Section Ordnance Division

FMC CORPORATION

August 31, 1961

R. N. Bibbens

FIGURE 4



No. 3 LVT P.A. 449

PROTOTYPE EHP VS. PROTOTYPE WATER SPEED

Level Trim Line. Model Tow Point - 1/2 in. Above Track Bottom
EHP Is For Fresh Water

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FIGURE 5

No. 4 LVT P.A. 449

PROTOTYPE EHP VS. PROTOTYPE WATER SPEED

Trim Lines Noted. Model Tow Point 1/2 in. Above Track Bottom
EHP Is For Fresh Water

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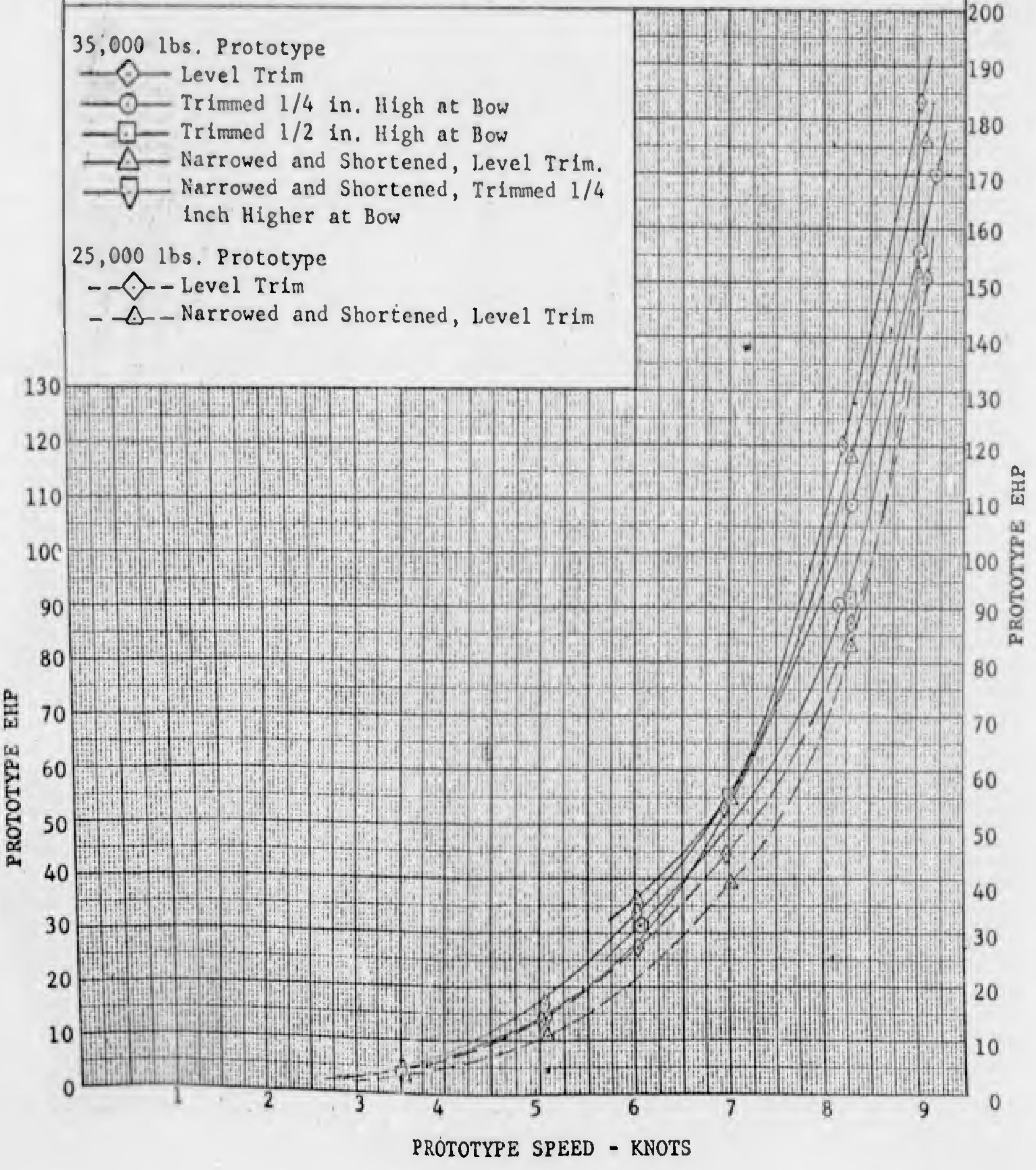

FIGURE 6

No. 5 LVT P.A. 149

PROTOTYPE EHP VS. PROTOTYPE WATER SPEED

Level Trim Line. Model Tow Point - 1/2 In. Above Track Bottom
EHP Is For Fresh Water

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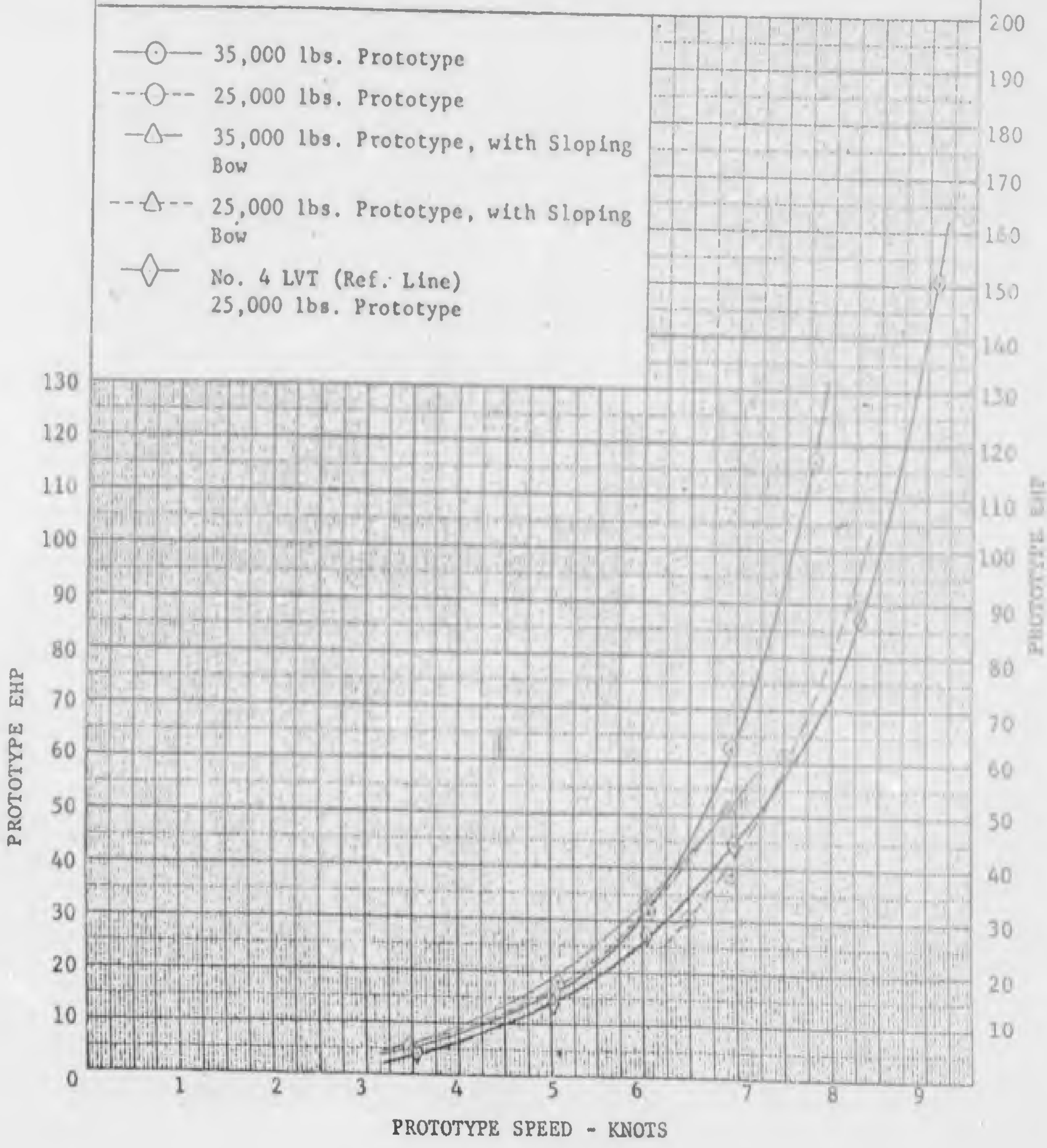
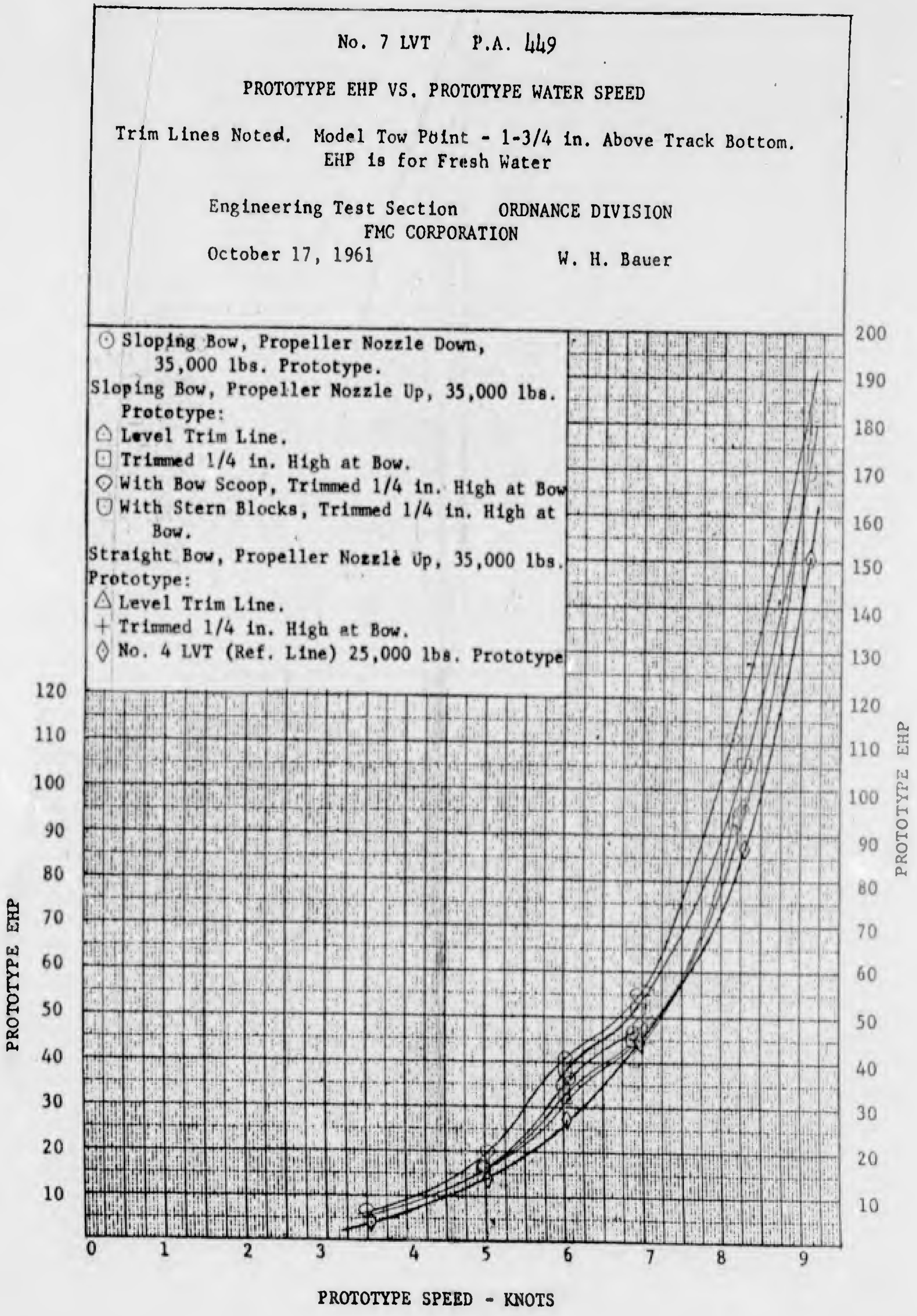


FIGURE 7



No. 7 LVT P.A. 449

PROTOTYPE EHP VS. PROTOTYPE WATER SPEED

Trim Lines Noted. Model Tow Point - 1-3/4 in. Above Track Bottom.
EHP is for Fresh Water

Engineering Test Section ORDNANCE DIVISION
FMC CORPORATION
October 17, 1961 W. H. Bauer

FIGURE 8

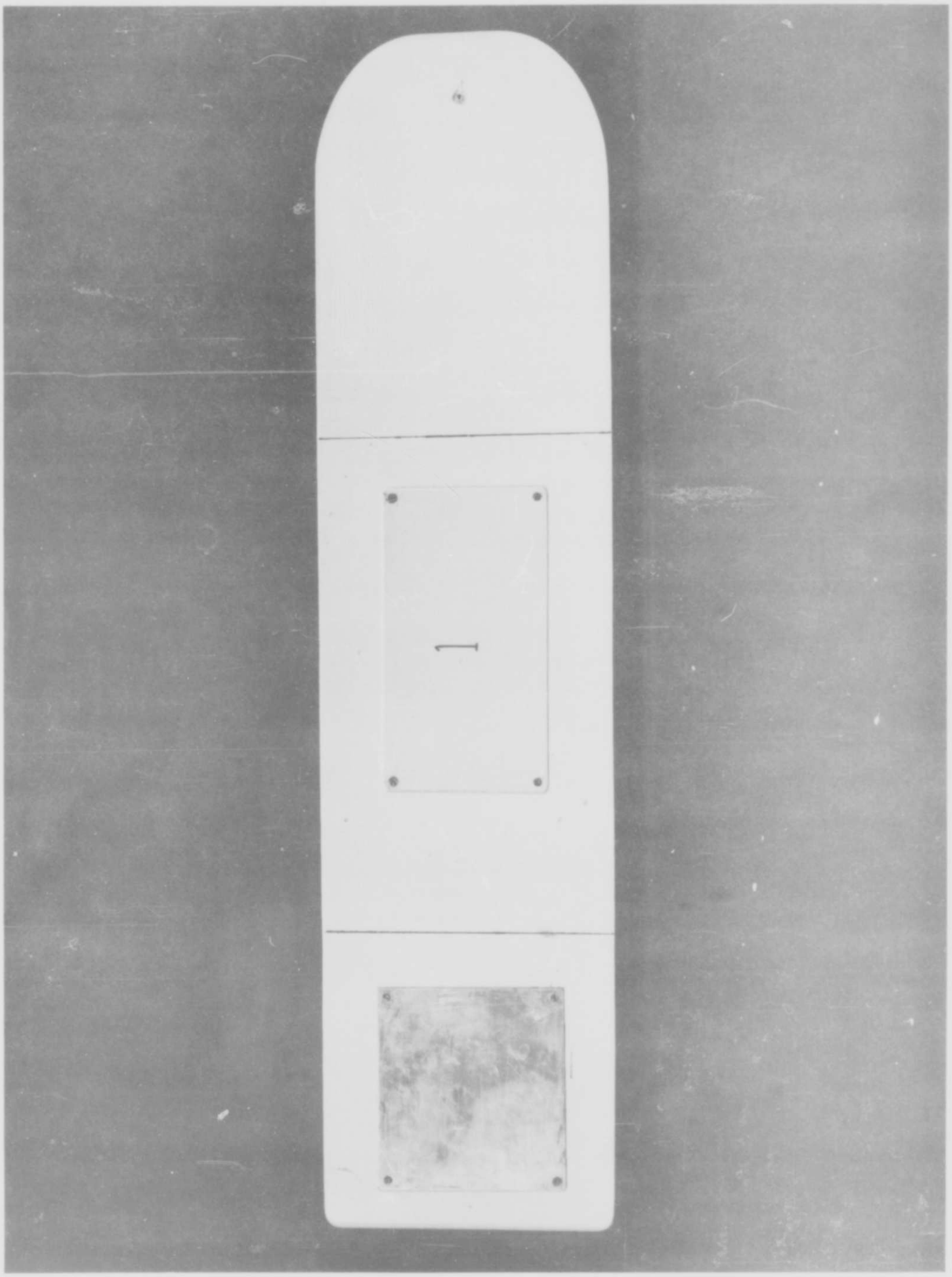


FIGURE 9

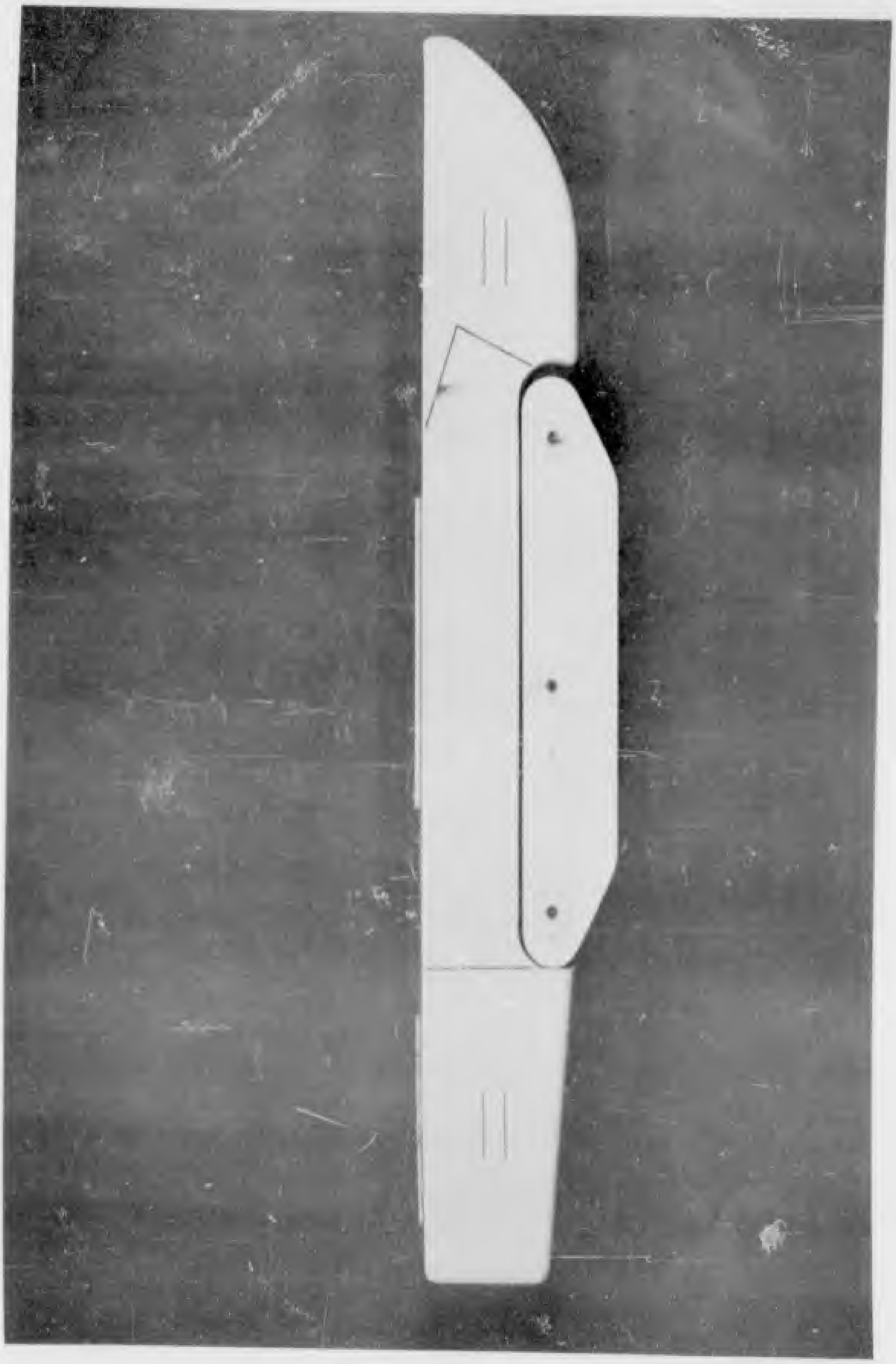


FIGURE 10

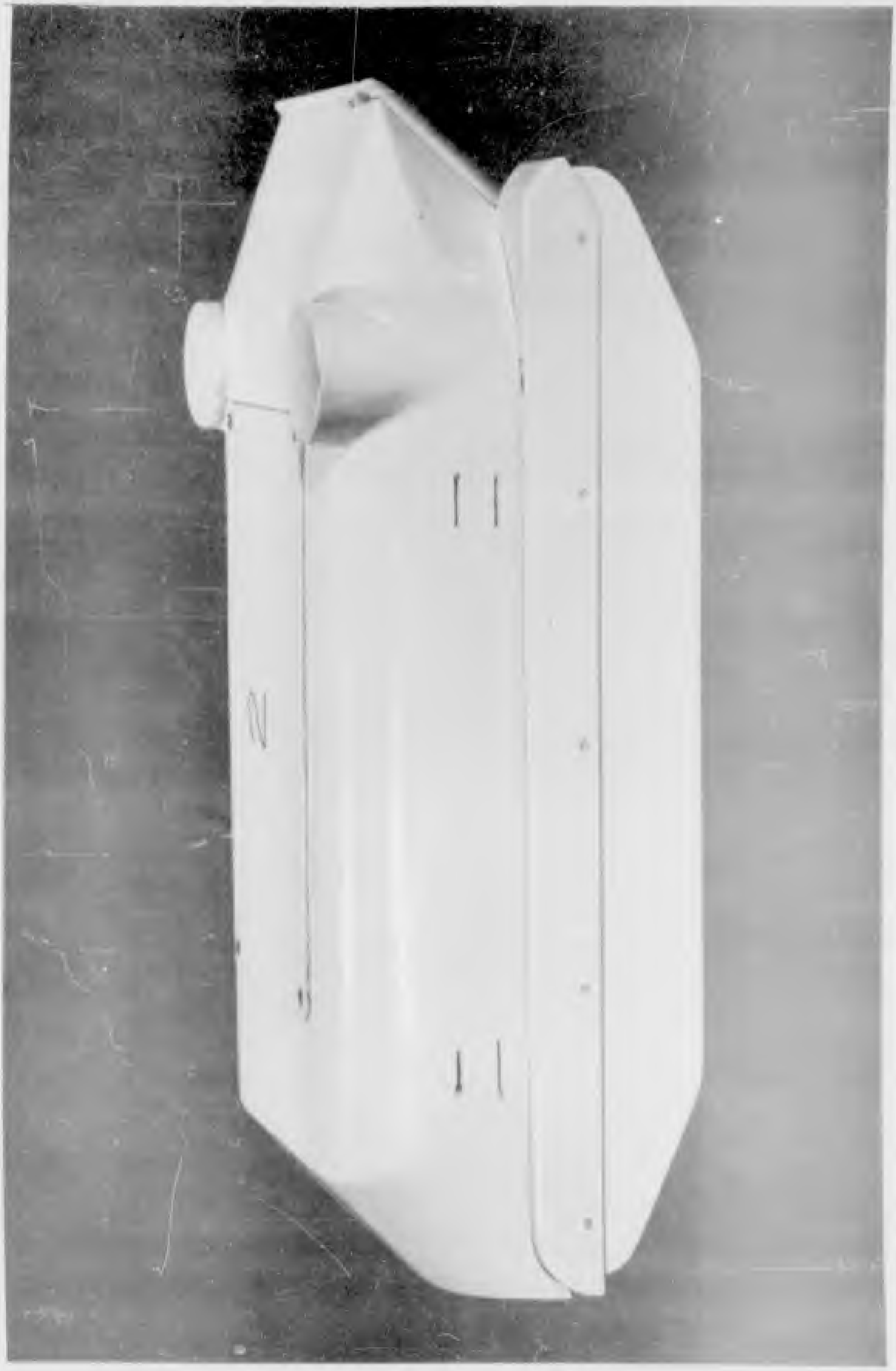


FIGURE 11

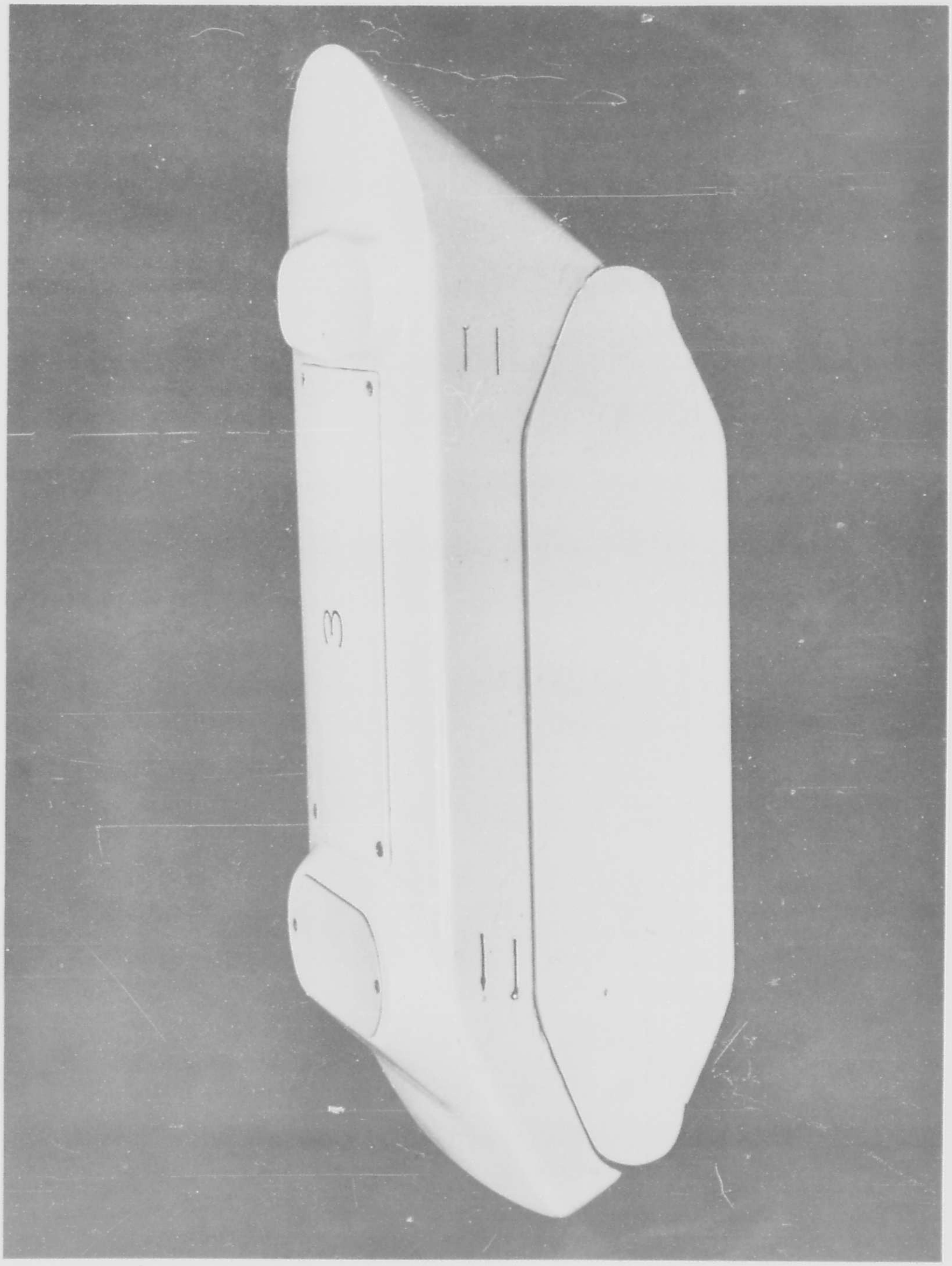


FIGURE 12

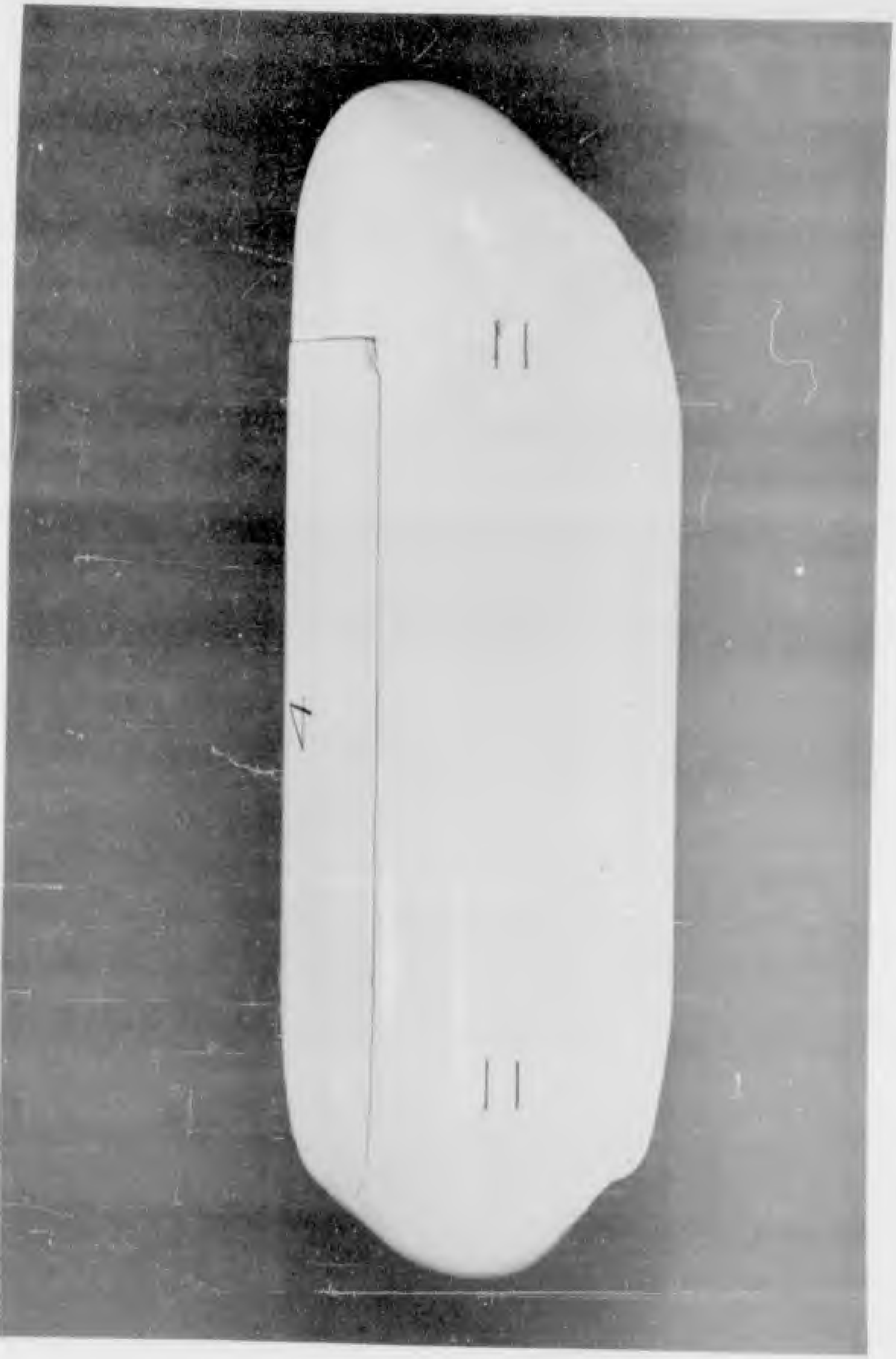


FIGURE 13

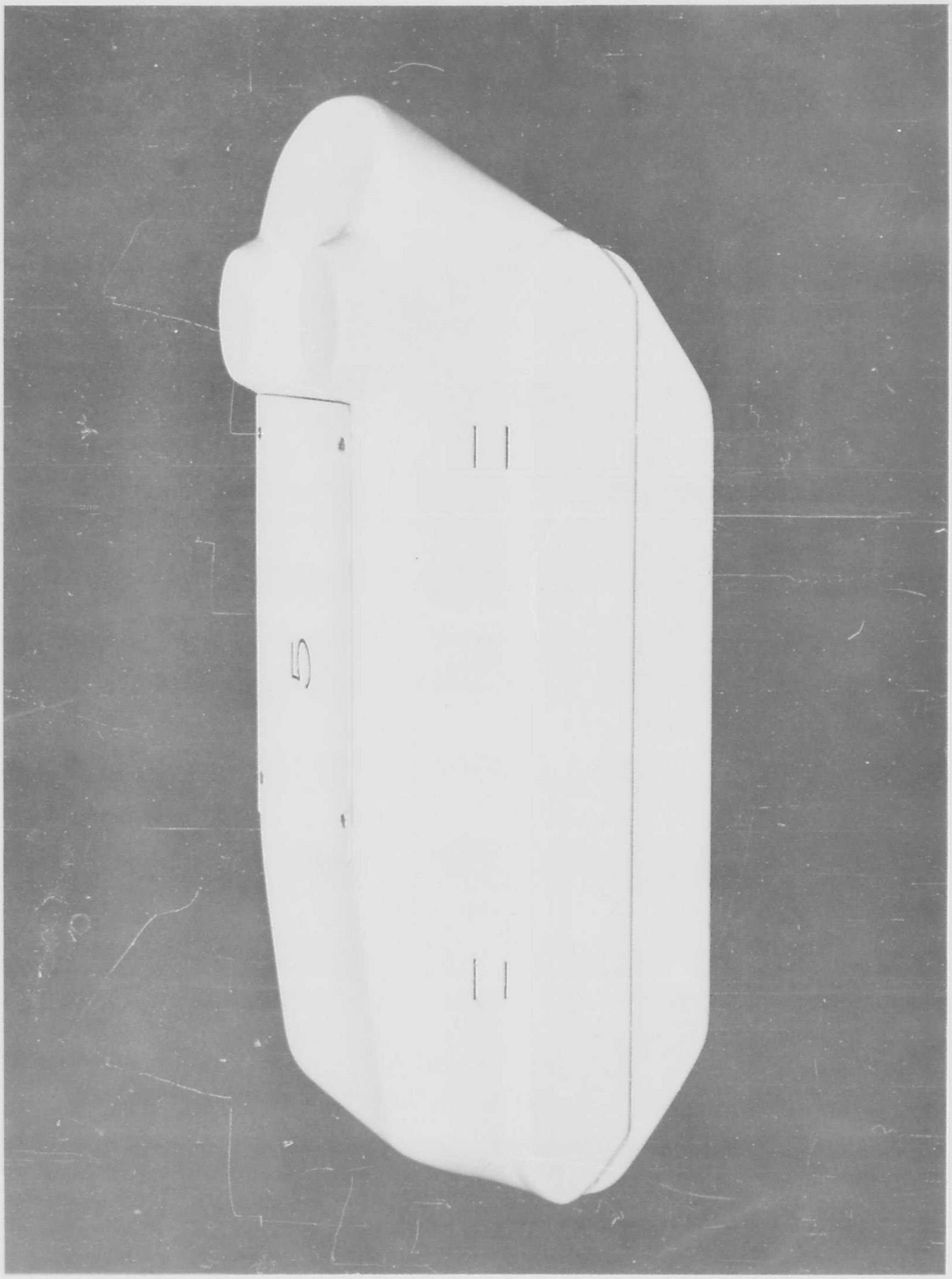


FIGURE 14

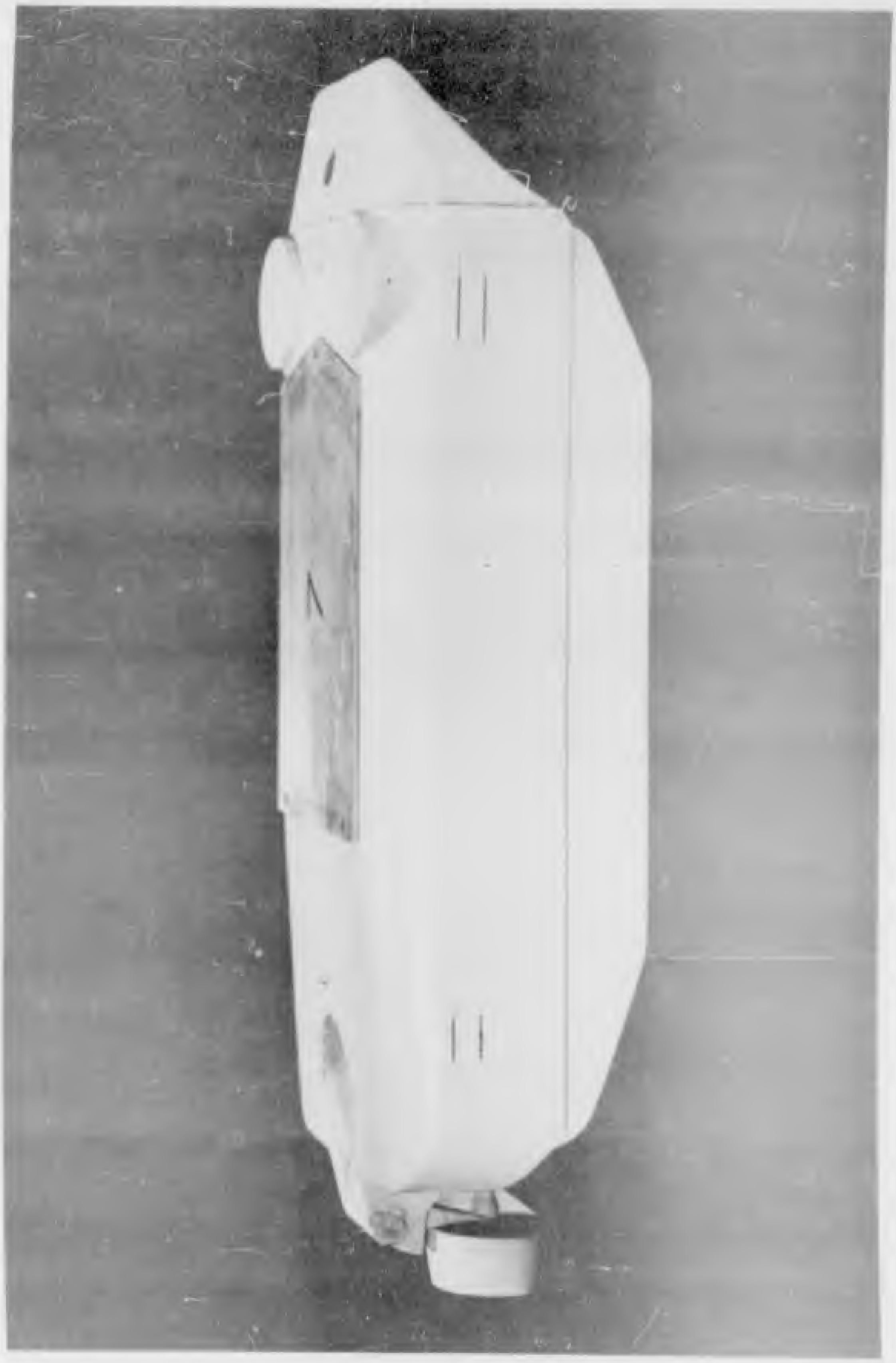


FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 18

APPENDIX G

TOW TEST FILM

This Appendix is 16mm motion-picture film included under separate cover and identified as Appendix G to this report.

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