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VIBRATION ANALYSIS"

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SM-48944

THOR-AGENA LATERAL BENDING
VIBRATION ANALYSIS

By

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FINAL REPORT
5 July 1965

Prepared for:
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ABSTRACT

B4126
A lateral bending vibration analysis for the first three structural modes of a Thor-Agena test vehicle, being tested at the Langley Research Center, is presented in this report. The analysis includes the effects of rotary inertia, transverse shear and propellant sloshing. Numerical results were obtained using a standard Douglas program (DBII) on the IBM 7094 computer.

DESCRIPTORS

Thor-Agena

Beam Dynamics

Propellant Sloshing

Myklestad's Method

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Nomenclature

x	Coordinate axis
z	Coordinate axis
α	Rotation about an axis normal to xz plane
F_1	Shear force at section (1)
M_1	Bending moment at section (1)
ψ_1	Rotation due to bending only
EI	Bending stiffness
A_sG	Shear stiffness
ω	A circular frequency
J_1'	Derivative of the Bessel function of the first kind and first order
u	Cross section shear factor
r	Radius in cylindrical coordinate form of Laplace's Equation.
f	A natural frequency (cps)
L_1	Length of beam section (1)
h	Fluid height
f_{OM}	Free-Free beam frequency, mode M
$\bar{m}_1$	Modal mass (mode 1) $\frac{\text{lb-sec}^2}{\text{in.}}$
P_{cr}	Euler buckling load



INTRODUCTION

The Langley Research Center (LRC) has been conducting a program to experimentally determine the vibration characteristics of a Thor launch vehicle and an Agena upper stage. This work began with the longitudinal oscillation characteristics and is now continuing to the lateral bending oscillation characteristics. In reference (1) the results of a vibration analysis for longitudinal frequencies and mode shapes of a number of test conditions are given. The purpose of this report is to present a similar analysis for the bending frequencies and mode shapes. The same beam type idealization of structure, the same numerical solution method and the same computer program (DBII) have been used. Shear and rotary inertia effects are included as is propellant sloshing. The results of the sloshing analysis are introduced into the bending analysis through a mechanical analogy.

The structural properties of the test vehicle given in (1) were expanded to include bending and shear stiffness for use in this analysis. There are small weight differences between these data and LRC's final measured values. To determine the influence of these differences, four of the cases were reevaluated using the LRC weights. The suspension system (Herr Harness) to be used in the test will also have some small influence on frequency and mode shape. To determine this effect, the above four cases were analyzed a third time with the vehicle restrained by springs to simulate the suspension system.

1.0 MATHEMATICAL MODELS

The vibration analyses of this report are based on two mathematical models. The bending analysis is based on the Timoshenko beam equation and the sloshing analysis on the potential function for a cylindrical tank containing a perfect fluid. The analysis of suspension system effects uses a set of equivalent springs determined from a LRC idealization of their cable system. The pertinent equations for each of these analyses are briefly developed in the following paragraphs.

1.1 Bending Vibration Analysis

The bending vibration of missile structures are most often analyzed using a beam idealization of structure. The comparisons with flight and ground test have in general been good (2). An exhaustive discussion of this entire subject may be found in (3) which also presents some comparisons between prediction and measurement on a one-fifth scale model of the Saturn. A very important but often overlooked feature of the Timoshenko beam equation that Keith et. al. (3) emphasize is the relative importance of shear and rotary inertia in the equation. For fineness ratios and (R/t) 's typical of missile structures, shear effects are much more important than rotary inertia effects. In the particular thin walled cylinder ($L/d \approx 7.5$, $R/t \approx 350$) Keith (3) uses to illustrate this point, rotary inertia is of negligible importance. The principal rotary inertia effect in the Thor-Agena analysis comes from the large concentrated mass items such as the engine section. The Timoshenko beam equation was used with the solution procedure as outlined in (1). The transfer matrix which the program (DBID) generates is,

TRANSFER MATRIX

$$\begin{bmatrix} 1 - \omega^2 [S_{ha} C_{ah} + m(C_{hh} + LC_{ah})] - \omega^2 [S_{ha} C_{aa} + m(C_{ha} + LC_{aa})] & \omega^2 m & \omega^2 (mL + S_{ha}) \\ -L - \omega^2 [IC_{ah} + S_{ah}(C_{hh} + LC_{ah})] & 1 - \omega^2 [IC_{aa} + S_{ah}(C_{ha} + LC_{aa})] & \omega^2 S_{ah} & \omega^2 (LS_{ha} + I) \\ -(C_{hh} + LC_{ah}) & -(C_{ha} + LC_{aa}) & 1 & L \\ -C_{ah} & -C_{aa} & 0 & 1 \end{bmatrix} \begin{matrix} \\ \\ \\ 1 \end{matrix}$$

where,

$$C_{zz} = \frac{L^3}{3EI} + \frac{Lu}{A_g} \quad C_{za} = C_{az} = \frac{-L^2}{2EI} \quad C_{aa} = \frac{L}{EI}$$

$$S_{za} = S_{az} = m(X_{CG_L} - X_{I+1})$$

$$\begin{bmatrix} F \\ M \\ Z \\ \alpha \end{bmatrix}_{i+1} = \begin{bmatrix} & & & \\ & & & \\ & & & \\ & & & \end{bmatrix} \begin{bmatrix} F \\ M \\ Z \\ \alpha \end{bmatrix}_i$$

When $s_{zx} = s_{xz} = 0$ these equations can be shown to be equivalent to (The sign convention for α and ψ is reversed.):

$$F_{i+1} = F_i + \omega^2 m_{i+1} z_{i+1}$$

$$M_{i+1} = M_i - F_i L_i - \omega^2 I_{i+1} \psi_{i+1}$$

$$\psi_{i+1} = \psi_i - F_i \frac{L_i^2}{2EI_i} + M_i \frac{L_i}{EI_i}$$

$$Z_{i+1} = Z_i - L_i \psi_i + F_i \left(\frac{L_i^3}{6EI_i} - \frac{\nu L_i}{A_s G_i} \right) - M_i \frac{L_i^2}{2EI_i}$$

which were developed (4) by Huang and Wu. In addition to the basic transfer matrix $[A]_i$, the branch modified transfer matrix $[A'']_i$ was used to include sloshing masses.

$$[A'']_i = \begin{bmatrix} I & M_N \\ 0 & I \end{bmatrix} [A]_i$$

where

$$[M_N] = \begin{bmatrix} \frac{\omega^2 m_N}{1 - \frac{\omega^2 m_N}{K_N}} & 0 \\ 0 & 0 \end{bmatrix}$$

The sloshing mass m_N , equivalent spring K_N and location (specified by i) were determined from the analysis of the next section. The branch modified

transfer matrix is substituted for the original transfer matrix of the section to which the branch attaches. Calculations are then made as before.

1.2 Propellant Sloshing Analysis

A simple mechanical analogy which represents the characteristics of fluid sloshing is a convenient device for studying the effects of sloshing on vehicle dynamic behavior. For equivalence, the forces and moments produced by the oscillating mechanical system are equated to those produced by the oscillating fluid. The mechanical analogy employed in this study is a mass-spring system for cylindrical tanks.

A Douglas 7094 computer program (CA04 Propellant Sloshing Parameters and Missile Physical Characteristics) was utilized to evaluate the characteristics for the mass-spring mechanical model. The program considers only the fixed mass and the fundamental sloshing mass. This simplified model produces forces equivalent to those obtained from the constant term plus the first term in the expansion of the sloshing force equation (6). The program treats the tapered Thor fuel tank by constructing an equivalent cylinder with radius equal to the radius of the conical tank at the fluid surface. The volume is made equal to that of the conical tank. The fuel tank sloshing mass-spring characteristics are then determined from the equivalent cylinder.

A complete derivation of the sloshing model characteristics employed by the program (CA04) is given in (6). The major assumptions made in the

hydrodynamical model are those that lead to Laplace's Equation.

Starting from the equation of continuity,

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_1} (\rho v_1) = 0$$

assume

$$\frac{\partial \rho}{\partial t} = 0 \quad \text{-----} \quad \text{Steady Flow}$$

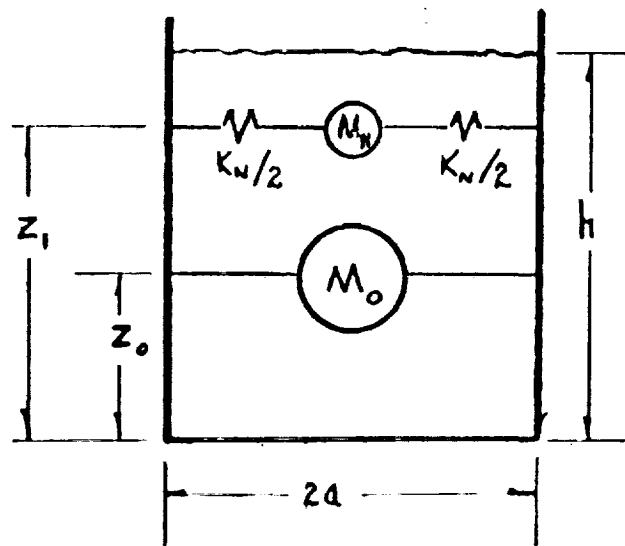
$$\frac{\partial \rho}{\partial x_1} = 0 \quad \text{-----} \quad \text{Incompressible Flow}$$

$$\nabla \times \mathbf{v} = 0 \quad \text{-----} \quad \text{Irrotational Flow}$$

which leads to Laplace's Equation.

$$\nabla^2 \phi = 0 \quad , \quad \mathbf{v} = \nabla \phi$$

The additional assumptions of a non-viscous fluid, smooth rigid tank walls and small amplitude disturbing forces are made. Applying the boundary conditions of; fluid velocity normal to the tank wall must coincide with the normal velocity of the wall and constant free surface pressure, the potential function ϕ for harmonic motion is found.



The natural frequencies and the forces and moments about the fluid center of mass are then found. The mechanical analog characteristics are determined by equating these forces and moments.

The resulting equations for one sloshing mass are:

$$f_1 = \frac{1}{2\pi} \left[\frac{g\epsilon_1}{a} \tanh \frac{\epsilon_1 h}{a} \right]^{1/2}$$

$$m_1 = \frac{M 2a \tanh \frac{\epsilon_1 h}{a}}{\epsilon_1 h (\epsilon_1^2 - 1)}$$

$$z_1 = \frac{h}{2} \left[1 - \frac{\tanh (\epsilon_1 h / 2a)}{\epsilon_1 h / 2a} \right]$$

$$m_o = M - m_1$$

$$z_o = \frac{Mh}{2m_o} - \frac{m_1 z_1}{m_o}$$

where

$$\epsilon_1 = 1.84135 \text{ (first root of } J_1'(r) = 0)$$

g = Vertical Acceleration

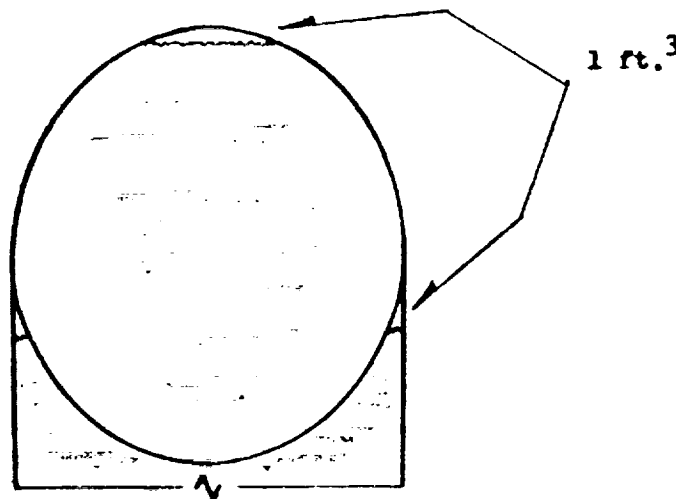
M = Total Fluid Mass

In the bending analysis, the fixed mass m_o is redistributed as a running weight (lbs/in) in the tanks. The sloshing mass is considered as a point mass in the bending analysis and sprung off the main beam on a linear spring determined by the sloshing frequency.

There is a cylindrical tube running the length of the LOX tank located approximately in the center of the tank. The effect of this tube on the sloshing analysis is negligible. Bauer (13) investigated the general case of a ring tank and shows almost no frequency shift in the

first mode over the case where there is no inner cylinder. In fact for diameter ratios under 10%, there is little change in frequency for any mode.

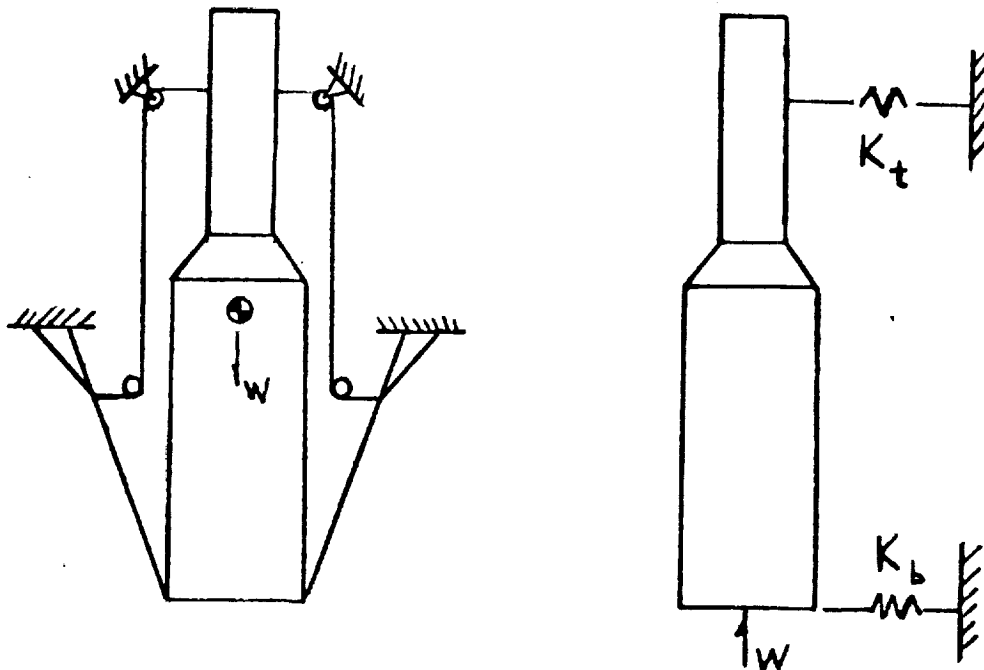
The fully loaded Agena was not given a sloshing mass because of the very small ullage volume (1 ft.³).



With the tank nearly full, the sloshing mass approaches zero in the spherical upper tank. Anderson (5) shows the ratio of sloshing mass to total mass goes linearly to zero with increasing aspect ratio ($h/2a$) in the 90 to 100% range. In the lower tank with the same ullage volume, the sloshing effects would seem even smaller because of the smaller free fluid surface. However there is no analysis to support this intuitive observation.

1.3 Herr Harness System

In the planned testing at LRC, the missile will be suspended vertically by a cable system known as the Herr Harness.



An analysis of this system by LRC produced the following equations for the effective springs K_t and K_b ;

$$K_t = \frac{W}{\frac{L^2}{d} - S} \qquad K_b = \frac{W}{S}$$

With this suspension arrangement, there will be a lg axial load condition which will have a small influence on frequency and mode shape. This influence will tend to cancel the lateral spring effect on frequency. Seide(8) has shown that the influence on free frequencies can be estimated by

$$\frac{f_M}{f_{OM}} = \left(1 - \frac{P}{P_{CM}} \right)^{2/3}$$

()
for a uniform beam. For $P = W$, the effect on the first mode is approximated by

$$\frac{f_1}{f_{01}} = \left(1 - \frac{g/\omega_1^2 L}{0.0513}\right)^{2/3}$$

The numerical results of this report do not reflect the axial load influence.

2.0 STRUCTURAL PROPERTIES

A tabular listing of the weight and stiffness properties of the test vehicle are presented in this section. Graphical displays of these same data are contained in Appendix A. The basic weight information was obtained from (1) the earlier longitudinal oscillation analysis. Modifications were made to this data per information received from the Langley Research Center on actual weight measurements.

The stiffness parameters (flexural rigidity EI and shear stiffness AG/μ) of the Thor-Agena test vehicle were analytically determined from the cross sectional properties (moment of inertia I and gross area A) and material properties (modulus of elasticity E and shear modulus G) at selected vehicle stations. Piecewise smooth curves of EI and AG/μ were constructed to obtain the stiffness distributions required for input to the DB-11 computer program.

The cross sectional properties for the skin and stringer construction of the Thor transition section, center body, skirt, and engine section employ the assumption that the moments of inertia of the stringers about their own axes may be neglected in the computation of the total section moment of inertia about the neutral axis.

The cross sectional area in every case is based on the total shear resistant area.

The properties for the waffle skin construction of the Thor fuel and lox tanks are based on the average thickness of the skin plus stiffeners

(weight average). These thickness values are;

$$\bar{t}_{\text{fuel tank}} = 0.0759 \text{ in.}$$

$$\bar{t}_{\text{lox tank}} = 0.0709 \text{ in.}$$

The assumption of thin circular shell sections was made and the following equations used for the gross area A and the moment of inertia I:

$$A = 2\pi r t$$

$$I = \pi r^3 t$$

where r = shell radius

t = skin thickness

The section form factor μ is equal to 2.0 for a thin walled cylinder (3).

In general, the material constants, E and G depend on temperature and rate of loading. However, for room temperature conditions, there is a lack of frequency dependence and the static values may be used (12).

The material values used for the Thor vehicle were

$$E (\text{aluminum alloy}) = 10.6 \times 10^6 \text{ psi}$$

$$G (\text{aluminum alloy}) = 4.0 \times 10^6 \text{ psi}$$

Those for the magnesium alloy sections of the Agena test vehicle were obtained from Mil HDBK-5

$$E (\text{magnesium alloy}) = 6.5 \times 10^6 \text{ psi}$$

$$G (\text{magnesium alloy}) = 2.4 \times 10^6 \text{ psi}$$

The Agena tank section stiffness characteristics were obtained from a Lockheed memorandum dated 12-17-59 for the "B" tank configuration.

2.1 Thor-Agena Structure

2.1.1 Test Vehicle Weights

Distributed Weight Coordinates (SM-46346)

<u>Station</u>	<u>Dry weight LB/in</u>	<u>Dry weight Lb/in</u>
-138.7	0	7.886
-111.9	7.886	9.071
- 88.5	9.182	1.296
- 83.4	2.681	1.938
- 73.6	1.938	3.458
- 44.7	3.117	1.834
- 11.1	1.834	3.957
- 5.9	3.480	5.044
6.0	4.234	7.268
17.1	6.669	4.961
64.1	6.590	2.840
107.0	3.138	3.537
141.0	14.847	13.635
151.0	11.595	3.016
336.0	4.672	5.854
369.0	6.272	3.907
600.0	3.624	1.305
636.7	17.719	9.673
722.4	10.223	0

Total Agena distributed weight (Sta. -138.7 to 107) =
1,181 Lbs. at Station -30.0

Total Thor Transition Section Distributed Weight

Sta. 107 to 151 = 439 Lbs. at Station 132.8

Total Thor Distributed Weight (Sta. 151 to 722.4) = 2,982 at Station 491.5

Concentrated Weights (SM-46346)

<u>Value (Lbs.)</u>	<u>C. G.</u>	<u>Cantilevered Station</u>	
55	-116.5	-116.5	} Total = 194 Lbs. at -110.5
25	-111.5	-111.5	
104	-107.5	-107.5	
10	-106.5	-106.5	
298	56.4	26.2	} Total = 467 Lbs. at 62.3
32	72.4	64.1	
72	72.4	64.1	
65	73.4	64.1	
56	148.4	153.5	} Total = 1,665 Lbs. at 598.4
85	345.1	333.5	
129	365.0	371.5	
125	610.8	600.0	
1,271	657.6	636.7	} Total = 608 Lbs. at 626.1
131	620.7	620.7	
122	351.7	351.7	
355	722.4	722.4	

Weight Totals (SM-46346)

Agena (including Thor Transition Section) = 2281 Lbs. at Station 13.4

Thor (Sta. 151 to 722.4) = 5,255 Lbs. at Station 540.9

Thor-Agena = 7536 Lbs. at Station 381.2

Distributed Weight Coordinates (Langley Modified)

<u>Station</u>	<u>Dry Weight Lb/in</u>	<u>Dry Weight Lb/in</u>
-138.7	0	7.886
-111.9	7.886	9.071
- 88.5	9.182	1.296
- 83.4	2.681	1.938
- 73.6	1.938	3.458
- 44.7	3.117	1.834
- 11.1	1.834	3.957
- 5.9	3.480	5.044
6.0	4.234	7.268
17.1	6.669	4.961
64.1	6.590	2.840
107.0	3.138	3.537
141.0	14.847	13.635
151.0	11.595	2.969
336.0	5.164	6.895
369.0	5.460	5.132
600.0	2.704	1.305
636.7	17.719	9.673
722.4	10.223	0

Total Agena Distributed Weight (Sta. -138.7 to 107) = 1,181 Lbs. at Station -30.0

Total Thor Transition Section Distributed Weight (Sta. 107 to 151) = 439 Lbs.
at Station 132.8

Total Thor Distributed Weight (Sta. 151 to 722.4) = 3063 Lbs. at Station 485.3

Concentrated Weights (Langley Modified)

<u>Valve (Lbs.)</u>	<u>C. G.</u>	<u>Cant. Station</u>	
54.8	-116.5	-116.5	} Total = 194.8 Lbs. at Sta. -111.2
25.9	-111.5	-111.5	
104.1	-107.5	-107.5	
10.0	-116.5	-116.5	
298	56.4	26.2	} Total = 467 Lbs. at Sta. 62.3
31.9	72.4	64.1	
72	72.4	64.1	
65.1	73.4	64.1	
56	148.4	153.5	} Total = 2368.6 Lbs. at Sta. 598.18
85	345.1	333.5	
9.68	142.0	153.5	
24.45	629.7	600.0	
10.3	635.0	600.0	
129	365.0	371.5	
125	610.8	600.0	
19.5	350.0	371.5	
1311.3	657.6	636.7	
44.85	688.0	636.7	
122.4	351.7	351.7	
136.1	620.0	620.0	
294.97	695.0	695.0	

Weight Totals (Langley Modified)

Agena (including Thor Transition Section) = 2282 Lbs. at Station 13.3

Thor (Sta. 151 to 722.4) = 5432 Lbs. at Station 534.5

Thor-Agena = 7713 Lbs. at Station 380.3

2.1.2 Test Vehicle Stiffness Properties

Flexural Stiffness Coordinates

<u>Station</u>	<u>EI LB-in²</u>	<u>EI LB-in²</u>
-138.7	0	.1237 x 10 ¹²
- 137.1	.0579 x 10 ¹²	.0579
-114.8	.0579	.0634
- 82.6	.0634	.0600
- 66.6	.0600	.0520
- 12.6	.0770	.0690
- 5.8	.0690	.0799
5.9	.0799	.0902
88.9	.0902	.0696
90.0	.0696	.0696
107.0	.0821	.0668
115.0	.0668	.0691
125.0	.0691	.0770
140.0	.0770	.0849
151.0	.0849	.439
156.9	.439	.137
200.0	.165	.165
250.0	.202	.202
300.0	.247	.247
330.1	.275	.924
336.0	.924	.240
369.0	.240	.924
374.9	.924	.262
596.6	.262	.924
604.6	.924	.225
636.7	.225	.402
641.8	.402	.402
688.0	.365	.336
715.0	.372	.372 x 10 ¹²
722.0	.372 x 10 ¹²	0

Shear Stiffness Coordinates

<u>Station</u>	<u>AG/μ Lbs.</u>	<u>AG/μ Lbs.</u>
-138.7	0	.478 x 10 ⁸
-137.1	.237 x 10 ⁸	.237
-114.8	.237	.260
- 82.6	.260	.225
- 66.6	.225	.200
- 12.6	.295	.285
- 5.8	.285	.328
5.9	.328	.367
88.9	.367	.283
90.0	.283	.283
107.0	.300	.417
115.0	.417	.360
125.0	.360	.392
140.0	.392	.470
151.0	.470	1.18
156.9	1.18	.360
330.1	.455	1.51
336.0	1.51	.470
369.0	.470	1.51
374.9	1.51	.427
596.6	.427	1.51
604.6	1.51	.542
636.7	.542	.915
641.8	.915	.915
688.0	.718	.718
715.0	.790	.790 x 10 ⁸
722.0	.790 x 10 ⁸	0

2.2 Sloshing Parameters

CHARACTERISTICS OF THOR FUEL AND LOX SLOSHING MASSES

(For 1stg" Axial Acceleration)

0% Burntime:

$m_f = 2,357$ Lbs.	$C.G._f = 202.55$	$f_f = .6912$ cps.	$K_f = 115.1$ Lb/in
$m_L = 6,468$ Lbs.	$C.G._L = 432.14$	$f_L = .6128$ cps.	$K_L = 248.2$ Lb/in

25% Burntime:

$m_f = 2,985$ Lbs.	$C.G._f = 258.86$	$f_f = .6646$ cps.	$K_f = 134.7$ Lb/in
$m_L = 6,468$ Lbs.	$C.G._L = 489.30$	$f_L = .6128$ cps.	$K_L = 248.2$ Lb/in

40% Burntime:

$m_f = 3,366$ Lbs.	$C.G._f = 288.63$	$f_f = .6513$ cps.	$K_f = 145.9$ Lb/in
$m_L = 6,467$ Lbs.	$C.G._L = 523.19$	$f_L = .6127$ cps.	$K_L = 248.1$ Lb/in

50% Burntime:

$m_f = 3,615$ Lbs.	$C.G._f = 306.04$	$f_f = .6430$ cps.	$K_f = 152.7$ Lb/in
$m_L = 6,465$ Lbs.	$C.G._L = 545.19$	$f_L = .6126$ cps.	$K_L = 248.0$ Lb/in

75% Burntime:

$m_f = 3,844$ Lbs.	$C.G._f = 334.27$	$f_f = .5953$ cps.	$K_f = 139.2$ Lb/in
$m_L = 6,257$ Lbs.	$C.G._L = 591.71$	$f_L = .6027$ cps.	$K_L = 232.2$ Lb/in

() 2.3 TEST VEHICLE LIQUID WEIGHTS

AGENDA (LOADED)

DISTRIBUTED WEIGHTS COORDINATES

<u>STATION</u>	<u>LIQUID WEIGHT</u>	<u>LB/IN</u>	<u>LIQUID WEIGHT</u>	<u>LB/IN</u>
-111.9	0		35.00	
-88.5	68.38		68.38	
-73.6	68.38		68.38	
-61.6	57.00		92.50	
-42.6	160.0		160.0	
-7.0	160.0		160.0	
17.1	35.00		0	

Total distributed weight (IRFNA plus UDMH) = 13,426 lbs.

Total IRFNA = 9650 lbs. (SM46346)

Total UDMH = 3776 lbs. (SM46346)

Total (IRFNA plus UDMH) = 13,426 lbs (SM 46346)

THOR LIQUID WEIGHTS

0 PERCENT BURNTIME

DISTRIBUTED WEIGHT COORDINATES

<u>STATION</u>	<u>LIQUID WEIGHT</u>	<u>LB/IN</u>	<u>LIQUID WEIGHT</u>	<u>LB/IN</u>
161.58	0		138.0	
194.975	152.7		0	
210.125	0		159.4	
333.50	217.52		0	
373.52	0		288.30	
420.925	288.30		0	
443.355	0		288.30	
600.00	288.30		0	

Total distributed weight (fuel plus lox) = 86,903 lbs.

CONCENTRATED WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	<u>CANTILEVERED STATION</u>	
1836	344.2	333.5	(Fuel)
2381	610.7	600.0	(lox)

Total concentrated weight (fuel plus lox) - 4217 lbs.

SLOSHING WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	
2357	202.55	(Fuel)
6468	432.14	(Lox)

Total sloshing weight (fuel plus lox) = 8825 lbs.

Total liquid weight (0% burntime) = 99,945 lbs.

Total lox weight - 67,675 lbs.

Total fuel weight = 32,270 lbs.

25 PERCENT BURNTIME

DISTRIBUTED WEIGHT COORDINATES

<u>STATION</u>	<u>LIQUID WEIGHT LB/IN</u>	<u>LIQUID WEIGHT LB/IN</u>
214.65	0	161.4
250.635	177.6	0
267.085	0	185.5
333.5	217.52	0
432.47	0	288.30
478.085	288.30	0
500.515	0	288.30
600.0	288.30	0

Total distributed weight (fuel plus lox) = 61,366 lbs.

CONCENTRATED WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	<u>CANT. STATION</u>	
1836	344.2	333.5	(fuel)
2381	610.7	6000.0	(lox)

Total concentrated weight (fuel plus lox) = 4217 lbs.

SLOSHING WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	
2985	258.86	(fuel)
6468	489.30	(lox)

Total concentrated weight (fuel plus lox) = 9453 lbs.

Total liquid weight (25% burntime) = 75,036 lbs.

Total lox weight = 50,679 lbs.

Total fuel weight = 24,357 lbs.

40 PERCENT BURNTIME

DISTRIBUTED WEIGHT COORDINATES

<u>STATION</u>	<u>LIQUID WEIGHT</u>	<u>LB/IN</u>	<u>LIQUID WEIGHT</u>	<u>LB/IN</u>
243.34	0		170.2	
280.030	191.6		0	
297.230	0		200.0	
333.5	217.52		0	
467.81	0		288.30	
511.975	288.30		0	
534.405	0		288.30	
600.0	288.30		0	

Total distributed weight (fuel plus lox) = 45,989 lbs.

CONCENTRATED WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	<u>CANT. STATION</u>	
1836	344.2	333.5	(fuel)
2381	610.7	600.0	(lox)

Total concentrated weight (fuel plus lox) = 4217 lbs.

SLOSHING WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	
3366	288.63	(fuel)
6467	523.19	(lox)

Total sloshing weight (fuel plus lox) = 9833 lbs.

Total Liquid weight (40% burntime) = 60,039 lbs.

Total lox weight = 40,492 lbs.

Total fuel weight = 19,547 lbs.

50 PERCENT BURNTIME

DISTRIBUTED WEIGHT COORDINATES

<u>STATION</u>	<u>LIQUID WEIGHT LB/IN</u>	<u>LIQUID WEIGHT LB/IN</u>
261.27	0	182.7
297.195	200.0	0
314.885	0	208.5
333.5	217.52	0
491.33	0	288.3
533.98	288.3	0
556.40	0	288.3
600.0	288.3	0

Total distributed weight (fuel plus lox) = 35,757 lbs.

() CONCENTRATED WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	<u>CANT. STATION</u>	
1836	344.2	333.5	(fuel)
2381	610.7	600.0	(lox)

Total concentrated weight (fuel plus lox) = 4217 lbs.

SLOSHING WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	
3615	306.04	(fuel)
6465	545.19	(lox)

Total sloshing weight (fuel plus lox) = 10,080 lbs.

Total liquid weight (50% burntime) = 50,054 lbs.

Total lox weight = 33,711 lbs.

Total fuel weight = 16,343 lbs.

75 PERCENT BURNTIME

DISTRIBUTED WEIGHT COORDINATES

<u>STATION</u>	<u>LIQUID WEIGHT LB/IN</u>	<u>LIQUID WEIGHT LB/IN</u>
302.75	0	202.5
323.00	212.5	0
333.50	0	0
549.88	0	288.3
580.86	288.3	0
600.00	0	0

Total distributed weight (fuel plus lox) = 13,162 lbs.

CONCENTRATED WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	<u>CANT. STATION</u>	
244	348.0	333.5	(fuel)
1643	611.6	600.0	(lox)

Total concentrated weight (fuel plus lox) = 1887 lbs.

SLOSHING WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	
3844	334.27	(fuel)
6257	591.71	(lox)

Total sloshing weight (fuel plus lox) = 10,101 lbs.

Total liquid weight (75% burntime) = 25,150

Total fuel weight = 8,319 lbs.

100 PERCENT BURNTIME

CONCENTRATED WEIGHTS

<u>VALUE</u>	<u>C.G.</u>	<u>CANT. STATION</u>	
268	348.0	333.5	(fuel)
132	615.0	600.0	(lox)

Total concentrated weight (fuel plus lox) = 400 lbs.

Total liquid weight (100% burntime) = 400 lbs.

2.4 Herr Harness Spring Constants

The equivalent lateral spring constants (K_b , K_t) for the Herr Harness were received from LRC.

Configuration		K_b (Lb/in)	K_t (Lb/in)
1. Thor (SM 46346)	Dry	8.7	4.4
2. Thor (LRC)	Dry	9.0	4.8
3. Thor (SM 46346)	0% B.T.	175.0	216.0
4. Thor (LRC)	0% B.T.	175.0	216.0
5. Thor-Agena (SM 46346)	Dry	12.5	14.9
6. Thor-Agena (LRC)	Dry	12.8	15.3
7. Thor-Agena (SM 46346)	0% B.T.	178.0	172.0
8. Thor-Agena (LRC)	0% B.T.	179.0	172.0

Spring K_b is located @ Station 722

Spring K_t is located @

Station 151 (Thor cases)

Station 107 (Thor-Agena cases)

3.0 NATURAL FREQUENCIES

The bending vibration analysis included twenty (21) configurations of the Thor-Agena test vehicle. A complete set of mode shapes and frequencies up to and including the third elastic bending mode were computed for each configuration.

3.1 Thor Cases

The Thor cases analyzed are described in the following table and given case designations.

<u>% Burntime</u>	<u>Unrestrained and SM 46346 Weights</u>	<u>Harness Suspension and SM 46346 Weights</u>	<u>Harness Suspension and LRC Weights</u>
0%	T1	T7	T9
25%	T2		
50%	T3		
75%	T4		
100%	T5		
Empty	T6	T8	T10

The natural frequencies for these cases are given in the following table.

<u>Case</u>	<u>f_1 (cps.)</u>	<u>f_2 (cps.)</u>	<u>f_3 (cps.)</u>
T1	9.975	19.49	29.21
T2	12.90	26.02	33.63
T3	17.23	37.31	42.96
T4	25.54	48.63	78.72
T5	36.87	69.35	123.19
T6	37.40	73.16	125.9

T 7	9.990	19.50	29.22
T 8	37.40	73.16	125.9
T 9	10.02	19.61	29.50
T 10	37.54	76.65	128.8

3.2 Thor-Agena Cases

The Thor-Agena cases are described in the following table and given case designations

<u>% Burntime</u>	<u>Unrestrained and SM 46346 Weights</u>	<u>Harness Suspension and SM 46346 Weights</u>	<u>Harness Suspension and LRC Weights</u>
0%	TA 1	TA 8	TA 10
25%	TA 2		
40%	TA 3		
50%	TA 4		
75%	TA 5		
100%	TA 6		
Empty	TA 7	TA 9	TA 11

The natural frequencies for these cases are given in the following table.

<u>Case</u>	<u>f_1 (cps.)</u>	<u>f_2 (cps.)</u>	<u>f_3 (cps.)</u>
TA 1	4.105	11.31	18.93
TA 2	4.560	13.64	20.32
TA 3	4.983	15.44	20.69
TA 4	5.361	16.74	21.29
TA 5	7.193	19.09	28.21
TA 6	9.712	22.29	43.53
TA 7	12.62	30.77	60.38

<u>Case</u>	<u>f₁ (cps.)</u>	<u>f₂ (cps.)</u>	<u>f₃ (cps.)</u>
TA 8	4.115	11.32	18.94
TA 9	12.62	30.77	60.38
TA 10	4.119	11.36	19.00
TA 11	12.53	30.73	62.70

3.3 Mount Mode Cases

In the harness suspension cases there are two "mount" modes below the elastic body free-free modes. These frequencies are tabulated in this section. There are also two sloshing modes below the first elastic body mode but these frequencies proved to be so close to an asymptote that they could not be evaluated using DB11.

THOR

<u>% Burntime</u>	<u>SM 46346 Weights</u>	<u>LPC Weights</u>
0	ST 1	ST 3
Empty	ST 2	ST 4

THOR-AGENA

<u>% Burntime</u>	<u>SM 46346 Weights</u>	<u>LPC Weights</u>
0	STA 1	STA 3
Empty	STA 2	STA 4

The natural frequencies for these cases are:

<u>Case</u>	<u>f₁ (cps.)</u>	<u>f₂ (cps.)</u>
ST 1	0.1892	0.4066
ST 2	0.1560	0.2506
ST 3	0.1891	0.4069
ST 4	0.1575	0.2564
ST 1	0.1633	0.2698
ST 2	0.1887	0.2038
ST 3	0.1634	0.2704
ST 4	0.1888	0.2068

4.0 SUMMARY

The bending vibration analysis performed for the Thor-Agena test vehicle was based on standard beam analysis methods. There were no unusual features in the results obtained. The transfer matrix technique used is noted (7) for numerical inaccuracies in the higher modes and care was taken on this point. The program orthogonality checks were monitored carefully. All frequency data reported are numerically accurate to four places after the decimal point. In a few cases where slow convergence of modal shape was suspected, the cases were re-analyzed and the iteration carried to two more digits accuracy on frequency.

Using a mechanical analogy for the sloshing analysis introduces local errors in the resulting mode shapes. A "sloshing mass" will cause the shear (hence mode shape) to change at the attachment point when the change is really distributed over a finite length. This discrepancy is greatly mitigated by the low sloshing frequencies. The influence of the Herr Harness suspension system was shown to be less than 1/2% on frequency and mode shape. (The modal mass was used as a measure of change in mode shape.) Even this small influence was only incurred in the 0% Burntime cases. Since the effective spring constants for the suspension system increase linearly with weight, this result is to be expected.

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13. Bauer, H. F., "Theory of the Fluid Oscillations in a Circular Cylindrical Ring Tank Partially Filled With Liquid", NASA TN-D-557, Dec. 1960.

Appendix A
Structural Properties

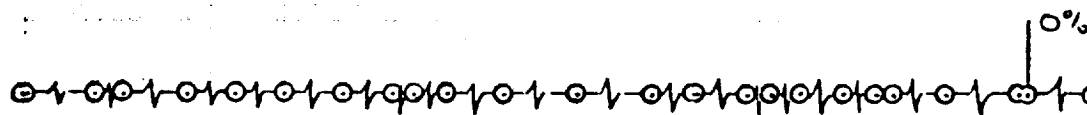
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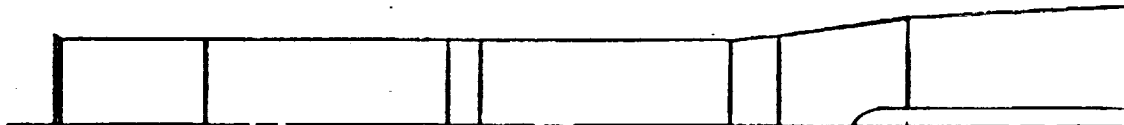


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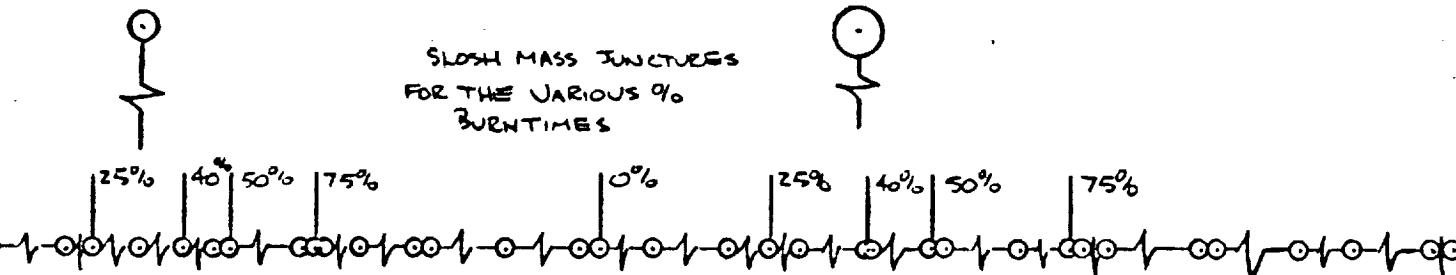


THOR-AGENA TEST VE

THOR FUEL SLOSH MASS

THOR LOX SLOSH MASS

SLOSH MASS JUNCTURES
FOR THE VARIOUS %
BURNTIMES



MAIN BEAM

59 MASSES WITH

58 INTERCONNECTING SPRINGS

TATION

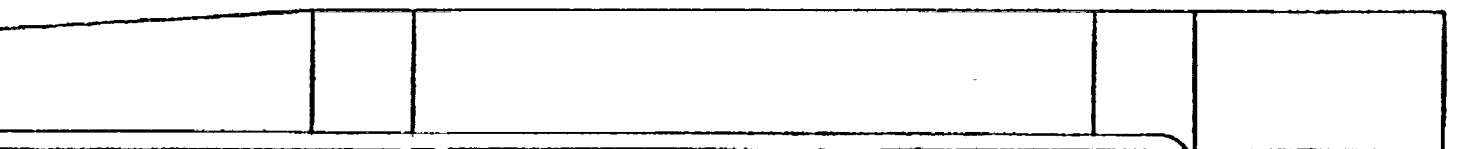
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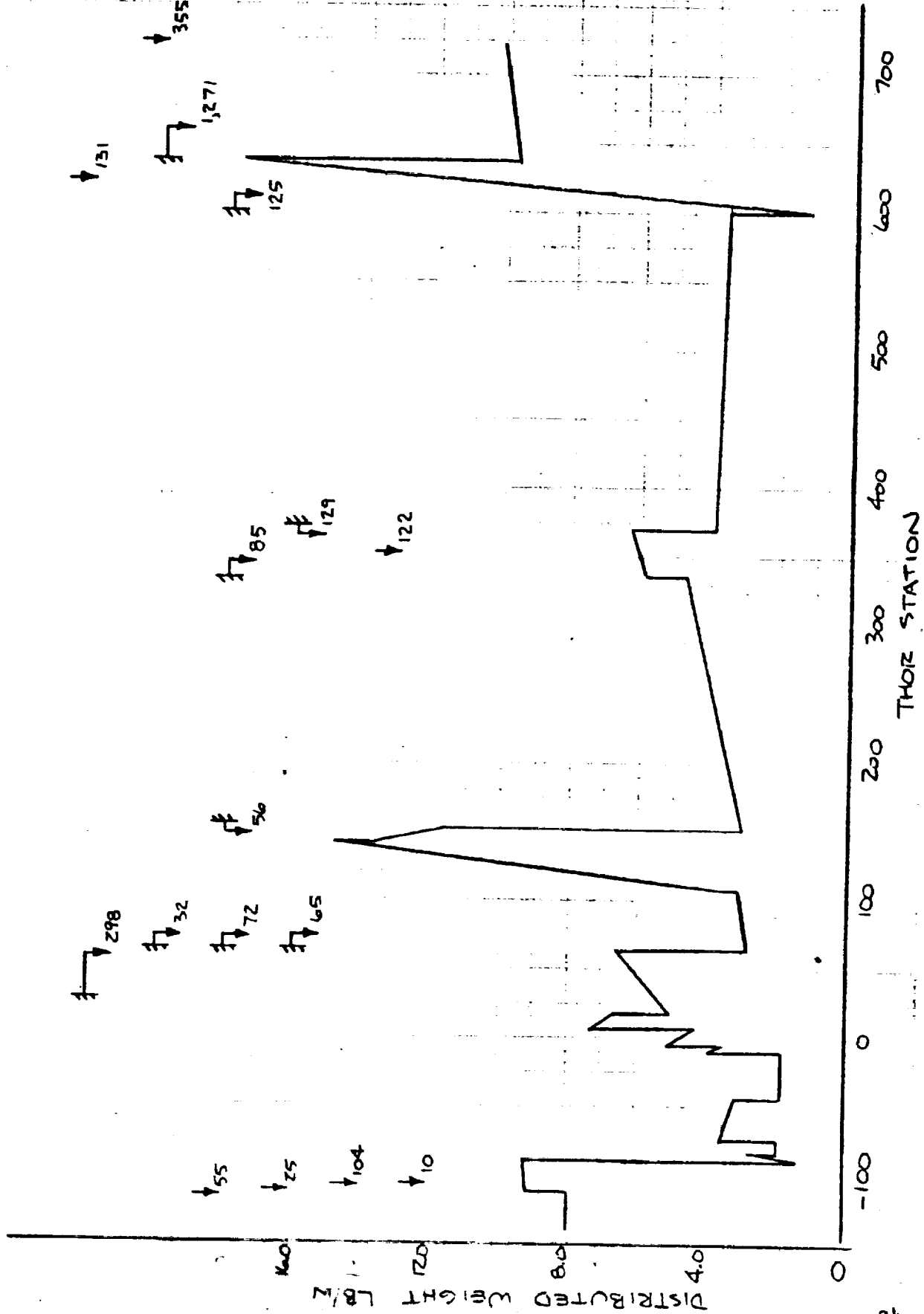
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VEHICLE & IDEALIZATION

THOR - AGENA DRY WEIGHTS



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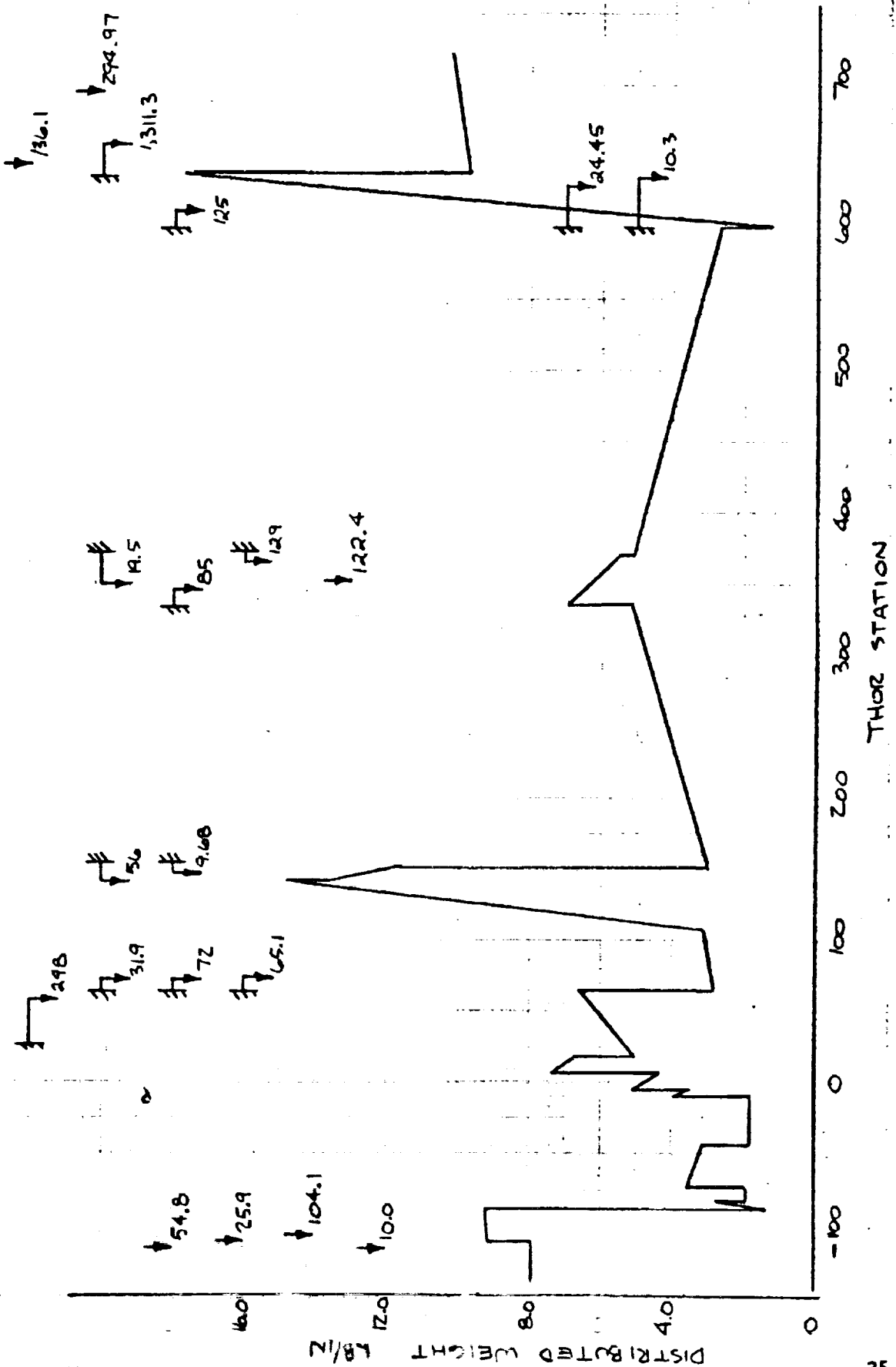
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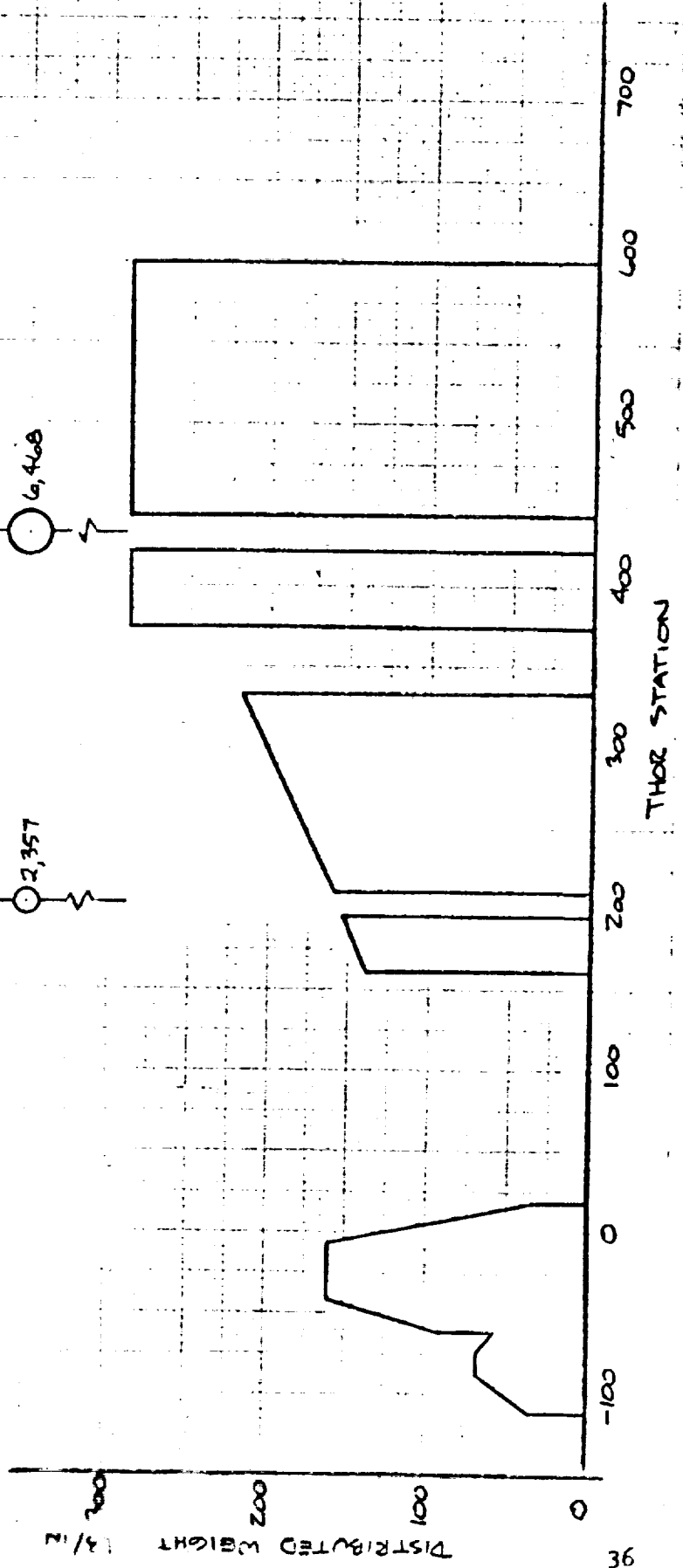
THOR-AGENA DRY WEIGHTS LANGLEY MODIFIED



THOR-AGENA LIQUID WEIGHTS 0% BURN TIME

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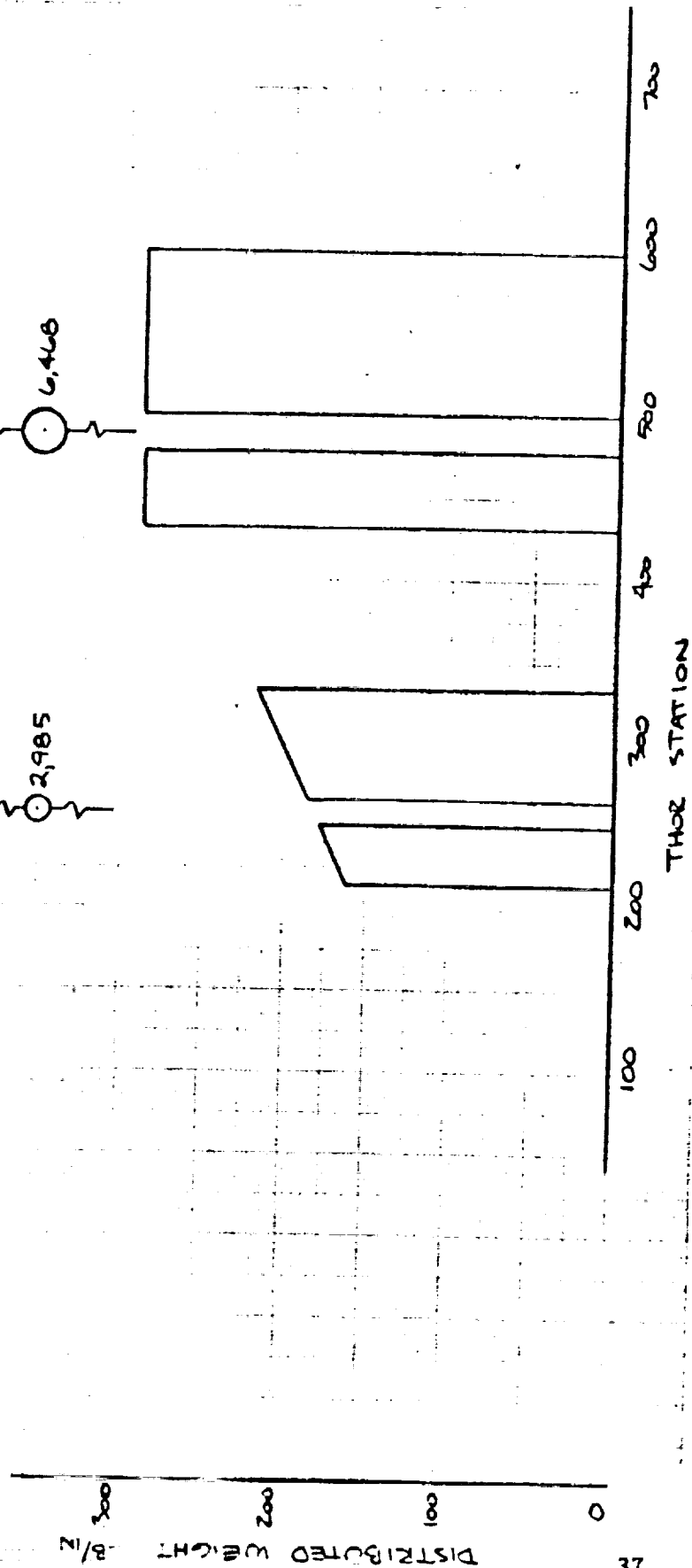
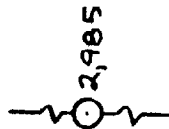
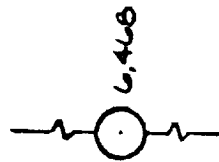
17 2,381



THOR LIQUID WEIGHTS
25% BURN TIME

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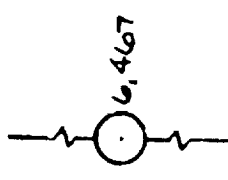
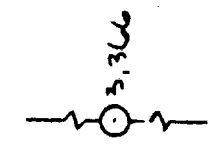


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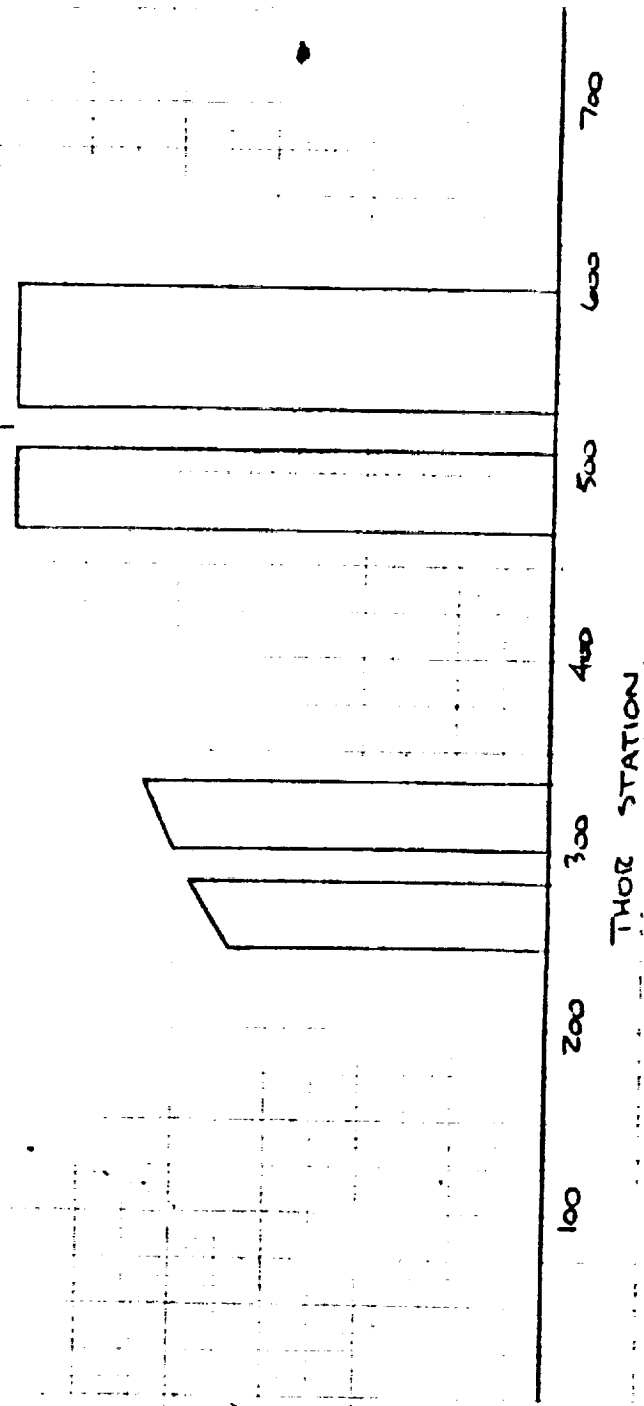
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40% BURN TIME

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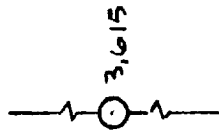
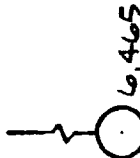


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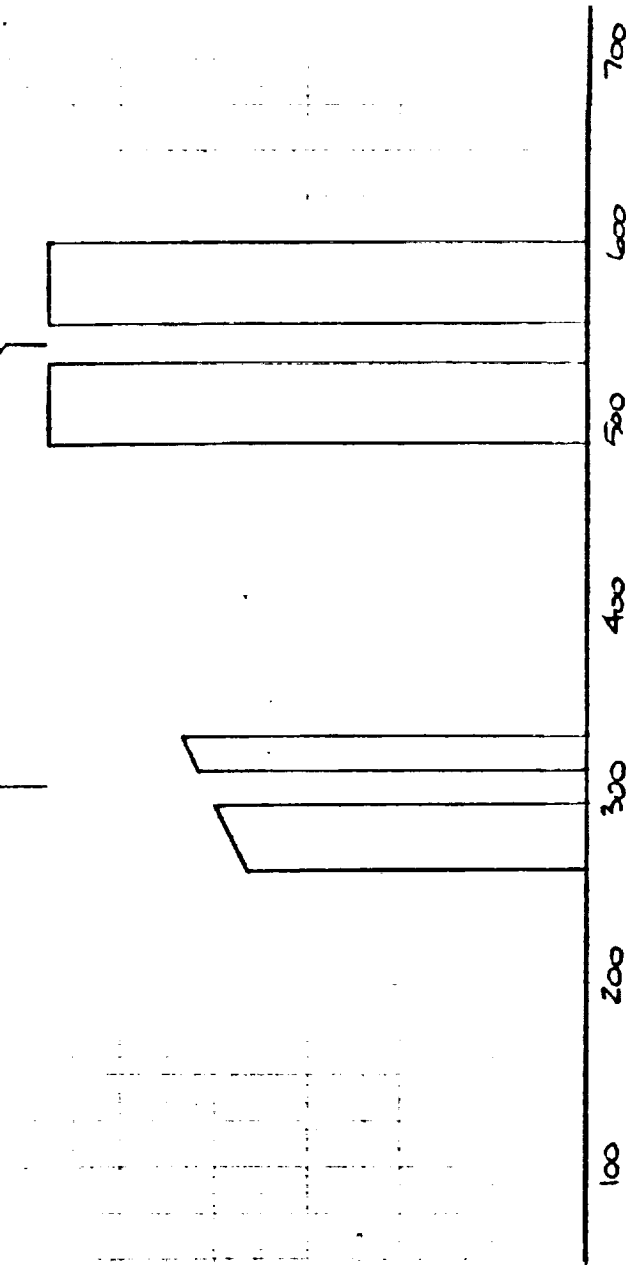
THOR LIQUID WEIGHTS
50% BURNTIME

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17 1,836



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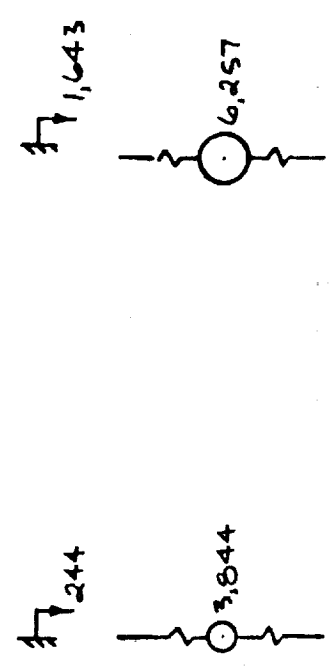


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THOR LIQUID WEIGHTS
75% BURNTIME



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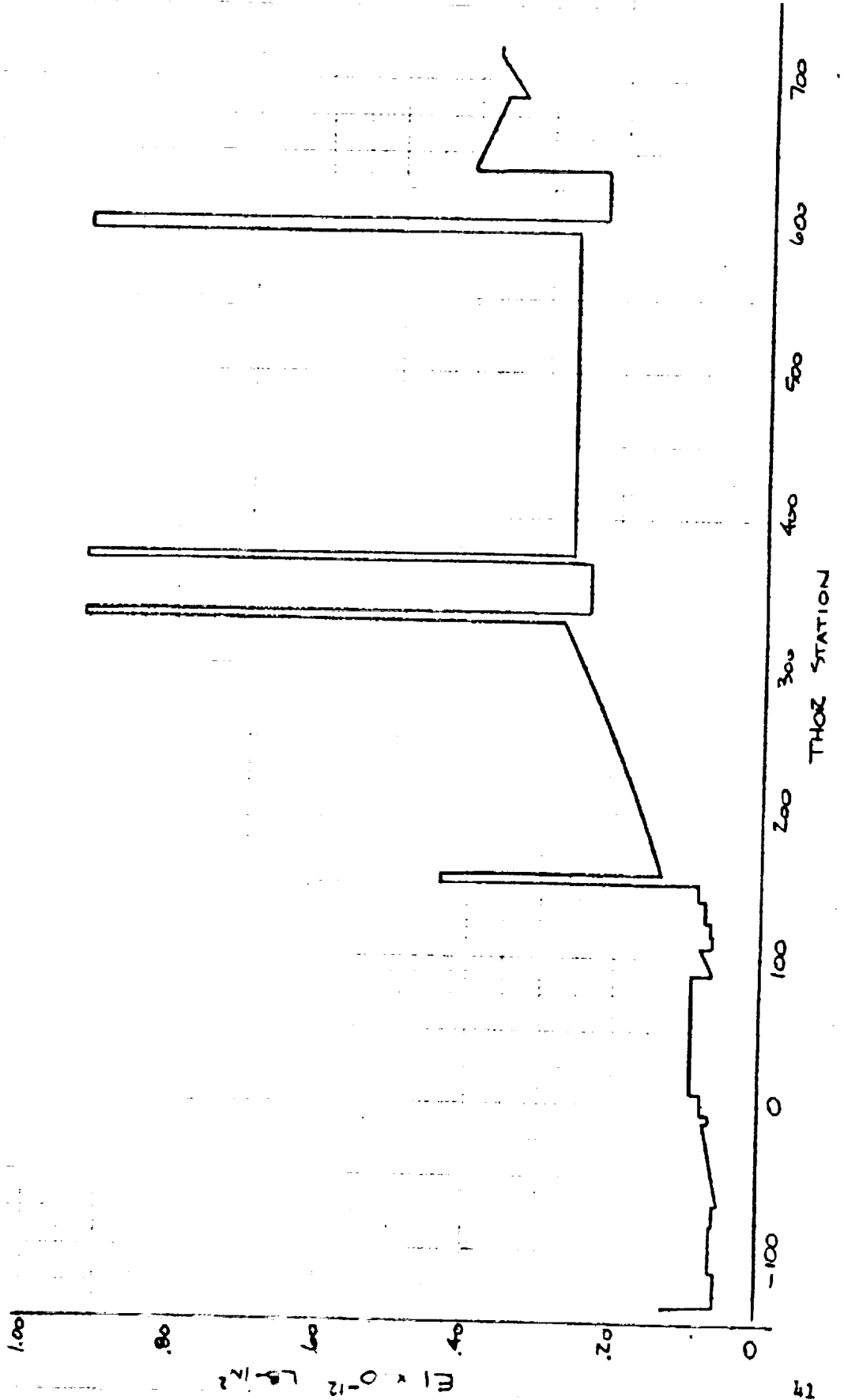
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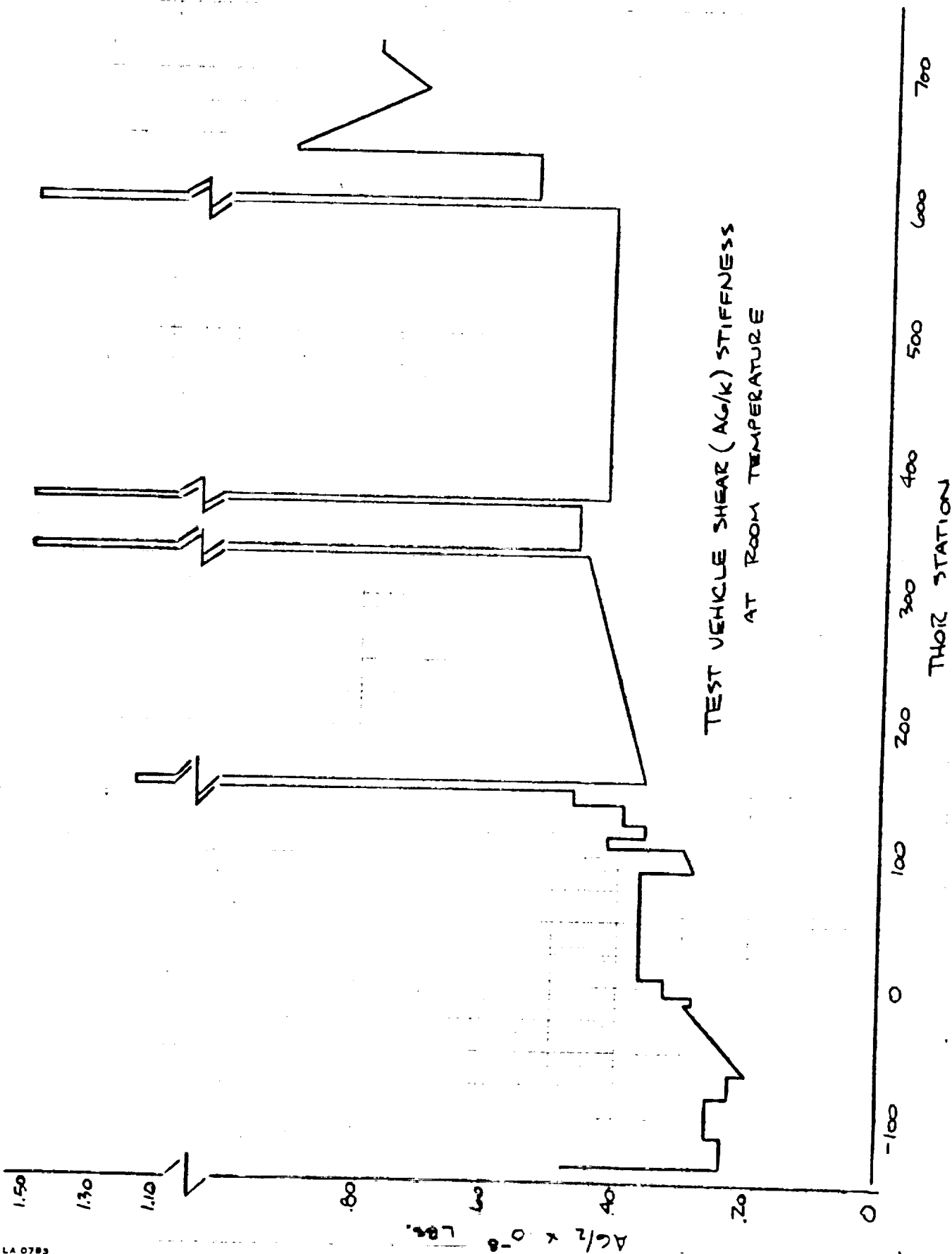
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Appendix B

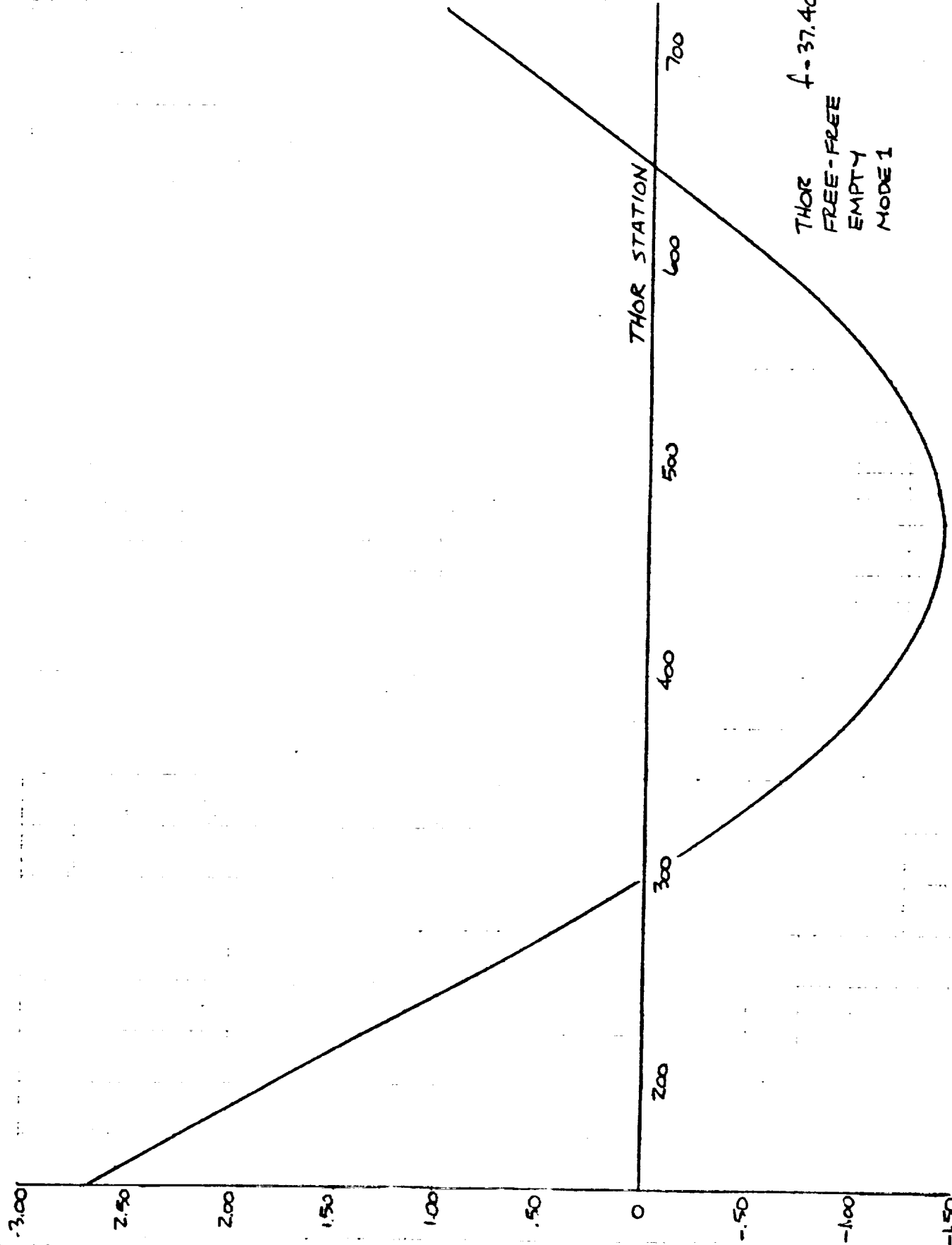
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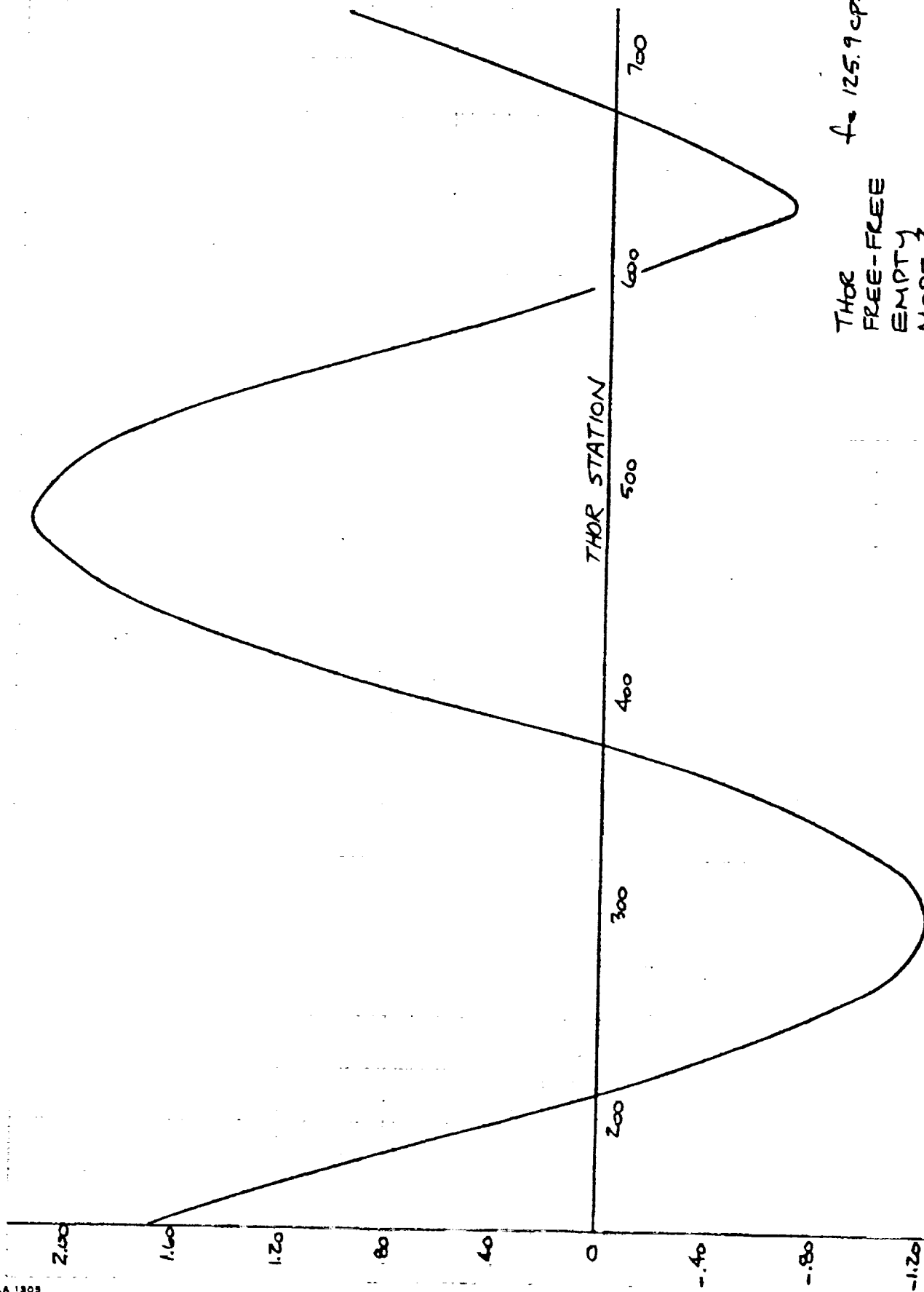
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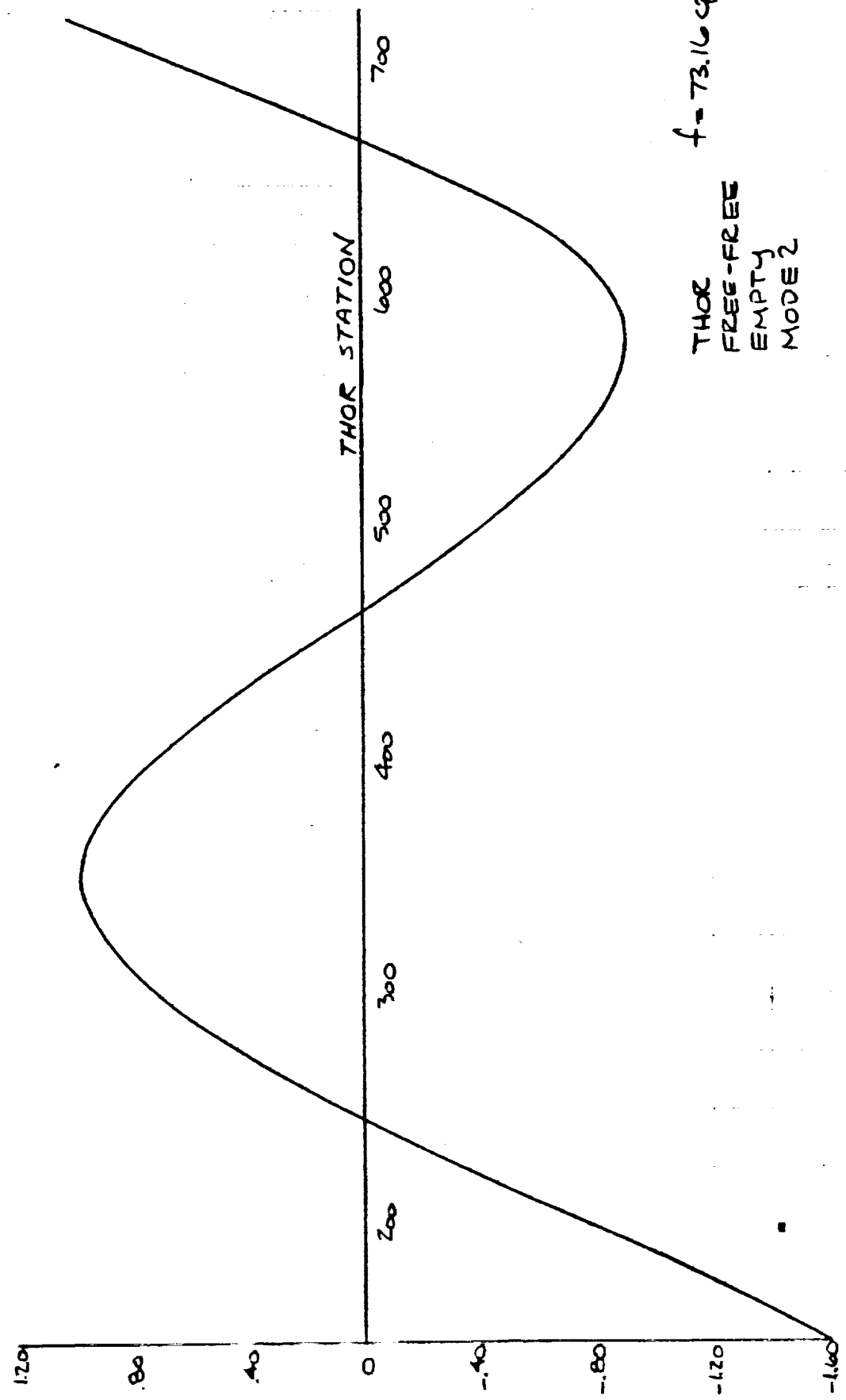


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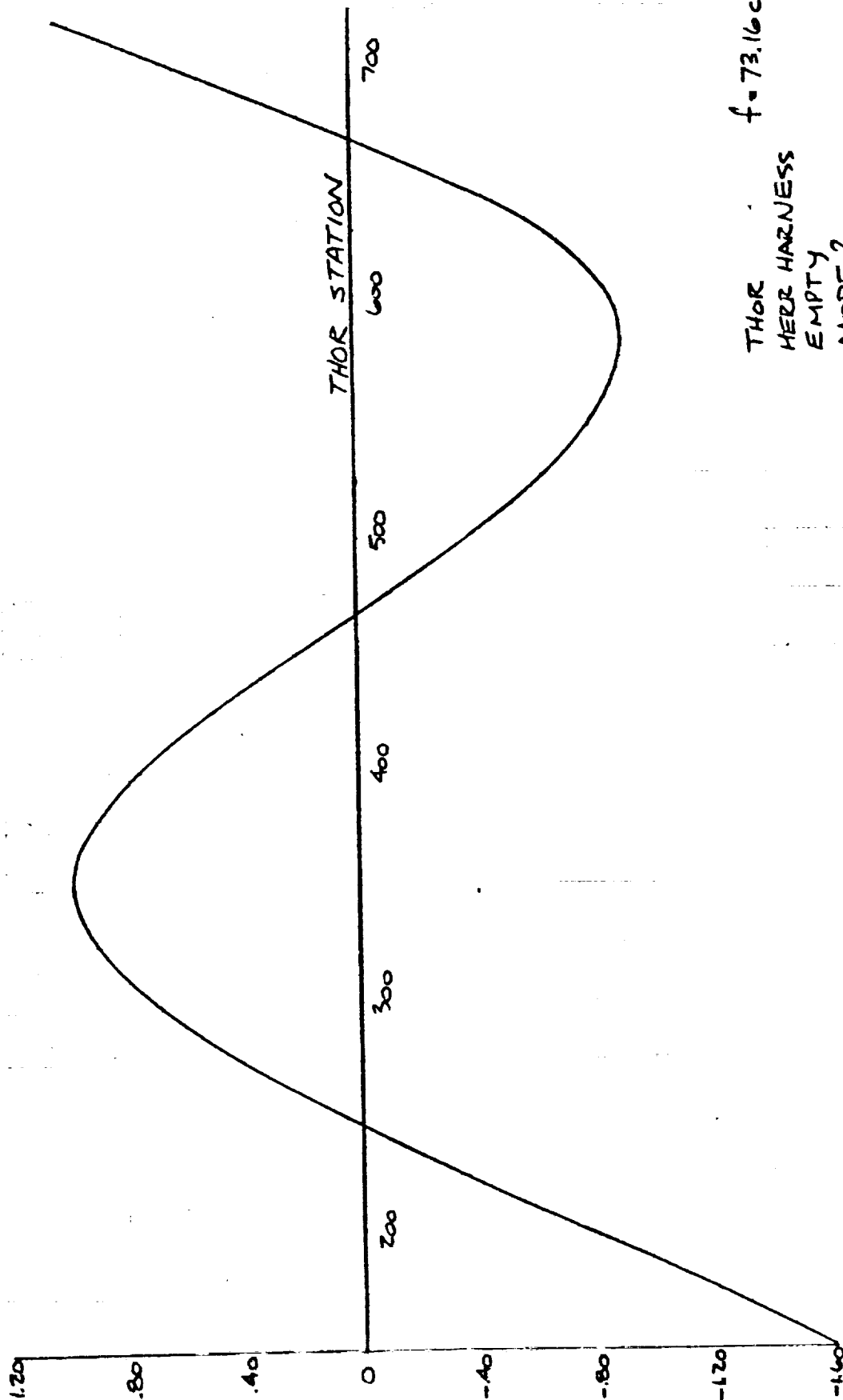
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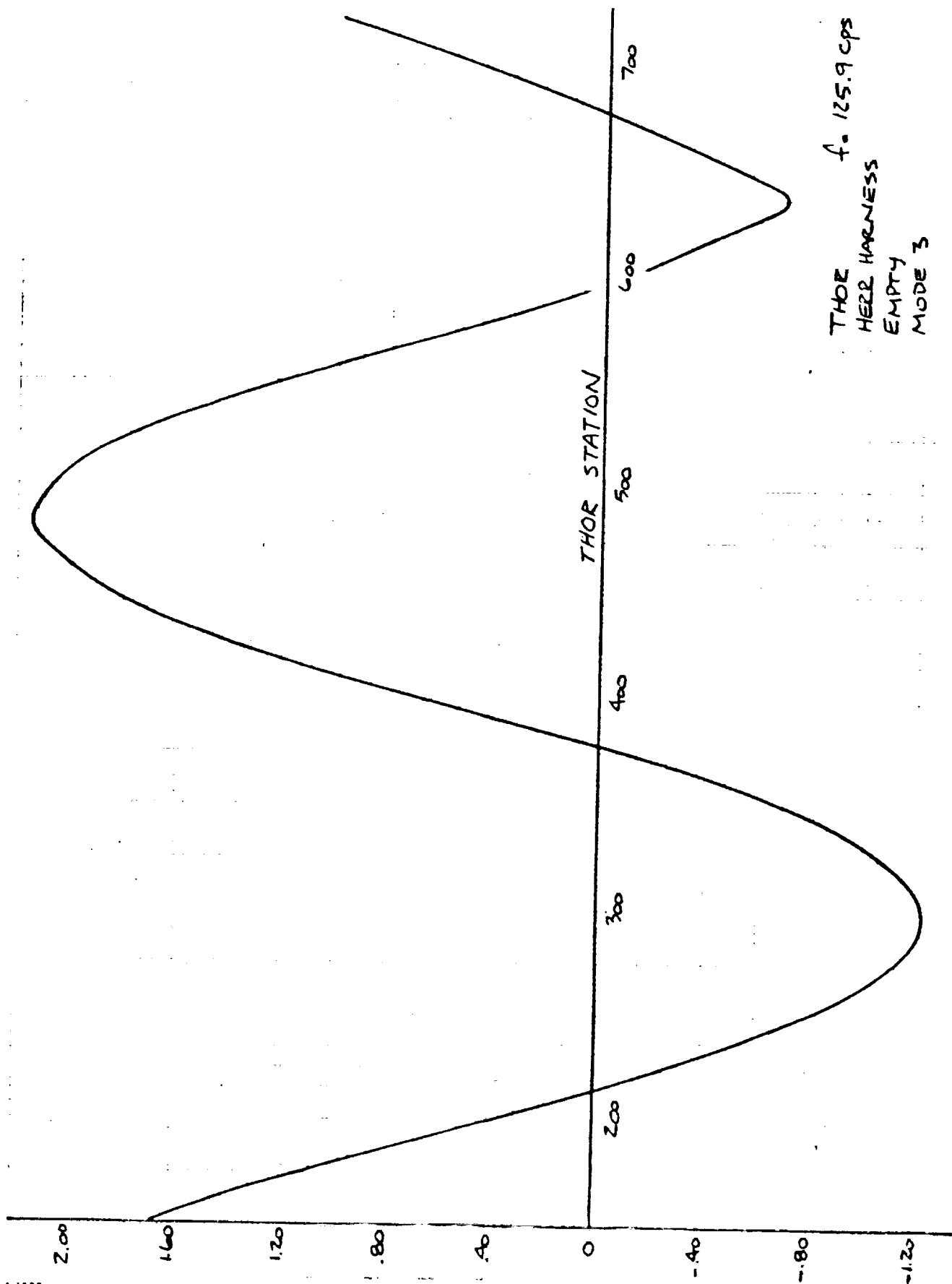
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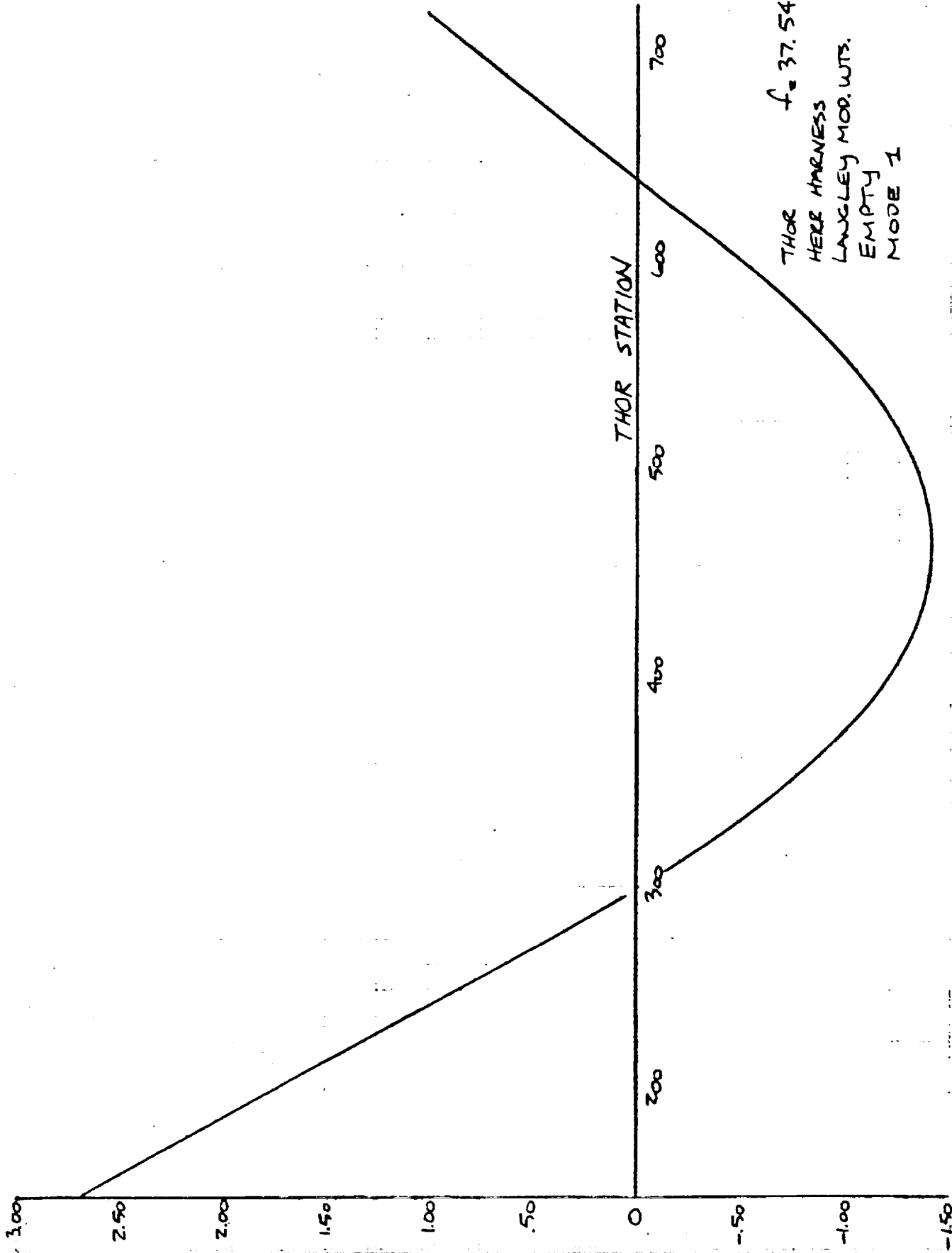
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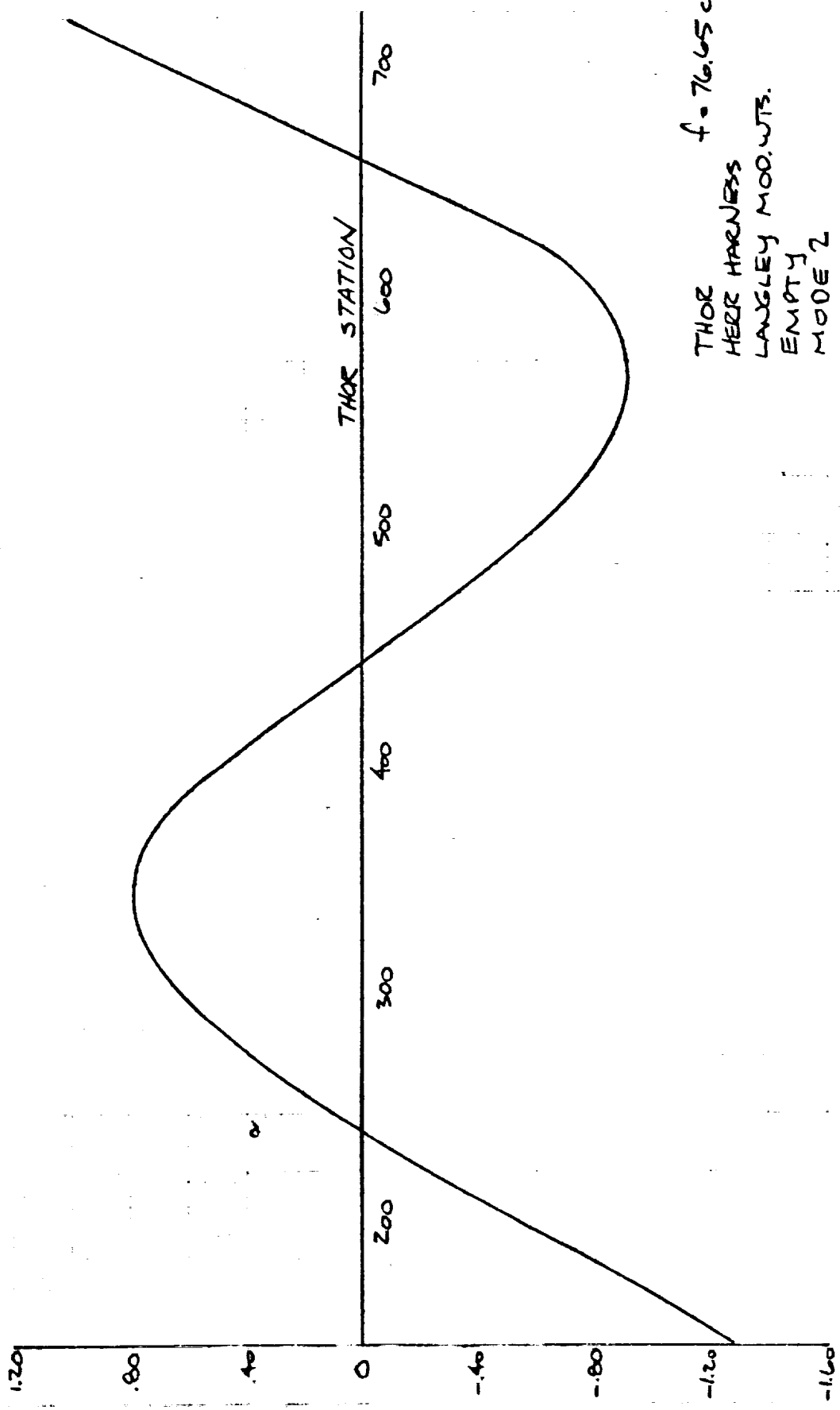


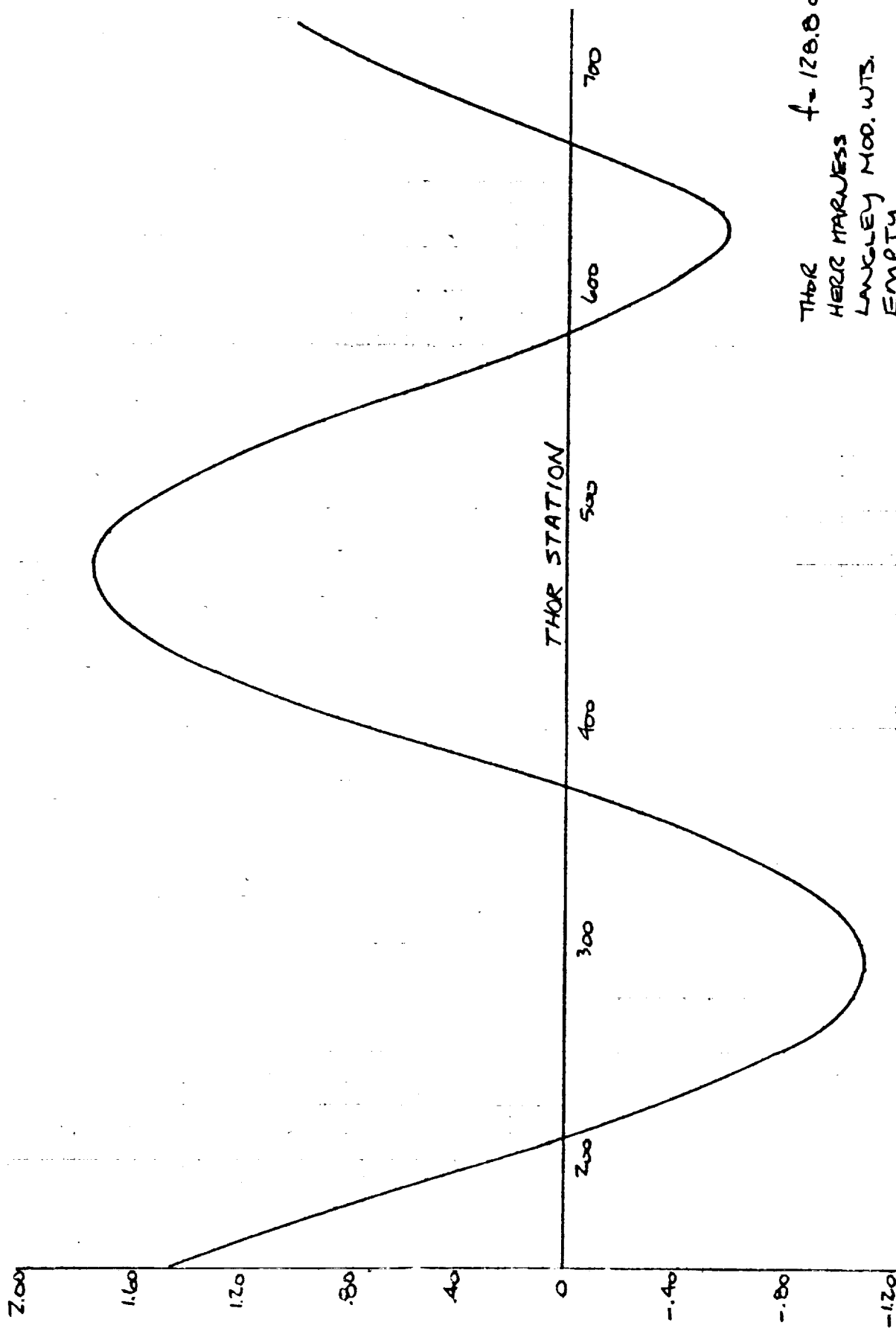
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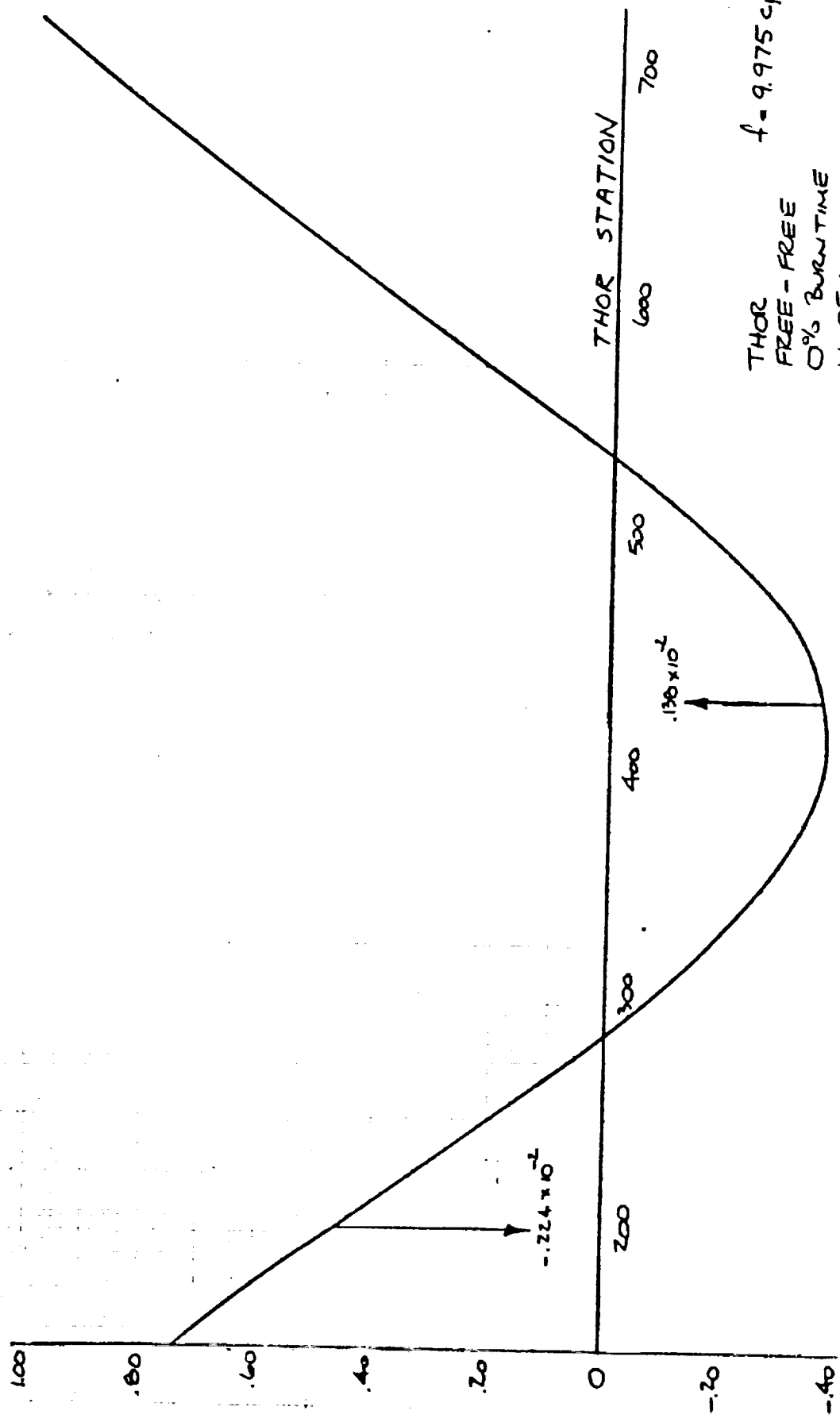




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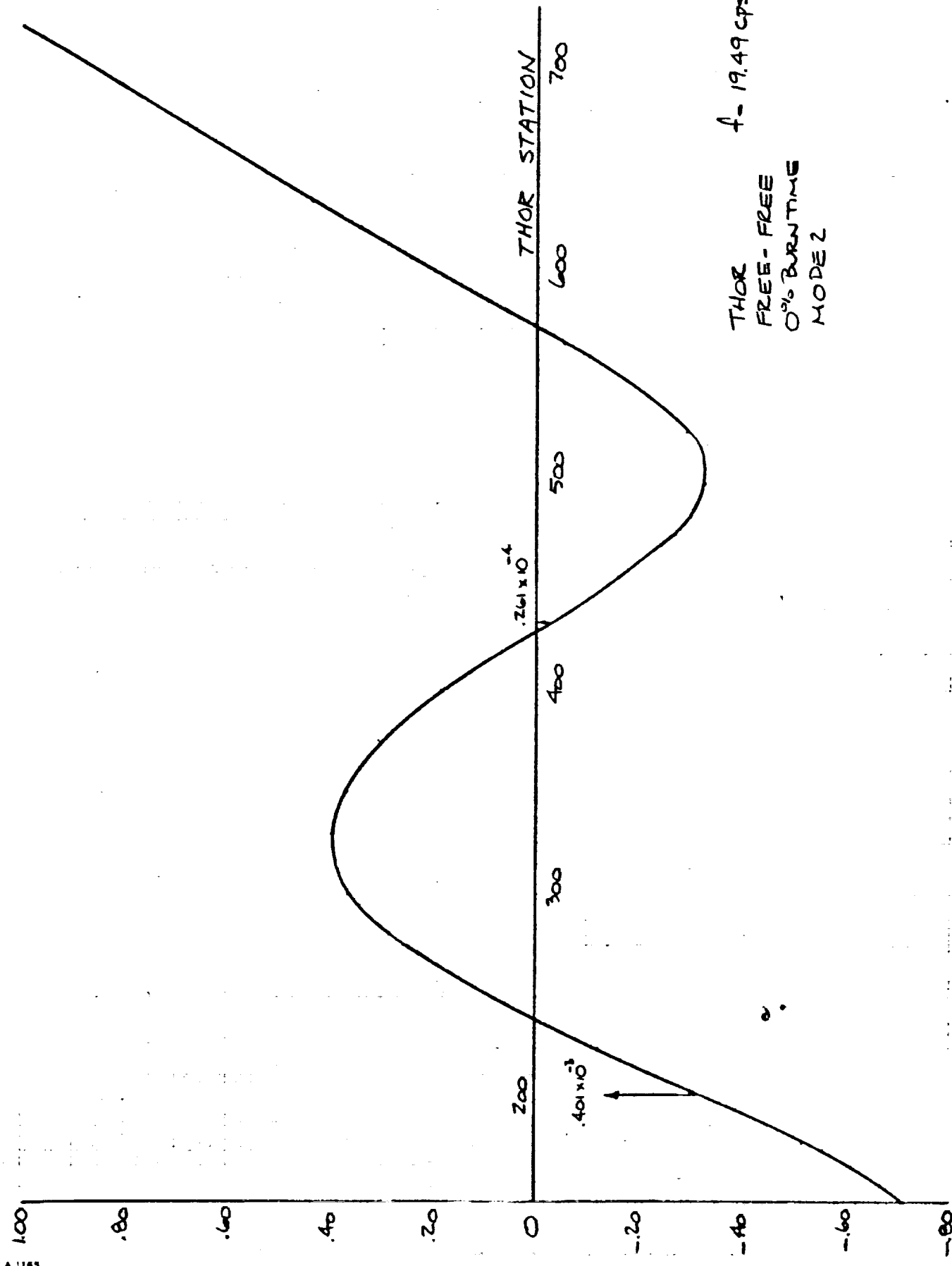
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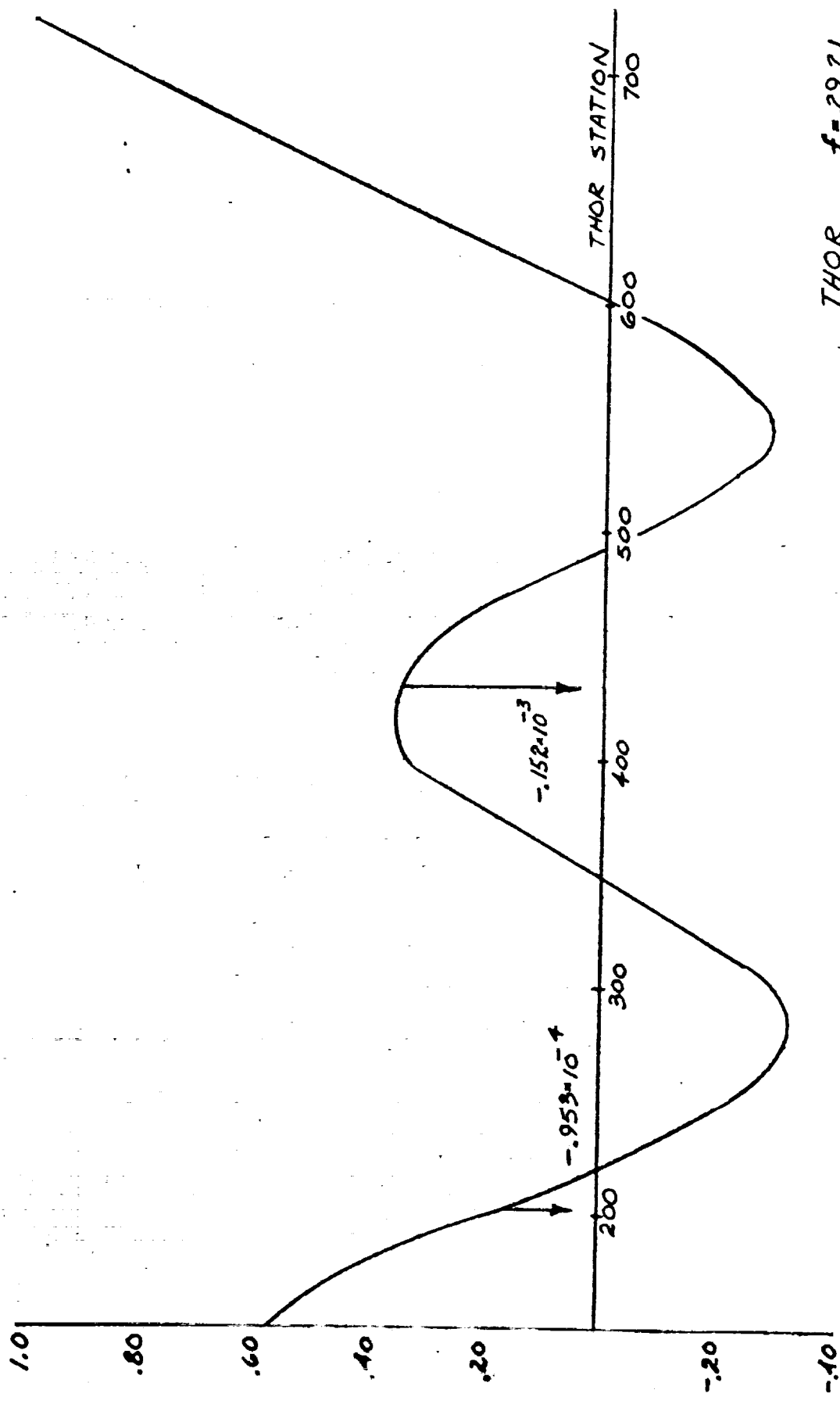
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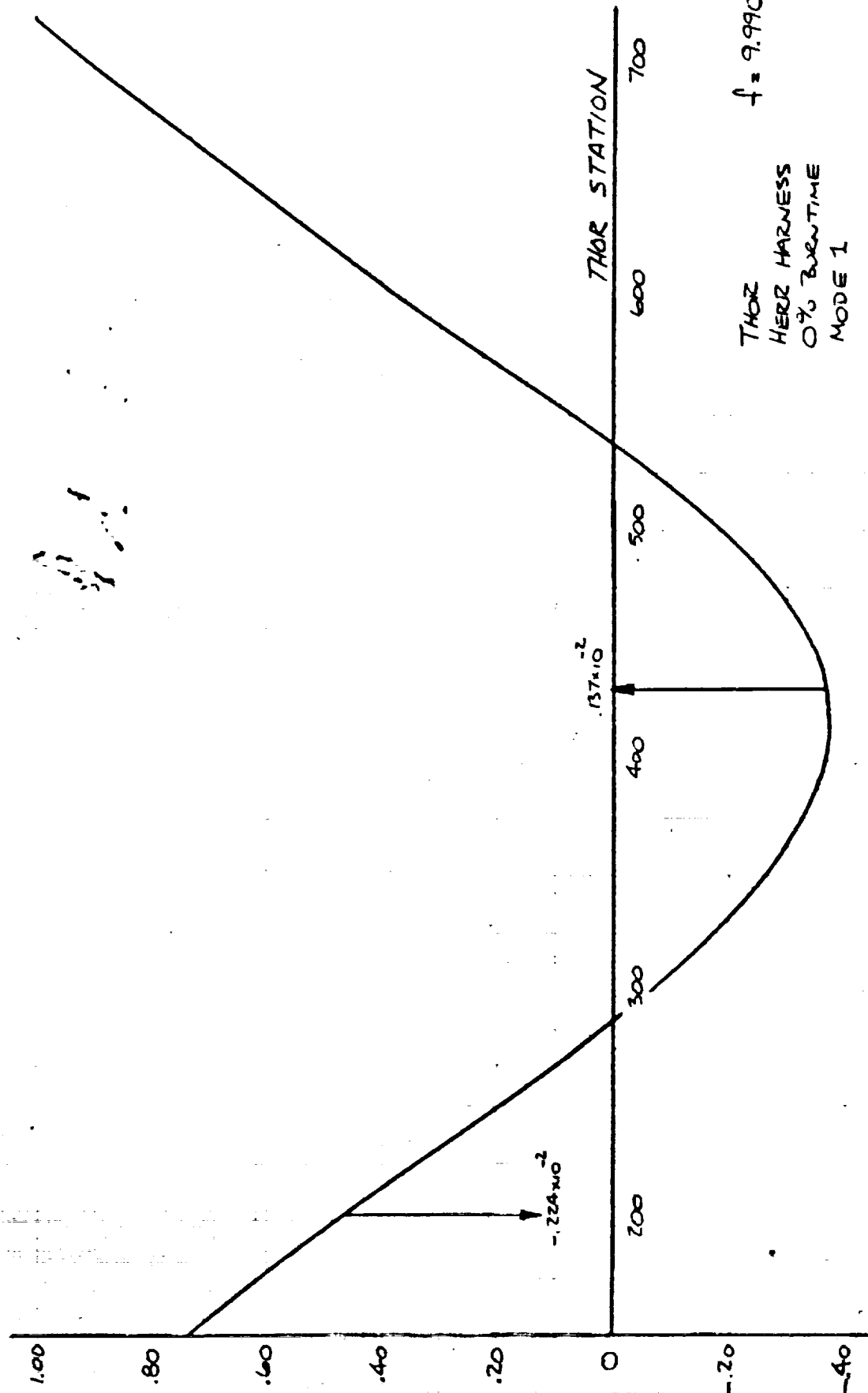


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REF. JOB PAGE NOS.

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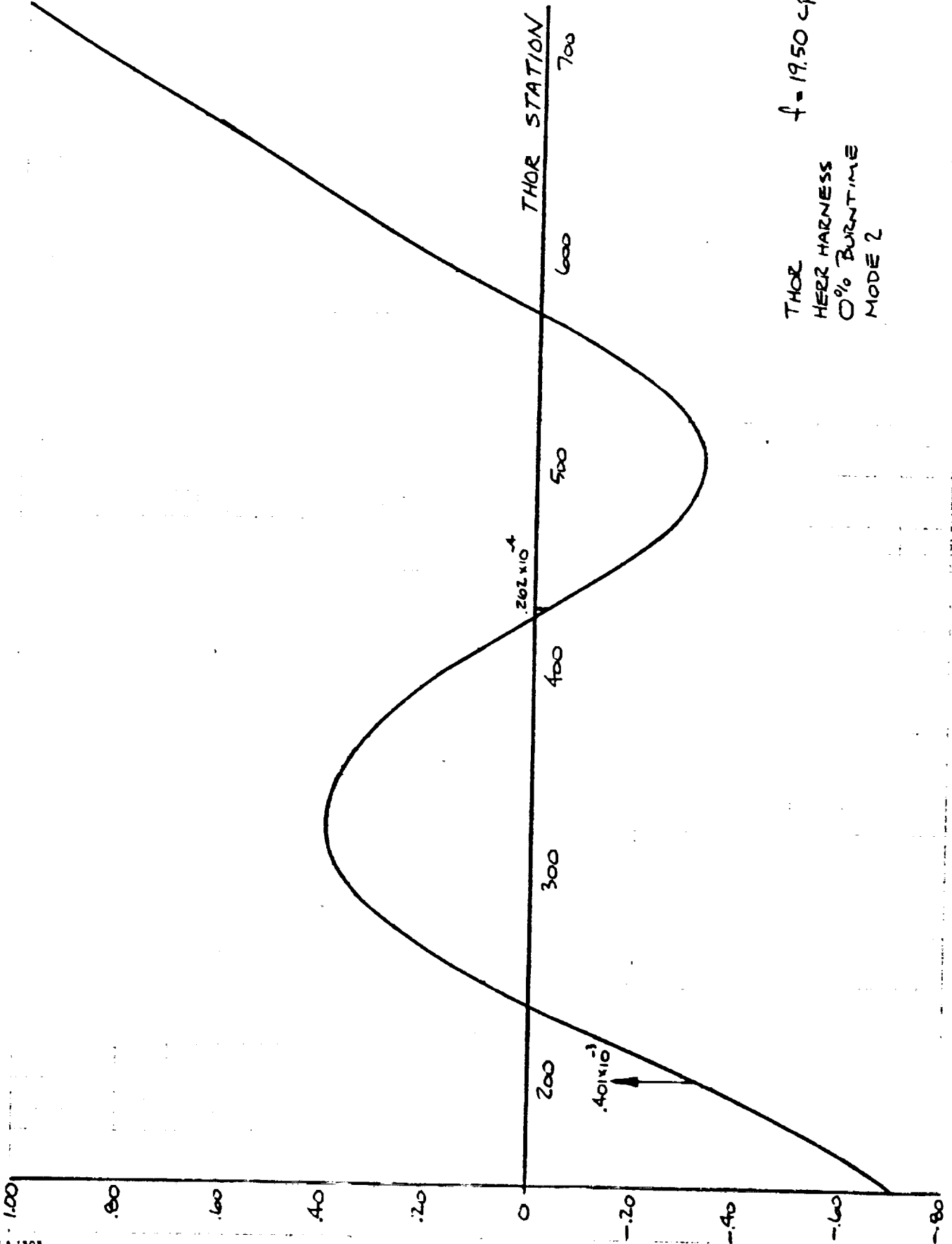
DATE

JOB PAGE NO.

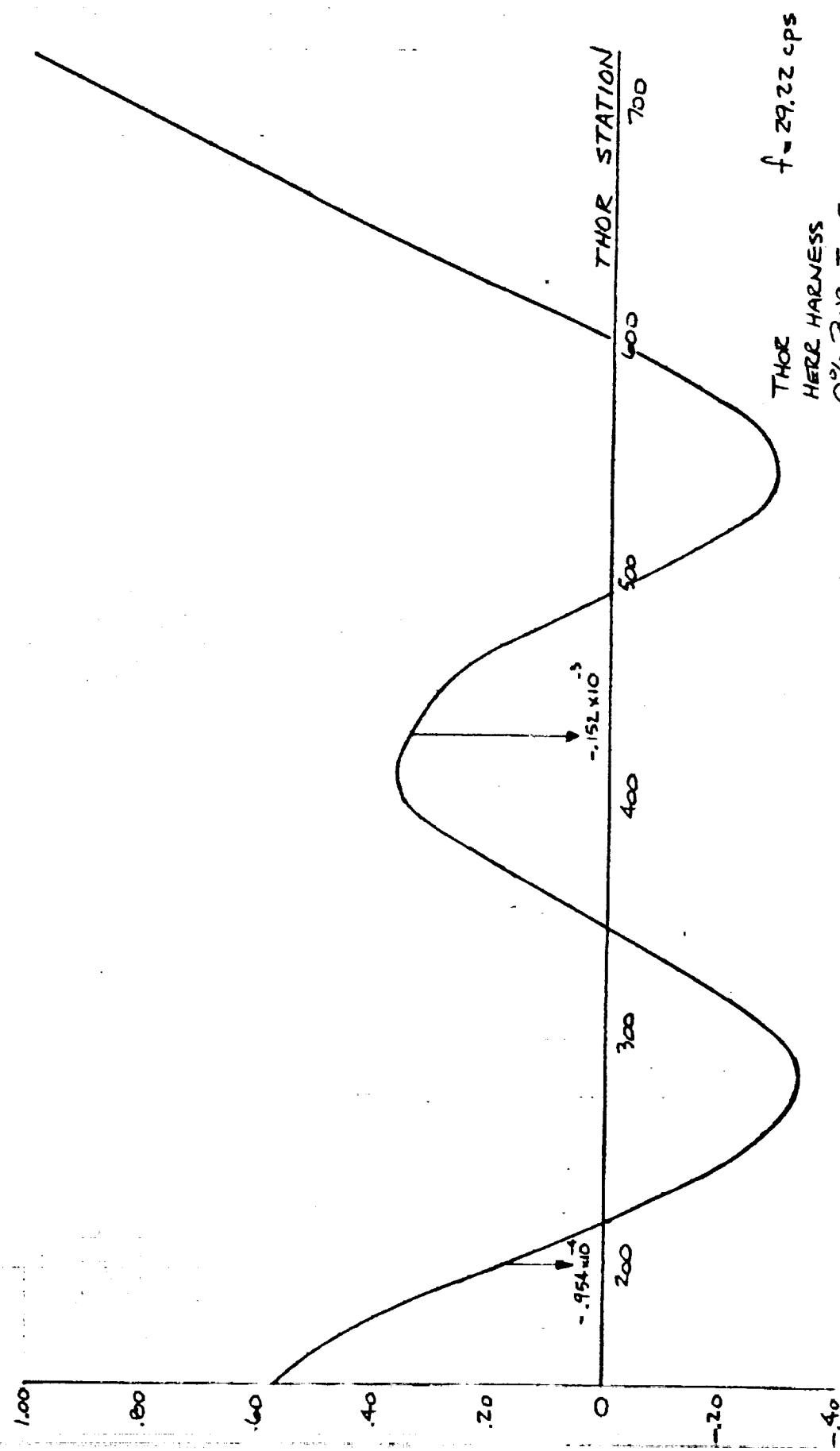
MODEL

REPORT NO.

DOUGLAS



THOR
HEER HARNESS
O% BURN TIME
MODE 2
 $f = 19.50 \text{ cps}$

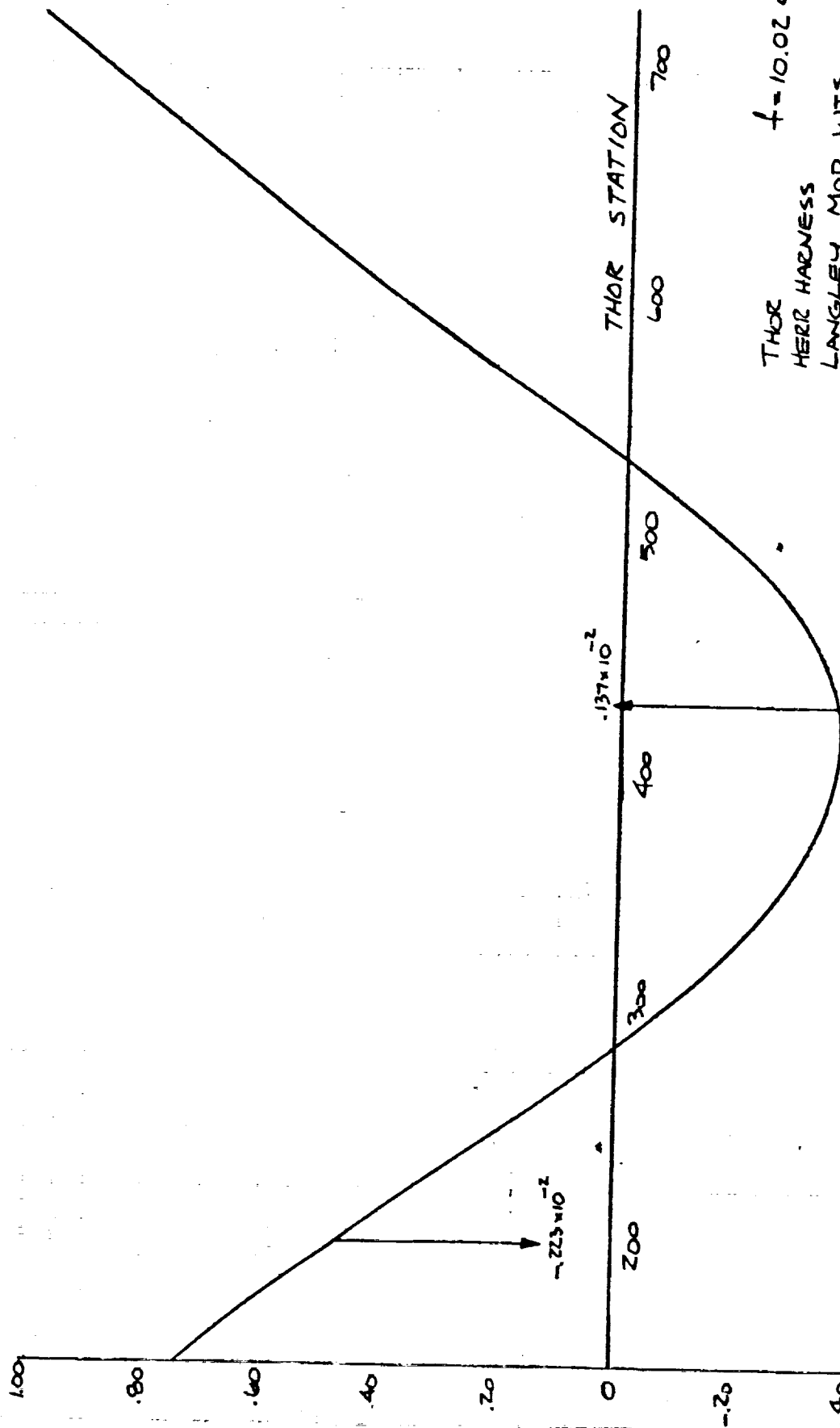


THOR
HERR HARNES
0% BURNTIME
MODE 3

 $f = 29.22 \text{ cps}$

REF. JOB PAGE NOS. _____ PREPARED BY _____ DATE _____
 JOB PAGE NO. _____ MODEL _____ REPORT NO. _____

DOUGLAS



THOR
 HERR HARNESS
 LANGLEY MOD. WTS.
 0% BURN TIME
 MODE 1
 $f = 10.02 \text{ cps}$

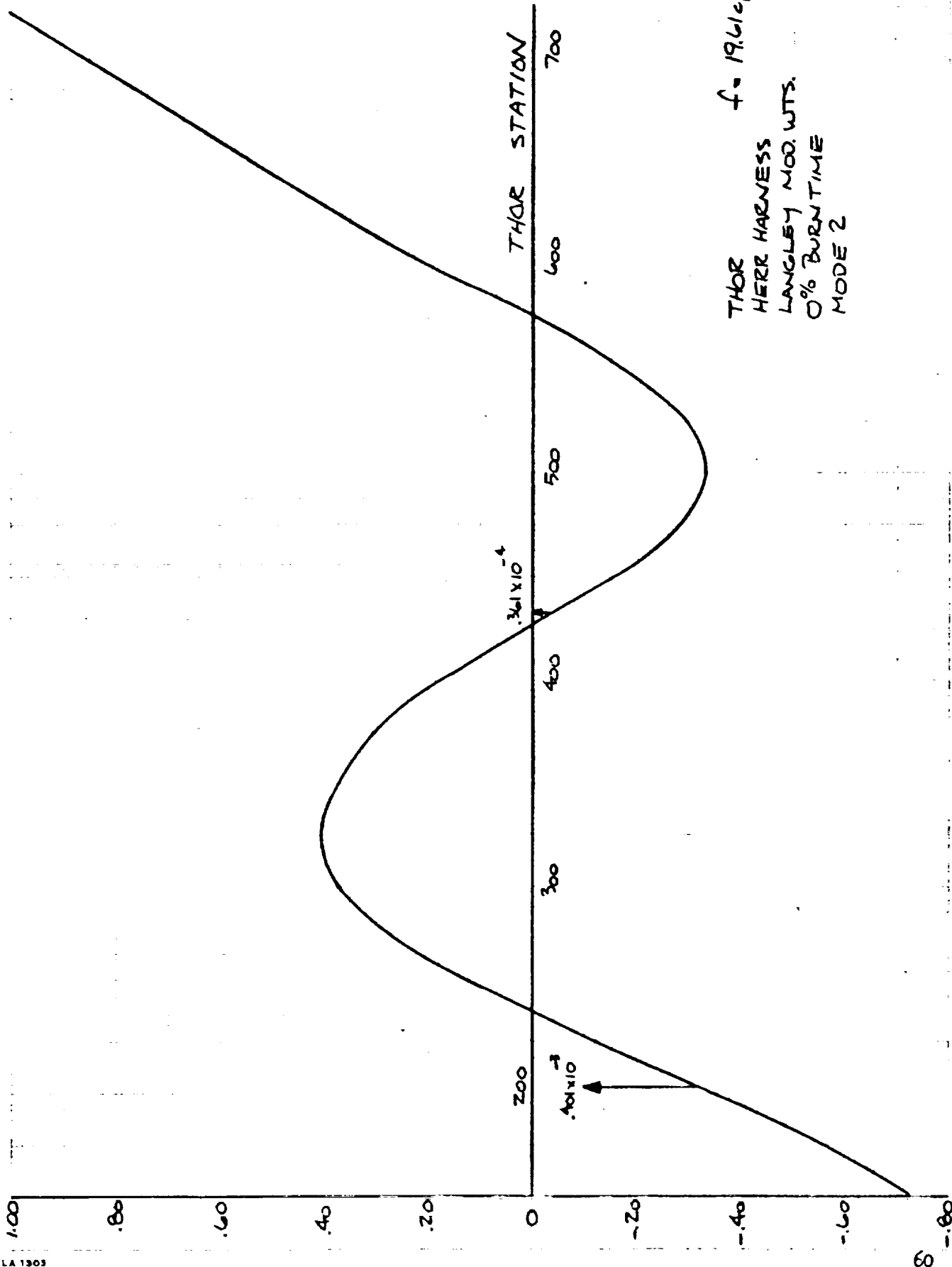
REF. JOB PAGE NOS. _____
PREPARED BY _____

DATE _____

JOB PAGE NO. _____
MODEL _____

REPORT NO. _____

DOUGLAS



f = 19.6 cps
THOR HARNES
HERR HARNES
LANGLEY MOD. WTS.
0% BURN TIME
MODE 2

REF. JOB PAGE NOS.

PREPARED BY

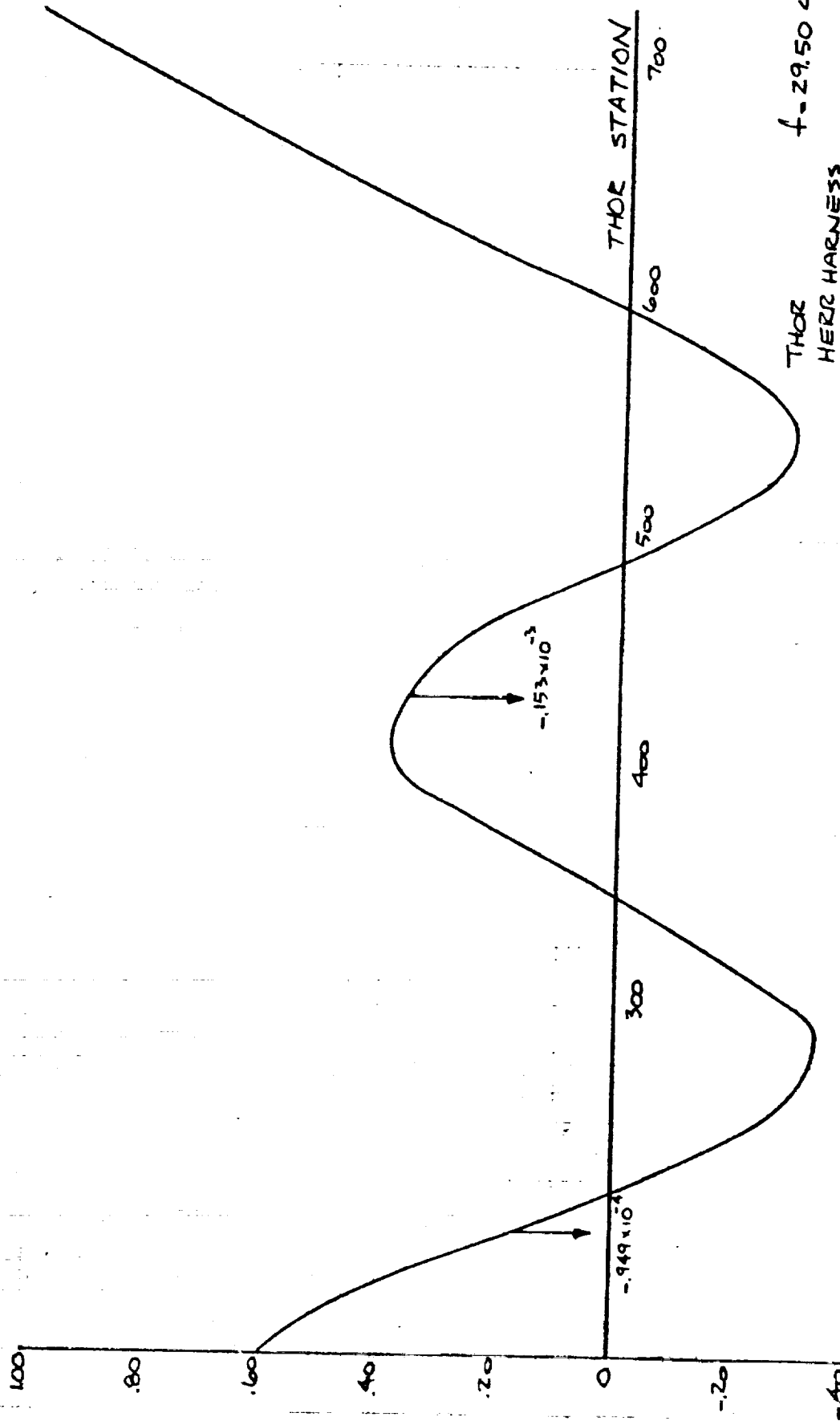
DATE

JOB PAGE NO.

MODEL

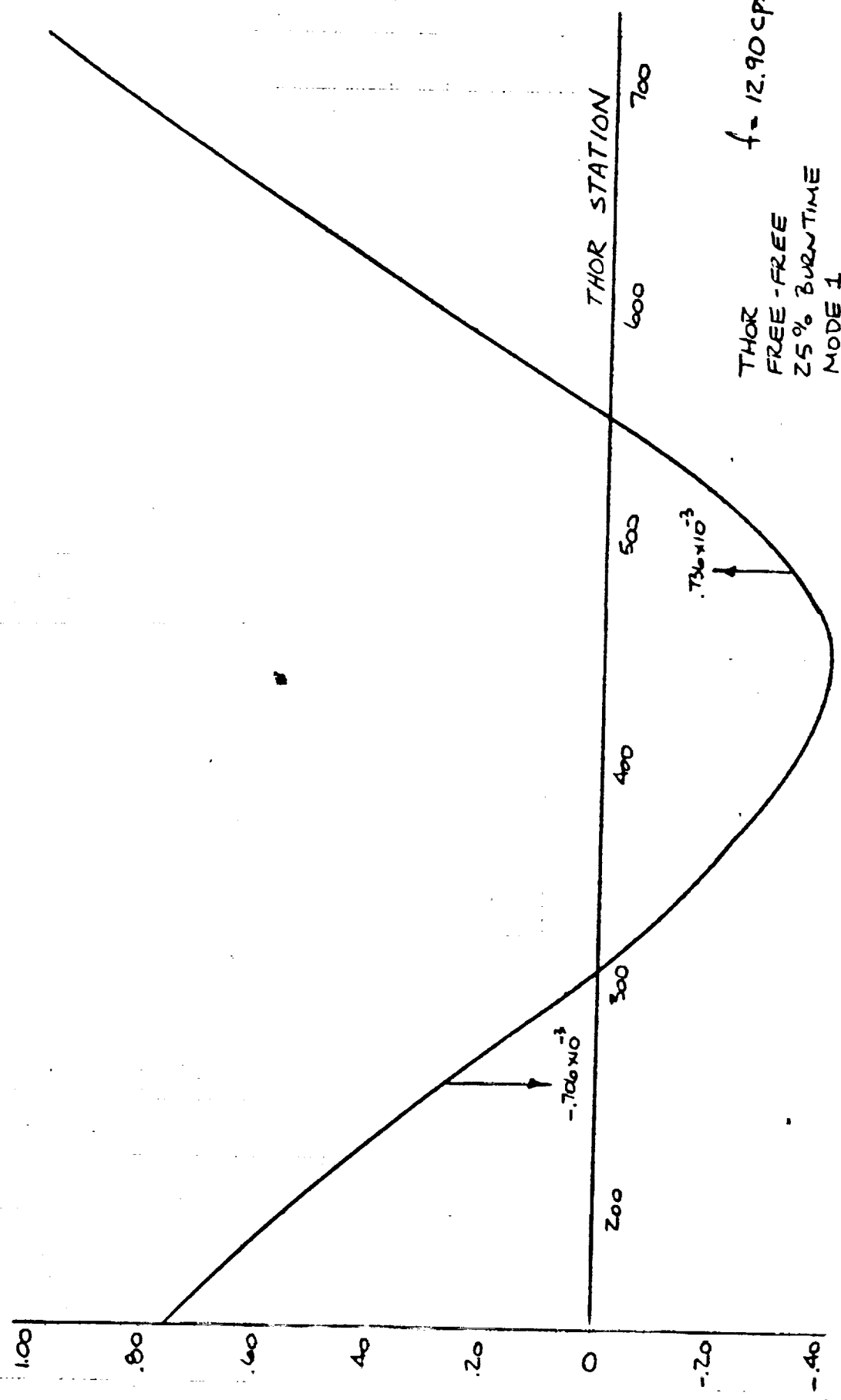
REPORT NO.

DOUGLAS



THOR
HERR HARNESS
LANGLEY MOD. WTS.
0% BURN TIME
MODE 3
 $f = 29.50 \text{ cps}$

DOUGLAS



THOR
FREE - FREE
25% BURN TIME
MODE 1

$f = 12.90 \text{ cps}$

FORM 30-B

REF. JOB PAGE NOS.

PREPARED BY

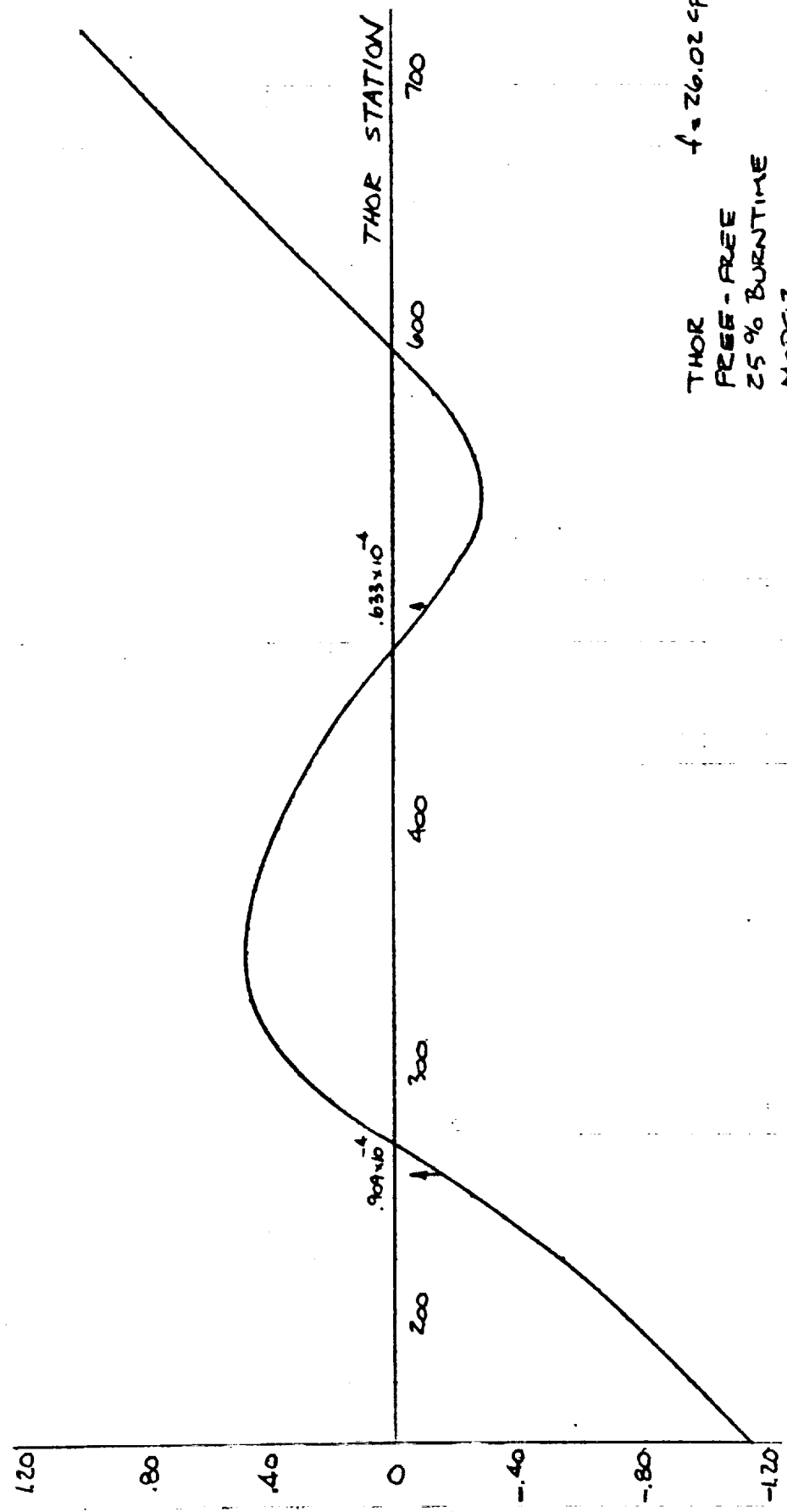
DATE

JOB PAGE NO.

MODEL

REPORT NO.

T 25%
MODE 2



THOR
FREE - FREE
25% BURN TIME
MODE 2
 $f = 26.02 \text{ cps}$

REV. JOB PAGE NO. _____
PREPARED BY _____

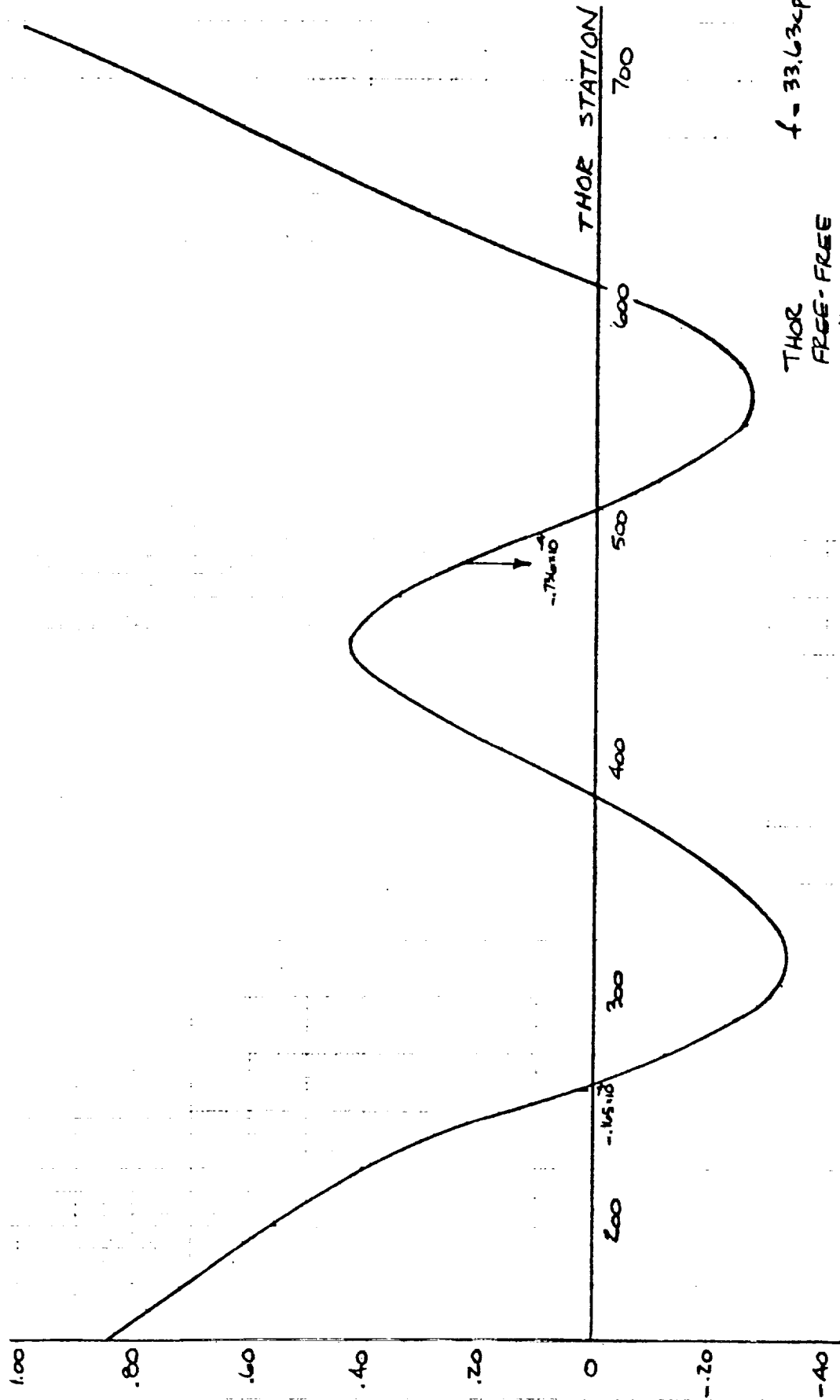
DATE _____

JOB PAGE NO. _____
MODEL _____

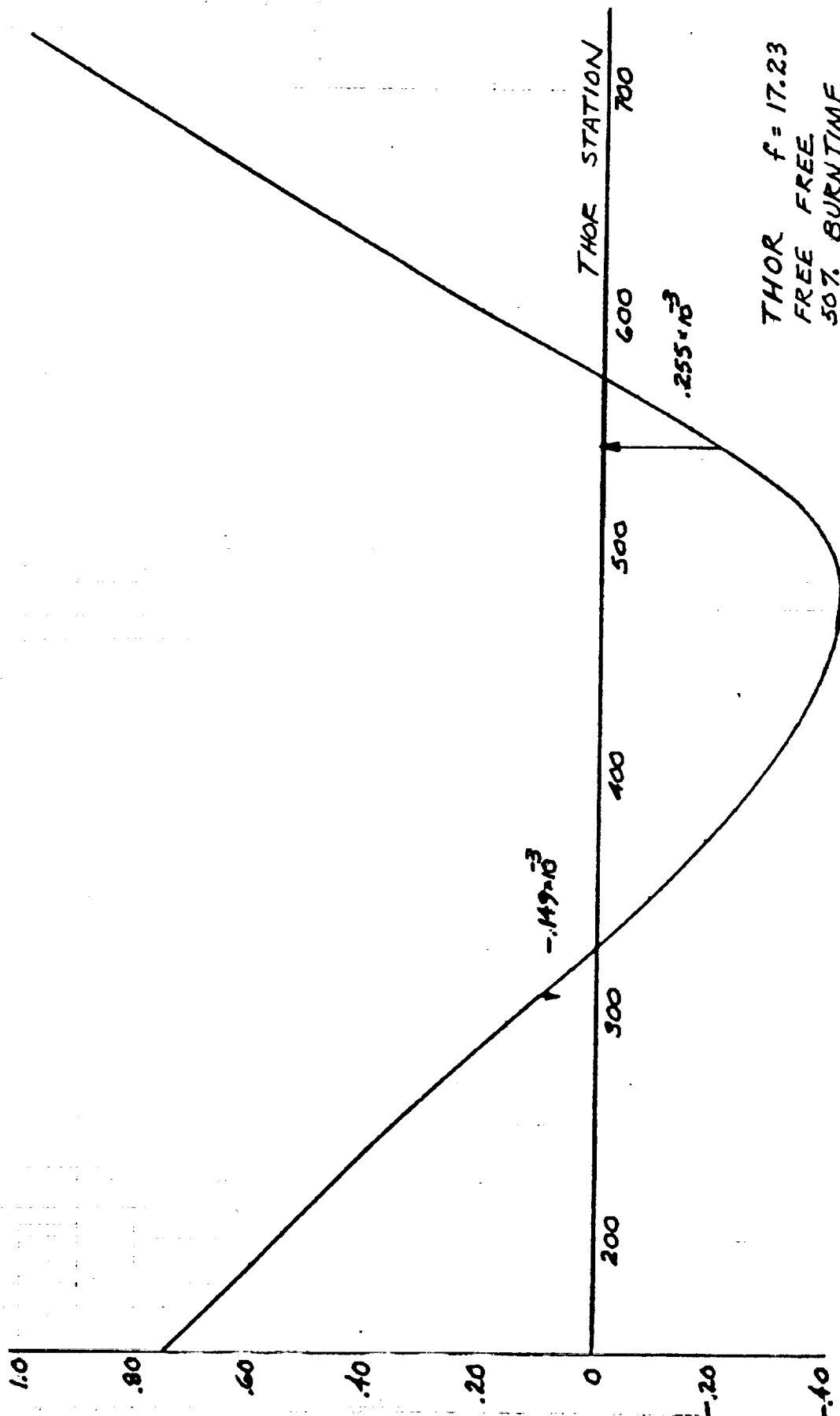
REPORT NO. _____

25 1/3

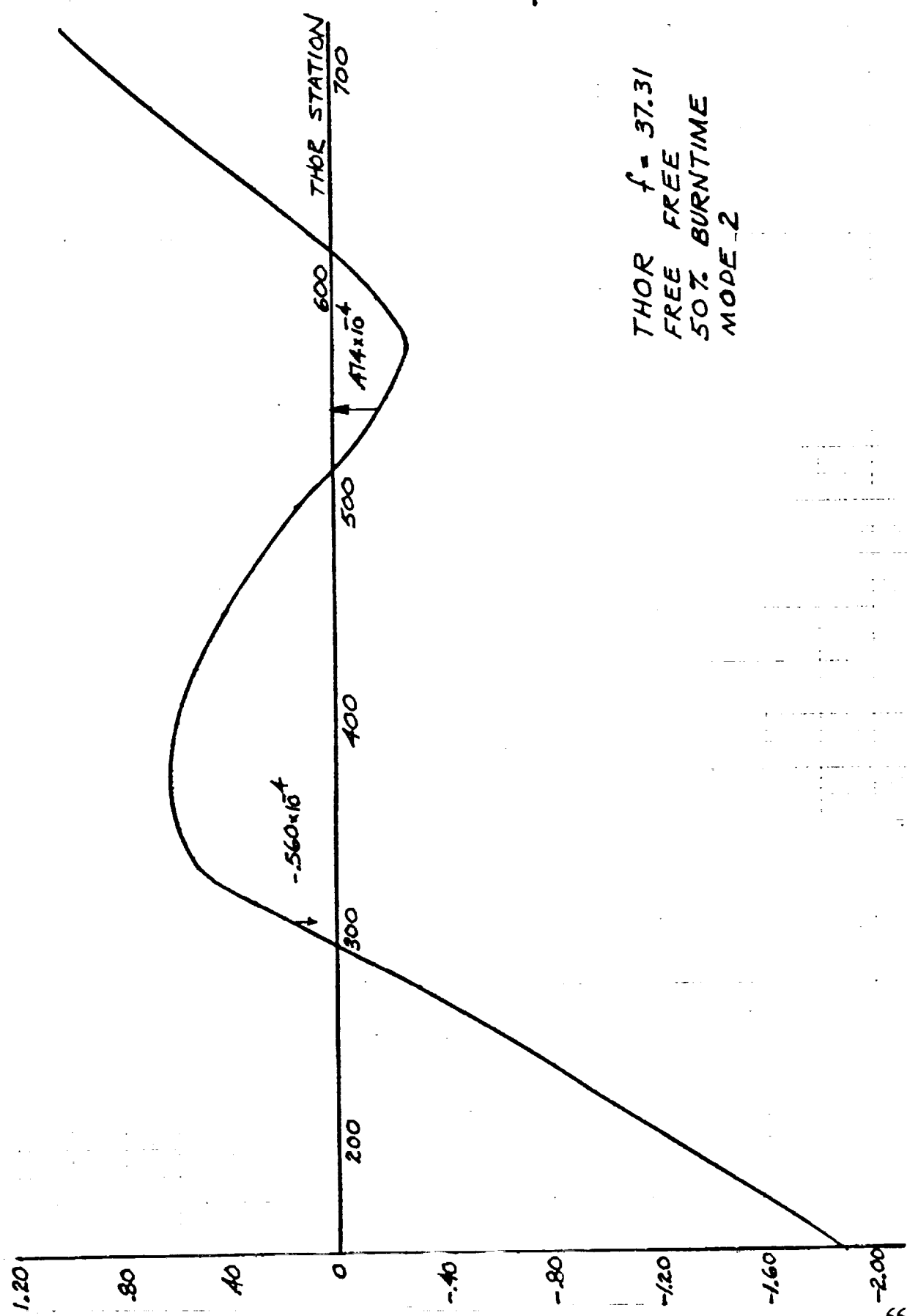
DOUGLAS



DOUGLAS



THOR $f = 17.23$
FREE
50% BURN TIME
MODE I



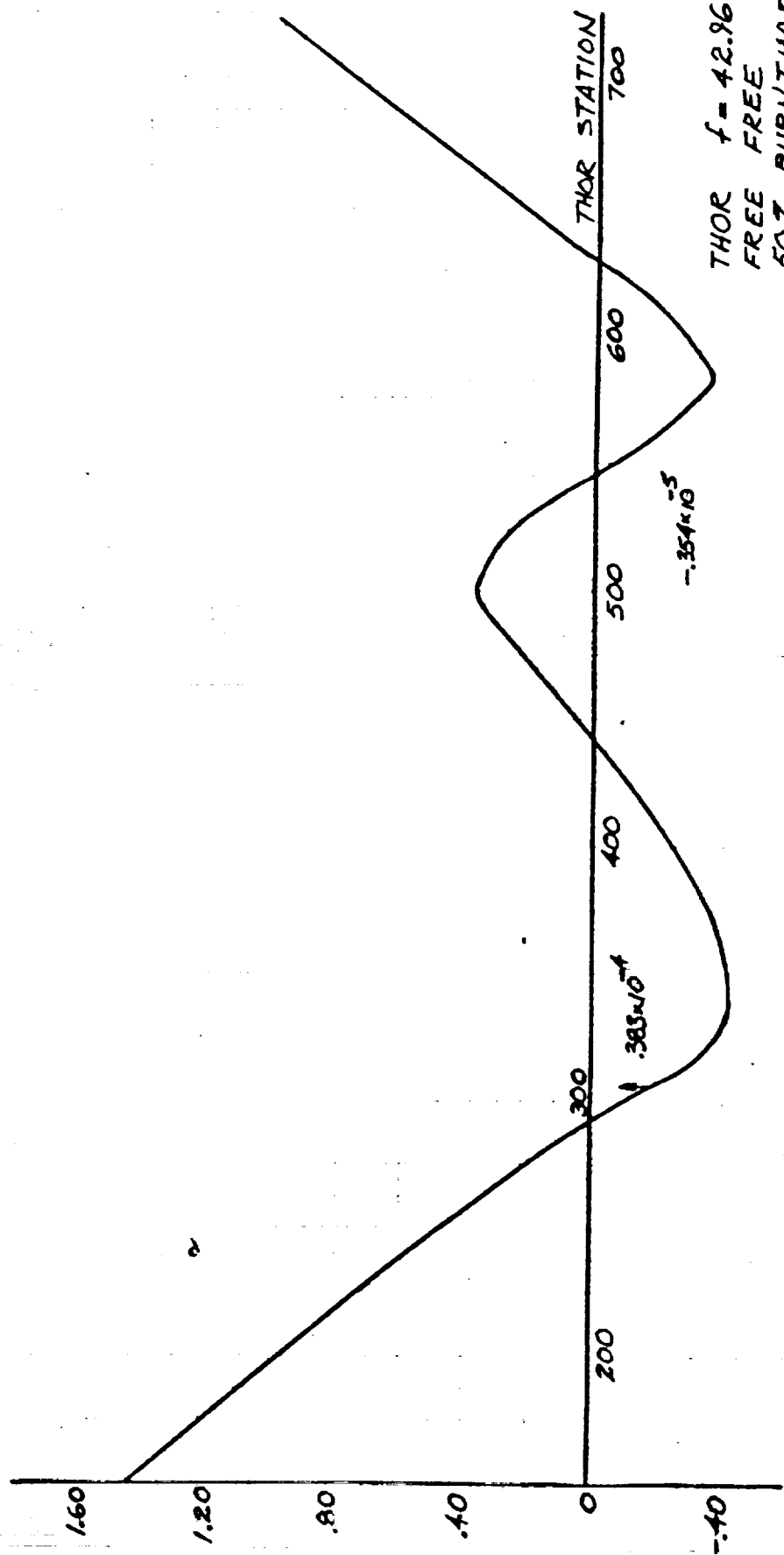
THOR $f = 37.31$
 FREE FREE
 50% BURN TIME
 MODE 2

REF. JOB PAGE NOS. _____
 PREPARED BY _____
 DATE _____

JOB PAGE NO. _____
 MODEL _____
 REPORT NO. _____

FORM 80-20
 REF. JOB PAGE NOS. _____
 PREPARED BY _____
 DATE _____

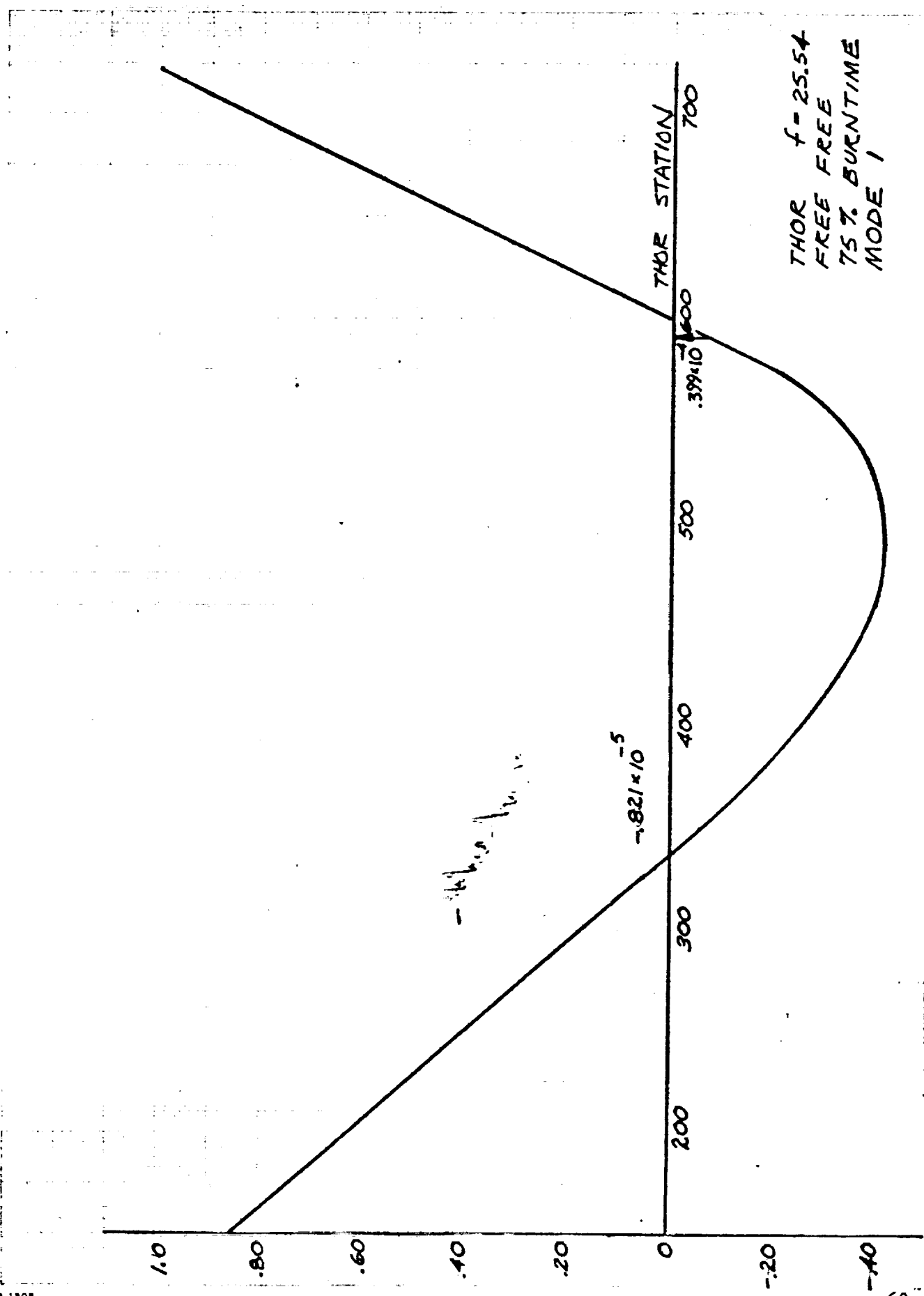
FORM 80-20



THOR $f = 42.96$
 FREE FREE
 50% BURN TIME
 MODE 3

$-.354 \times 10^{-5}$

$.383 \times 10^{-4}$



THOR $f = 25.54$
FREE FREE
75% BURNTIME
MODE 1

FORM 33 64

REF. JOB PAGE NOS.

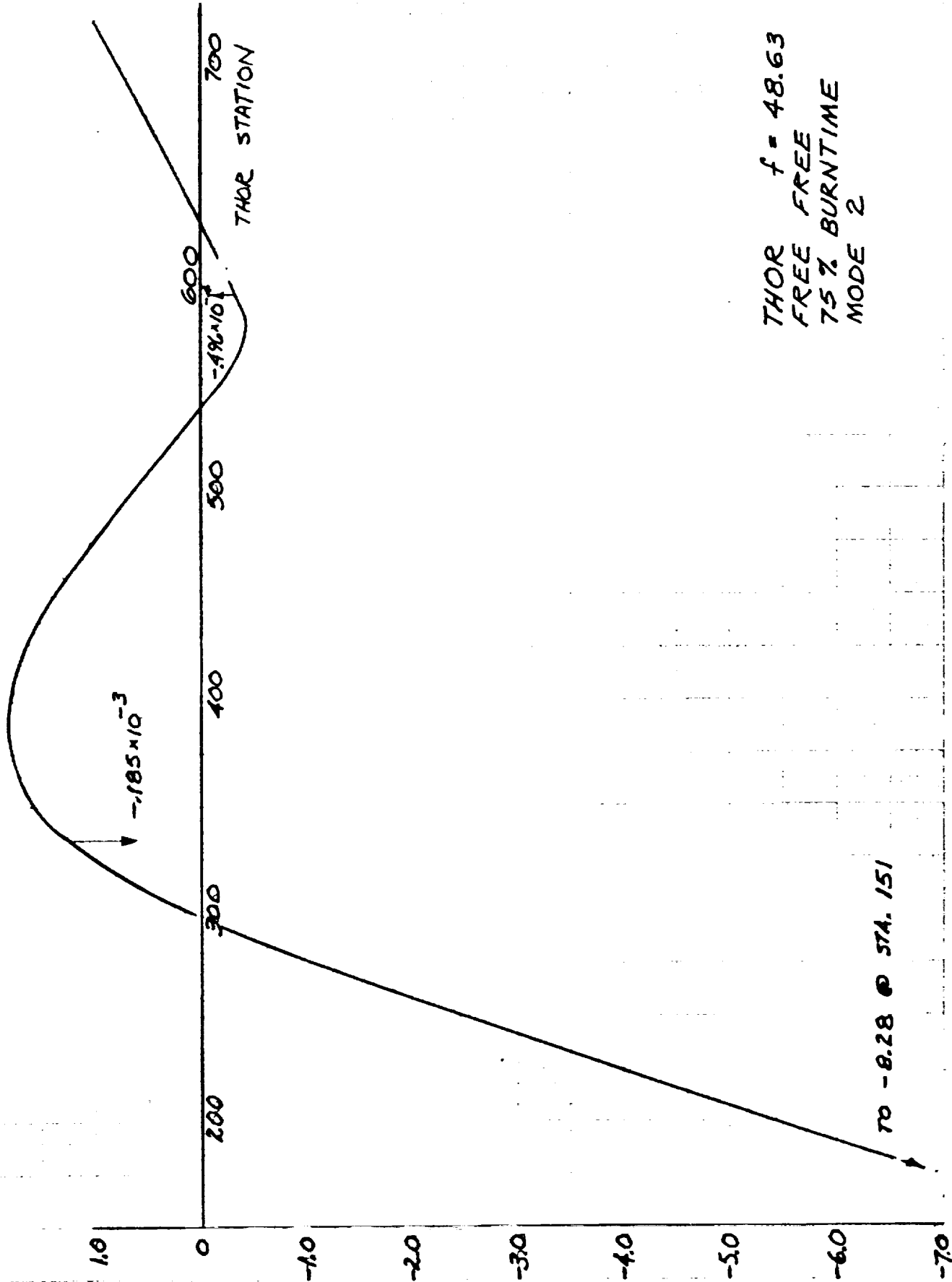
DATE

JOB PAGE NO.

MODEL

REPORT NO.

MODE 2



THOR $f = 48.63$
FREE
75% BURN TIME
MODE 2

DOUGLAS

REF. JOB PAGE NOS.

PREPARED BY

DATE

JOB PAGE NO.

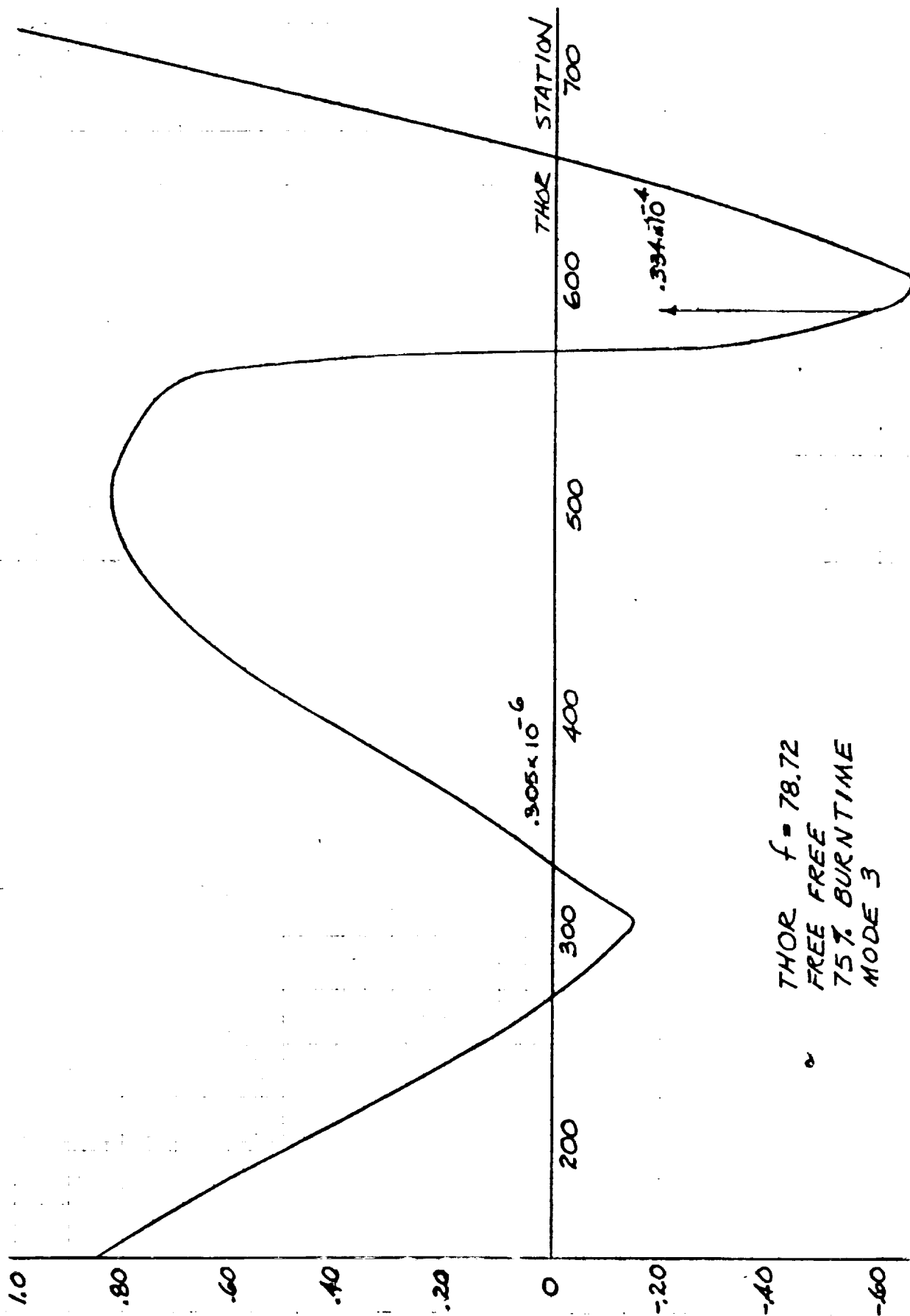
MODEL

REPORT NO.

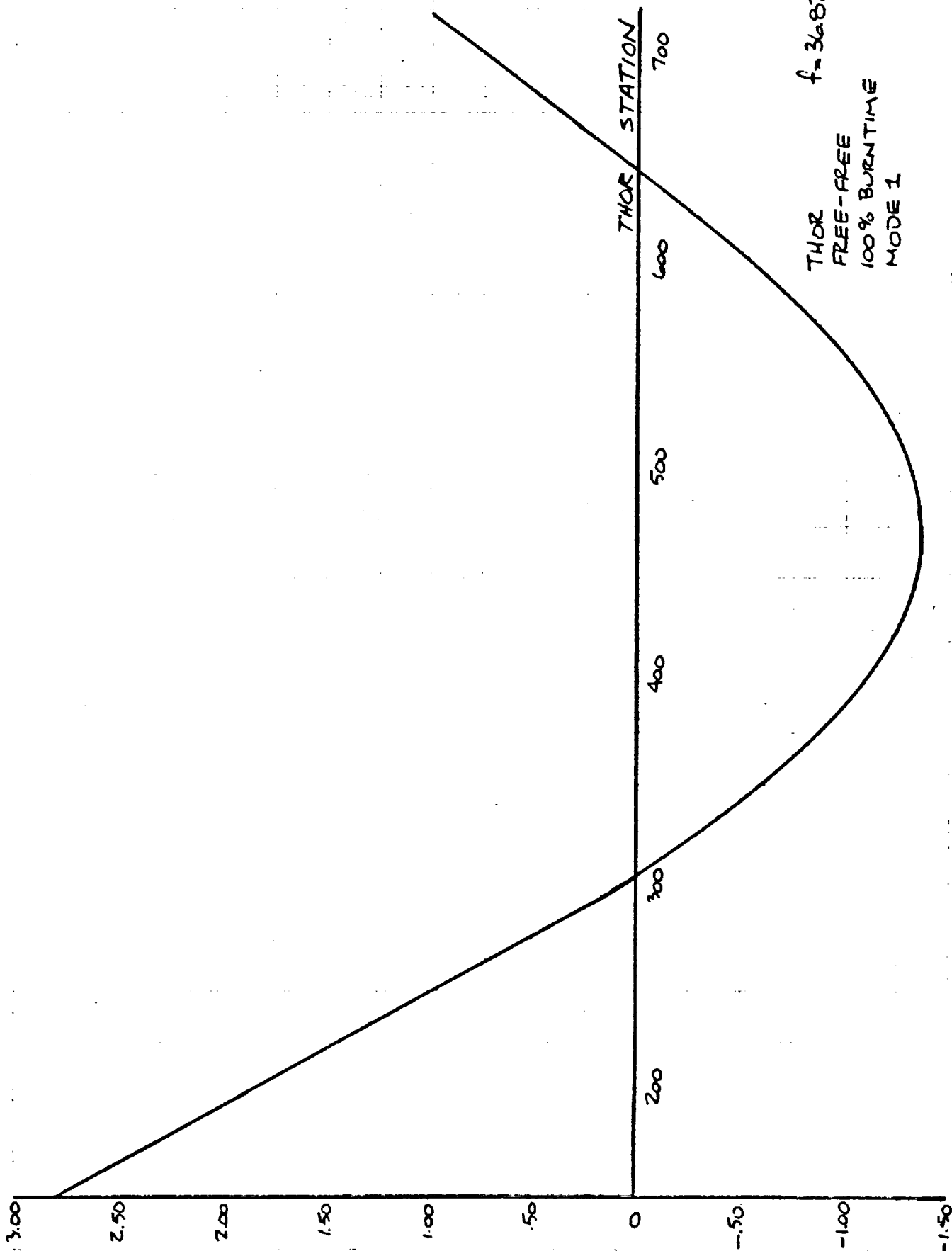
75%

MODE 3

DOUGLAS

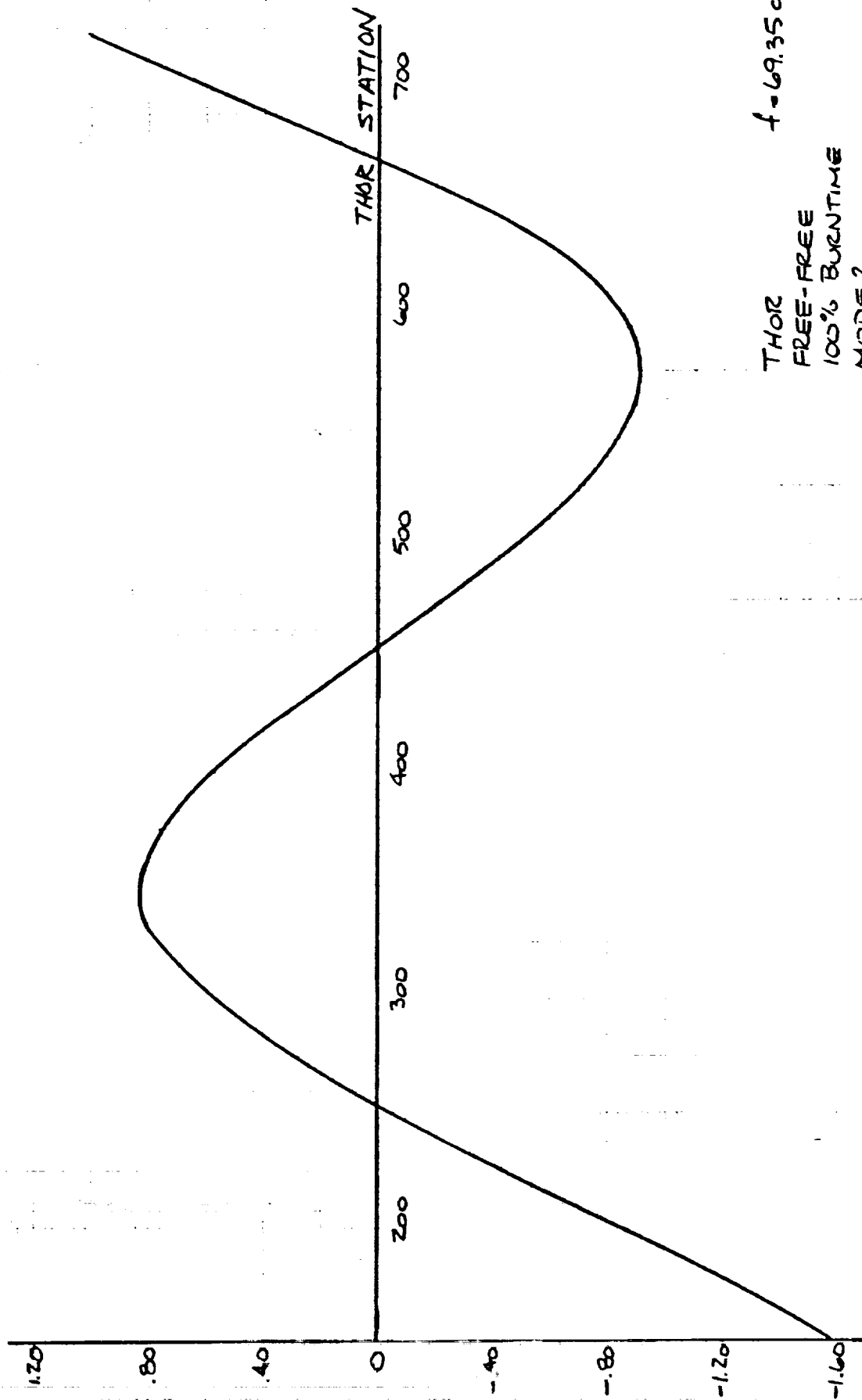


THOR $f = 78.72$
 FREE FREE
 75% BURNTIME
 MODE 3



THOR
FREE-FREE
100% BURN TIME
MODE 1
 $f = 3687 \text{ cps}$

DOUGLAS



THOR
FREE-FREE
100% BURNTIME
MODE 2
 $f = 69.35 \text{ cps}$

REF. JOB PAGE NOS.

PREPARED BY

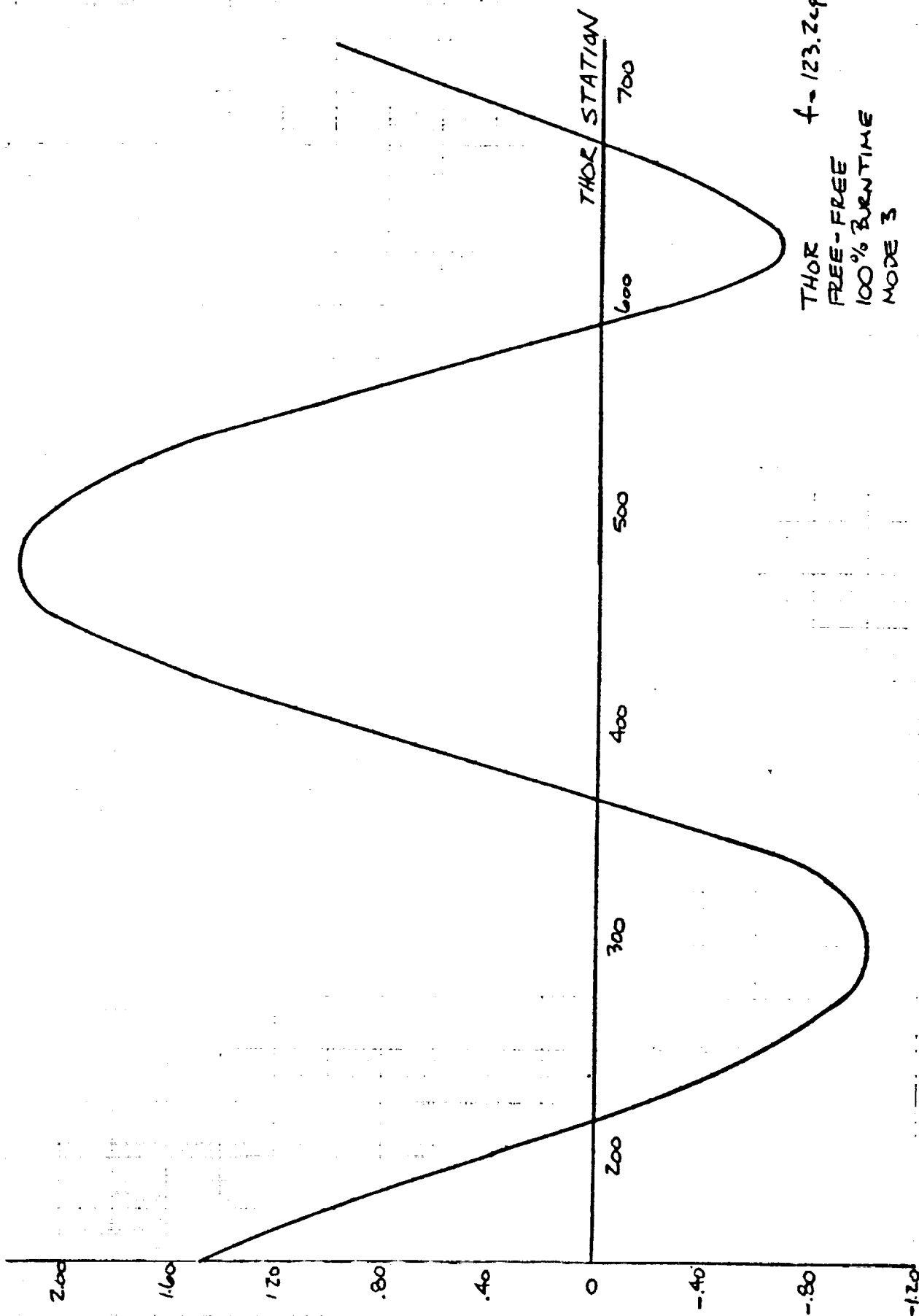
DATE

JOB PAGE NO.

MODEL

REPORT NO.

DOUGLAS



THOR STATION

700

600

500

400

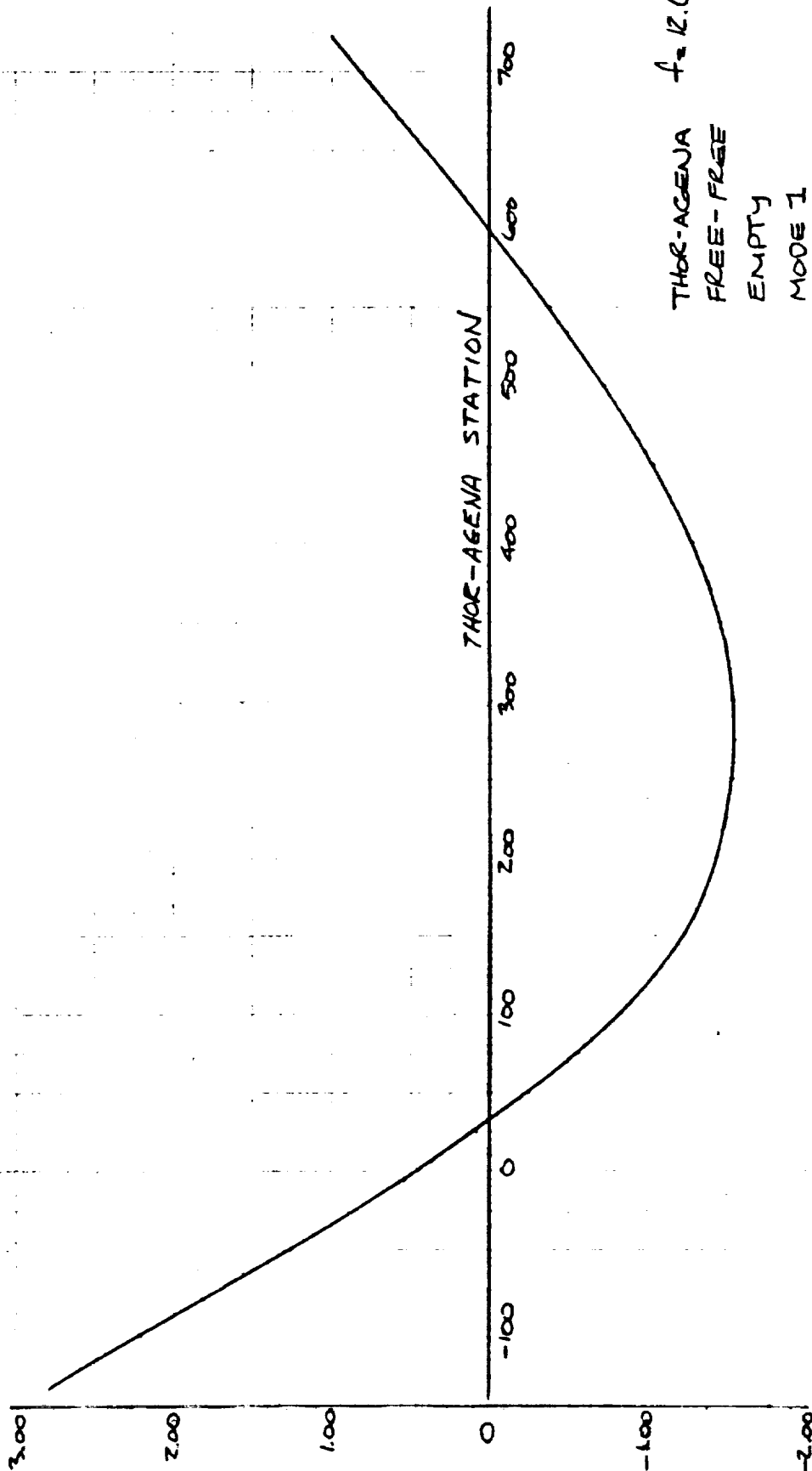
300

200

THOR
FREE-FREE
100% BURN TIME
MODE 3
f = 123.2 cps

Appendix C

Thor-Agena Mode Shapes



DOUGLAS

$f = 12.62 \text{ cps}$

THOR-AGENA
FREE-FREE
EMPTY
MODE 1

REF. JOB PAGE NOS.

PREPARED BY

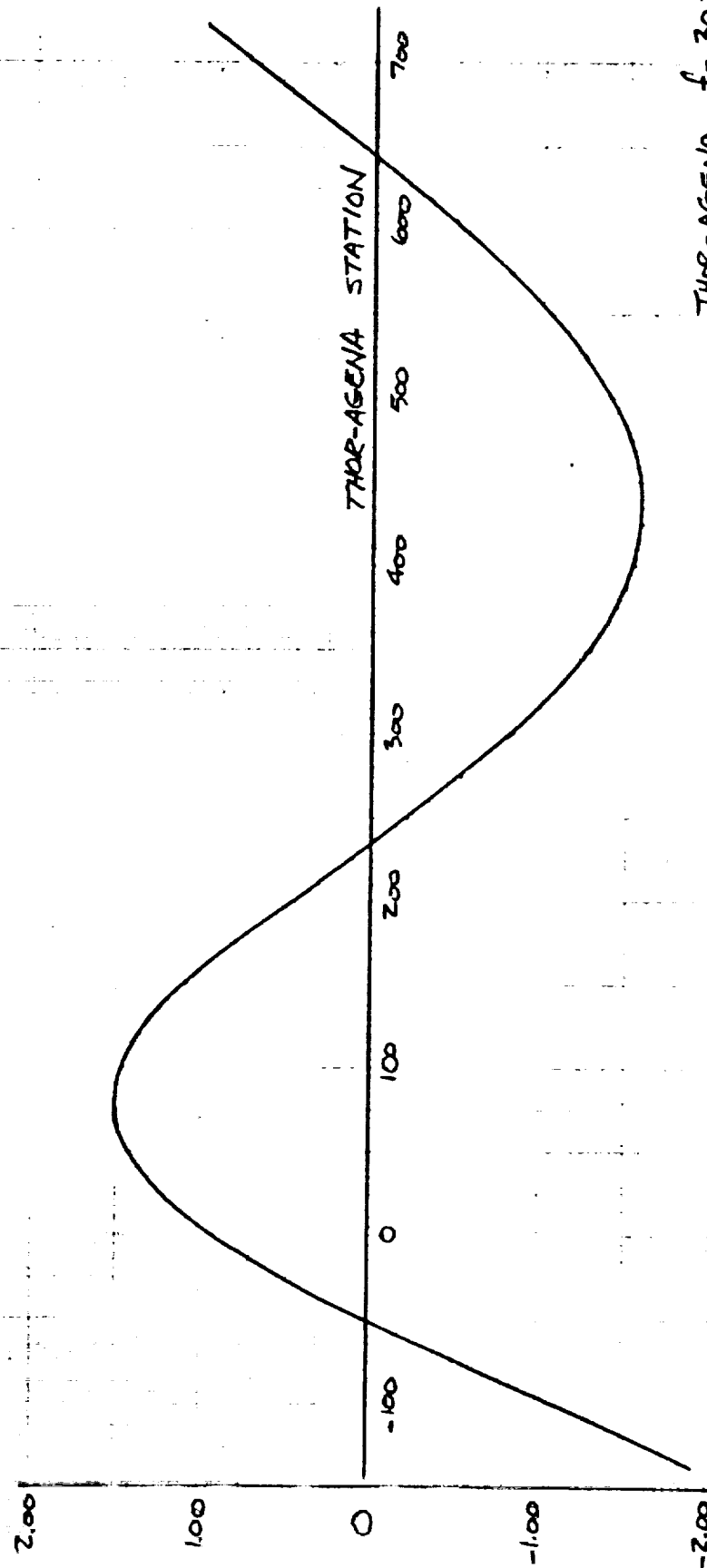
DATE

JOB PAGE NO.

MODEL

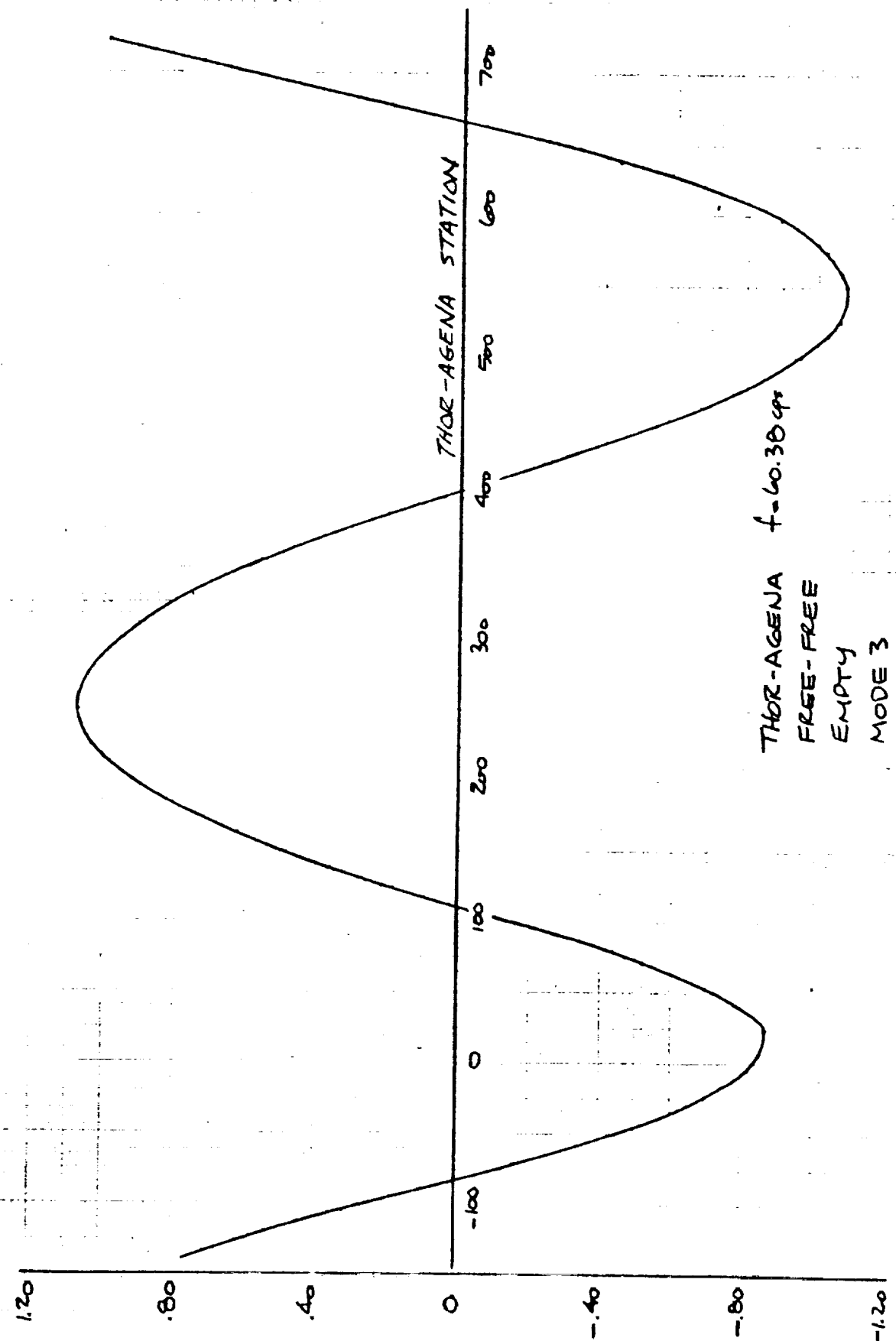
REPORT NO.

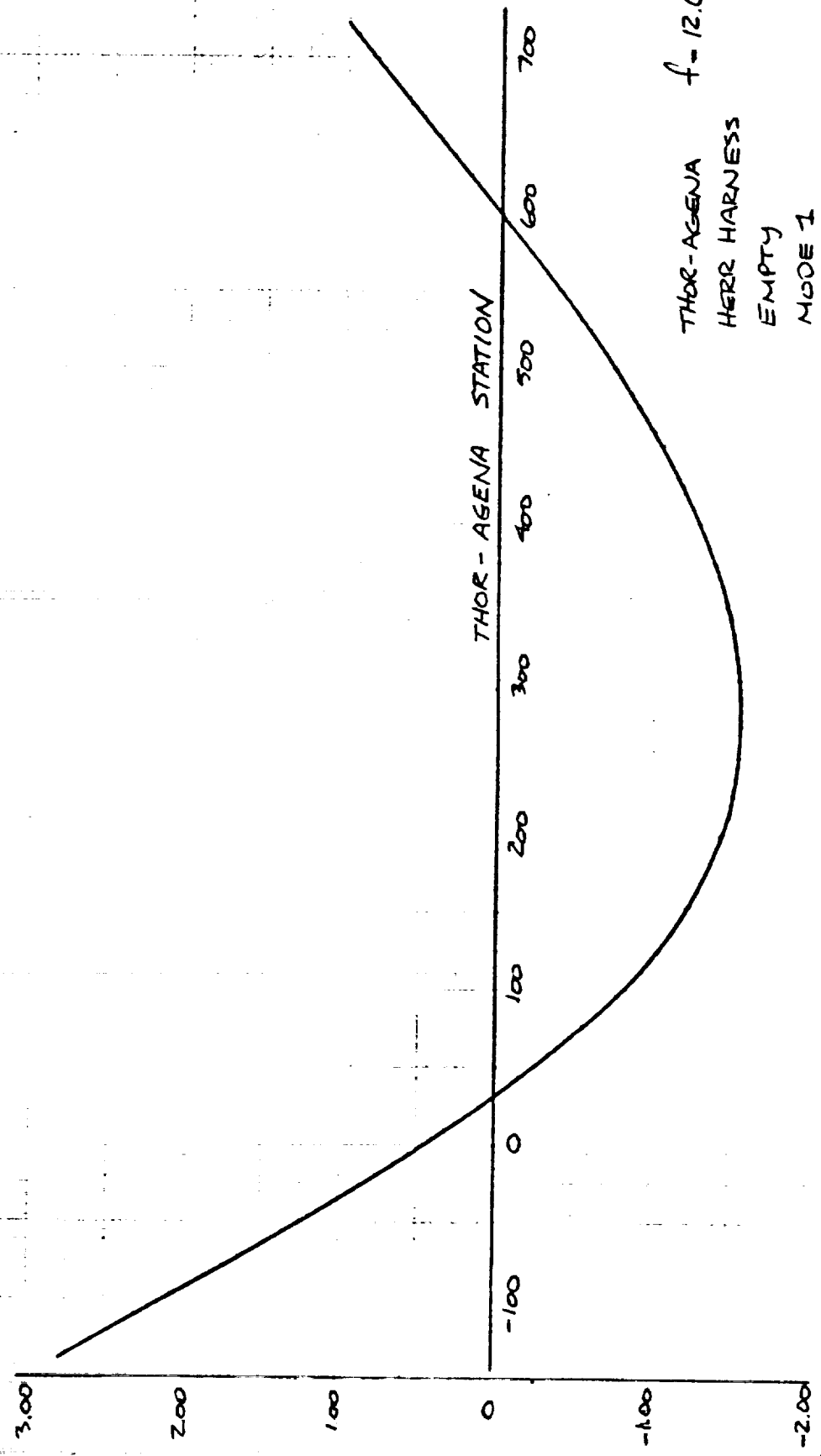
T-A F.F.
EMPTY
MODE 2



THOR-AGENA $f = 30.77$ cps
FREE-FREE
EMPTY
MODE 2

DOUGLAS





THOR-AGENA $f = 12.62 \text{ cps}$
 HERC HARNESS
 EMPTY
 MODE 1

REF. JOB PAGE NOS.

JOB PAGE NO.

DATE

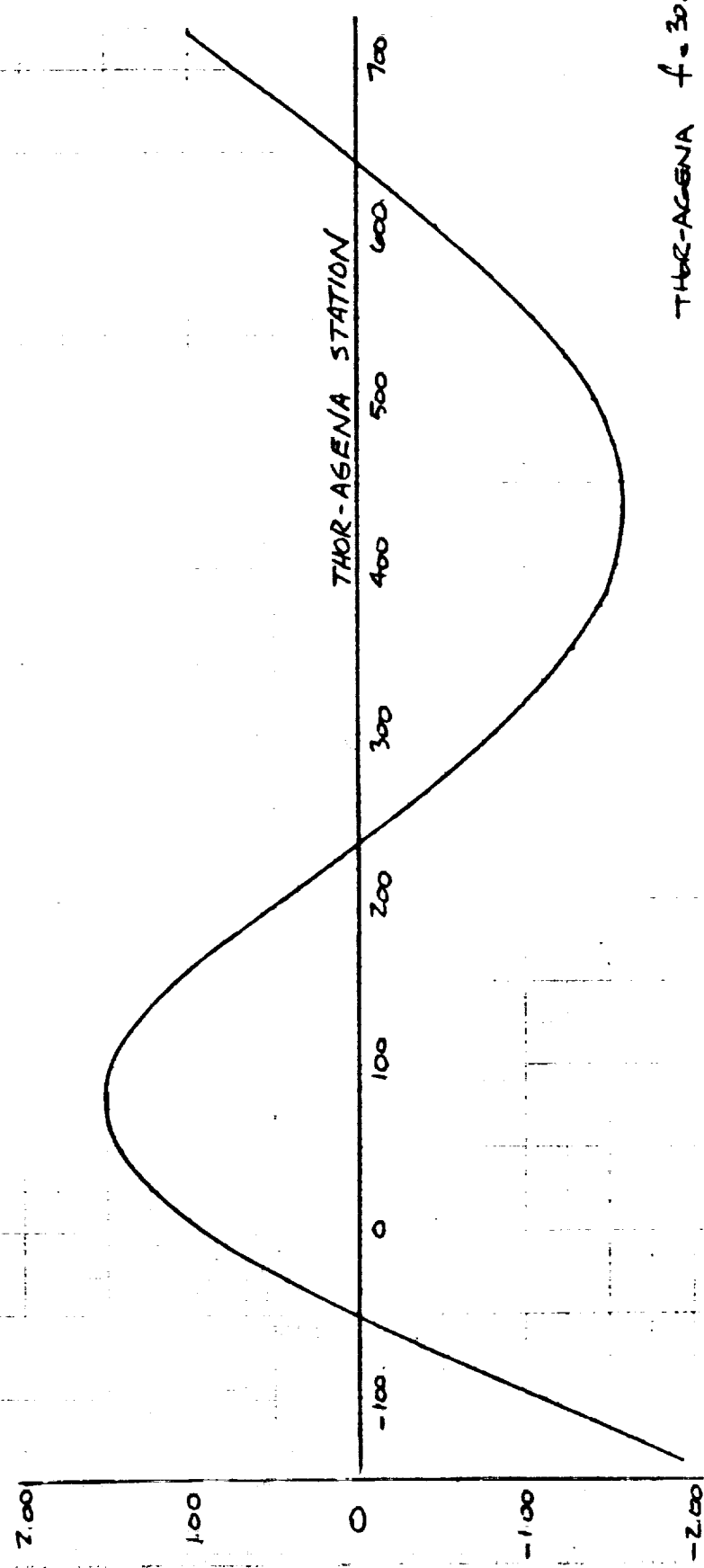
PREPARED BY

REPORT NO.

MODEL

MODE 2

DOUGLAS



THOR-AGENA f. 30.77cps
 HERE HARNNESS
 EMPTY
 MODE 2

REF. JOB PAGE NOS.

PREPARED BY DATE

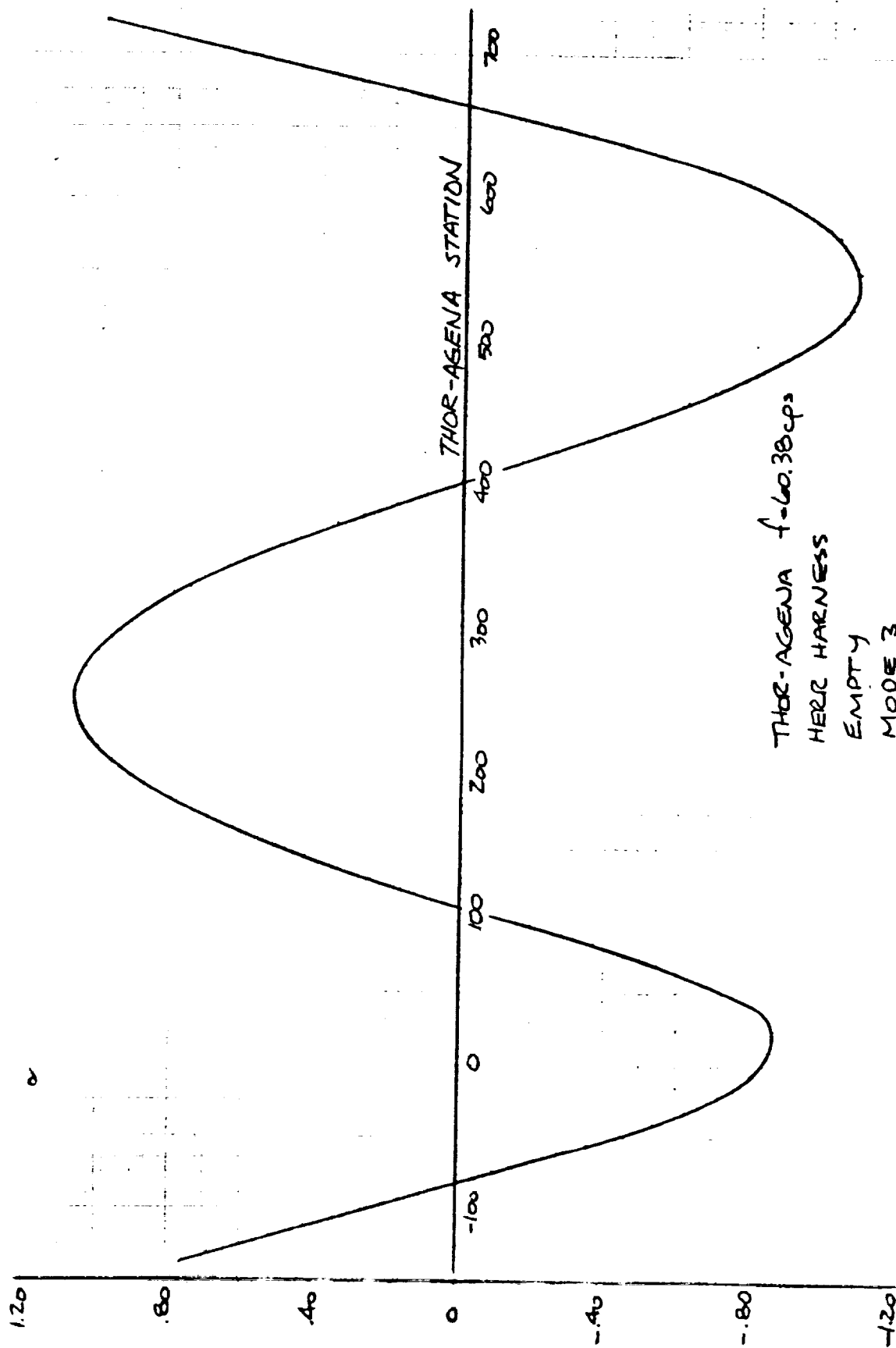
JOB PAGE NO.

MODEL

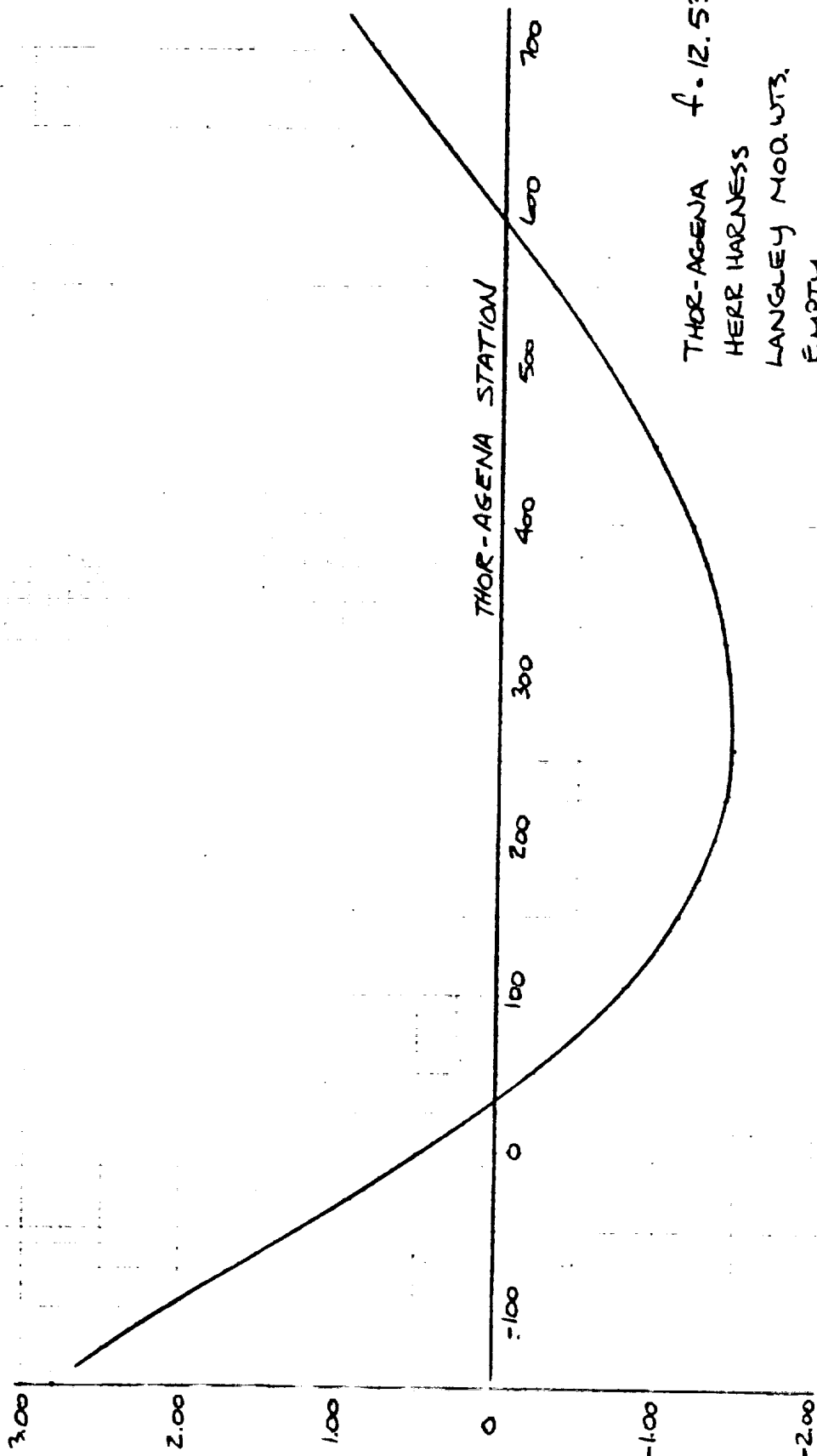
REPORT NO.

1 A HOUR
EMPTY
MODE 3

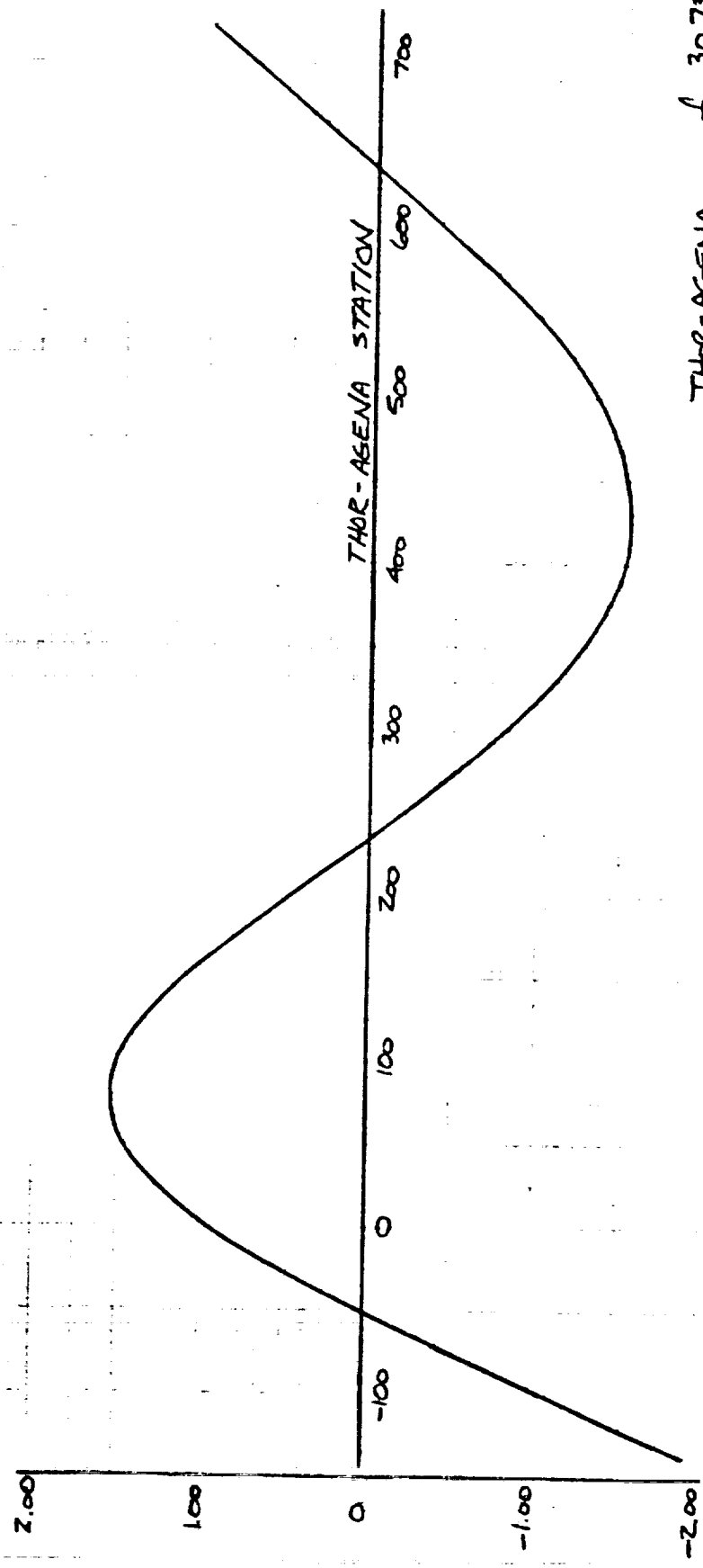
DOUGLAS



DOUGLAS



THOR-AGENA f. 12.53 cps
HERR HARNES
LANGLEY MOD. WTS.
EMPTY
MODE 1

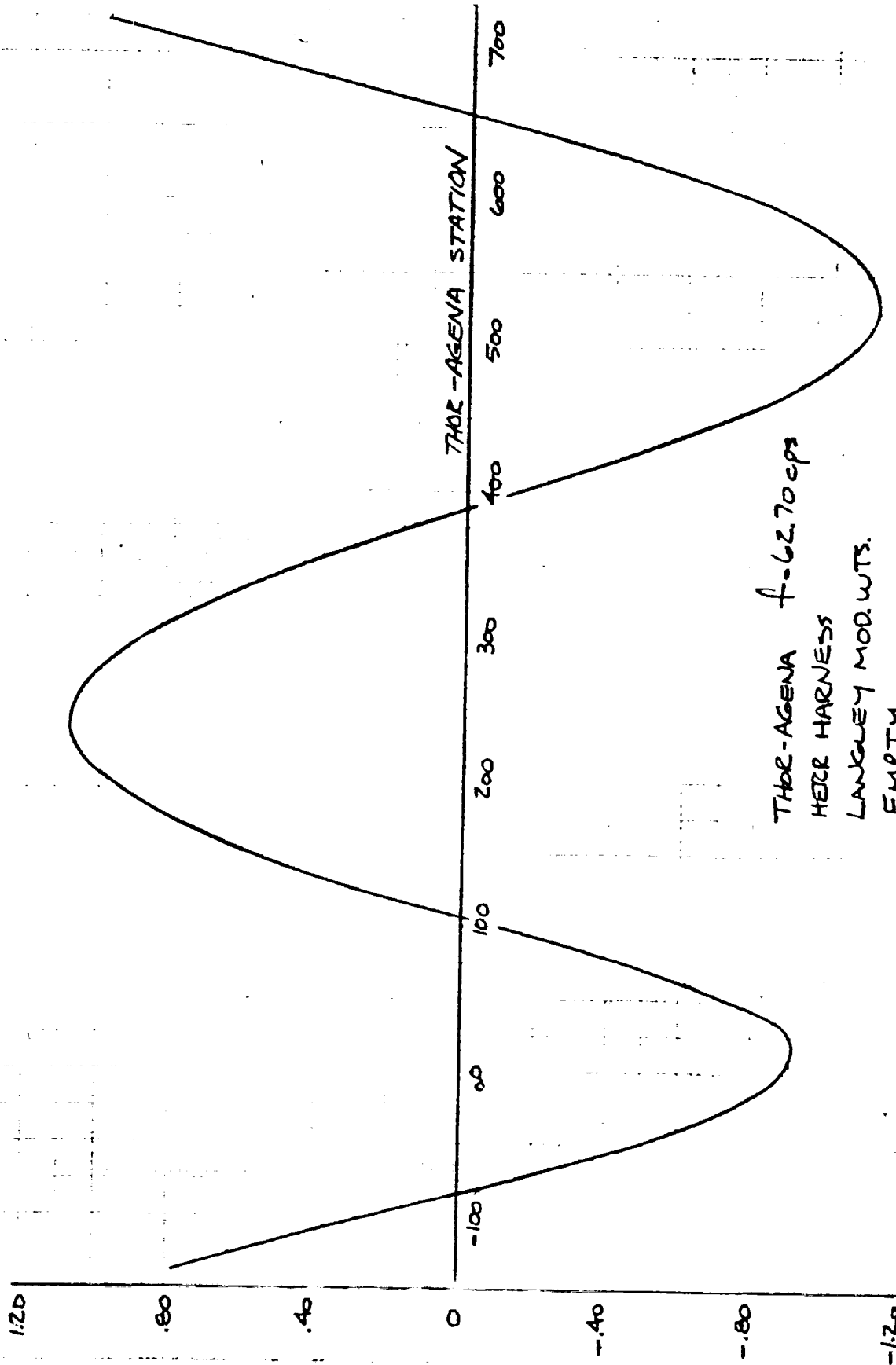


THOR-AGENA $f = 30.73 \text{ cps}$
HERR HARNESS
LANGLEY MOD. WTS.
EMPTY
MODE 2



-A HERR
EMPTY
MOD WTS.
MODE 3

DOUGLAS

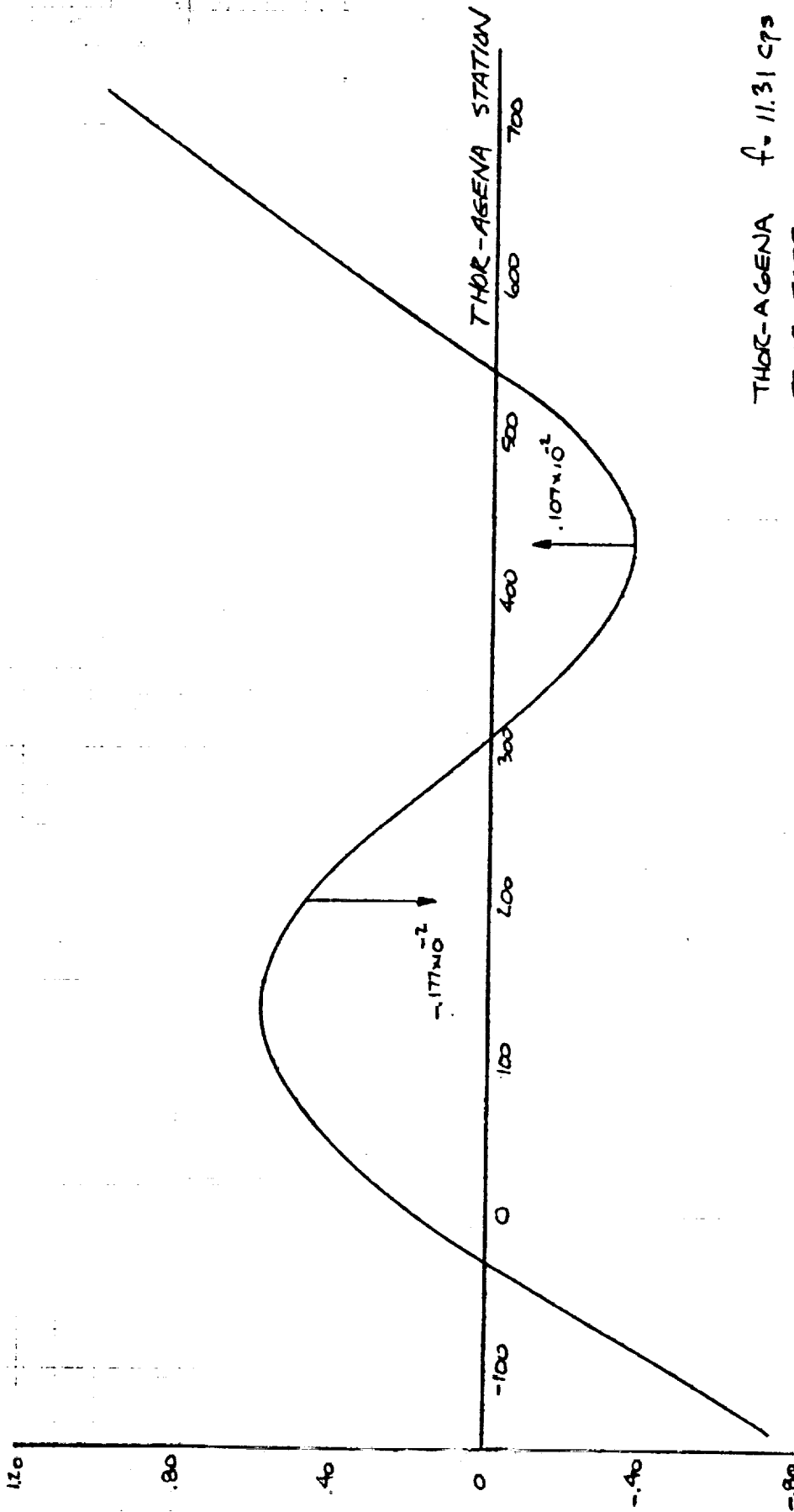


THOR-AGENA f-62.70 cps
HERR HARNESS
LANGLEY MOD. WTS.
EMPTY
MODE 3



THOR-AGENA $f = 4.105 \text{ cps}$
 FREE-FREE
 0% BURN TIME
 MODE 1

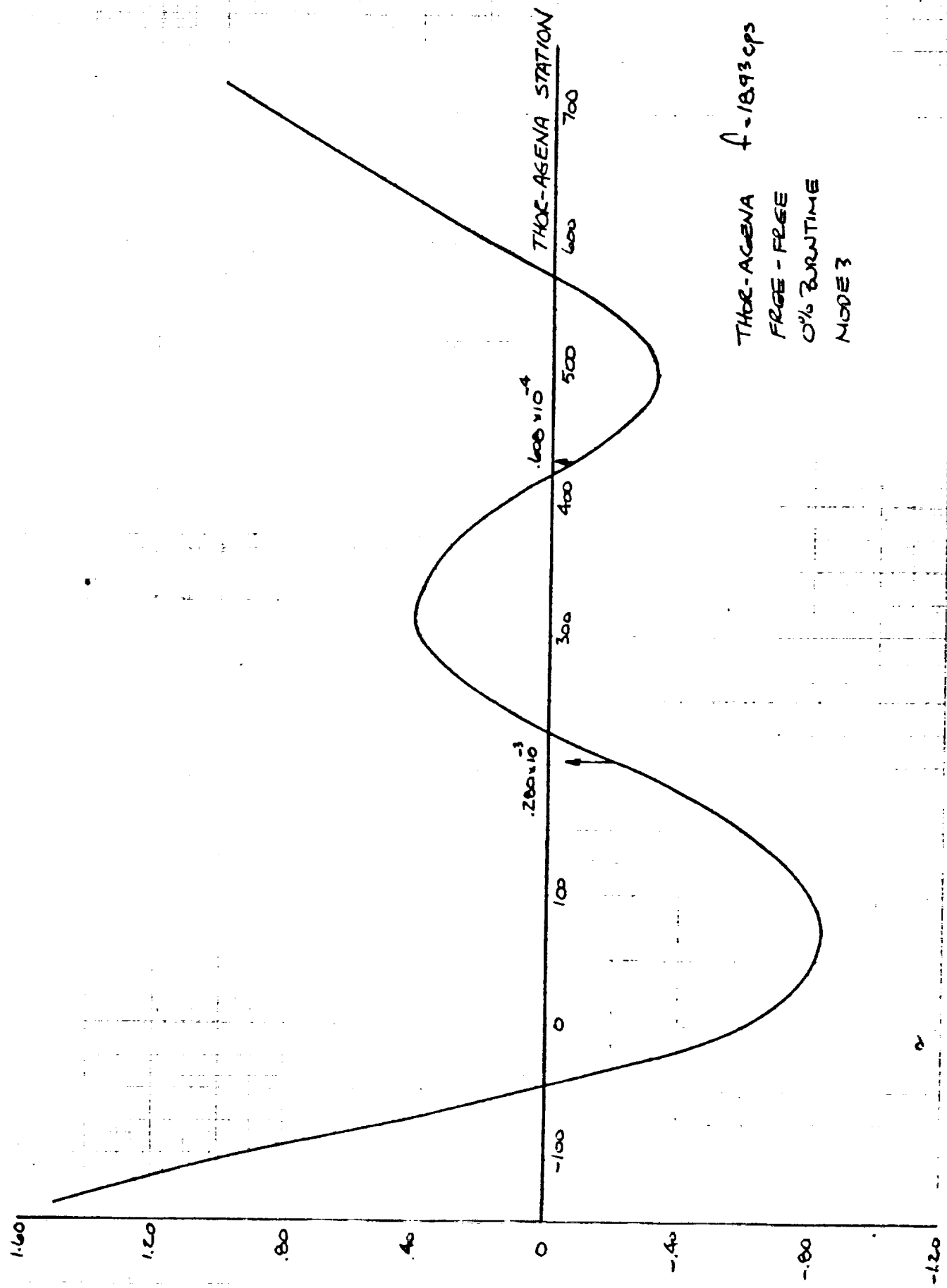




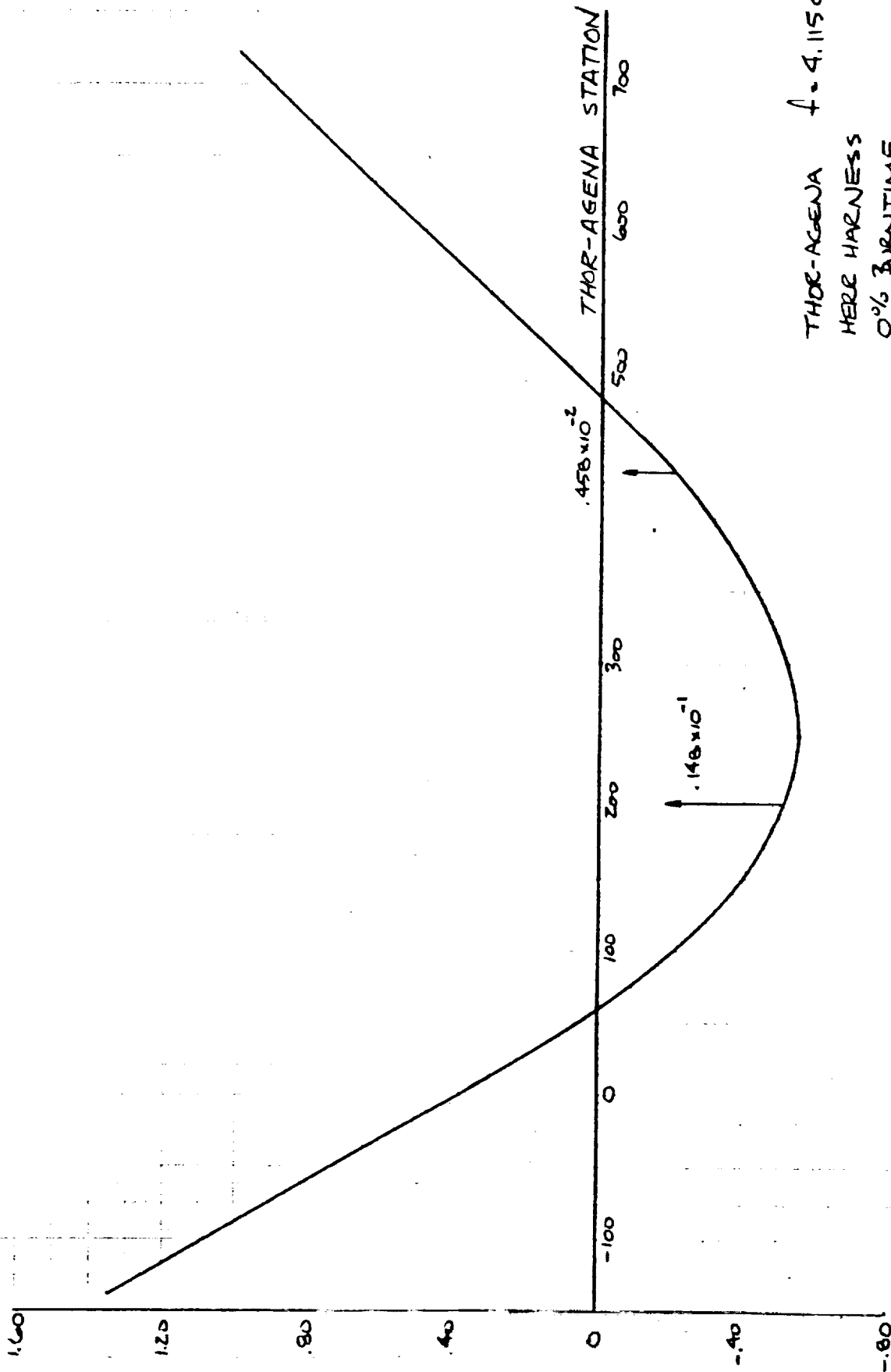
THOR-AGENA $f = 11.31 \text{ cps}$
 FREE-FREE
 0% BURN TIME
 MODE 2



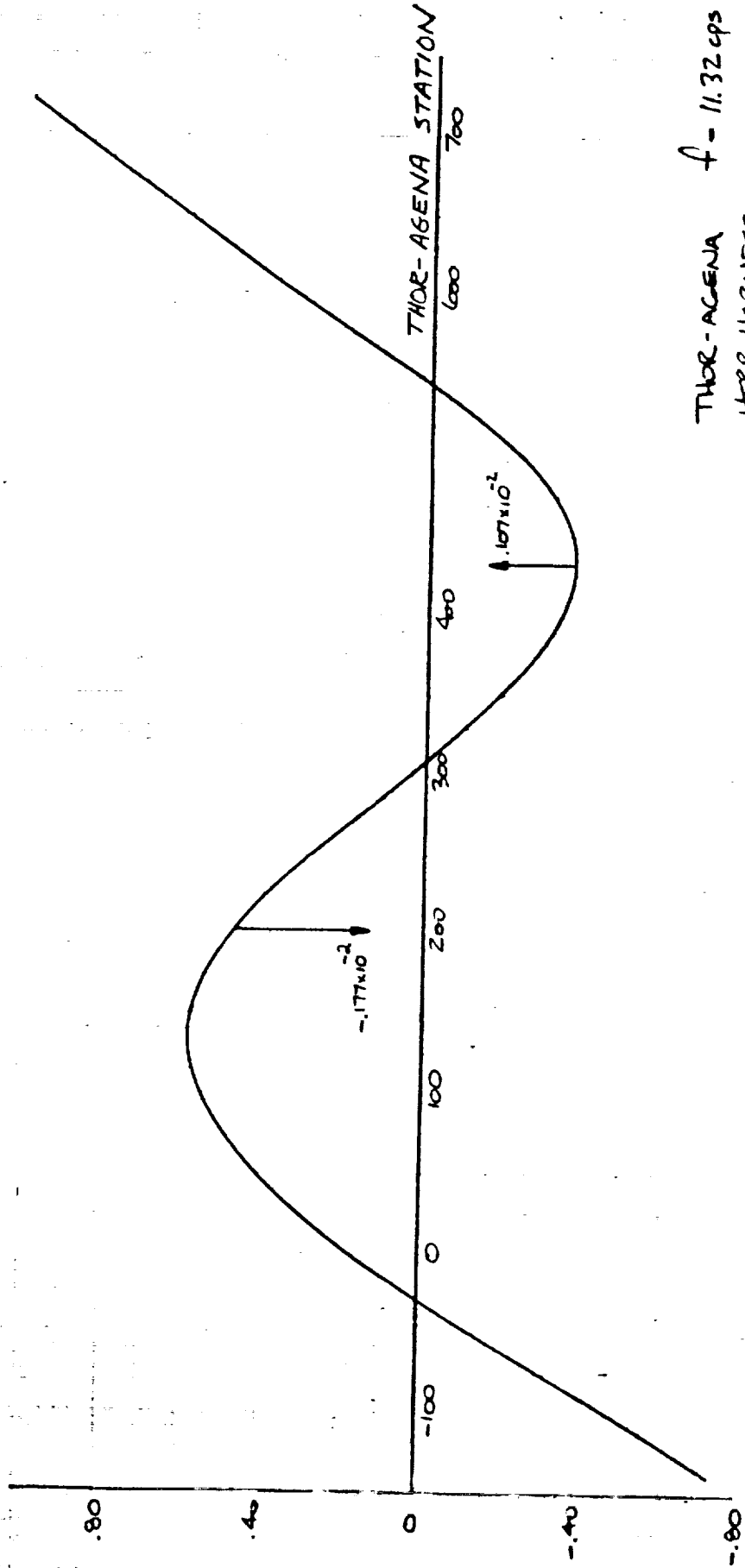
DOUGLAS



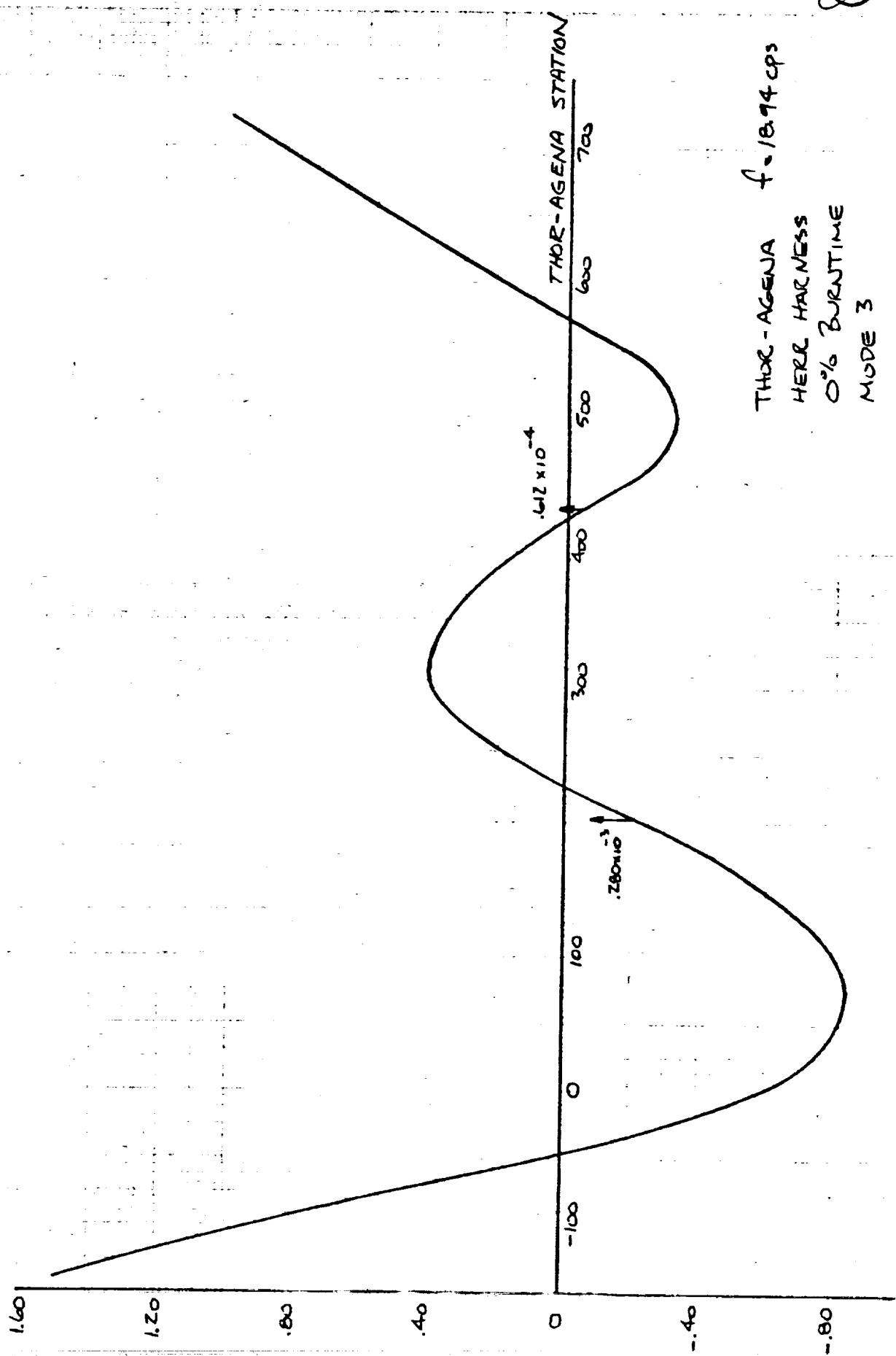
THOR-AGENA $f = 1893 \text{ cps}$
FREE - FREE
0% BURN TIME
MODE 3



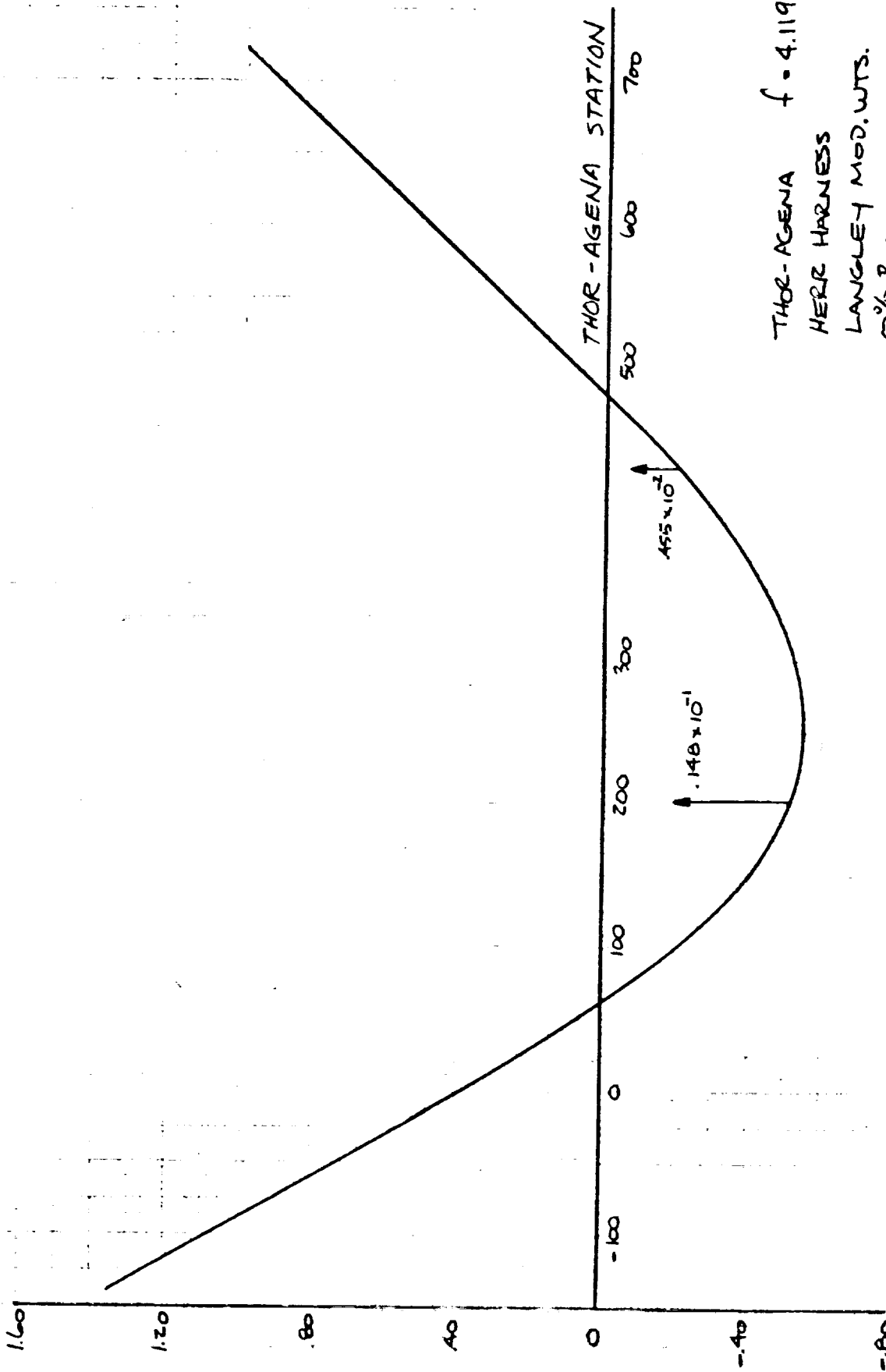
THOR-AGENA 4.4.115 cps
 HERE HARNNESS
 0% BURN TIME
 MODE 1



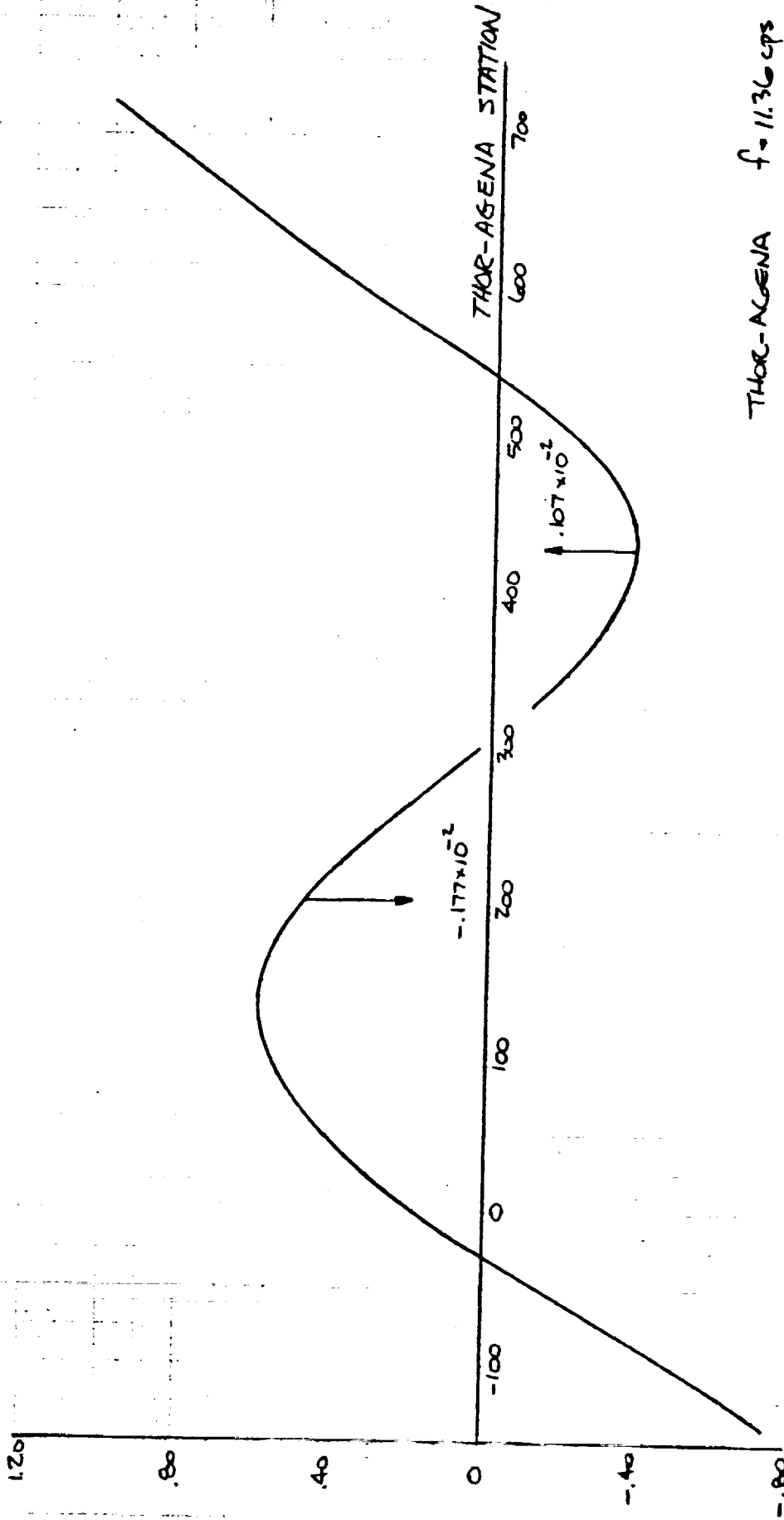
THOR-AGENA
 HELL HARNES
 0% BURN TIME
 MODE 2
 $f = 11.32 \text{ cps}$



THOR-AGENA $f = 18.94 \text{ cps}$
HERZ HARNESS
0% BURN TIME
MODE 3



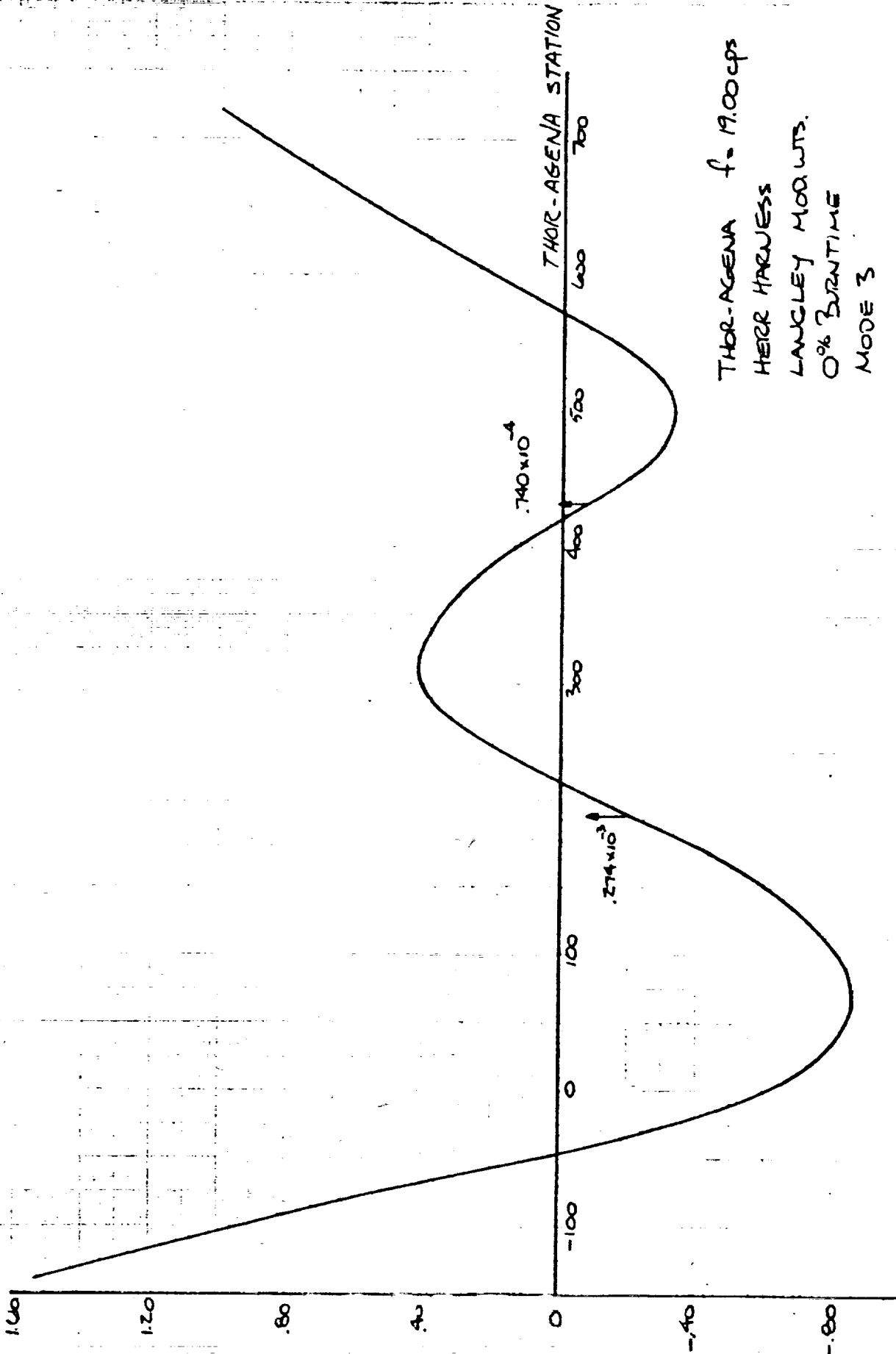
THOR - AGENA $f = 4.119 \text{ cps}$
 HERB HARNES
 LANGLEY MOD. WTS.
 0% BURN TIME
 MODE 1



THOR-AGENA $f = 11.36$ cps
 HERR HARNESS
 LANGLEY MOD. WTS.
 0% BURN TIME
 MODE 2



DOUGLAS



THOR-AGENA $f = 19.00$ cps
 HERR HARNWESS
 LANGLEY MOQWTS.
 0% BURNING
 MODE 3

REP. JOE PAGE NOS.

PREPARED BY

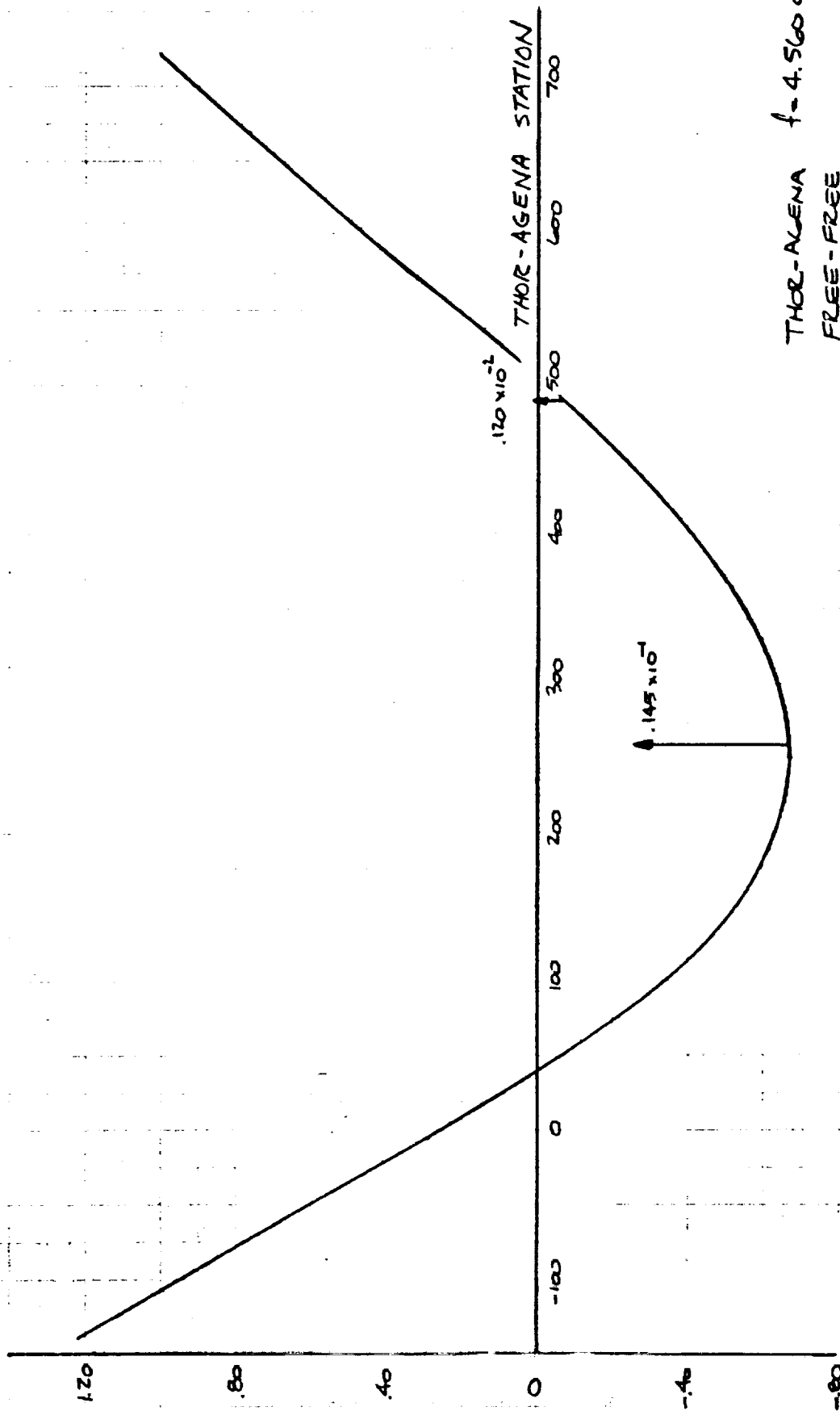
DATE

JOS PAGE NO.

MODEL

REPORT NO.

DOUGLAS



THOR-AGENA $f = 4.560 \text{ cps}$
 FREE-FREE
 25% BURNTIME
 MODE 1

REF. JOB PAGE NOS. _____

JOB PAGE NO. _____

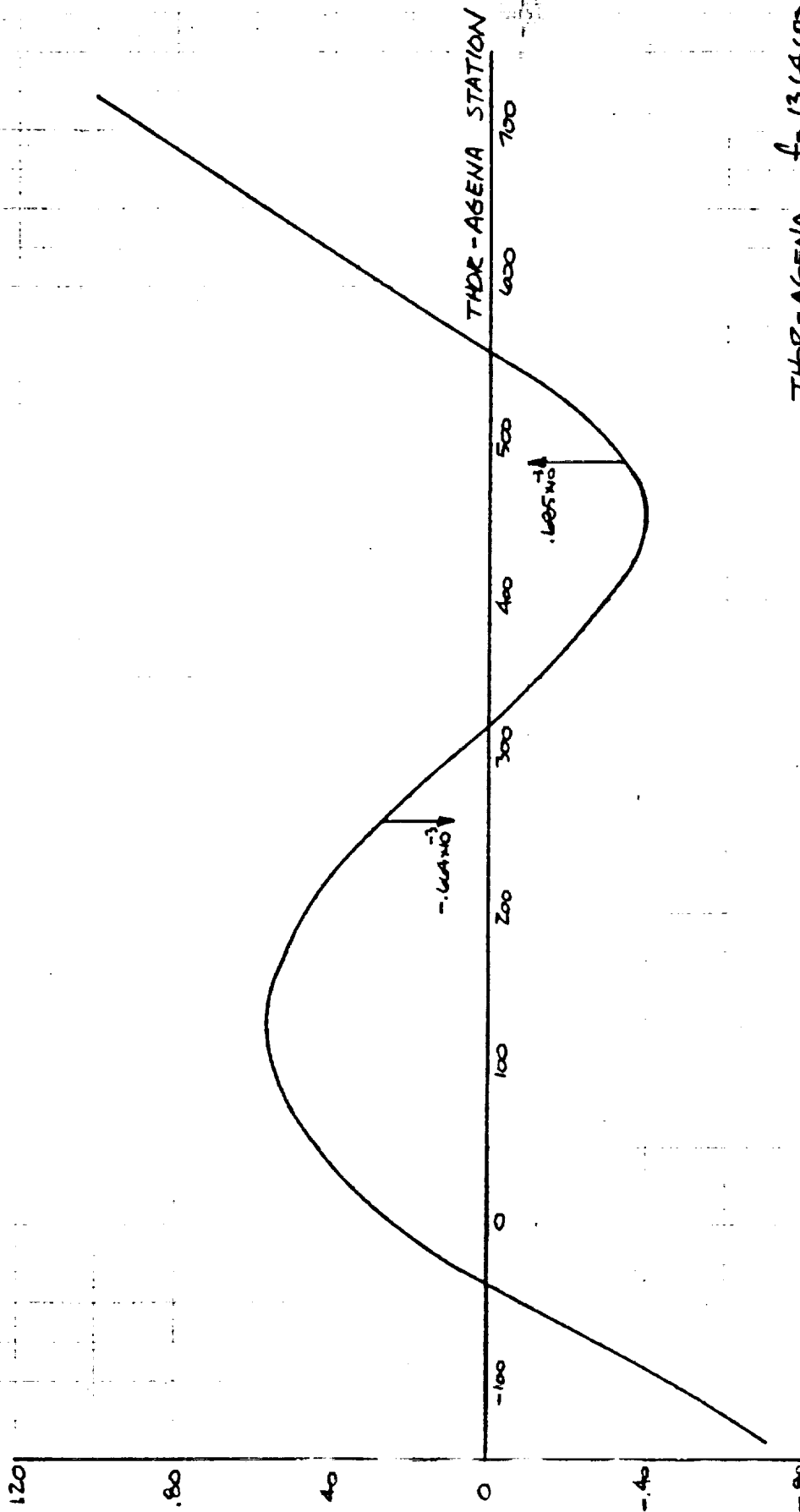
PREPARED BY _____

DATE _____

MODEL _____

REPORT NO. _____

DOUGLAS



THOR-AGENA $f = 13.6 \text{ cps}$
 FREE-FREE
 25% BURN TIME
 MODE 2

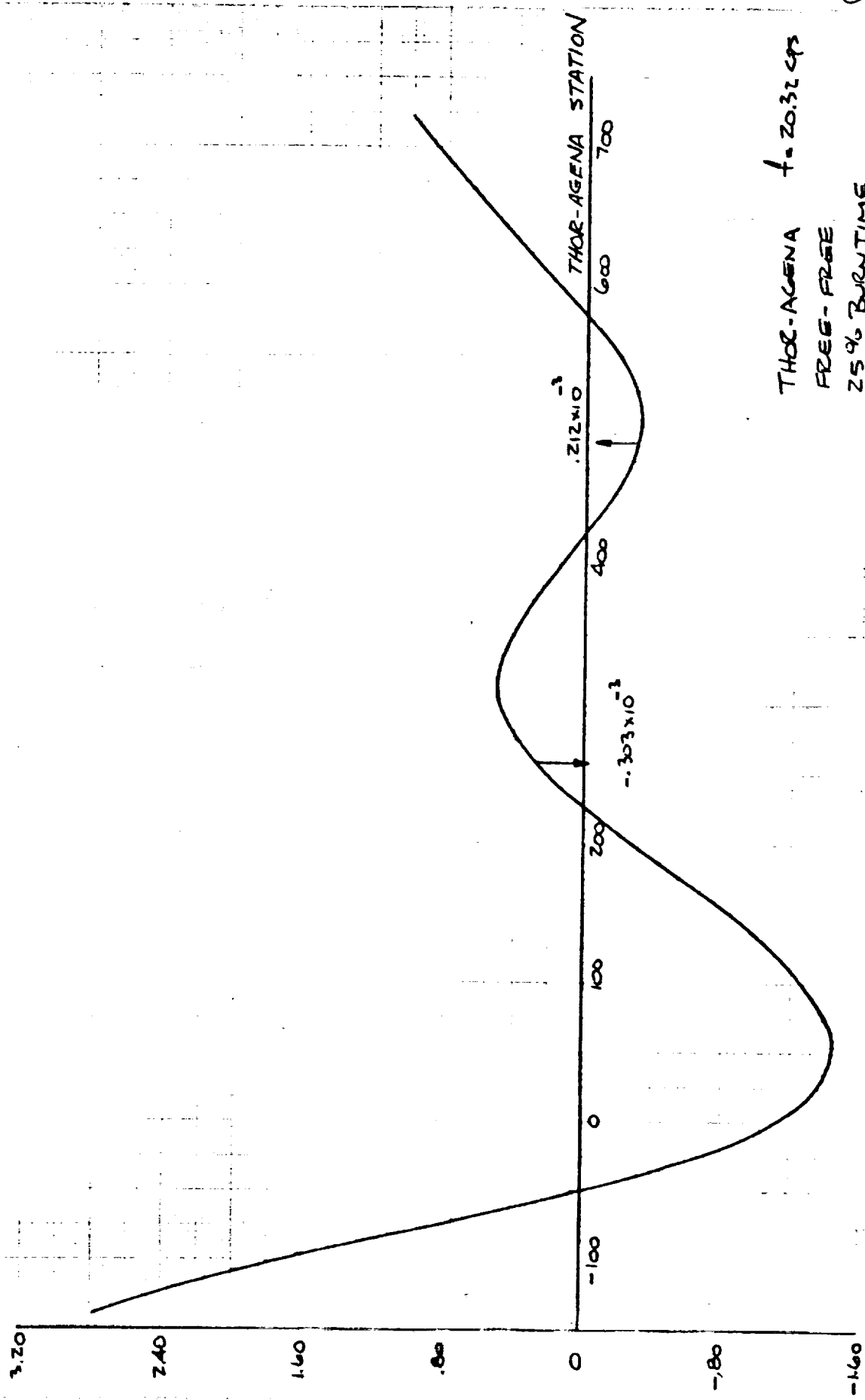
REF. JOB PAGE NOS. _____
 PREPARED BY _____

JOB PAGE NO. _____
 MODEL _____

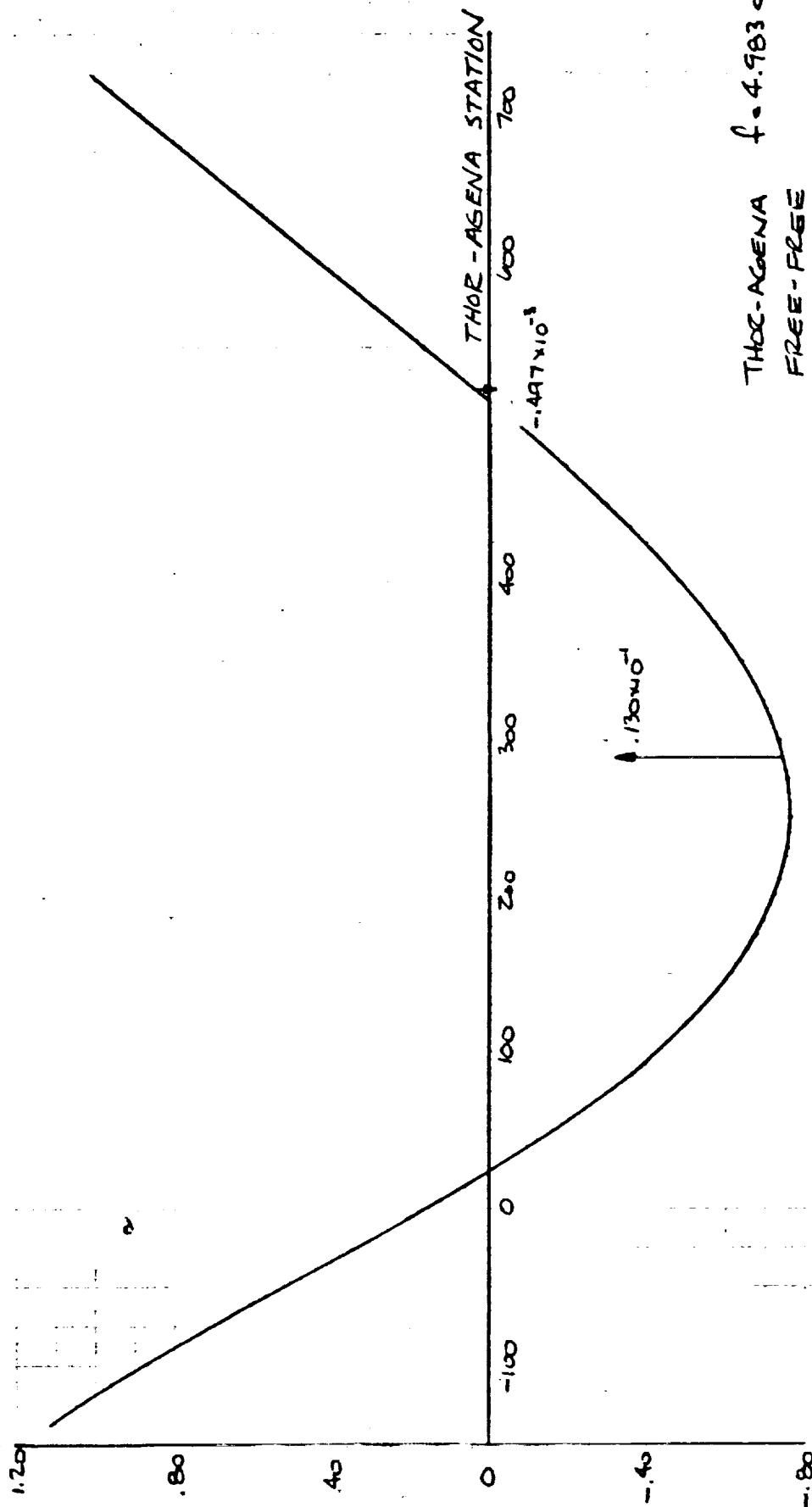
DATE _____

REPORT NO. _____

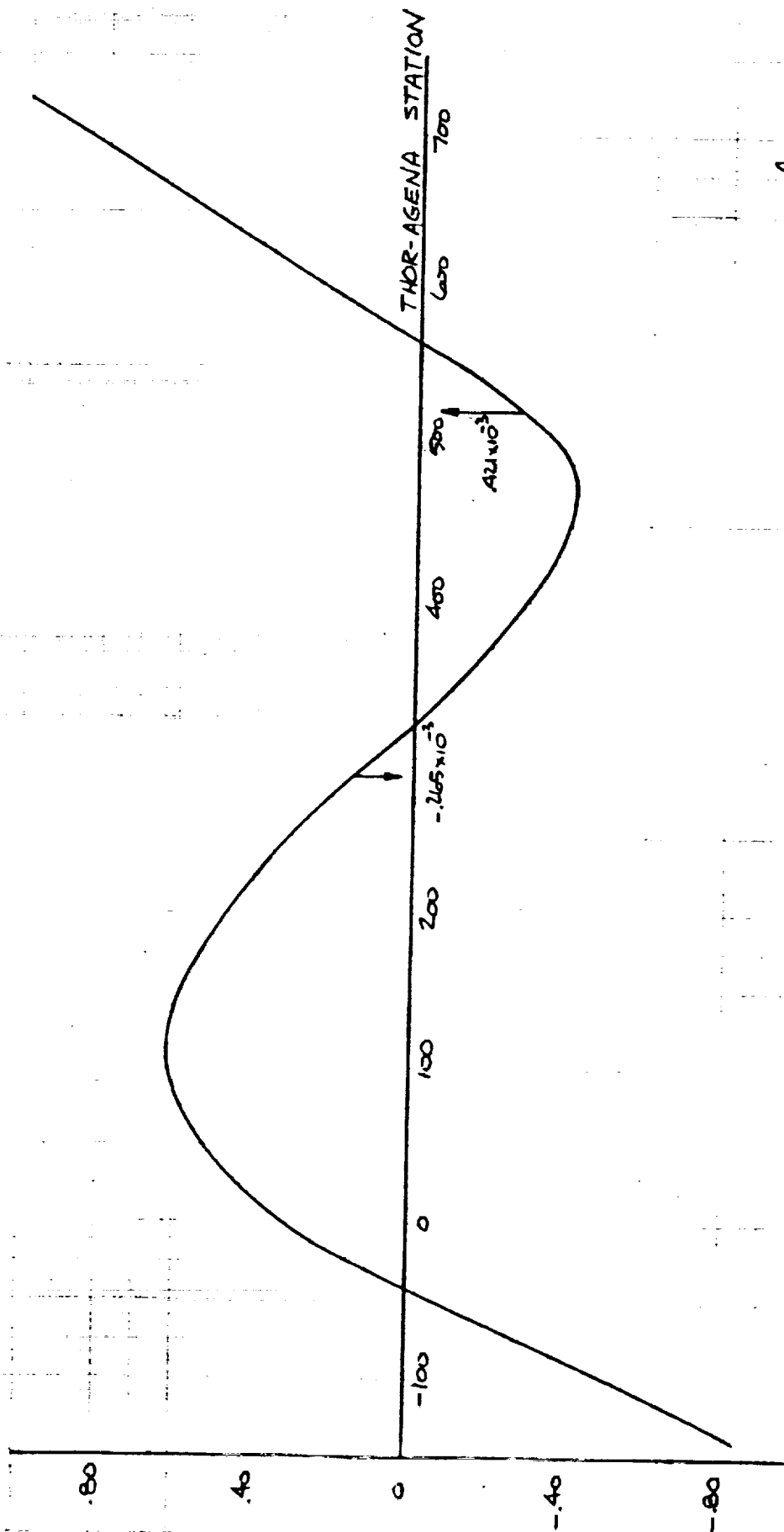
Page 2



THOR-AGENA $f = 20.32 \text{ cps}$
 FREE-FREE
 25% BURNING
 MODE 3

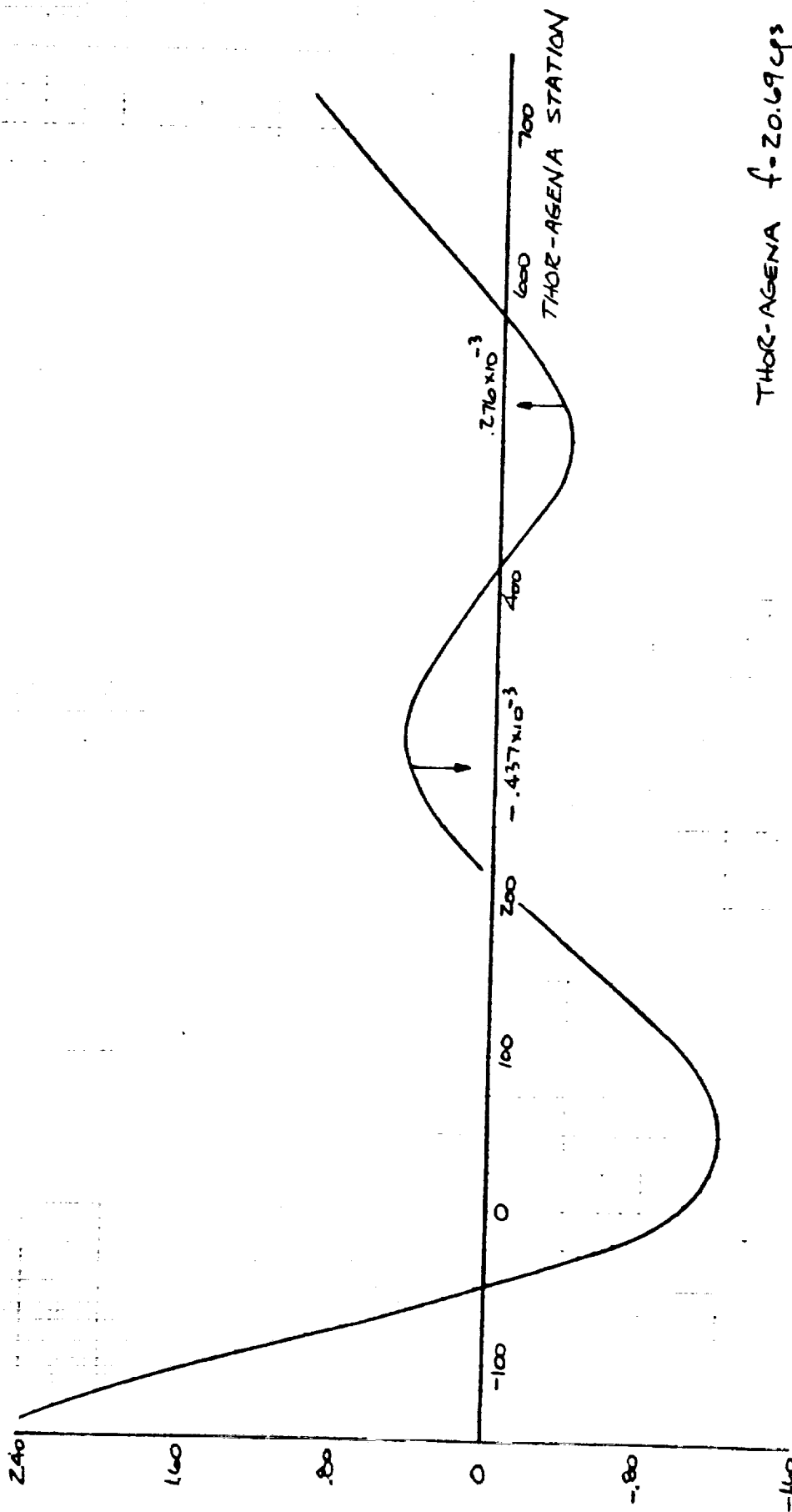


THOR-AGENA $f = 4.983 \text{ cps}$
 FREE-FREE
 40% BURNTIME
 MODE 1



THOR-AGENA $f = 15.44$ cps
 FREE-FREE
 40% BURN TIME
 MODE 2

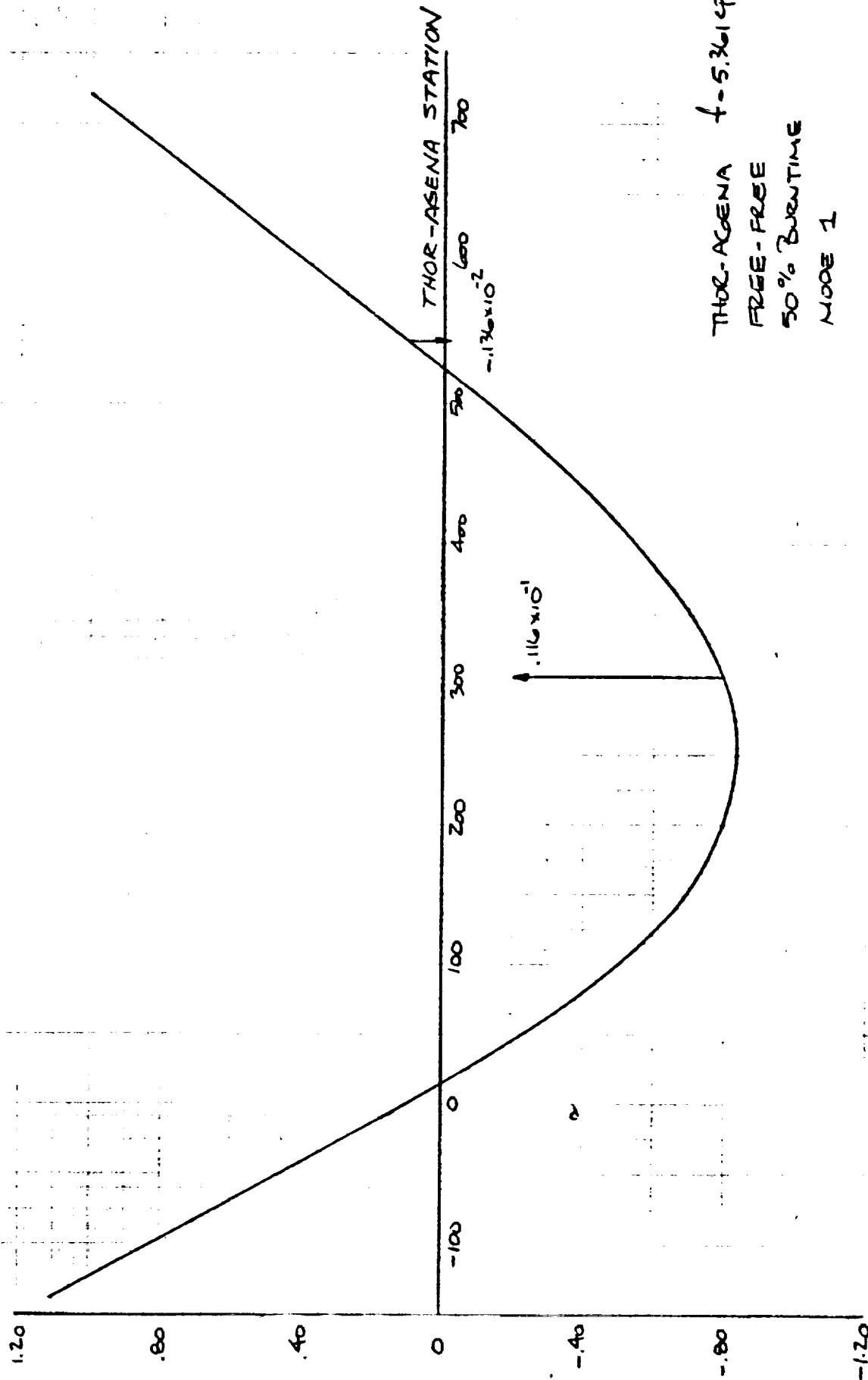
DOUGLAS

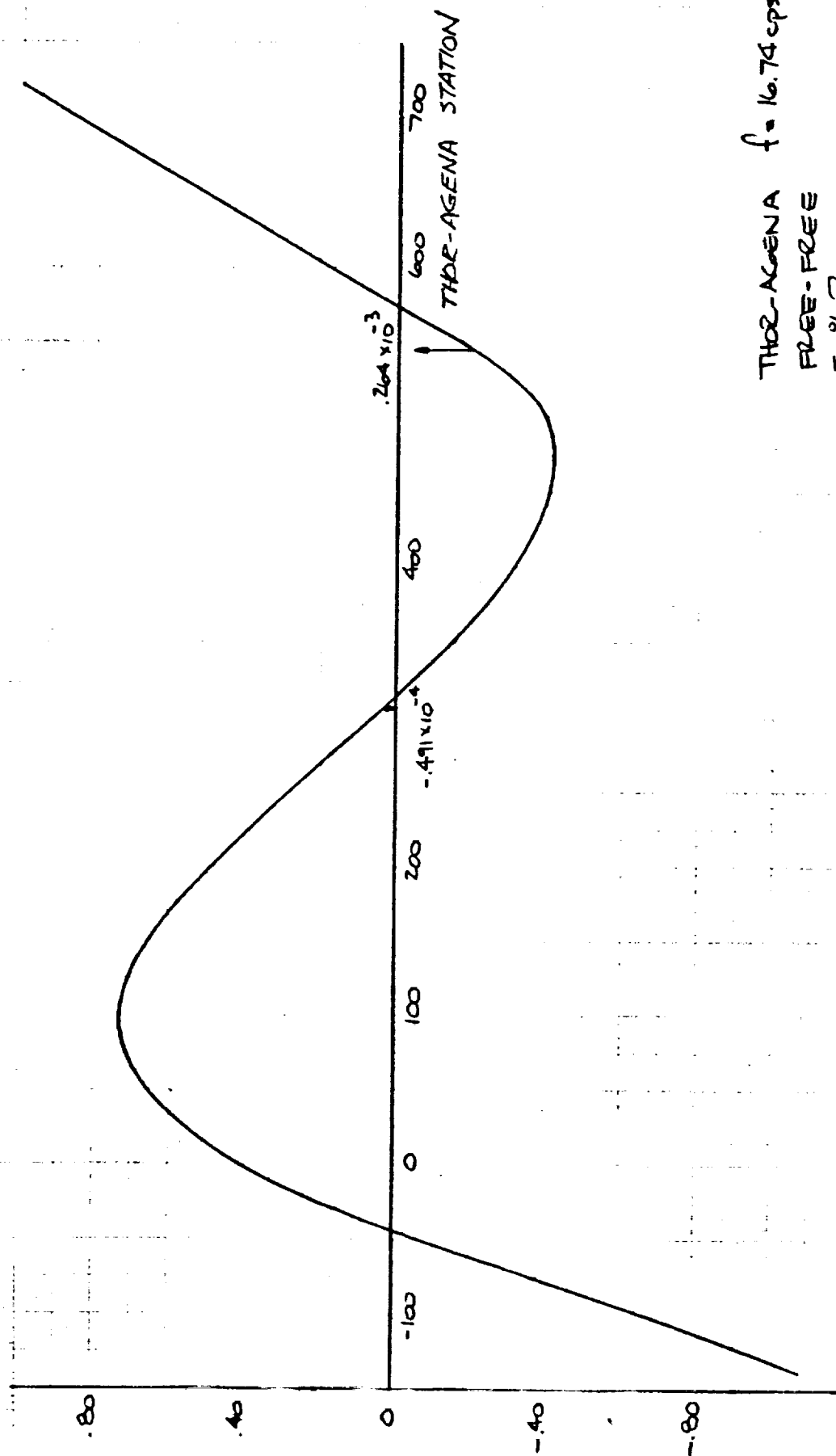


THOR-AGENA $f=20.69 \text{ cps}$
FREE-FREE
40% BURN TIME
MODE 3

DOUGLAS

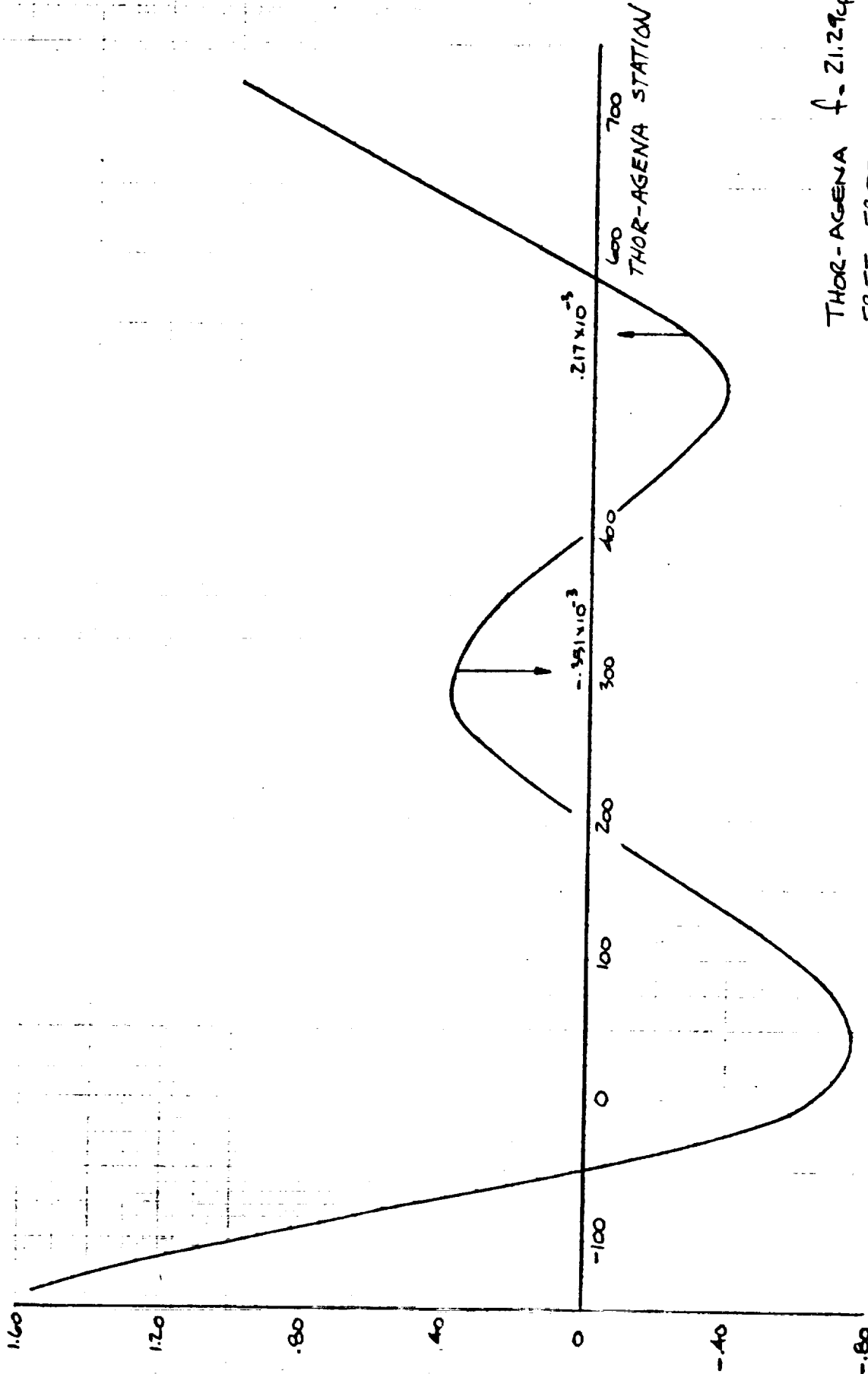
THOR-AGENA $f=5.361 \text{ cps}$
 FREE-FREE
 50% BURN TIME
 MODE 1





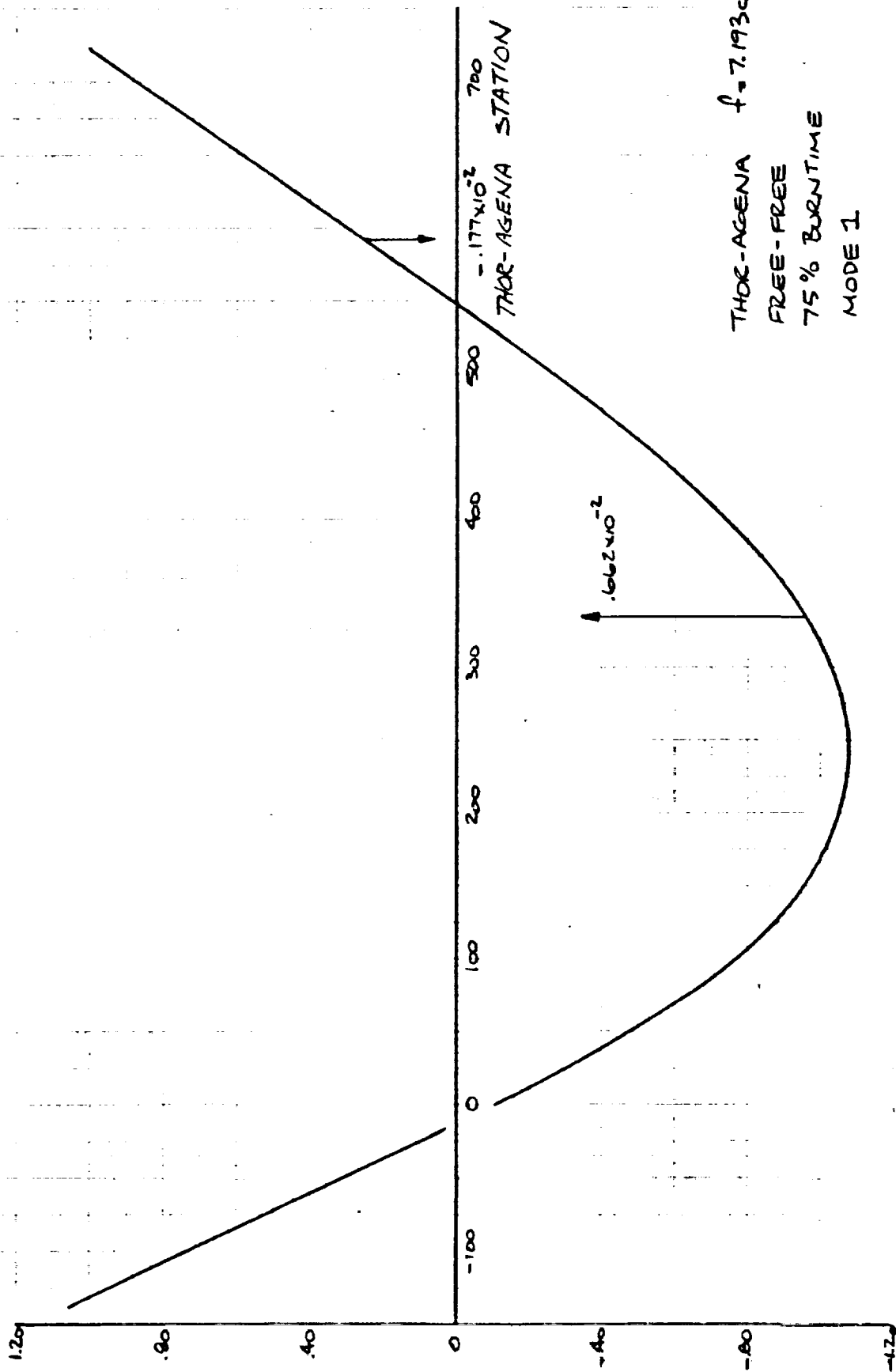
THOR-AGENA $f = 16.74 \text{ cps}$
 FREE-FREE
 50% BURNTIME
 MODE 2





DOUGLAS

THOR-AGENA $f = 21.29 \text{ cps}$
 FREE-FRGE
 50% BURNTIME
 MODE 3

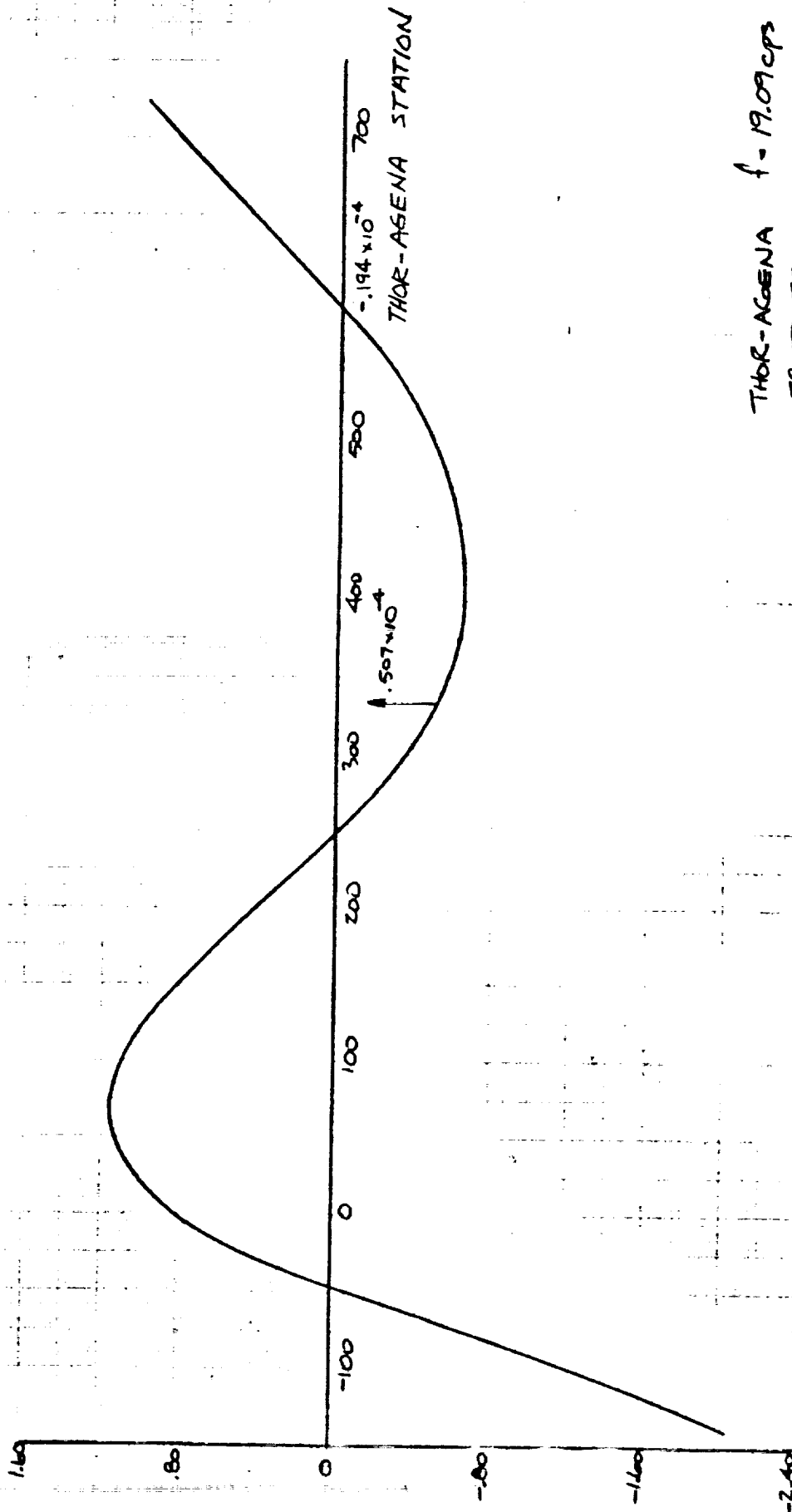


FORM 38-B-64

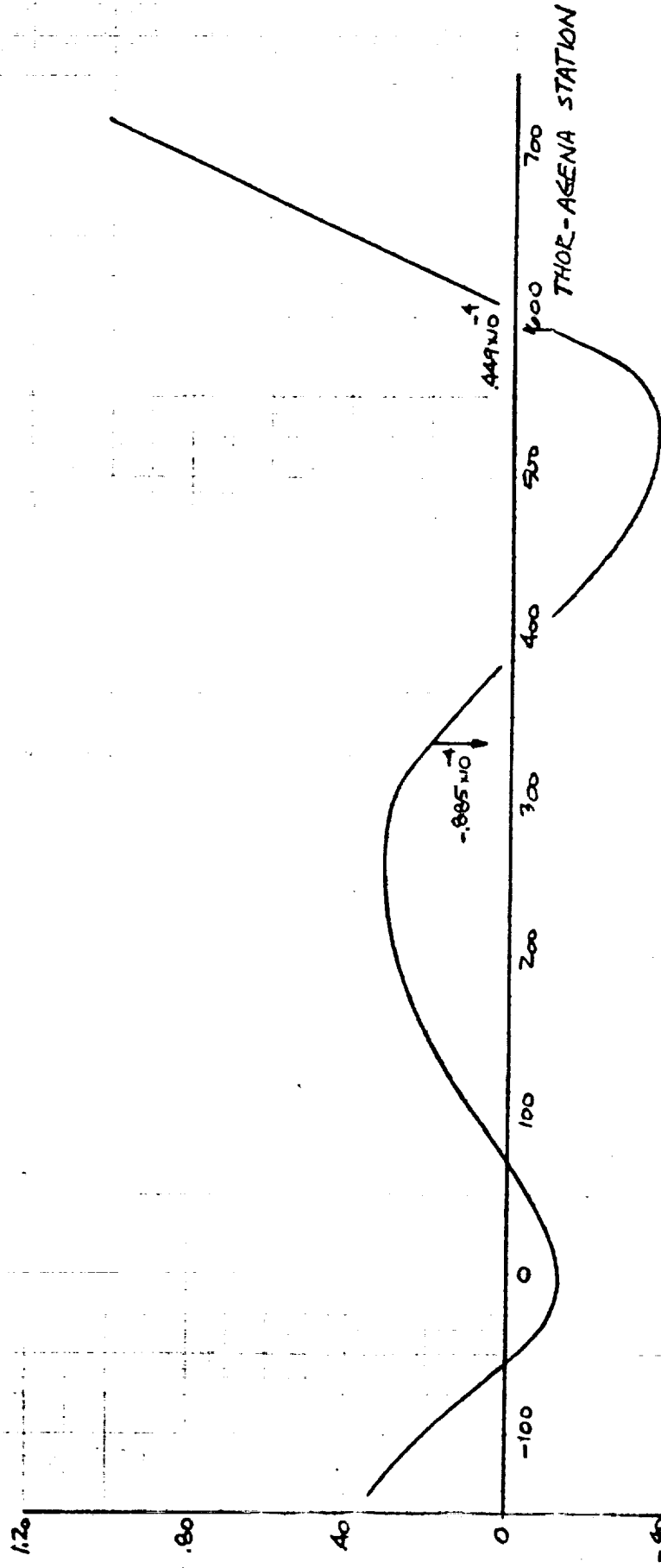
REF. JOB PAGE NO. _____
PREPARED BY _____ DATE _____

JOB PAGE NO. _____
MODEL _____ REPORT NO. _____

DOUGLAS



THOR-AGENA f = 19.09 cps
FREE-FREE
75% BURN TIME
MODE 2



DOUGLAS

THOR-AGENA f-28.214ps
FREE - FREE
75% BURN TIME
MODE 3

REF. JOB PAGE NOS.

JOB PAGE NO.

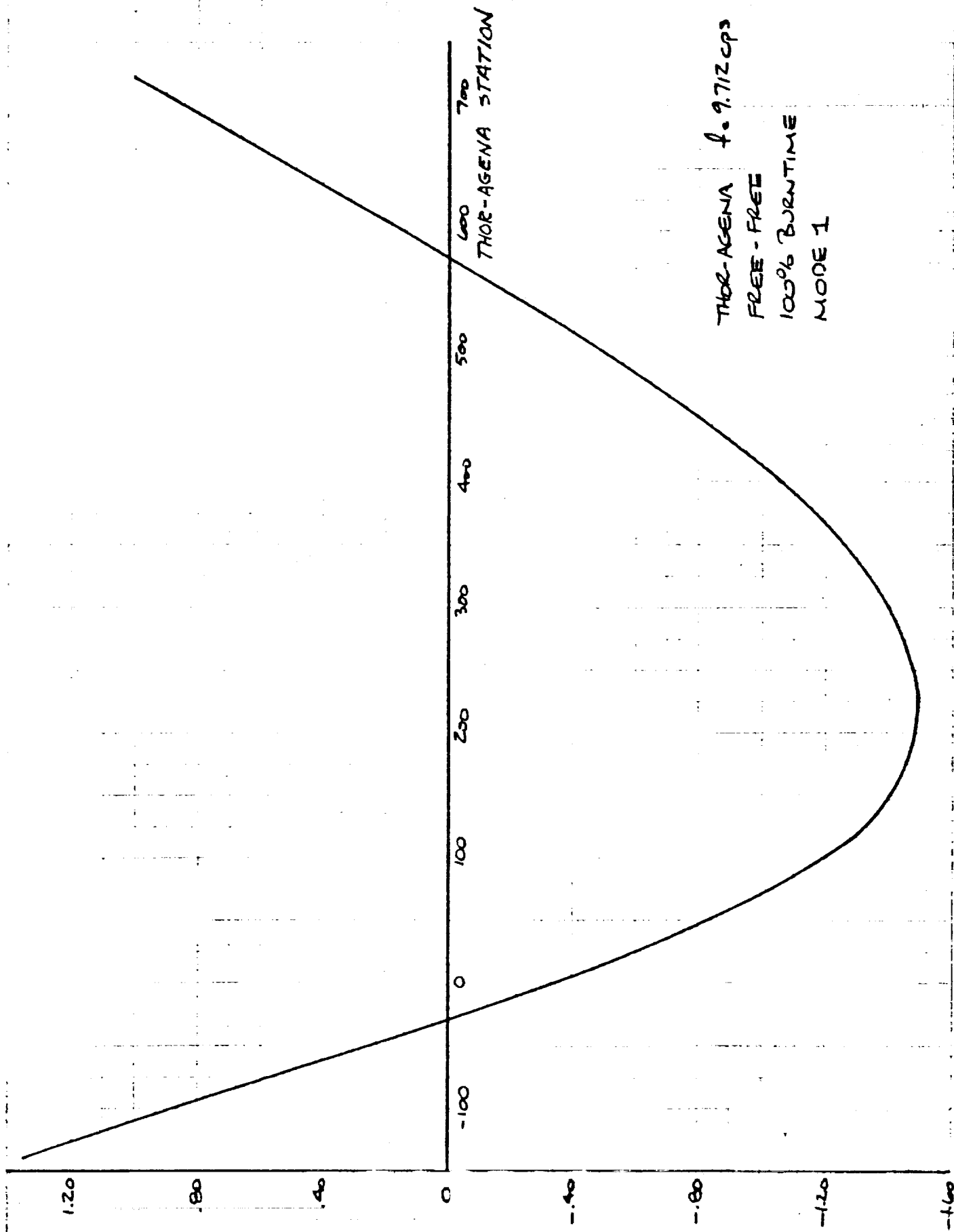
PREPARED BY

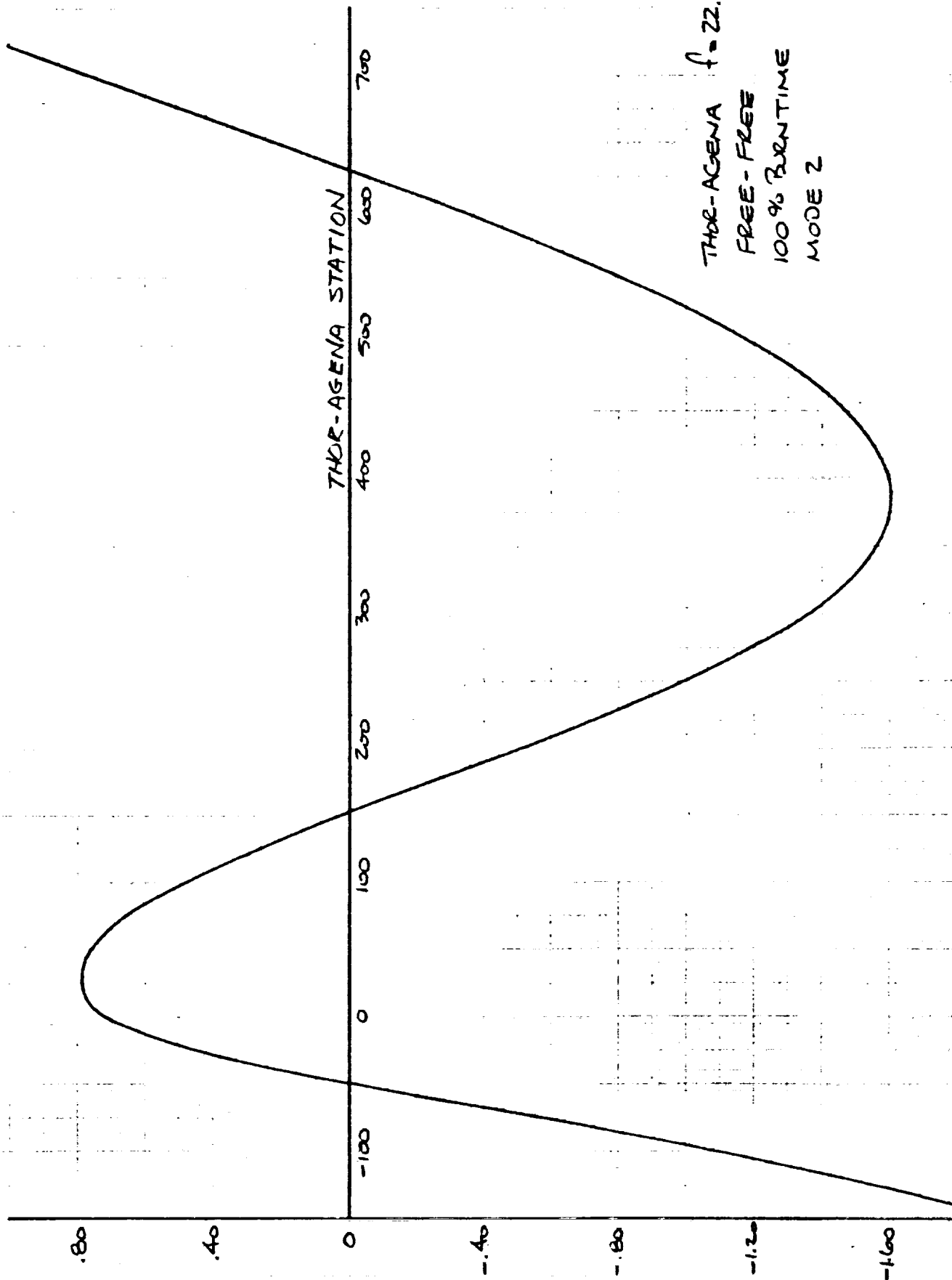
DATE

MODEL

REPORT NO.

DOUGLAS

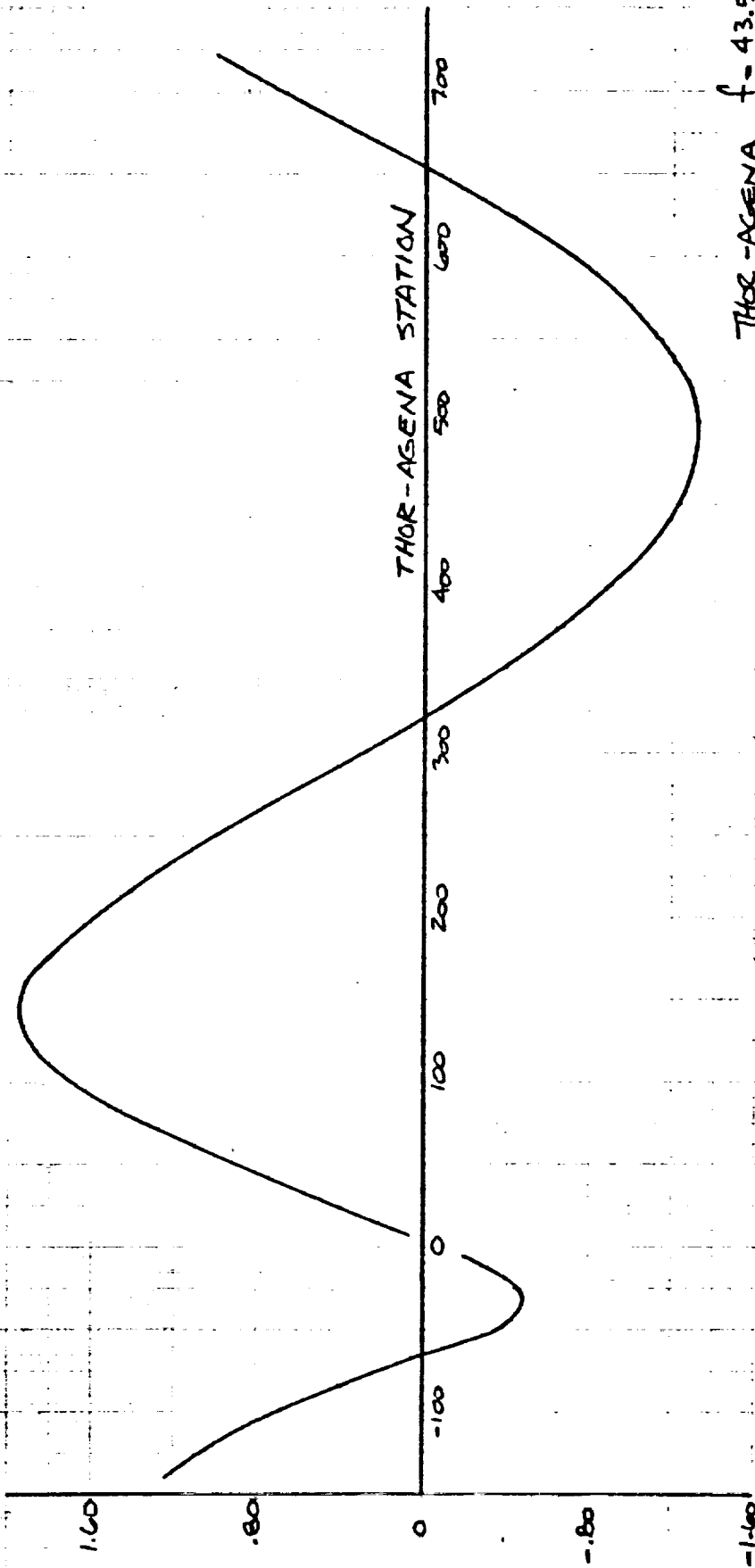




THOR-AGENA $f = 22.29 \text{ cps}$
 FREE - FREE
 100% BENTIME
 MODE 2



DOUGLAS



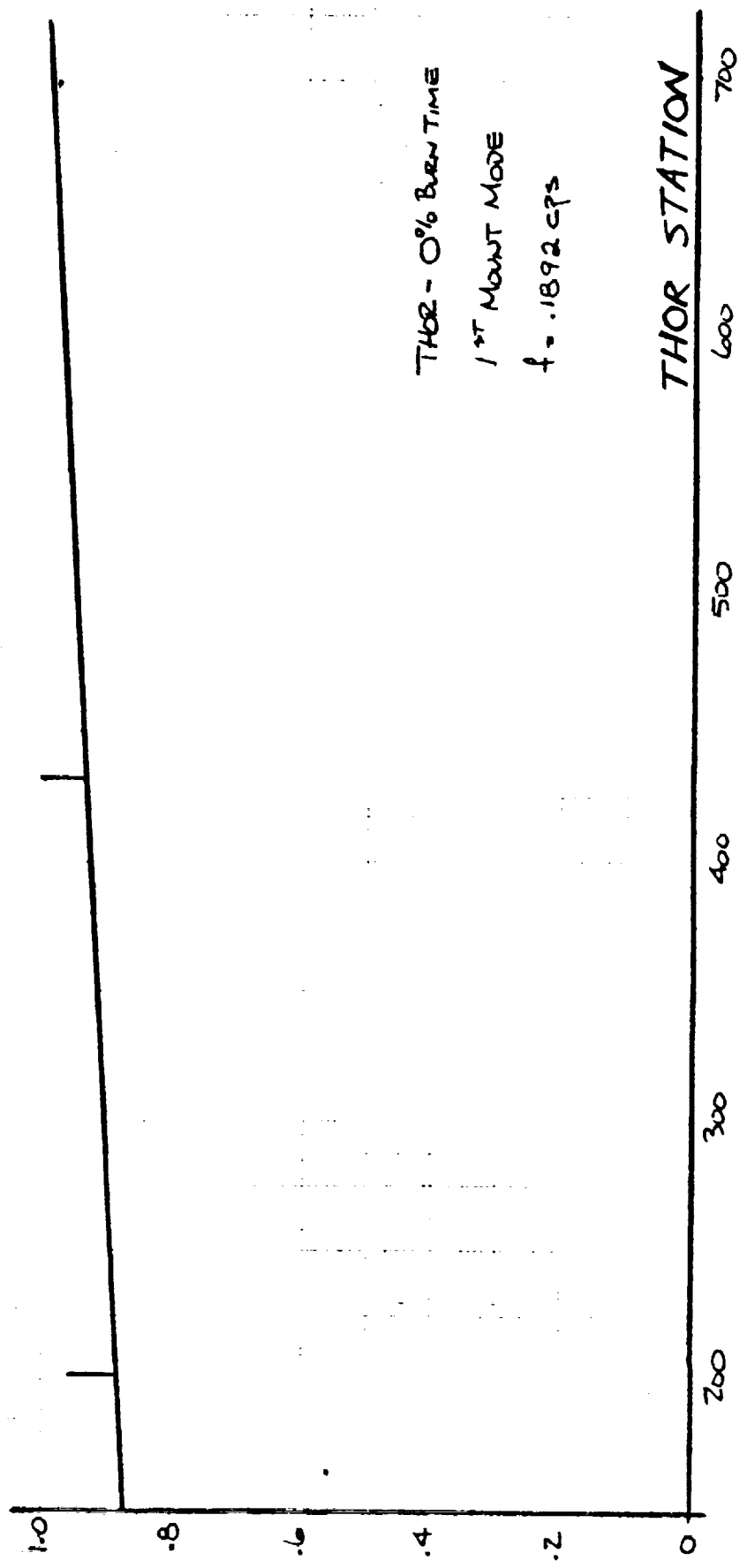
THOR-AGENA $f = 43.53 \text{ cps}$
 FREE-FREE
 100% BURNTIME
 MODE 3

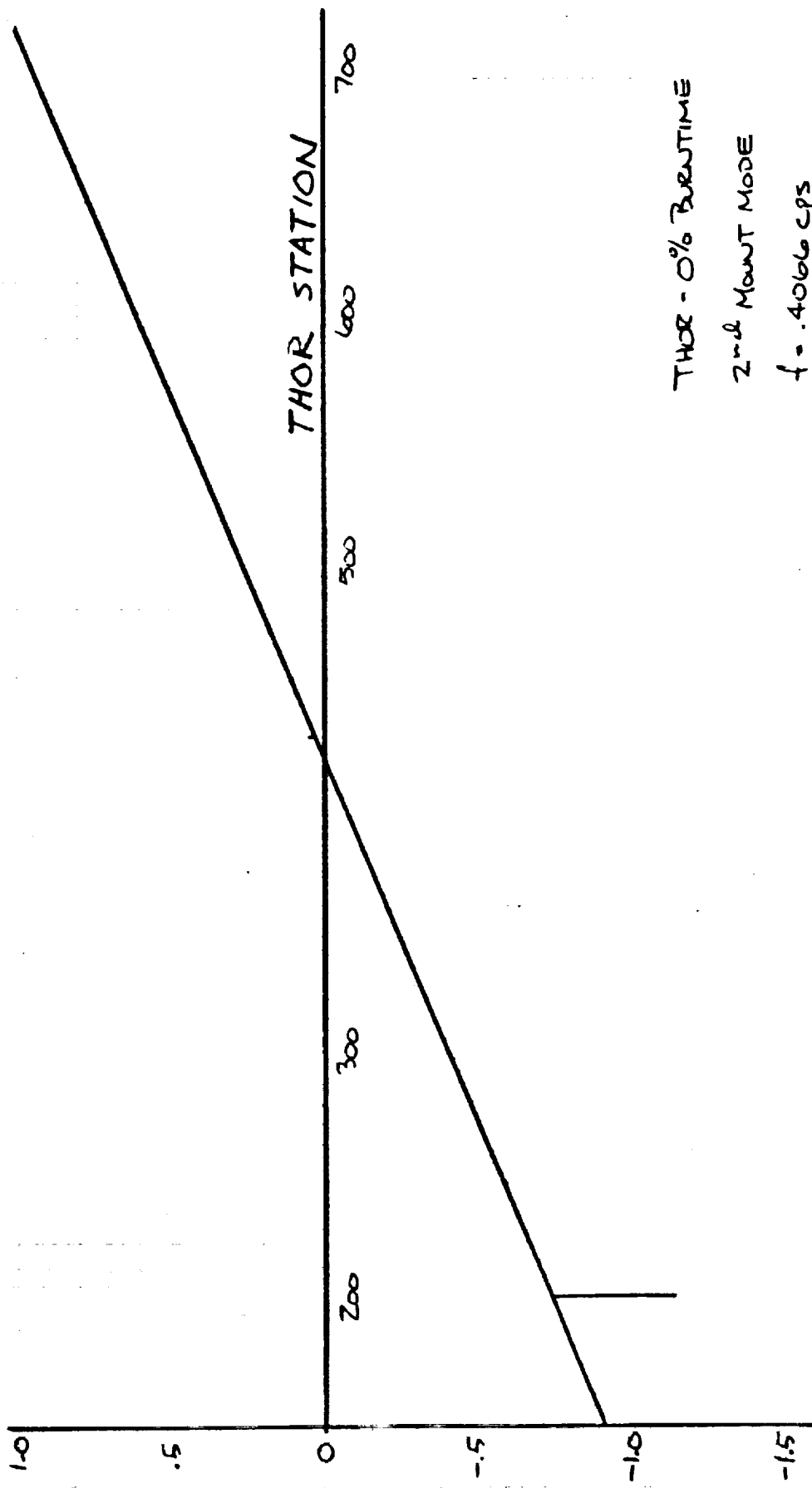
Appendix D

Mount Mode Shapes

FORM 38-101
REF. JOB PAGE NOS. _____
PREPARED BY _____ DATE _____
JOB PAGE NO. _____
MODEL _____ REPORT NO. _____
T.O. 11-1
1ST EDITION 1962
4-18120

DOUGLAS





THOR - 0% BURETIME
 2nd Mount Mode
 f = 4066 cps



FORM 30 (Rev. 1-64)

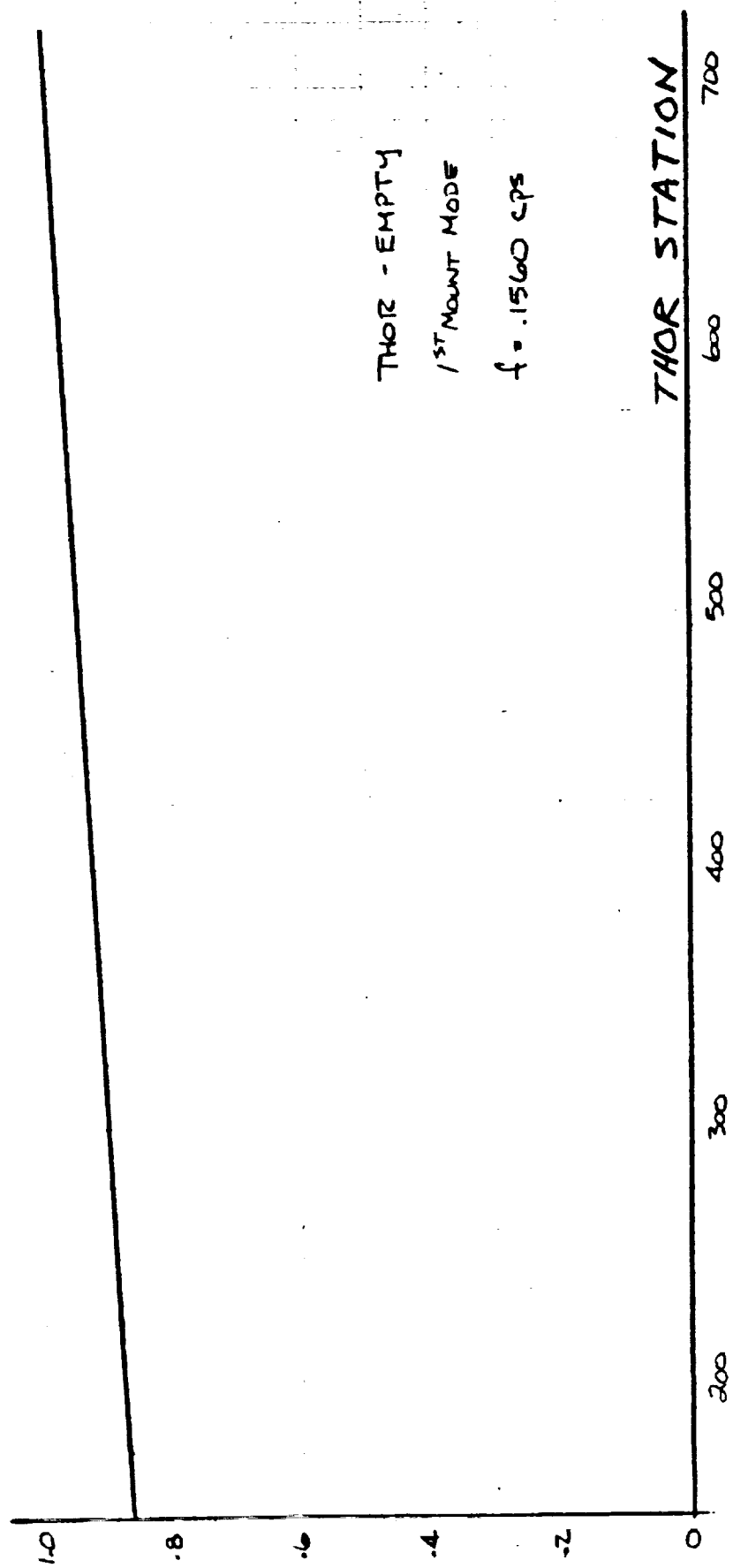
REF. JOB PAGE NOS. _____

PREPARED BY _____ DATE _____

JOB PAGE NO. _____

MODEL _____ REPORT NO. _____

THOR STATION
1000
1000

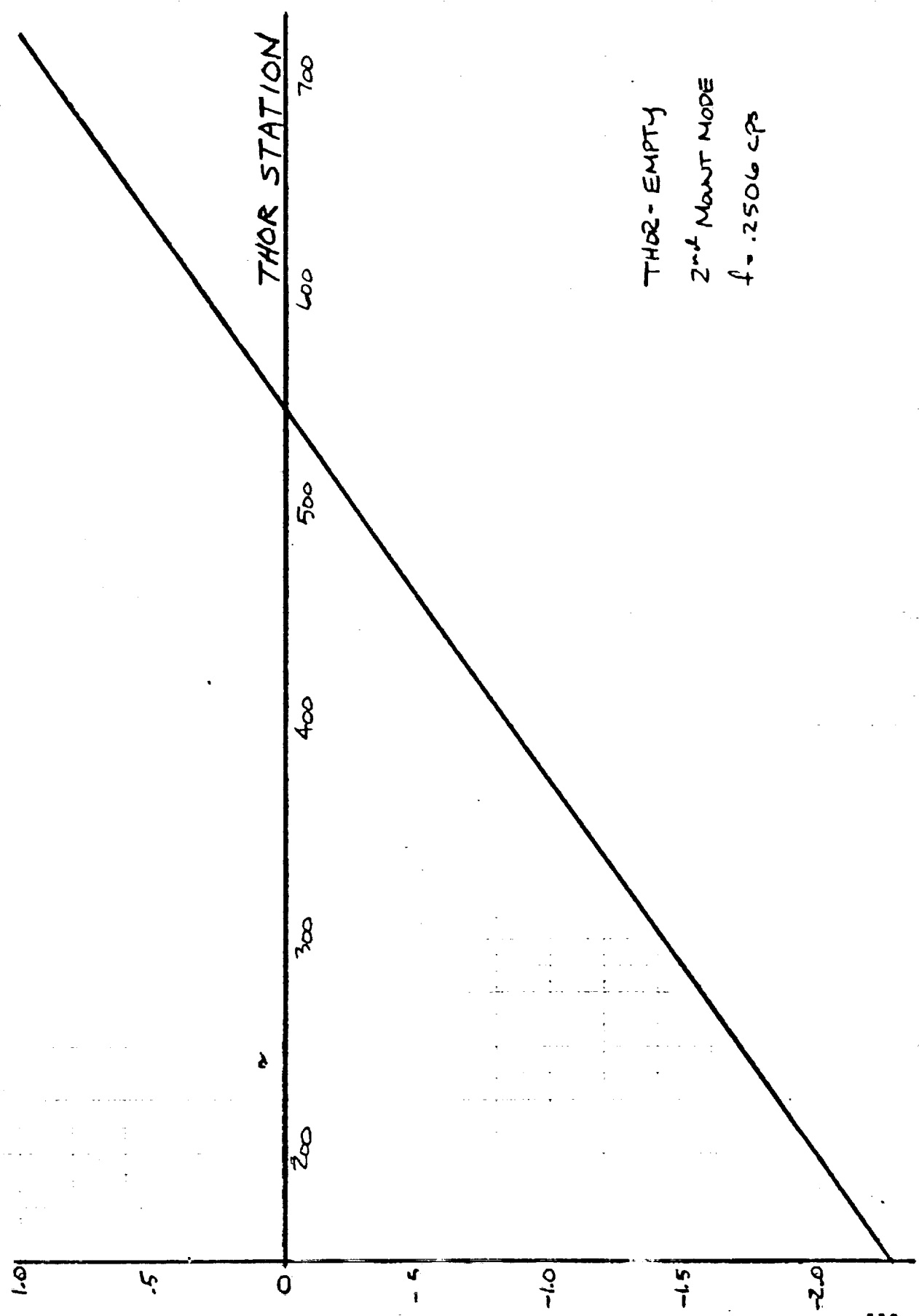


FORM 88-64

REP. JOB PAGE NO. _____
PREPARED BY _____ DATE _____

JOB PAGE NO. _____
MODEL _____ REPORT NO. _____

END
2nd MOUNT MODE
f = .2506



THOR - EMPTY
2nd MOUNT MODE
f = .2506 cps

FORM 20 504

REF. JOB PAGE NOS.

PREPARED BY

DATE

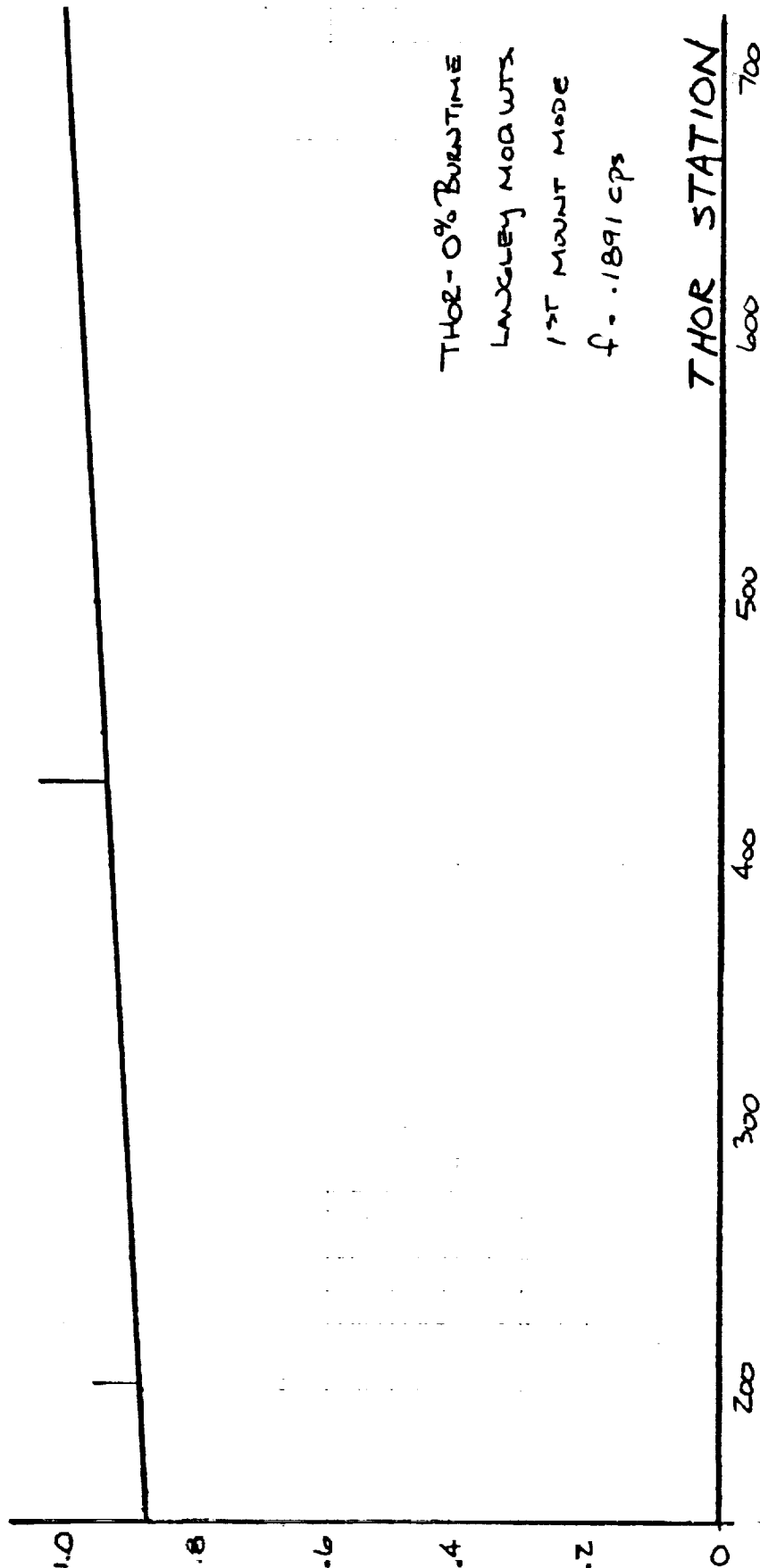
JOB PAGE NO.

MODEL

REPORT NO.

T 0% BURNTIME
MAGLEY MOD WTS
1ST MOUNT MODE
f - .1891 cps
1.18906

DOUGLAS



FORM 38-B

REF. JOB PAGE NOS.

PREPARED BY

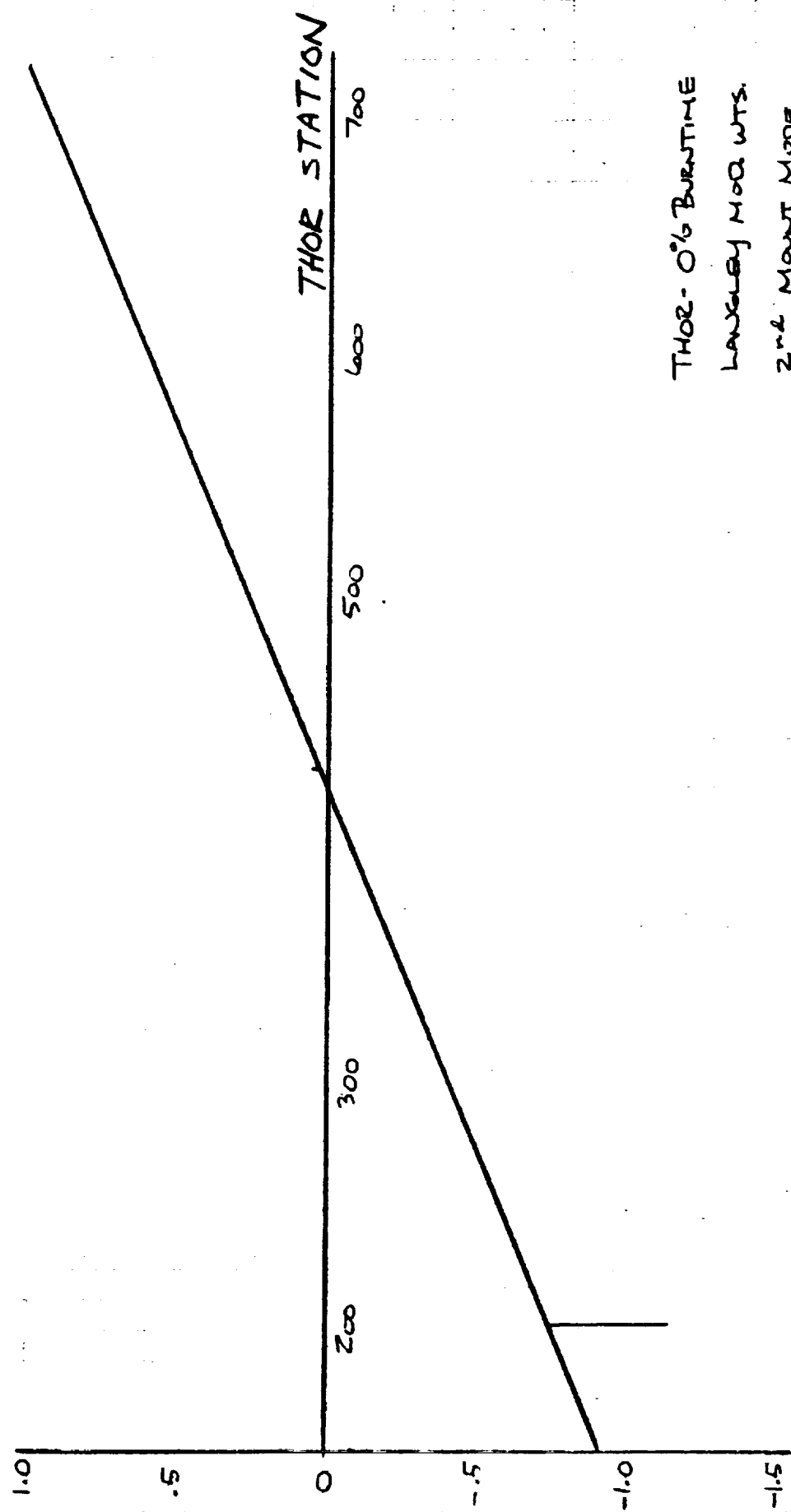
DATE

JOB PAGE NO.

MODEL

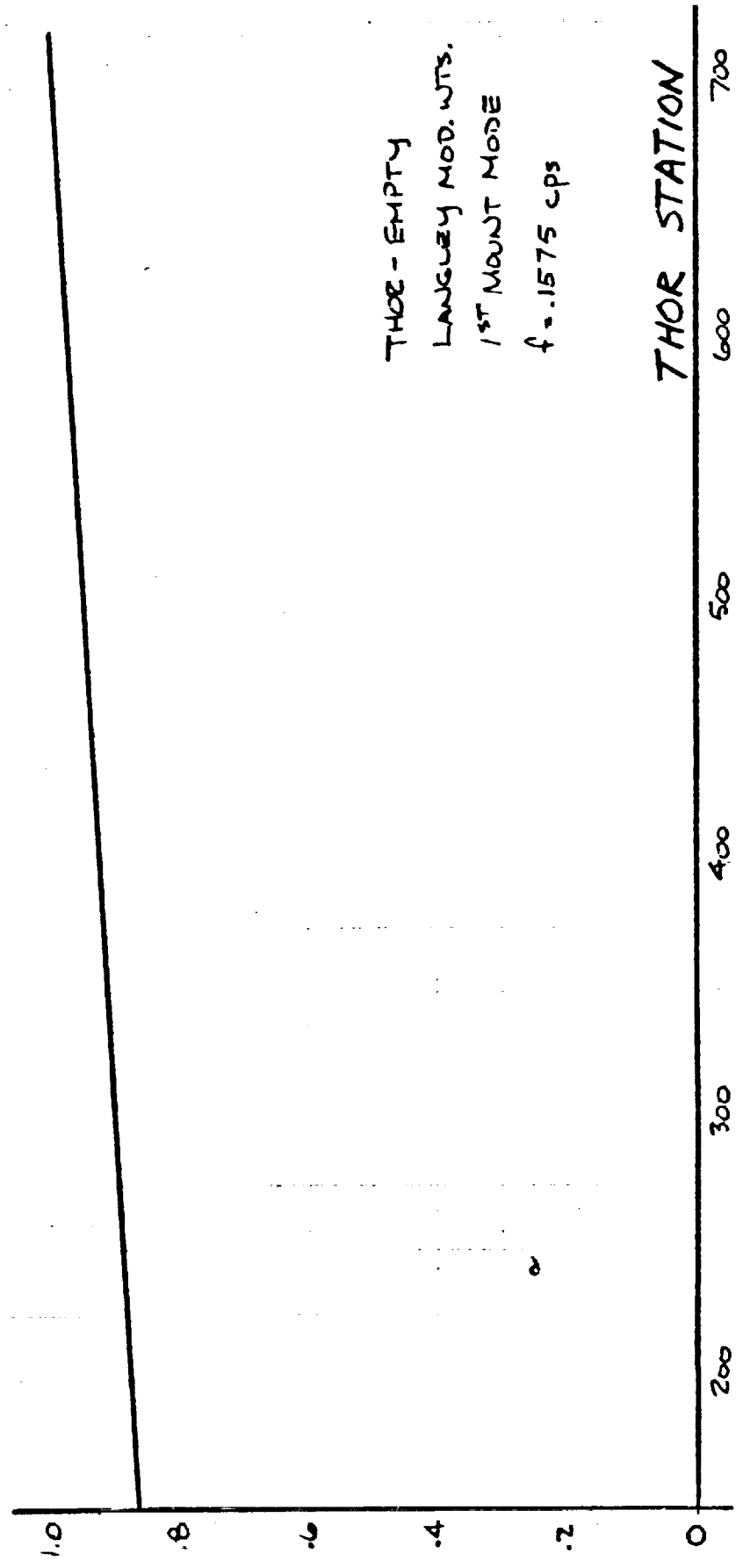
REPORT NO.

1. 0% BURNTIME
2nd MANT MODE
f. 4069



THOR- 0% BURNTIME
LAWRENCE MOD WTS.
2nd MANT MODE
f. 4069 cps

FORM 38 OF () REF. JOB PAGE NOS. () JOB PAGE NO. ()
 PREPARED BY () MODEL () REPORT NO. ()
 T. 1100 WTS
 EMPLOYER'S
 1ST MOUNT MODE
 f = .15749



FORM 26-B

REF. JOB PAGE NOS.

PREPARED BY

DATE

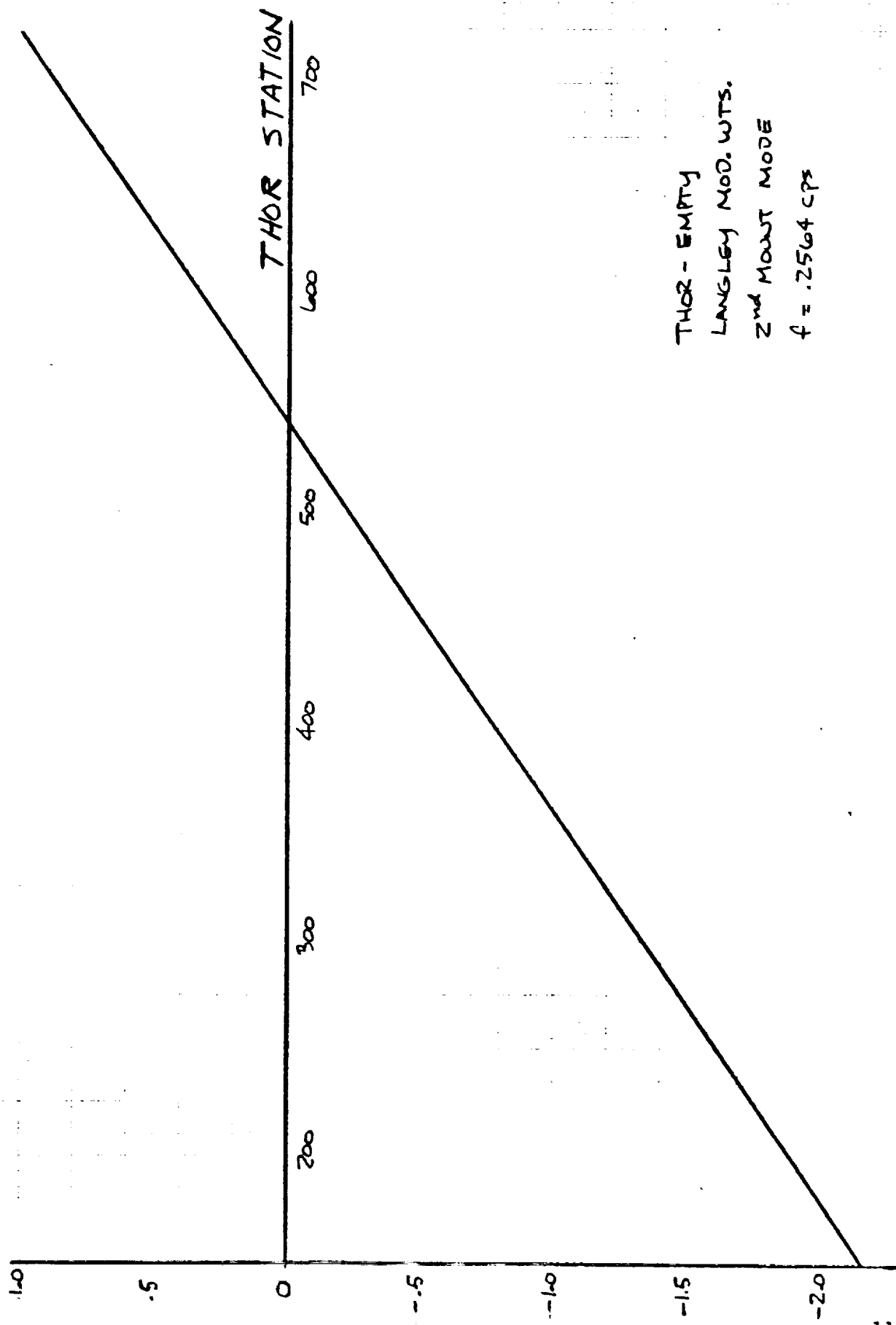
JOB PAGE NO.

MODEL

REPORT NO.

1. MOD. WTS.
2. LANGLEY MOD. WTS.
3. 2nd MOD. MODE
f = .2564

DOUGLAS



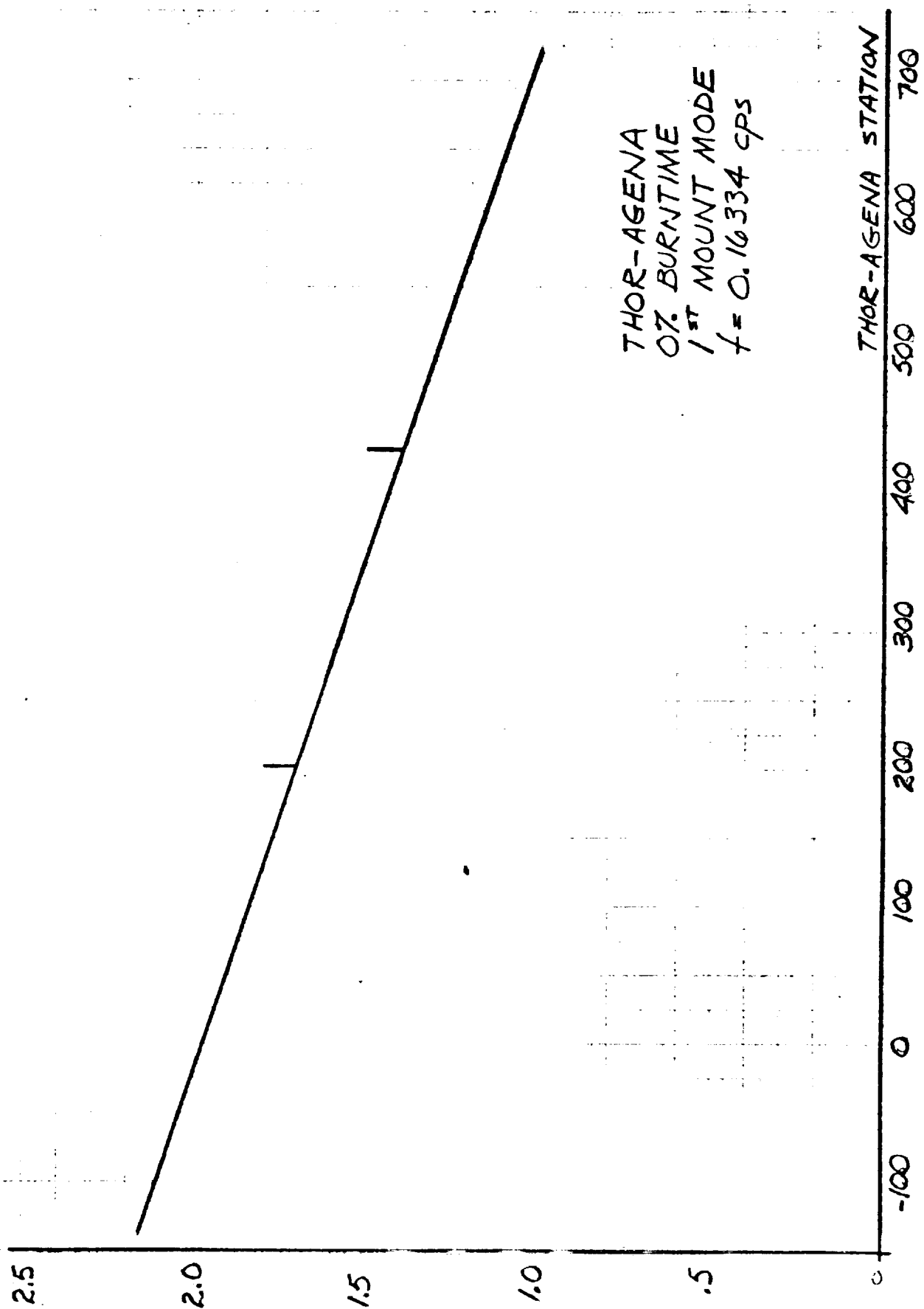
THOR - EMPTY
LANGLEY MOD. WTS.
2nd MOD. MODE
f = .2564 cps

0%
MONT
MONT
f-16339

REF. JOB PAGE NOS. -

JOM PAGE No. -

0%
MONT
MONT
f-16339



THOR-AGENA
0% BURNTIME
1ST MOUNT MODE
 $f = 0.16334 \text{ cps}$

DOUGLAS

FORM 28 804

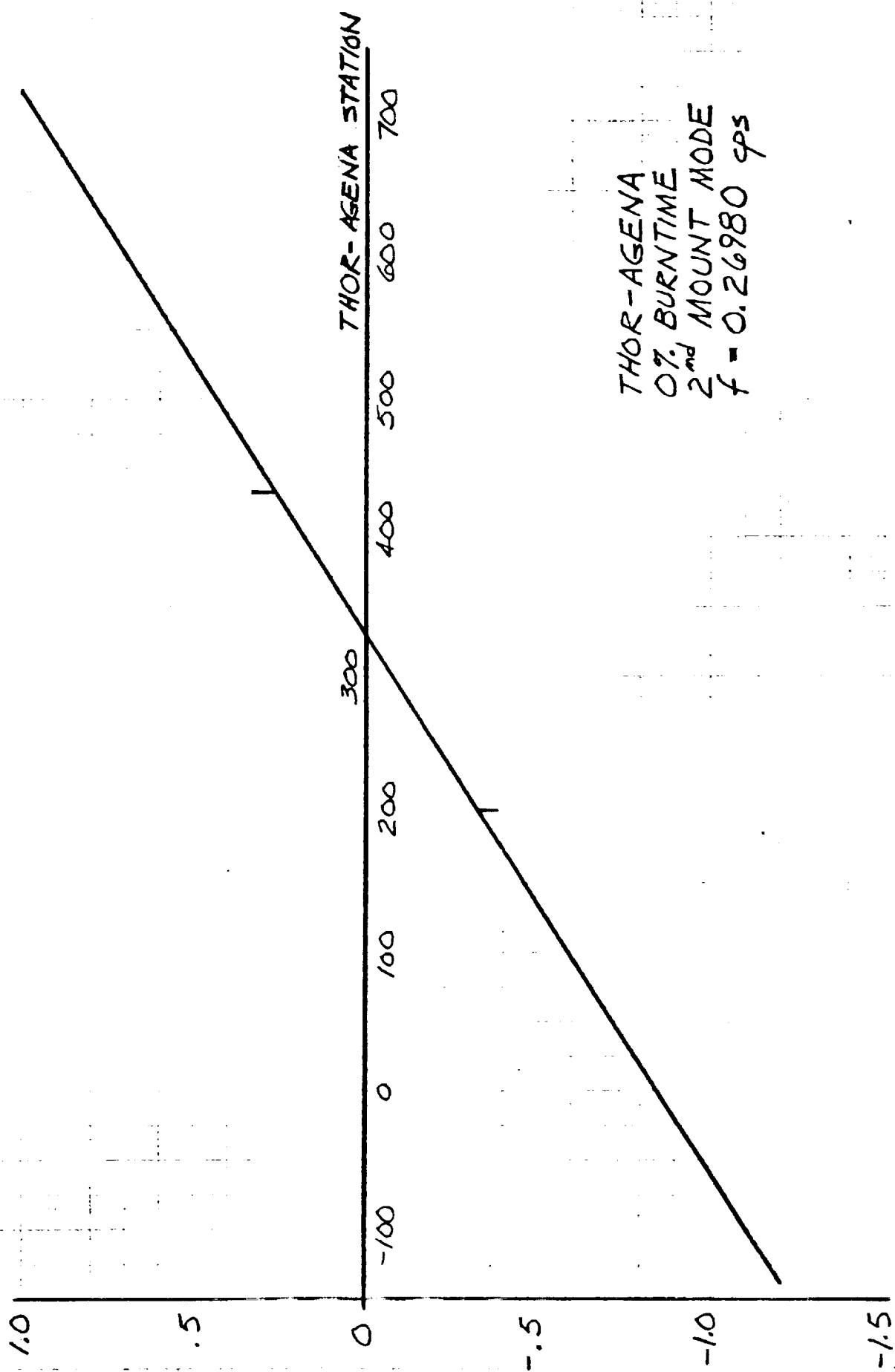
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JOB PAGE NO. _____

PREPARED BY _____ DATE _____

MODEL _____ REPORT NO. _____

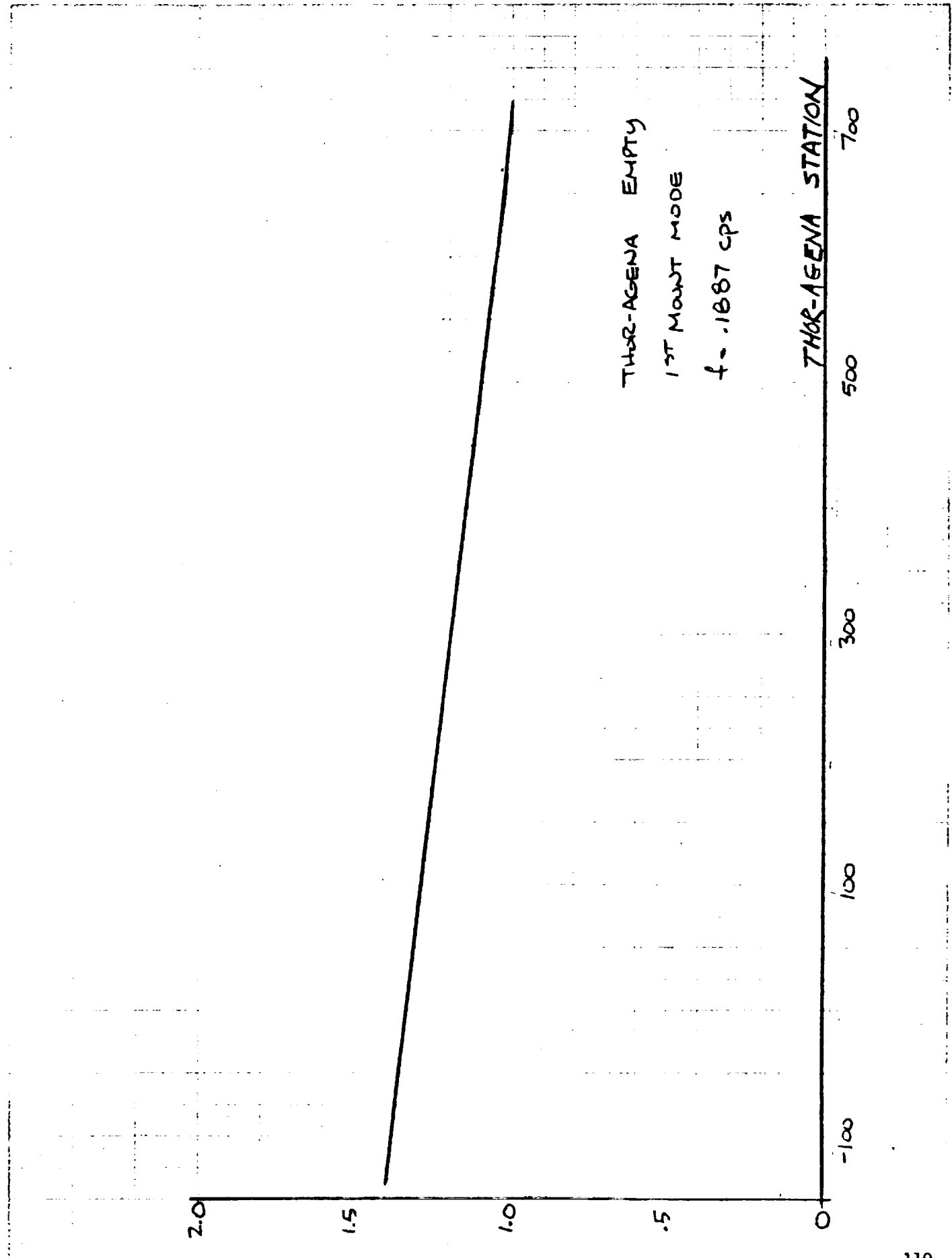
7 A 0%
10 Mounting
f = 0.26980



THOR-AGENA
0% BURN TIME
2nd MOUNT MODE
f = 0.26980 cps

FORM 28-B-64
REF. JOB PAGE NOS. ()
PREPARED BY ()
DATE ()
JOB PAGE NO. ()
MODEL ()
REPORT NO. ()
TA
MIN
EMPTY
f-12866

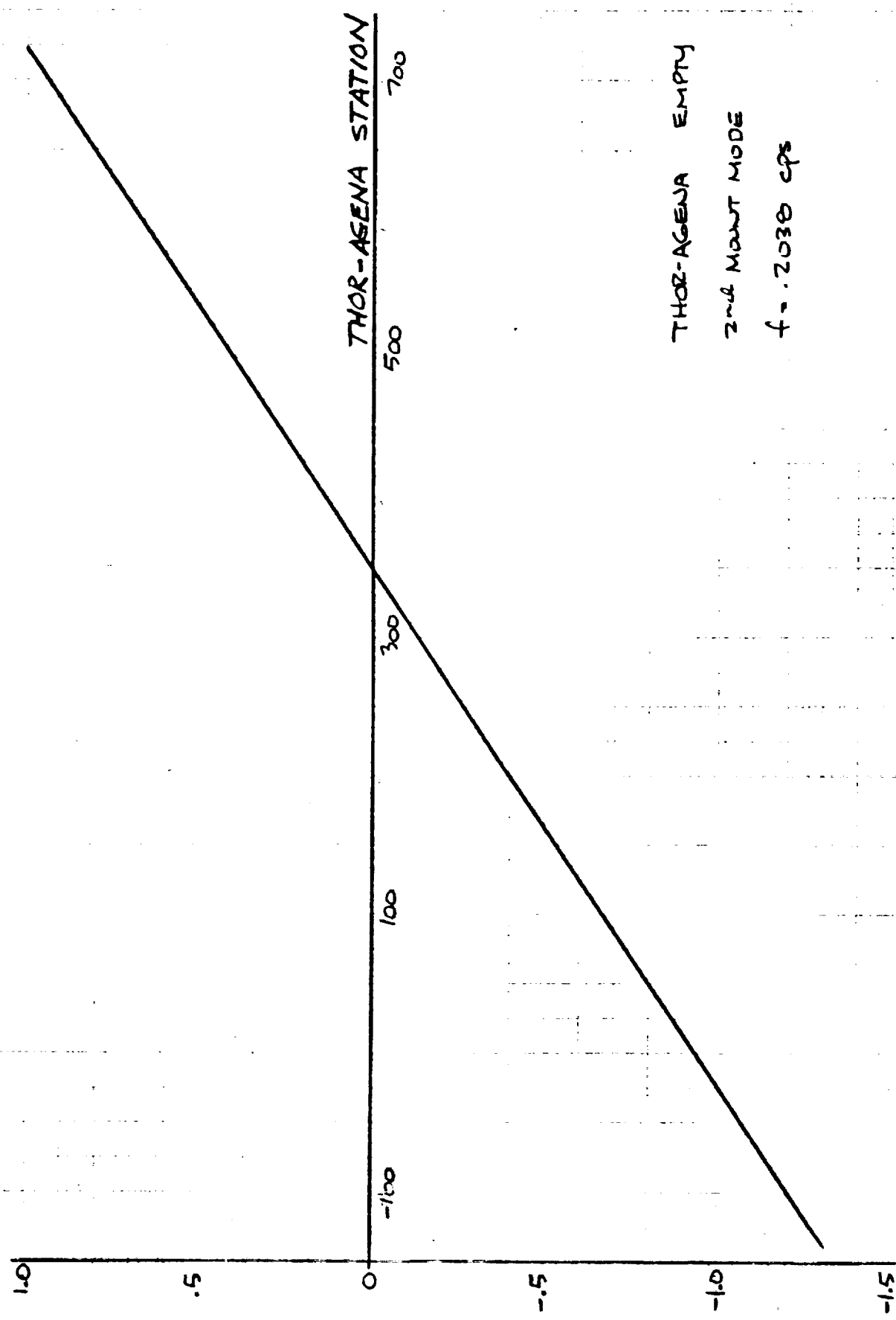
DOUGLAS



2nd MOUNT
MODE
f = 2030



FORM 35 80-4
REF. JOB PAGE NOS. _____
PREPARED BY _____ DATE _____
JOB PAGE NO. _____
MODEL _____ REPORT NO. _____



THOR-AGENA EMPTY
2nd MOUNT MODE
f = 2030 cps

FORM 38-20-1

REF. JOB PAGE NOS.

PREPARED BY

DATE

JOB PAGE NO.

MODEL

REPORT NO.

2.5

2.0

1.5

1.0

.5

0

-100

100

300

500

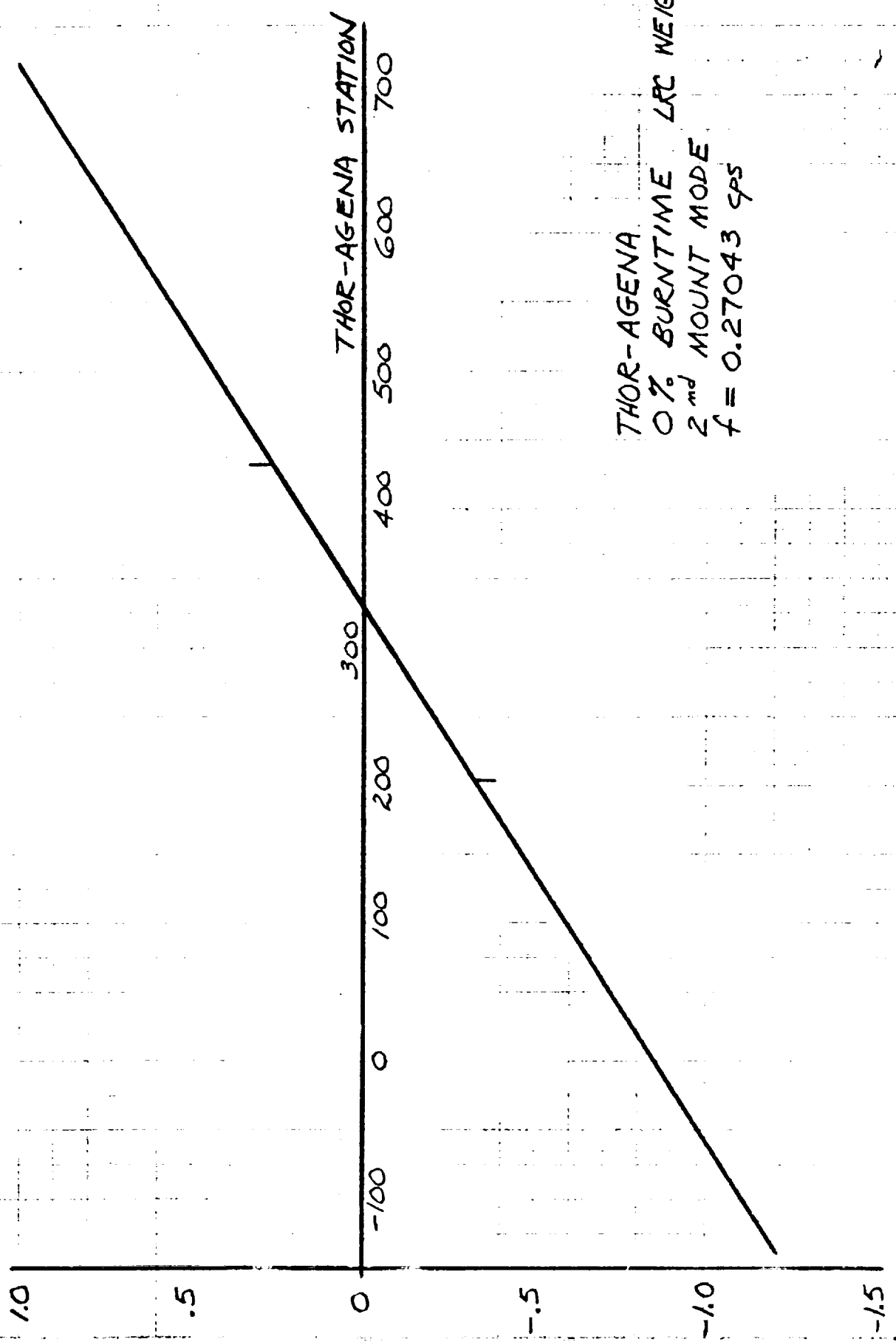
700

THOR-AGENA
O% BURNTIME
LANGLEY MOD. WTS.
1ST MOUNT MODE
f = .1634 cps

THOR-AGENA STATION

DOUGLAS

LA 0783
 1-27043



REF. JOB PAGE NO.

PREPARED BY

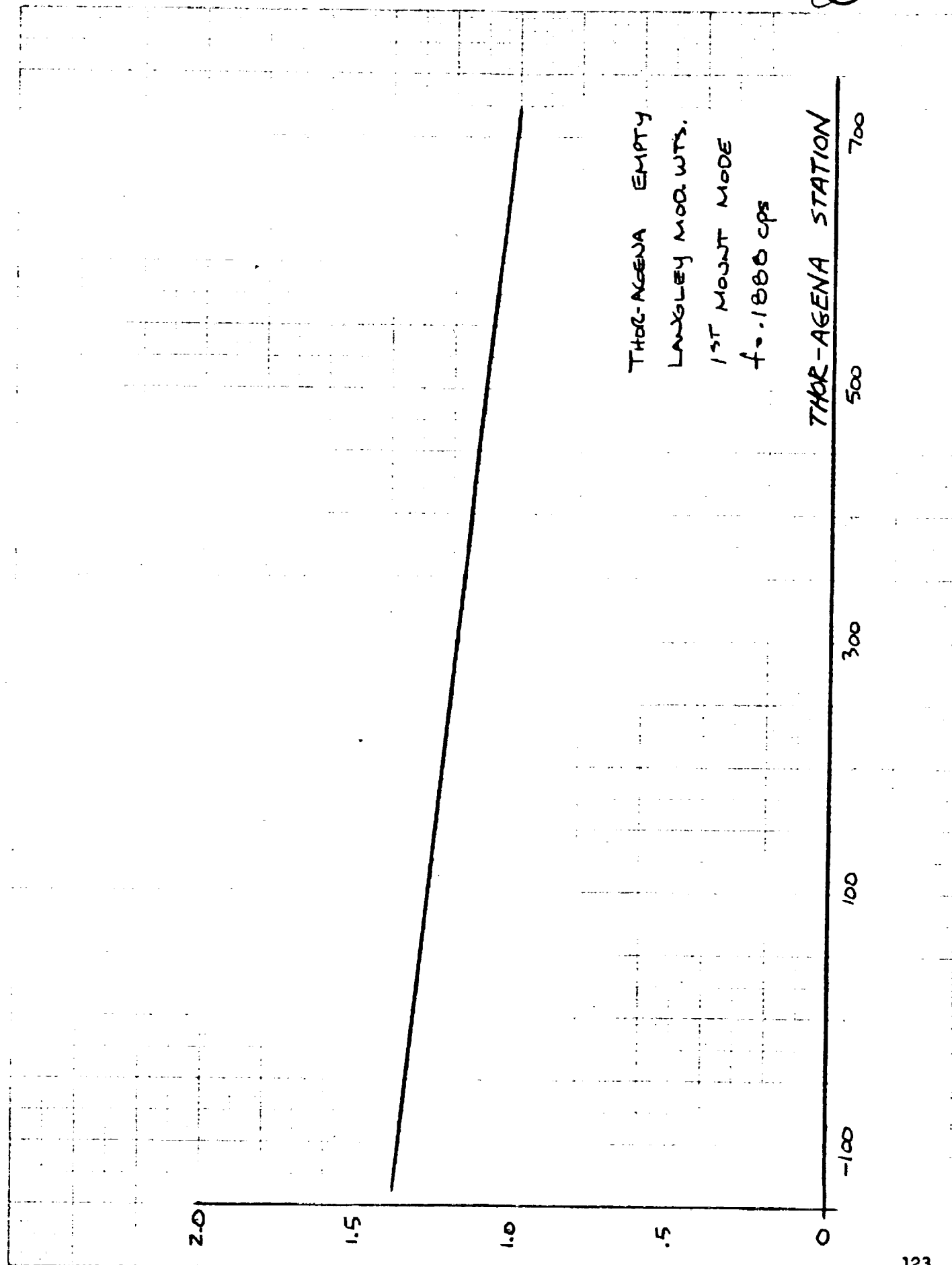
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MODEL

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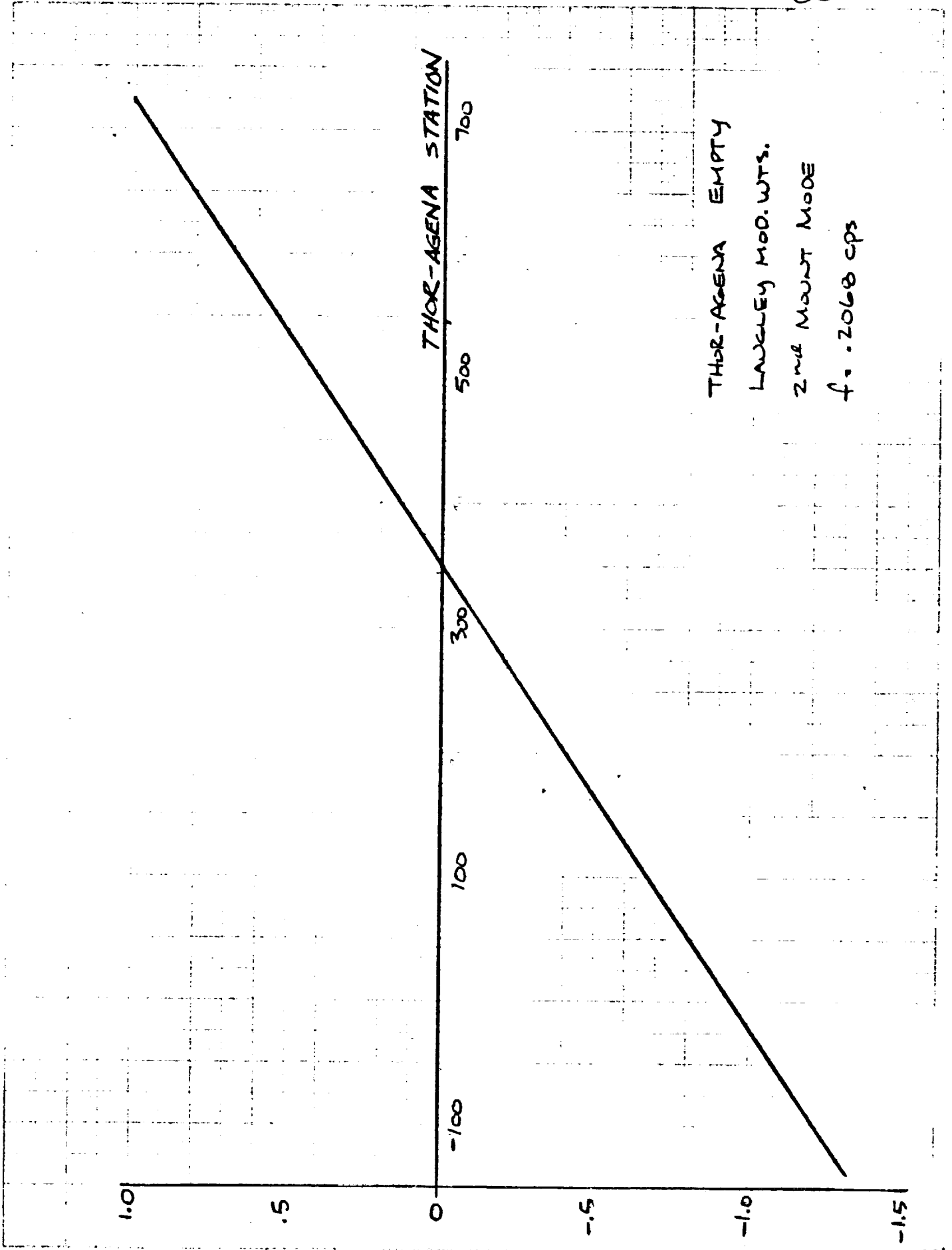
DOUGLAS



THOR-AGENA EMPTY
LANGLEY MOD. WTS.
1ST MOUNT MODE
f=1800 cps

THOR-AGENA STATION

DOUGLAS



THOR-AGENA EMPTY
LAJEWELRY MOD. WTS.
2nd MOUNT MODE
f. 20682 cps

Appendix E

Table of Modal Masses

Thor Cases

<u>Case</u>	<u>$\bar{m}_1$</u>	<u>$\bar{m}_2$</u>	<u>$\bar{m}_3$</u>
T 1	23.81	21.46	17.53
T 2	16.03	17.15	16.60
T 3	10.25	13.19	13.86
T 4	5.533	57.66	12.24
T 5	11.31	7.438	10.64
T 6	10.96	7.391	10.96
T 7	23.84	21.47	17.53
T 9	24.06	22.04	18.42
T 10	10.93	5.481	7.791

Thor-Agena Cases

<u>Case</u>	<u>$\bar{m}_1$</u>	<u>$\bar{m}_2$</u>	<u>$\bar{m}_3$</u>
TA 1	58.07	26.02	32.91
TA 2	49.86	18.64	60.82
TA 3	44.30	16.25	47.44
TA 4	40.22	16.61	26.13
TA 5	27.05	31.26	65.67
TA 6	23.52	29.61	22.48
TA 7	23.89	20.55	8.759
TA 8	57.90	26.04	32.93
TA 9	23.88	20.55	8.758
TA 10	57.89	26.38	34.11
TA 11	22.47	20.51	8.109

Mount Mode Cases

<u>Case</u>	<u>$\bar{m}_1$</u>	<u>$\bar{m}_2$</u>
ST 1	242.8	57.52
ST 2	12.52	12.71
ST 3	243.3	57.40
ST 4	12.89	12.10
STA 1	721.6	82.51
STA 2	26.42	11.48
STA 3	731.4	82.39
STA 4	26.67	11.49