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PARAMETRIC STUDIES ON USE OF BOOSTED ARTILLERY PROJECTILES FOR HIGH ALTITUDE RESEARCH PROBES. PROJECT HARP

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PARAMETRIC STUDIES ON USE OF BOOSTED ARTILLERY PROJECTILES FOR HIGH ALTITUDE RESEARCH PROBES, PROJECT HARP

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SUMMARY

A general parametric and preliminary design study has been completed defining the potential capabilities of rocket boosted artillery projectiles for high altitude probes when fired from existing gun systems.

The following systems were studied:

5" diameter boosted projectile fired from a 5" gun

4.5" diameter boosted projectile fired from a 7" gun

7" diameter boosted projectile fired from a 7" gun

8.4" diameter boosted projectile fired from a 16.4" gun

13.8" diameter boosted projectile fired from a 16.4" gun

16.4" diameter boosted projectile fired from a 16.4" gun

The study indicates that single stage vehicles fired from a 5" gun can lift a 10-pound payload to 650,000 feet and a 50-pound payload to 250,000 feet. Two stage vehicles fired from a 16.4" gun can lift payloads of 100 pounds to altitudes greater than 400 miles.

A 4.5" rocket boosted artillery projectile, sub-calibered in the 7" gun, was designed for a specific requirement for delivering a 20-pound payload to an altitude of 500,000 feet with a minimum impact dispersion; however, this does not represent the maximum payload or altitude possible for probes fired from the 7" gun.

The study included a limited dispersion analysis for a 5" round fired from a smooth-bored 120mm gun as well as a general but limited aerodynamic analysis to point out the areas which will require extensive study in any development program.

Comparisons were made between long burning sustainer designs with zero ignition delay and short burning booster designs with an optimum ignition delay. The comparisons indicated that both types will, for similar payloads and propellant weights, reach approximately the same altitude.

A brief discussion of the orbiting capabilities of rocket boosted artillery projectiles is presented.

In general, these studies indicate that rocket boosted artillery projectiles (BAP's) can be developed to accomplish payload weight and altitude missions presently being achieved by use of free rocket systems. The cost per round using BAP's is expected to be significantly lower. In addition, because of the much lower dispersion of BAP's (as low as 1/10 that of free rockets in cases where high launch velocities are used), real estate requirements for launch-recovery areas with BAP's can be reduced to a small fraction of that required for free rockets. Besides the cost advantages implied, this greatly reduces restrictions on launch sites and data acquisition locations.

CONCLUSIONS

1. Rocket boosted artillery projectiles afford a relatively cheap method of placing atmospheric sounding equipment at any desirable altitude with smaller altitude and range dispersions than present unguided, free-rocket configurations.

2. Because of the smaller range dispersion of large boosted artillery projectiles as compared with free-rocket sounding missiles, relatively small flight range areas are required.

3. Because of the smaller dispersion in maximum altitude and/or time-to-altitude of rocket boosted artillery projectiles as compared with free-rocket sounding missiles, certain altitude-sensitive experiments can be accomplished with greater reliability. Similarly, experiments whose success are dependent on accurate release of payload in a precise location in space could also be accomplished with greater reliability.

4. The potential exists for using boosted artillery projectile vehicles fired from existing guns to place small payloads into orbit.

5. The major deficiency of the BAP in altitude probe application is the necessity for the payload to withstand the relatively high stresses imposed by gun launch conditions. Developmental programs are in progress under supervision of BRL, however, to provide "high-g" payload packages for most experiments of meteorological and scientific interest.

RECOMMENDATIONS

A program should be initiated to design, fabricate and test boosted artillery projectiles to demonstrate and confirm the feasibility of achieving the altitude, payload and accuracy potentials discussed herein. Missions should be selected which will provide a vehicle needed for accomplishing a current scientific payload delivery requirement.

Because of the intriguing possibilities of the low cost orbiting potential of rocket boosted projectiles, it is strongly urged that additional investigations in this field be supported.

INTRODUCTION

Various areas of scientific interest have motivated considerable effort toward development of high altitude research probes. It was generally accepted that investigations at altitudes beyond 100,000 feet would require use of rockets; however, using the advances made in development of high performance tank gun systems, the Ballistic Research Laboratories have shown that an altitude capability of at least 240,000 feet is possible with an existing 5" gun system (Reference 1).

It became apparent, therefore, that gun probes could be used to provide an accurate and relatively inexpensive method for high altitude vertical soundings. Further studies have shown that additional benefits, in terms of attainable altitude and delivered payload can be realized by using larger gun systems. The latter potential is currently being studied by McGill University of Montreal, Canada under contract with the U.S. Army Materiel Command using a modified 16-inch naval gun (Reference 2).

To provide a further extension in the payload and altitude capability of the gun probe system, consideration was given to the use of rocket assisted projectiles. Because of recent advances demonstrated by Picatinny Arsenal in the state-of-the-art of rocket boosted artillery projectiles in areas of propulsion efficiency, precision and payload delivery capabilities (References

3 and 4), this Arsenal was requested to perform the studies covered in this report for BRL and the Army Research Office. The study began in September 1962 and consisted essentially of parametric analyses to determine the altitudes that can be reached as functions of missile diameter, missile weight, payload weight, thrust, burning time, specific impulse, drag coefficient and launch velocity. In addition, preliminary design studies were performed and limited dispersion analyses were completed for a number of configurations.

Three smooth-bore gun systems were considered as a basis in the studies for determining the altitude and payload capabilities of rocket assisted projectiles. These were: a 5" gun (modified 120mm T123 Tank Gun), a 7" gun (modified 175mm gun) and a 16.4" gun (modified 16" naval gun). The 5" gun has been used at Aberdeen Proving Ground and Wallops Island by BRL for investigating gun probe systems for measurement of atmospheric characteristics. The 7" gun probe system is currently under qualification by BRL. The 16.4" gun is installed at Barbados, West Indies for studies by McGill University on Project HARP (High Altitude Research Program) under initial auspices of the U.S. Army Research Office. The Army Materiel Command is the current sponsor of the program.

A preliminary report covering studies of the capabilities of boosted artillery projectiles for the 5" and 16.4" guns was issued in

April 1963 (Reference 9). This final report includes all information contained in that report and also gives additional data on the 5" and 16.4" BAP designs as well as results of a study requested by BRL for a boosted artillery projectile having the capability of being fired from the 7" gun to an altitude of 500,000 feet with a 20-pound payload. A revised error analysis for the 5" BAP based on smaller input perturbation values suggested by BRL, is also included.

BASIS OF CALCULATIONS

GENERAL:

The basic parameters considered in this study were missile diameter, launch velocity, in-gun weight, payload weight, propulsion system weight, thrust, burning time, form factor and, in a very limited manner, staging. In conducting the parametric trajectory and dispersion analyses, point mass and six degree of freedom trajectories, programmed on the Picatinny Arsenal IBM 709 Computer, were used. All trajectories were based on an ARDC atmosphere where applicable and on an extrapolation of the ARDC tables where no data were available.

Fin-stabilized and flare-stabilized configurations were considered as the basis for design of the rocket boosted artillery sounding projectiles. The drag coefficient vs. mach number curves used in the parametric and trajectory analyses were based on extropolation of experimental wind tunnel and free flight data.

A rigorous study of the aerodynamics and stability of the various projectiles included in the study was not made because of the preliminary nature of the designs. The performance capabilities of the various rocket propulsion designs were conservatively limited to propellants delivering a sea level specific impulse of approximately 200 seconds, unless otherwise indicated. Specific design parameters applicable to the various BAP's considered for the three gun systems are as follows:

Five-Inch Gun System:

The primary objective and the basis of calculation for the 5-inch gun system were to determine the performance capabilities of a 150-pound rocket assisted projectiles when fired at a muzzle velocity of 1000 fps. These parameters were specified by BRL since they were of particular interest to that agency.

In considering the various designs possible in this caliber, payload weight was varied by two methods while essentially retaining the limiting muzzle momentum specified by BRL. One method was to keep the muzzle velocity and in-bore weight constant, and to reapportion the component weight, i.e., rocket propulsion weight was decreased as payload weight was increased. The second method was to keep the rocket propulsion weight constant and add payload weight. In the latter case, muzzle velocity was reduced accordingly, either to retain the specified muzzle momentum or to prevent an overstress of the rocket motor due to the heavier payload.

In addition, it was understood that the 5" smooth bore tank gun (modified T123 Gun Tube) was fitted with a barrel extension and was mounted to a 155mm gun carriage. Since this would permit increased muzzle energy and momentum, a limited study was made to determine the altitude which could be attained when firing the 150-pound vehicle at a velocity of 2000 fps. This level of muzzle energy and momentum is considered to be within the capability of this gun system.

Seven-Inch Gun System:

Initially, the objective for the limited study performed for the 7" gun system was to provide general data on the altitude payload capabilities which could be achieved with a BAP. The projectile design and launch conditions were based on using a smooth bore 175mm gun, with a standard length tube fired at 120% of maximum rated pressure.

The initial studies showed promise and upon publication of the preliminary report, a firm objective was provided in a meeting with BRL, viz., to determine design parameters for delivering a 20-pound payload to an altitude of 500,000 feet with a minimum of dispersion.

The design and performance characteristics of the rocket boosted artillery projectile were to be compatible for firing from a modified smooth bore 175mm gun, fitted with a 25-caliber barrel extension. Optimization of gun charge was not considered. The muzzle momentum limitation which was used for the latter phase of the study was 15,000 lb-sec, which is the same as that obtained with the standard projectile (weight of 147 pounds) fired at 120% of the MRP (velocity of 3300 fps).

To meet the requirement for minimizing dispersion, effort in design was directed toward producing a BAP which could be launched at the highest velocity possible. In effect this approach was intended to reduce the major source of error, i.e., that of wind.

A flare-stabilized configuration was selected as the basis for design because of the high mach numbers anticipated in flight.

A sub-caliber 4.5-inch projectile, typified in Figure 4, which used the basic structural discarding sabot design concept, was evolved from the studies.

The basis of calculation for a sequel to the above study considered the use of adding a 300" (43 caliber) barrel extension to the 7" gun. A limited optimization study of the gun charge was made to lower the setback level and thus simplify sabot and motor design as well as to reduce fabrication cost.

16.4-Inch Gun System:

The objective and basis of calculation for the 16.4" gun system was to determine very high altitude delivery capabilities for payloads of up to 100 pounds.

In-gun BAP weights of 4480 pounds and 560 pounds were arbitrarily selected as the upper and lower weight limits. BAP diameters of 8.4", 8.7", 13.8" and 16.4" were selected. A standard gun charge was assumed (Figure 4, Reference 2), and the MRP for the 16" naval gun was the upper limit of gun pressures considered.

AERODYNAMICS:

The basic drag coefficient curve used for fin-stabilized projectiles is presented in Figure 1. For the 5" BAP, drag form factor variations of 1.0 and 2.0 were used, while for the 16.4" round, form factors of 1.0, 2.0, 3.0 and 4.0 were used. A preliminary analysis indicates that a form factor of 2.0 or slightly above 2.0 would be expected for all flare-stabilized rounds.

The aerodynamic problem of primary concern is the method of stabilization. Preliminary calculations for the 5" BAP indicate that a fin-type stabilizing device would probably be inadequate because of the high mach number attained during flight. A folding flare stabilizer would be more desirable. The cone shaped afterbody would increase the drag coefficient of the round such that a form factor of approximately 2.0 would be expected.

The optimum burning time for the 5" rocket is comparatively long and results in powered flight to altitudes of approximately 100,000 feet. At these altitudes, the exhaust gas plume effect (Reference 5) might tend to destroy the static stability of fin or aft cone stabilized bodies. A burning time of 30 seconds may have to be used with a slight degradation in performance in order to keep the round in the sensible atmosphere during burning and to

minimize the plume effect.

An aft cone stabilizing device would also be required for the single stage BAP, used in the 7" and 16.4" gun systems. However, the two-stage BAP used in the 16.4" gun may require a different approach in cases where the second stage motor burns outside the atmosphere. Here, the first stage can be separated and the relatively smaller second stage motor and payload can be spin-stabilized.

PROJECTILE DESIGN:

The basic design for the rocket boosted projectiles considered in the studies is that of a tail-cone flare-stabilized configuration using a discarding sabot. Where possible, the structure which is required to resist stress during the gun launch phase, but which is not required for the rocket flight phase, is incorporated into the discarding sabot so that the weight of the flight round is kept to a minimum. Hence, the maximum rocket efficiency is obtained.

Designs which were considered include full caliber boosted artillery projectiles designed for the 5", 7" and 16.4" smooth bore guns, and sub-caliber BAP's for the 7" and 16.4" guns.

Figure 2 illustrates a section of a 16.4" projectile which is typical of the discarding sabot rocket design. The payload is located in the forward section of the vehicle. The motor is compartmented in tandem. Each compartment contains an end burning

rocket grain with a controlled burning rate core. The rocket is supported about the periphery of the base of each compartment by the sabot. The sabot also envelopes the base of the projectile including the nozzle and folding flare stabilizer. The rocket igniter assembly is located within the nozzle. A sabot drag device is housed within the hemispherical base of the sabot.

The same general type design was assumed for the high "g" launched 5" projectiles (2000 fps) and the full caliber 7" projectiles, i.e., the motor was compartmented with traps at suitable intervals to preclude overstressing of the rocket grain.

At gun launch, the propellant setback load is transmitted to the trap located at the base of each compartment. This load, in turn, is transferred to the sabot along with the setback loads developed by the weight of the motor wall and trap. Payload setback weight is also transmitted to the sabot. Gun gases enter the hemispherical compartment at the base of the sabot which contains the drag device. Upon emerging from the gun, the residual pressure in the hemispherical compartment ejects the cover plate and releases a drag device. The device retards the velocity of the sabot and allows the rocket to withdraw from the sabot. Upon fully emerging from the sabot, the cowl expands into a stabilizing flare and also actuates the igniter delay element. The rocket grain ignites

and burns for the time required to provide optimum propulsion performance.

Figure 3 illustrates the general design of a variable wall thickness, case-bonded BAP. The projectile weighs 126 pounds (flying weight), has a 10-pound payload and utilizes a discarding sabot. The payload is located in the forward section of the projectile. The motor consists of a single compartment 16 calibers in length. The insulator is bonded to the motor wall and the propellant is case-bonded to the insulator. The grain is an end burning design and contains a controlled burning rate core. The rocket is supported by the sabot at suitable intervals about the periphery of the motor. The sabot envelops the nozzle and the retracted flare stabilizer. The rocket igniter assembly is located within the nozzle. A sabot drag device is housed within the hemispherical base of the sabot.

Figure 4 illustrates a similar design concept for a 4.5" BAP, sub-calibered for the 7" gun, having a fixed-flare stabilizer.

The basic design parameters used in the BAP design calculations were as follows:

Rocket Internal Operating Pressure: 1000 psi

Rocket Design Pressure: 3000 psi

Rocket Wall Material: Alloy steel; allowable stress of 180,000 psi

Rocket Propellant: Allowable bearing stress of 3000 psi
Allowable shear stress of 300 psi (later increased to 1000 psi for the 4.5"/7" BAP)

Rocket Trap Material: Alloy steel; allowable stress of 180,000 psi

Rocket Trap Configuration: 2/1 elliptical pressure head, to withstand 3000 psi bearing pressure of the propellant

Rocket Insulator: Asbestos filled phenolic

Rocket Trap: Fiberglass filled phenolic

Rocket Nozzle Insert: Pyrolitic graphite

Rocket Nozzle: Glass phenolic

Projectile Stabilizer: Aluminum web and flare

Sabot: Alloy steel; allowable stress 180,000 psi

Payload: Payload weight is a gross weight which includes forward bulkhead of motor

Gun Pressures: Specific pressure used in each of the BAP designs are listed in Table II. Estimates of peak gun pressures used in this report are conservatively high.

Detailed design parameters for the various rounds considered are shown in Table II.

DISPERSION ANALYSIS:

A limited dispersion analysis was conducted for the 5" diameter round to determine the variations in maximum altitude and range impact as a function of various perturbations. The analysis was run with point mass and 6 degree of freedom trajectories programmed on the Arsenal's IBM 709 Computer.

The parameters into which perturbations were introduced are as follows:

Muzzle Velocity

Metal Parts Weight

Propellant Weight

Air Density

Spin Rate

QE

Range Wind

Cross Wind

Specific Impulse

Drag Coefficient

Thrust Malalignment with Spin

The specific perturbation input values and the resulting dispersions are presented in Table III.

The results indicate that the largest dispersion is expected to be due to wind. The particular wind profile used in the study was compiled from Reference 6 and is presented in Figure 5. The profile is not meant to be a realistic single day profile but rather it represents an extreme wind contour. The wind perturbations used in the dispersion analysis were assumed to be 5% of the actual wind at every altitude, i.e., the wind will be known to within $\pm$ 5% of the actual value. The 5% value was obtained from BRL.

RESULTS OF CALCULATIONS

FIVE INCH DIAMETER GUN SYSTEM:

In the study of the five inch system, the following parameters were varied to determine the effect on altitude attainable:

Payload Weight (Keeping Over-all Round Weight Constant):

Payload weights were varied from 10 pounds to 50 pounds by keeping the over-all weight constant and redesigning the propulsion system for each payload. The missile unburnt weight was kept at 126 pounds with a sabot weight of 24 pounds. The initial velocity was maintained at 1000 fps.

The results are plotted in Figure 6 at different burning times with a launch elevation angle of 85° and form factor of 2.0. The plot shows that a 10-pound payload can be lifted to altitudes in excess of 650,000 feet while a 40-pound payload can reach altitudes greater than 200,000 feet.

Payload Weight (Keeping Propulsion System Constant):

Again payload weights were varied from 10 to 50 pounds. However, in this case, the largest propulsion system (which was designed for the 10-pound payload) was used for all payloads and the weight of larger payloads was added to the over-all weight of the projectile. The gun muzzle velocity was reduced accordingly to keep the muzzle momentum and recoil of the gun constant, as well as to prevent any stress increases in the rocket motor as a result of the heavier payload. Figure 7 is a plot of the performance expected with various burning times. The launch elevation angle was

85° and form factor was 2.0. In this case, a 50-pound payload can be propelled to altitudes greater than 250,000 feet. An obvious advantage of this method besides giving higher altitudes (albeit at the expense of heavier launch vehicles) would be that a large number of payloads can be mated to essentially the same propulsion system.

A comparison of the performance of Items 1 and 2 is shown in Figure 8 as a plot of maximum altitude vs. payload weight for the 40-second burning time.

Form Factor:

Form factors of 1.0 and 2.0 were used in the study. Figure 9 shows the effects on maximum altitude attained due to form factor changes for the 10-pound payload at a launch angle of 75°.

Burning Time:

An attempt was made to optimize the performance by varying the burning time of the propulsion system. Burning times of 10, 20, 30 and 40 seconds were considered. The effects are shown in Figures 9, 10, 11, 12 and 13. A launch angle of 85° seems to indicate an optimum burning time of 40 seconds while the 75° launch angle has an optimum burning time of approximately 30-35 seconds.

Launch Angle:

Initially, a launch angle of 75° was used to determine the performance of various projectile designs. However, the preliminary dispersion analysis showed that launch angles of 85° could be safely used.

Figure 10 shows the altitudes which were obtained with launch angles of 75° and 85° for the 10-pound payload as a function of burning time. Results indicate that the higher launch elevation, combined with the optimum 40-second burning time, will increase the maximum altitude at 75° by approximately 20 percent.

Ignition Delay Time:

An attempt was also made to optimize the performance of the rocket by varying the ignition delay time after ejection from the gun (Figures 12 and 13). A zero ignition delay time was found to be optimum for a 40-second burning time. However, ignition delay times of up to 5 seconds will not greatly affect the maximum altitudes attained. Ignition delay times will probably be required to permit sufficient time for initial disturbances, imparted to the projectile from the gun, to dampen out.

Muzzle Velocity:

A limited study was made to determine the effect of increasing muzzle energy and momentum for the 5" gun system. By increasing velocity to 2000 fps for a 150-pound projectile, the rated energy capability of the 5" gun tube, and the rated momentum capability of the 155mm gun recoiling system (which would be used in conjunction with the 5" gun tube), would both be exceeded by approximately 15 percent.

Using these launch parameters, i.e., a launch weight of

150 pounds and a muzzle velocity of 2000 fps, a flying weight of 93.4 pounds was evolved. The performance of this round with a 10-pound payload and form factors of 1.0 and 2.0 is plotted in Figures 14 and 15. The launch angle of 75° indicates an optimum burning time of from 30 to 40 seconds at zero ignition delay.

The comparison of performance of the 5" projectiles which would be launched at 1000 fps and 2000 fps is shown in Figure 16. The apparently deficient performance shown by the projectile which will be launched at 2000 fps velocity may be attributed to use of trap supports, rather than case bonding as would be used in the projectile launched at 1000 fps, and the resulting lower mass fraction of propellant in the motor. The limiting shear stress value used as a basis for this study is 300 psi. This value is considered to be conservative. It is believed that certain available nitrocellulose-based, high strength propellants may withstand up to 1000 psi in shear under impulsive loading. This would permit the use of case bonding for grain support at the 2000 fps launch velocity and thus should improve altitude performance significantly.

Dispersion Analysis:

The results of the dispersion analysis for the 5" BAP are shown in Table III for the projectile fired at a muzzle velocity of 1000 fps, reaching an altitude of 457,030 feet. This analysis

showed a 3σ value of 23,118 feet in range impact accuracy.

7" DIAMETER GUN SYSTEM:

Full Caliber Projectile:

Initial limited studies for the 7" gun system considered a 10-pound payload and two projectile "in-gun" weights; 113 pounds and 226 pounds. Subjecting these projectiles to 120 percent of maximum rated pressure, launch velocities of 3680 and 2700 fps would be obtained from a standard length tube. The 113-pound projectile would not exceed the momentum limitation of the 175mm Self-Propelled Gun. The 226-pound projectile would exceed the recoil capability of the Self-Propelled vehicle, but would be within the capabilities of an 8" gun mount.

The altitude capabilities of the two projectiles are indicated in Figures 17 thru 24. Optimized buring times for zero ignition delay, 75° and 85° launch angles and form factors of 1.0, 2.0, 3.0 and 4.0 are shown in Figures 17 thru 20. The attainable altitude as functions of ignition delay time, burning time, form factors of 1.0 and 4.0 and a launch angle of 75° are presented in Figures 21 thru 24.

Sub-Caliber 4.5" Projectile:

The sub-caliber 4.5" projectile approach was used to meet a requirement for delivery of a 20-pound payload to 500,000 feet altitude with a minimum dispersion. Figure 4 typifies the design

approach used. Coefficient of drag vs. mach number curves are shown in Figure 25 for both free flight and jet burning conditions. Figure 26 is a plot of maximum altitude vs. burning time at zero ignition delay. The optimum burning time is from 26 to 40 seconds. The muzzle velocity is 2650, "in-gun" weight is 183 pounds and the flight weight is 90 pounds. Propellant weight is 44.8 pounds and has a specific impulse of 214 seconds. The design approach illustrated in Figure 4 is intended to withstand a peak setback level of 7000 G's. The "g" level is based on utilizing the standard chamber volume of the 175mm gun (mod.) and a tube extension of 25 calibers without optimization of the standard gun charge grain configuration.

It was later determined that the 7" gun tube could be increased to 600 inches of travel. Accordingly, a limited gun charge optimization study was conducted on an analog computer in an attempt to provide the same velocity (2650 fps) at a greatly reduced "g" level. The purpose of the study was to determine whether or not the rocket walls could be made to support the projectile without structural assistance of the side sabots. Assuming optimistic allowable compressive loadings of 100,000 psi on an aluminum alloy motor wall, it was determined that the initial flight weight parameters for the 90-pound round could be maintained at a "g" level of 4000. Figure 26a illustrates a pressure-velocity vs. travel curve for a hypothetical gun charge which is capable of meeting the 4000 "G" restriction. Structural side sabot weight was drastically reduced. An "in-gun" projectile weight of 116 pounds was estimated for the study. The round was indexed

into the bore 60 inches to increase the chamber volume from the standard 2800 cubic inches to 5109 cubic inches. The peak pressure is 12,000 psi and the muzzle velocity 2700 fps.

Further investigation of gun charge optimization may prove lucrative for pure projectiles or BAP designs intended for the 7" gun system with its extended length barrel.

16.4" DIAMETER GUN SYSTEM:

16.4" Diameter Single Stage BAP (Excess Metal Sabotted):

A 16.4" diameter round having a missile unburnt weight of 1680 pounds and a sabot weight of 560 pounds (2240 pounds total in-gun weight) was chosen as an appropriate example of an indication of the capabilities of other 16.4" diameter rounds of this type, i.e., the metal which is required for structural integrity during launch phase only is sabotted where possible.

The attainable altitudes as functions of burning time, payload weight and form factor for zero ignition delay time and a velocity of 2925 fps are presented in Figures 27 thru 35. The figures are cross-plots of the altitudes vs. the various parameters. As can be seen from the figures, a 10-pound payload will reach altitudes in excess of 1,450,000 feet while the 100-pound payload can be projected to approximately 1,250,000 feet. A burning time of 30 to 40 seconds appears to be optimum.

Figure 61 indicates the altitude capabilities of a 1120-pound "in-gun" weight BAP as a function of launch velocity and burning time. The launch angle is 75^{o}; the form factor 1.0; the payload, 47 pounds and the ignition delay time, zero. The rocket propellant weight to flying weight ratio is shown at velocity levels of 2000 fps and 4000 fps. The higher mass fraction of propellant resulting at the 2000 fps velocity is due to a larger rocket motor design (less sabot structure) made possible by the lower launch setback level, which is experienced at the 2000 fps velocity launch condition. The figure illustrates that at least for this particular case, advantage should be taken of the gun energy (at some expense of propellant mass fraction) for optimum altitude performance.

16.4" Diameter Single Stage BAP (Pusher Plate Sabotted Only):

A series of designs were established for initial "in-gun" weights of 4480 pounds, 2240 pounds, 1120 pounds and 560 pounds including a constant weight of 125 pounds for a sabotted pusher plate. These configurations differ from the previously discussed rounds in that the metal parts which are required for structural integrity during launch remain with the round during flight (the pusher plate excepted). The launch velocities corresponding to each initial weight are as follows:

In-Gun Weight (lb)	4480	2240	1120	560
Flight Weight (lb)	4355	2115	995	435
Vo (fps)	2150	2925	4000	5000

The expected altitudes as functions of burning time, ignition delay, launch angle and payload weight for a form factor of 1.1 and flight weights of 4355 pounds (Vo of 2150 fps) are shown in Figures 36 thru 45. The effect of form factor for one launch condition is presented in Figure 46.

Similar data for the 2115-pound vehicle (Vo of 2925 fps) are presented in Figures 47 thru 54.

Figure 55 depicts altitude as a function of delay time and burning time for the 995-pound projectile, launched at an elevation of 75° with a form factor of 1.1 and a 47-pound payload. The effect of form factor on altitude is shown in Figure 56 for an ignition delay of zero and a burning time of 12 seconds.

Similar data for the 435-pound projectile (Vo of 4000 fps) are presented in Figures 57 and 58.

The altitude capabilities, as a function of form factor, of the four latter 16.4" projectiles are plotted for selected launch conditions in Figure 59.

16.4" BAP Dispersion Analysis:

The dispersion due to wind of a 16.4" round launched at 4000 fps will be 10,000 feet in range due to a head wind and 6200 feet in deflection due to a cross-wind. The interplay of the cross-wind on

the range dispersion has not been calculated for this particular projectile, but will be smaller than those presented for the 5" diameter round (Figure 3).

It is to be noted that the dispersions of the BAP projectiles should be approximately as little as 1/10 those of a free flight rocket launched at velocities of 200 fps to 300 fps.

16.4" Diameter Single Stage BAP (Comparison of Projectiles with Excess Metal Sabotted and that with Pusher Plate Sabotted Only):

Figure 60 compares the two types of 16.4" BAP's discussed in the previous sub-sections. The extent of improvement in performance resulting from discarding launch structure, where possible, is shown in the plots of the two projectiles launched at 4000 fps. The 845-pound projectile discards an additional 150 pounds of structure above that which is sabotted by the 995-pound flying weight projectile; and maximum altitude is consequently increased by 27 percent.

In the same figure, the 995-pound projectile, launched at 2000 fps, contains a high rocket propellant to flying weight ratio due to less stringent launch conditions. This enables its performance to approach that of the 4000 fps, 845-pound BAP.

Figure 61 is a cross-plot of the upper two curves in Figure 60.

Staging (16.4" Diameter BAP):

Various sample two stage configurations were studied to determine the maximum altitudes that could be reached as functions of the following parameters:

1. First stage burning time
2. Payload weight
3. Form factor
4. Delay time between stages

The attainable altitude vs. delay time as a function of form factor, for a two-stage vehicle launched at 2150 fps is presented in Figures 62 and 63. The burning time of the first stage motor of Figure 62 is 15 seconds, while the burning time of the first stage motor for Figure 63 is 20 seconds.

No excess metal, other than a 125-pound pusher plate, was discarded from the projectiles at launch. It can be seen that as the burning time of the first stage increases the attainable altitude also increases. No attempt was made to optimize the burning time.

The effect of ignition delay time on maximum altitude as a function of payload weight and first stage burning time is presented in Figure 64 for a 2115-pound flight weight projectile launched at 2925 fps. Again, no metal parts other than the 125-pound pusher plate were discarded. The form factor was taken as 1.0. The altitude is seen to approach a maximum as the delay time between stages approaches zero.

The maximum altitude vs. first stage burning time as a function of payload weight for a 1680-pound flight-weight projectile which is launched at a velocity of 2925 fps is presented in Figure 67. All excess weight was discarded from this particular projectile at launch.

As can be seen, the optimum first stage burning time for both the 50-pound and 100-pound payload configurations is approximately 24 seconds. The two stage 16.4" rounds consisted of a 16.4" first stage diameter and an 11-inch second stage diameter. The stabilization device for the first stage would be a folding fin assembly or a collapsible flare assembly. The stabilization device for the second stage vehicle would be an aft flare configuration.

8.4 and 8.7" Diameter BAP Sub-Calibered in the 16.4" Gun:

Maximum altitude performance for an 8.4" projectile is depicted in Figures 68 thru 73. The figures illustrate the altitude capability of an 8.4" projectile with an "in-gun" weight of 1120 pounds, a launch weight of 410 pounds, a payload of 47 pounds, and a launch elevation of 75°. The projectile is designed for a launch velocity of 4000 fps. The effect of reduced launch velocity (without optimization of design), form factor, burning time and ignition delay time is shown in Figures 68 thru 71. The effect of nozzle expansion ratio at a launch velocity of 4000 fps for ignition delays of zero and five seconds and form factors of 1.25 and 1.50, as a function of burning time, is plotted in Figures 72 thru 74.

Maximum altitude performance for 8.7" projectiles is shown in Figures 75 thru 80. Figures 75 and 76 indicate the altitude capability of a projectile with an "in-gun" weight of 560 pounds, a payload of 47 pounds, and a launch elevation of 75° with a zero ignition delay time.

Figure 75 illustrates maximum altitude vs. muzzle velocity as a function of burning time, at a form factor of 1.0. In these cases, the rocket motor and sabot weight relationship was optimized for each velocity. An increase in maximum altitude capability is apparent at reduced muzzle velocity due to a higher mass fraction of propellant. Figure 76 is a similar plot for a form factor of 2.0, and indicates the same trend as for a form factor of 1.0.

Figures 77 and 78 are cross-plots of the previous two figures showing maximum altitude vs. burning time as a function of form factor. Form factors of 3.0 and 4.0 are also shown.

Figure 80 depicts maximum altitude vs. burning time as a function of form factor for a projectile with an "in-gun" weight of 1120 pounds. The flight weight is 604 pounds and the payload, 47 pounds. The projectile is launched at 3000 fps at an elevation of 75°. The increase in maximum altitude capability of this round vs. a similar round of half the "in-gun" weight, but launched at the same velocity (Figure 78) is approximately 32 percent.

13.8" Diameter BAP Sub-calibered in the 16.4" Gun (Single Stage):

Maximum altitude performance of a 13.8" projectile is depicted in Figures 81 thru 95 as functions of the following parameters:

Burning time

Form factor

Initial velocity

Ignition delay time

Payload weight

Maximum altitude vs. burning time as a function of form factor is presented in Figures 81 and 82 for a flight weight of 660 pounds and payloads of 25 pounds and 50 pounds, respectively.

Maximum altitude vs. burning time as a function of ignition delay and form factor is presented in Figures 83 and 84 for payload weights of 25 pounds and 50 pounds, respectively.

Maximum altitude vs. delay time as a function of burning time is presented in Figures 85 and 86 for payload weights of 25 pounds and 50 pounds, respectively.

The launch velocity considered for Figures 81 thru 86 was 4000 fps.

Maximum altitude vs. burning time as a function of form factor is presented in Figures 87 and 88 for payloads of 50 pounds and 100 pounds, respectively. The launch velocity considered is 2925 fps.

Maximum altitude vs. burning time as a function of ignition delay and form factor for payloads of 50 pounds and 100 pounds, respectively, and a launch velocity of 2925 fps is presented in Figures 89 and 90.

Maximum altitude vs. ignition delay time as a function of burning time is presented in Figures 91 and 92 for payloads of 50 pounds and 100 pounds and a launch velocity of 2925 fps.

Maximum altitude vs. form factor as a function of burning time is presented in Figure 93 for a payload of 50 pounds and a launch velocity of 2925 fps.

It is to be noted that for the relatively long burning times, an ignition delay of zero seconds is optimum. As the burning time is decreased to 12 seconds, a delay time of 10 seconds is found to be optimum. The maximum altitude attained is greater for the long burner in this particular case (Figure 91). This point will be further discussed in a proceeding section of this report.

Staging (13.8" Diameter BAP):

A limited study was made of the increase in altitude which could be obtained by staging a 13.8" projectile. Figures 96 and 97 present the maximum altitude of a 13.8", two-stage projectile vs. delay time between stages, as a function of first stage burning time and form factor. The data for a 50-pound payload are presented in Figure 96, while the data for a 100-pound payload are presented in Figure 97. As can be seen the maximum altitude attained is essentially independent of first stage burning time when the form factor is 1.0. With a form factor of 4.0, the projectile with a longer burning time in first stage operation attains a higher altitude than the shorter burner. This effect may be attributed to the projectile with a longer burning time as having a greater sustainer action and, thereby, utilizing its energy more efficiently to overcome drag forces.

The diameter of the second stage was taken to be 9.4 inches.

Optimum Ignition Delay and Burning Time for Martlet IIIA:

During the course of the program reported herein, a question arose as to whether or not a short burning time rocket with an optimum ignition delay would yield more altitude than a long burning time rocket with an ignition delay of zero seconds. The Canadian Martlet IIIA vehicle was used as an example of a short burning time round. Utilizing the same propellant weights and metal parts weights as the Martlet IIIA, a long burning time was assigned to the Canadian projectile. For comparison purposes the projectile will be described as the Martlet IIIA short burner and Martlet IIIA long burner.

Trajectories were run on the Martlet IIIA using burning times of two and thirty-five seconds.

On the two-second burner, the optimum ignition delay is twenty seconds for both a fifteen and thirty-five-pound payload. A significant increase in altitude is obtained by assuming that a portion of the motor casing is sabotted (40 pounds) in both the two and thirty-five-second burners.

The maximum altitude versus round weight for the long and short burning projectile is presented in Figure 98. It can be seen that the thirty-five-second burner would reach approximately the same altitude as the two-second burner.

Increasing the form factor to 1.5 decreased the maximum altitude by approximately 25 percent (not shown in the figure). The drag

coefficient vs. mach number values used for the analysis is shown in Figure 99.

Orbiting Capability:

The possibility of utilizing rocket boosted projectiles to place significant payloads into orbit has been studied.

A vehicle weighing 1680# exclusive of sabot, with an initial launch velocity of 2925 fps was chosen as a representative flight configuration. Mass ratio factors ($\frac{W_{Propellant}}{W_{Propellant}+W_{Metal\ Parts}}$) of 0.7, 0.8, 0.9 were assumed for the motor sections. The metal parts weight includes the weights of both the stabilization devices and the separation devices. Sea level specific impulse values of 200 sec. and 220 sec. were used. A linear increase in specific impulse was assumed from sea level to an altitude of 100,000 feet. The specific impulse at 100,000 feet was taken to be 20% higher than the sea level value.

The results indicate that orbital velocities, in the order of 26,000 feet per second at an orbit entry altitude of 150 miles, are feasible for the following staging, specific impulse, mass ratio and payload combinations:

SEA LEVEL SPECIFIC IMPULSE (SEC)	MOTOR MASS RATIO	NO. OF STAGES	PAYLOAD
220	0.9	3	40#
220	0.8	3	10#
200	0.7	6	½#

The conservative values for specific impulse used in this study can be significantly increased thereby decreasing the mass ratio requirement, and/or increasing the payload potential.

Since this study was very cursory in nature, much additional effort must be placed on the various critical aspects of an orbiting program including final stage orientation techniques and mechanisms.

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4. SECOND STATUS REPORT - RESEARCH & DEVELOPMENT OF BOOSTED ARTILLERY PROJECTILES FOR DIRECT SUPPORT FIELD ARTILLERY WEAPONS, Picatinny Arsenal dated July 1962 thru April 1963.
5. Hinson, William F., Falanga, Ralph A., EFFECT OF JET PLUMING ON THE STATIC STABILITY OF CONE-CYLINDER-FLARE CONFIGURATIONS AT A MACH NUMBER OF 9.65, NASA TN D-1352 September 1962.
6. HANDBOOK OF GEOPHYSICS (REVISED EDITION), U.S.A.F./Geophysics Research Directorate, MacMillian Co., 1960.

7. Bull, G. V. and Eyre, F. W., PRELIMINARY ESTIMATES OF THE PERFORMANCE ACHIEVED USING A SMALL ROCKET BOOSTED PAYLOAD FROM THE 16" GUN AT BARBADOS, August 1962.

8. Eyre, F. W., PRELIMINARY AERODYNAMICS NOTE ON MARTLET I STATIC STABILITY AND PERFORMANCE, McGill University Report TN 62-1, April 1962.

9. Wasserman, S., Lattal, G., Smolnik, J., PRELIMINARY PARAMETRIC AND DESIGN STUDIES ON USE OF BOOSTED ARTILLERY PROJECTILES FOR HIGH ALTITUDE RESEARCH PROBES, Report No. 1, Picatinny Arsenal Dover, N.J., April 1963.

TABLE I

SUMMARY OF PERFORMANCE

RD. DIA. IN.	GUN DIA IN.	(THOUSAND FEET) ALTITUDE	PAYLOAD WT., LBS	IN-GUN WT LBS(1)	INITIAL FLYING WT. LBS(2)	PROP WT. LBS	BURN TIME, SEC.	MV FPS	SEA LEVEL THRUST, LBS	NO. OF STAGES	FORM FACTOR FF.	Q.E.
4.5	7.0	505,000	20	183	90	44.8	40	2650	240	1	Fig. 25	80
5.0	5.0	250,000	10	50	50	20	30-40	1000	-	1	-	-
5.0	5.0	706,437	10	150	126.2	80	30	1000	528	1	1.0	75
5.0	5.0	648,899	10	150	93.4	52	30	2000	343	1	1.0	75
5.0	5.0	664,969	10	150	126	80	40	1000	395	1	2.0	85
5.0	5.0	552,680	15	150	126	75	40	1000	377	1	2.0	85
5.0	5.0	452,803	15	150	126	75.7	30	1000	503	1	2.0	80
5.0	5.0	384,878	25	150	126	68	40	1000	340	1	2.0	85
5.0	5.0	151,636	50	150	126	50	30	1000	320	1	2.0	85
*5.0	5.0	576,433	15	155	131	80	40	972	395	1	2.0	85
*5.0	5.0	442,277	25	165	141	80	40	900	395	1	2.0	86
*5.0	5.0	262,374	50	190	166	80	40	793	395	1	2.0	85
7.0	7.0	457,566	10	113	69.1	30	30	3680	198	1	1.0	85

(1) In gun weight includes sabot weight.

(2) Initial flying weight = in gun weight less sabot weight.

TABLE I (Cont'd)

RD. DIA. IN.	GUN DIA. IN.	(THOUSAND FEET) ALTITUDE	PAYLOAD WT., LBS	IN-GUN WT LBS(1)	INITIAL FLYING WT. LBS(2)	PROP WT. LBS	BURN TIME SEC.	MV FPS	SEA LEVEL THRUST, LBS	NO. OF STAGES	FORM FACTOR FF.	Q.E.
7.0	7.0	405,368	10	113	69.1	30	30	3680	198	1	1.0	75
7.0	7.0	763,503	10	226	150	79	30	2700	521	1	1.0	85
7.0	7.0	686,460	10	226	150	79	30	2700	521	1	1.0	75
8.4	16.4	1,009,611	50	1120	410	208	31.0	4000	1329	1	1.25	75
8.7	16.4	962,993	50	560	282	144	36	4000	793	1	1.0	75
8.7	16.4	1,089,097	50	560	373	218	36	3000	1200	1	1.0	75
8.7	16.4	1,434,156	50	1120	604	376	24	3000	3100	1	1.0	75
13.8	16.4	1,048,187	25	1120	660	353	36	4000	1941	1	1.0	75
13.8	16.4	966,448	50	1120	660	337	36	4000	1854	1	1.0	75
13.8	16.4	1,727,364	25	1120	660	1-200 2-129	1-24 2-10	4000	1-1650 2-2558	2	1.0	75
13.8	16.4	1,430,204	50	1120	600	1-200 2-113	1-24 2-10	4000	1-1650 2-2239	2	1.0	75
13.8	16.4	1,350,449	50	2240	1315	824	36	2925	4530	1	1.0	75
13.8	16.4	2,198,085	50	2240	1315	1-412 2-376	1-24 2-10	2925	1-3402 2-7445	2	1.0	75

TABLE I (Cont'd)

RD. DIA. IN.	GUN DIA IN	(THOUSAND FEET) ALTITUDE	PAYLOAD WT., LBS	IN-GUN WT LBS(1)	INITIAL FLYING WT. LBS(2)	PROP WT. LBS	BURN TIME, SEC.	MV FPS	SEA LEVEL THRUST, LBS	NO. OF STAGES	FORM FACTOR FF.	Q.E.
13.8	16.4	1,203,242	100	2240	1315	790	24	2925	6520	1	1.0	75
13.8	16.4	1,820,093	100	2240	1315	1-400 2-363	1-24 2-10	2925	1-3300 2-7190	2	1.0	75
16.4	16.4	411,609	50	560	435	133	36	5000	732	1	1.0	75
16.4	16.4	710,850	50	1120	995	433	36	4000	2380	1	1.1	75
16.4	16.4	1,167,570	50	1120	995	1-210 2-210	1-12 2-12	4000	1-3462 2-3462	2	1.1	75
**16.4	16.4	934,266	50	1120	845	433	36	4000	2380	1	1.0	75
16.4	16.4	851,383	10	2240	2115	1094	30	2925	7240	1	1.1	75
16.4	16.4	819,624	25	2240	2115	1076	30	2925	7100	1	1.1	75
16.4	16.4	804,045	50	2240	2115	1066	30	2925	7040	1	1.1	75
16.4	16.4	750,160	100	2240	2115	1030	30	2925	6800	1	1.1	75
**16.4	16.4	824,328	50	2240	1680	1070	24	3000	8840	1	1.0	75
**16.4	16.4	2,561,604	50	2240	1680 463	1-750 2-288	1-24 2-10	2925	1-6461 2-5760	2	1.0	75
**16.4	16.4	2,054,256	100	2240	1680 463	1-750 2-253	1-24 2-10	2925	1-6461 2-5060	2	1.0	75

TABLE I (Cont'd)

RD. DIA. In.	GUN DIA IN	(THOUSAND FEET) ALTITUDE	PAYLOAD WT., LBS	IN-GUN WT LBS(1)	INITIAL FLYING WT. LBS(2)	PROP WT. LBS	BURN TIME, SEC	MV FPS	SEA LEVEL THRUST, LBS	NO. OF STAGES	FORM FACTOR FF.	Q.E.
16.4	16.4	820,402	10	4480	4355	2286	20	2150	23,620	1	1.1	75
16.4	16.4	895,359	10	4480	4355	2386	20	2150	23,620	1	1.1	85
16.4	16.4	809,312	25	4480	4355	2374	20	2150	23,440	1	1.1	75
16.4	16.4	793,983	50	4480	4355	2355	20	2150	23,300	1.	1.1	75
16.4	16.4	771,304	100	4480	4355	2317	20	2150	22,900	1	1.1	75
16.4	16.4	3,597,731	50	4480	4355	1-1745 2-588	1-20 2-10	2150	1-17,290 2-11,640	2	1.0	75

*Varied payload with propulsion system kept constant.

**Excess metal sabotted.(All other 16.4" rounds did not employ discarding side sabot; however, all 16.4" rounds listed employed a discarding base piston weighing 125 lbs.)

TABLE II

TABULATION OF DESIGN PARAMETERS

GUN DIA (IN)	BAP DIA (IN)	WT. OF BAP IN GUN (LB)	WT. OF BAP IN FLIGHT (LB)	MUZZLE VELOCITY, MAX (FPS)	WEIGHT OF PAYLOAD (LB)	TYPE OF SUPPORT FOR PROPELLANT
16.4	16.4	4480	4355	2150	10-100	Trap
16.4	16.4	2240	2115	2925	10-100	Trap
16.4	16.4	2240	1680	2925	10-100	Trap
16.4	16.4	1120	995	4000	47	Trap
16.4	16.4	1120	845	4000	47	Trap
16.4	16.4	560	435	5000	47	Trap
16.4	13.8	2240	1315	2925	50-100	Trap
16.4	13.8	1120	660	4000	25-50	Trap
16.4	8.7	1120	604	3000	47	Trap
16.4	8.7	560	373	3000	47	Trap
16.4	8.7	560	282	4000	47	Trap
16.4	8.4	1120	410	4000	47	Trap
7	7	226	150	2700	10	Case bonded
7	7	113	69	3680	10	Trap
7	4.5	183	90	2650	20	Case bonded
7	4.5	116	90	2700	20	Case bonded
5	5	150	93	2000	10	Trap
5	5	150	126	1000	10-50	Case bonded
5	5	155	131	972	15	Case bonded
5	5	165	141	900	20	Case bonded
5	5	190	166	793	50	Case bonded

TABLE III

TYPICAL 5-INCH ROUND DISPERSION RESULTS

Initial Weight = 150 lbs

Launch Weight = 126 lbs

QE = 80°

Form Factor = 2.0

Muzzle Velocity = 1000 fps

Sea Level Thrust = 503 lbs

Burning Time = 30 sec.

Propellant Weight = 75.7 lbs

Payload = 15 lbs

Standard Range = 457,030 feet; Standard Altitude = 452,803 feet

ESTIMATED 3 σ PERTURBATION	Δ MAXIMUM ALTITUDE (FEET)	Δ IMPACT RANGE (FEET)	Δ AZIMUTH AT IMPACT (FEET)
1. QE = 1 mil	+418	-2248	
2. ΔW (Metal Parts Weignt) = 0.2%	-2712	-2635	
3. ΔTotal Impulse = 1%	+10,484	+10,037	
4. ΔAir Density = 3%	-6224	-5978	
5. ΔMuzzle Velocity =1%	+2089	-1233	
6. ΔHead Wind) Taken as 5% of the values presented	-1987	+17,979	
7. ΔCrosswind) in Figure 4.	+9600	+14,475	18,681
8. ΔDrag Coefficient = 3%	-6224	-5978	
9. Thrust Malalignment	-450	+5050	

Based on the above listed values, the 3σ difference in range between the predicted and measured impacts would be 23.118×10^3 feet. The difference in deflection would be 18.681×10^3 feet.

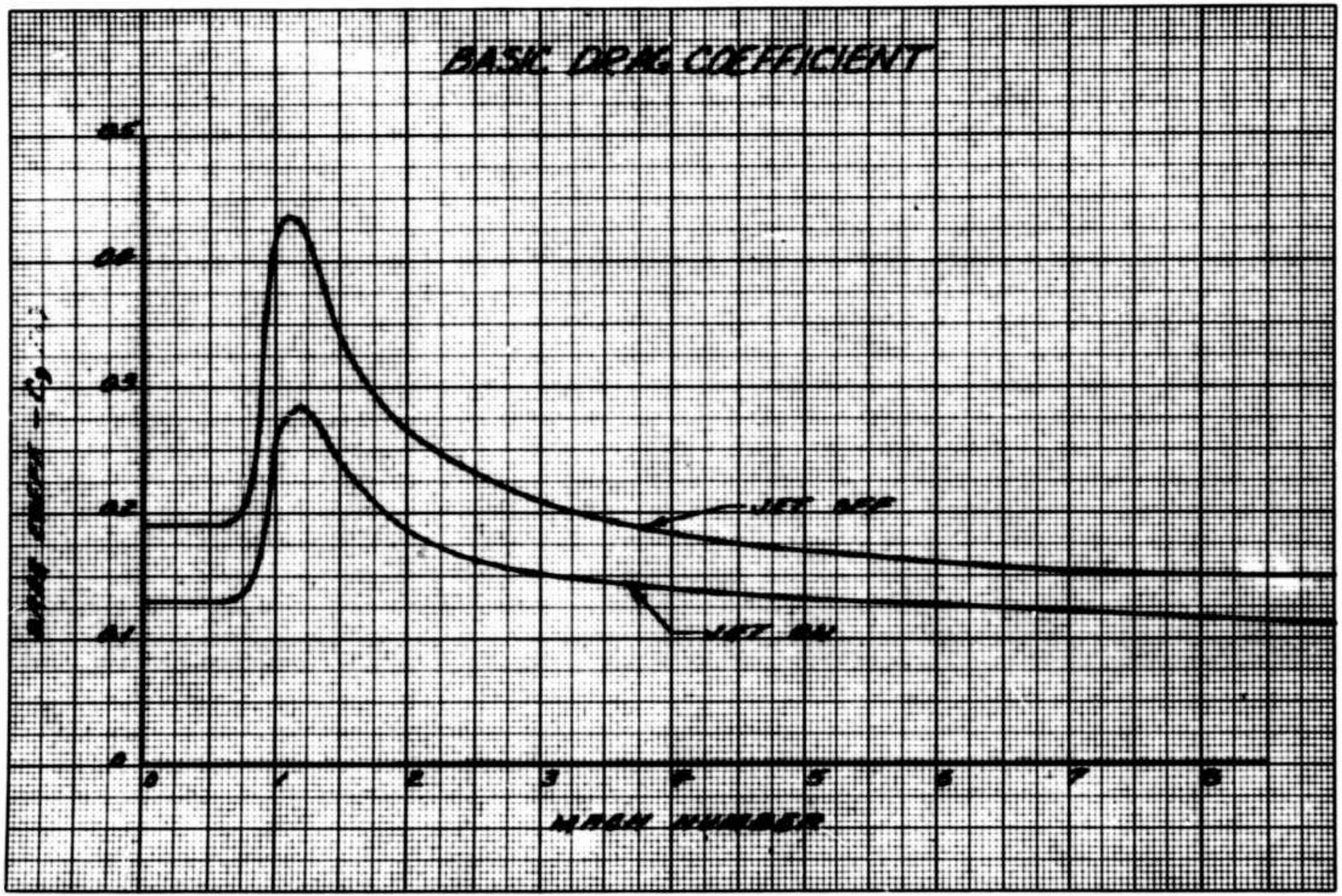
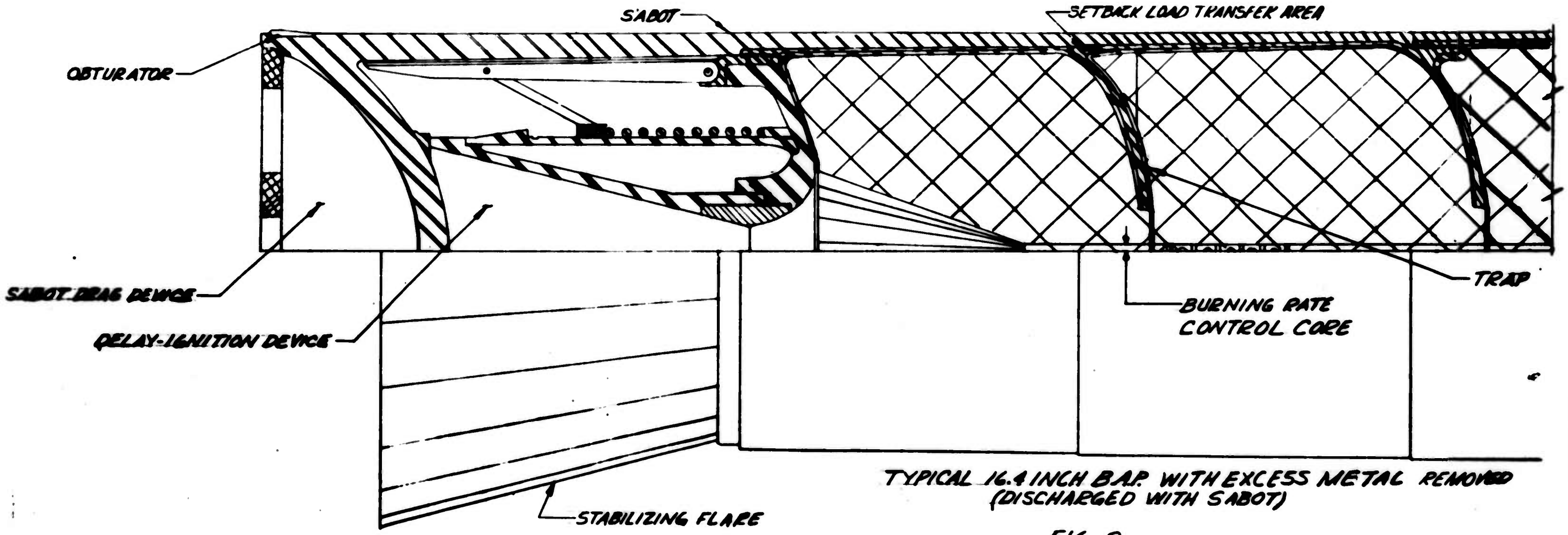
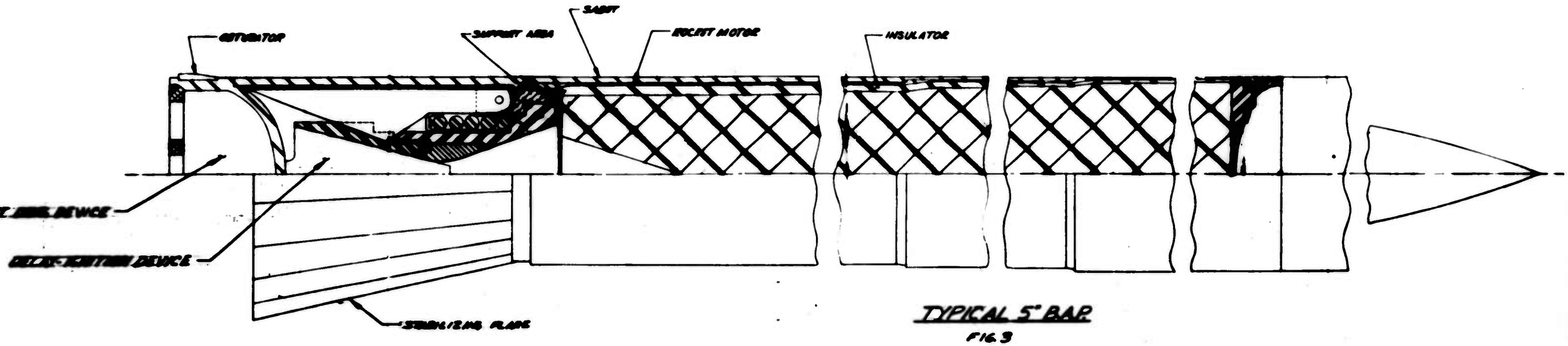


FIG. 1



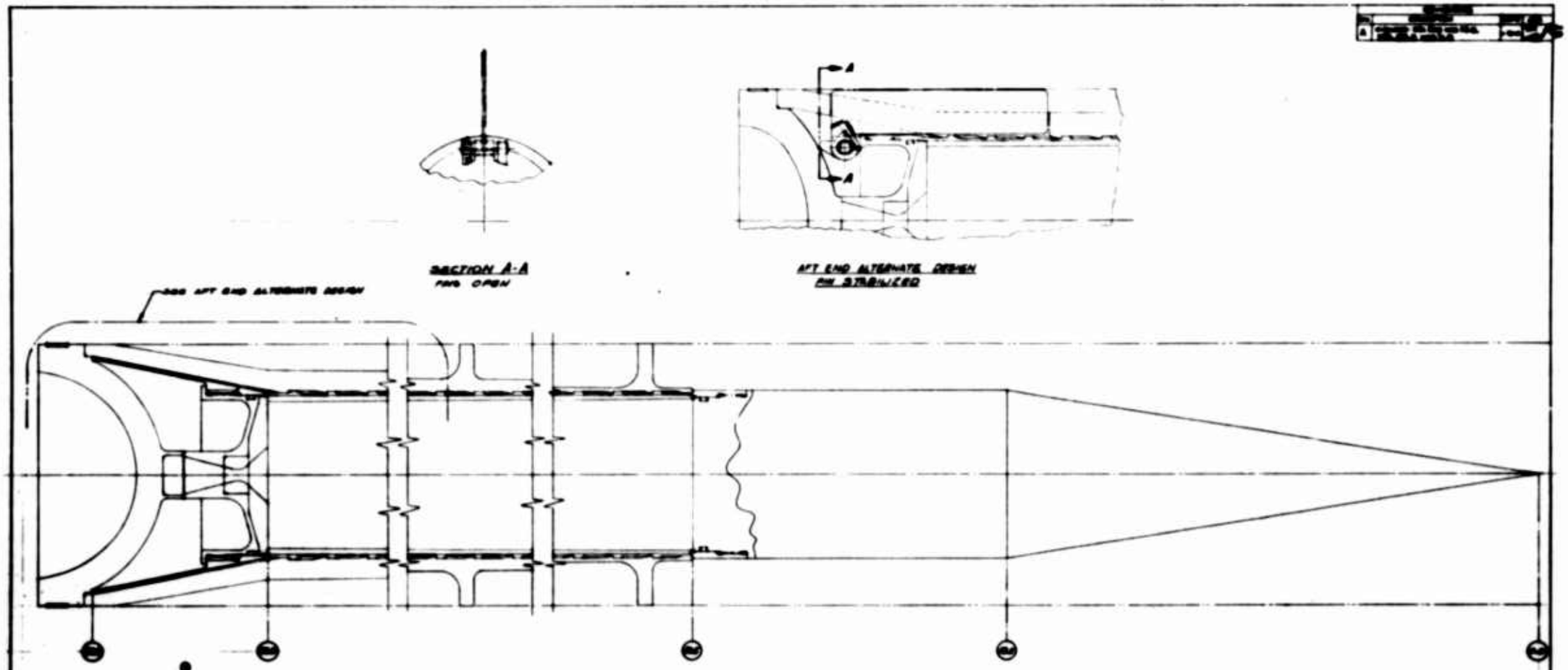
TYPICAL 16.4 INCH B.A.P. WITH EXCESS METAL REMOVED
(DISCHARGED WITH SABOT)

FIG. 2



TYPICAL 5" BAR

FIG 3



BAP FOR SEVEN INCH GUN

FIGURE 4

S-2089

A

4.50 DIA. HARP

S-2089

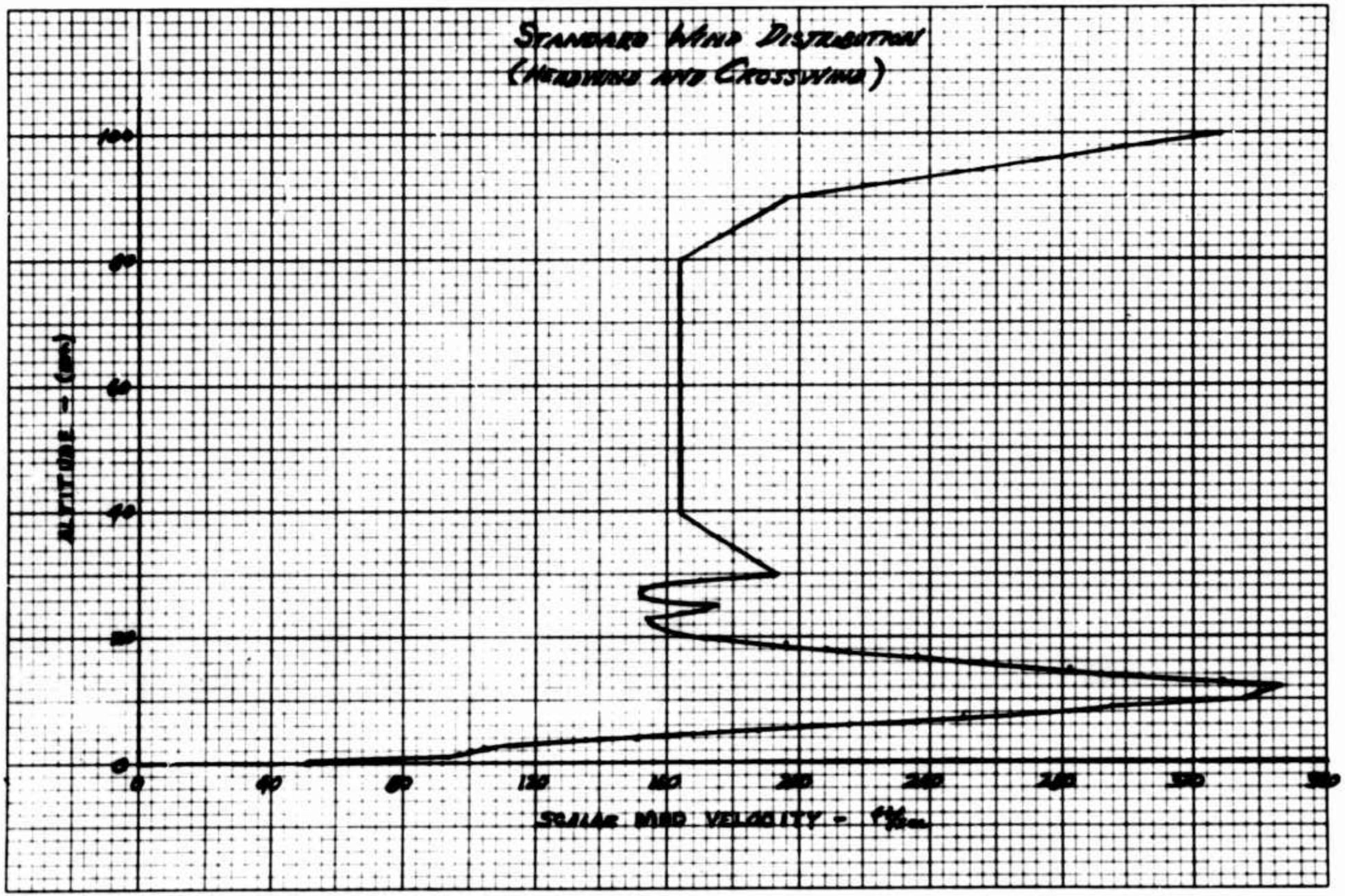

STANDARD WIND DISTRIBUTION
(HEADWIND AND CROSSWIND)
ALTITUDE - (FEET)
0
40
60
120
160
200
240
280
320
360
SCALAR WIND VELOCITY - KNOTS

FIG. 5

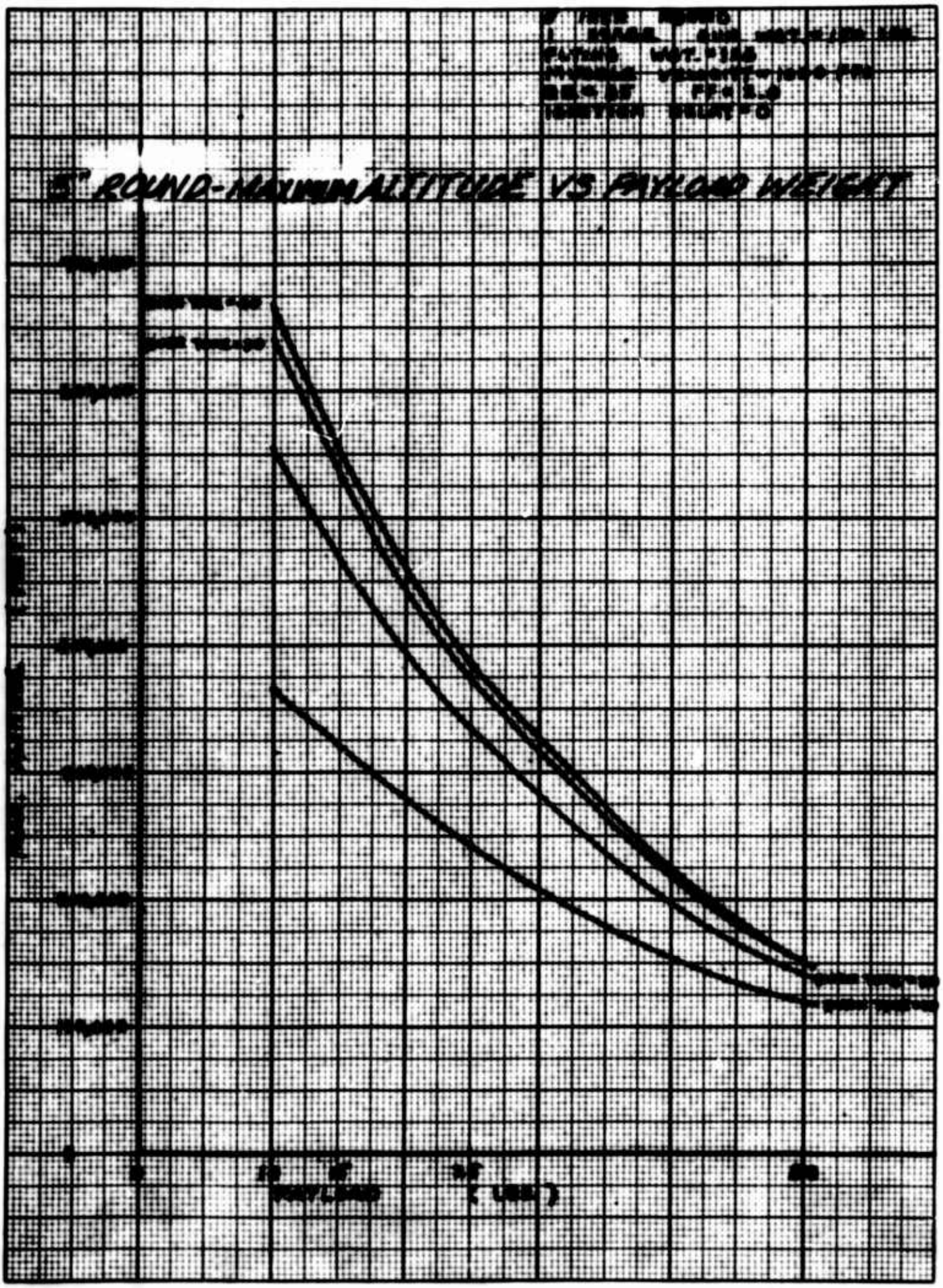


FIG. 6

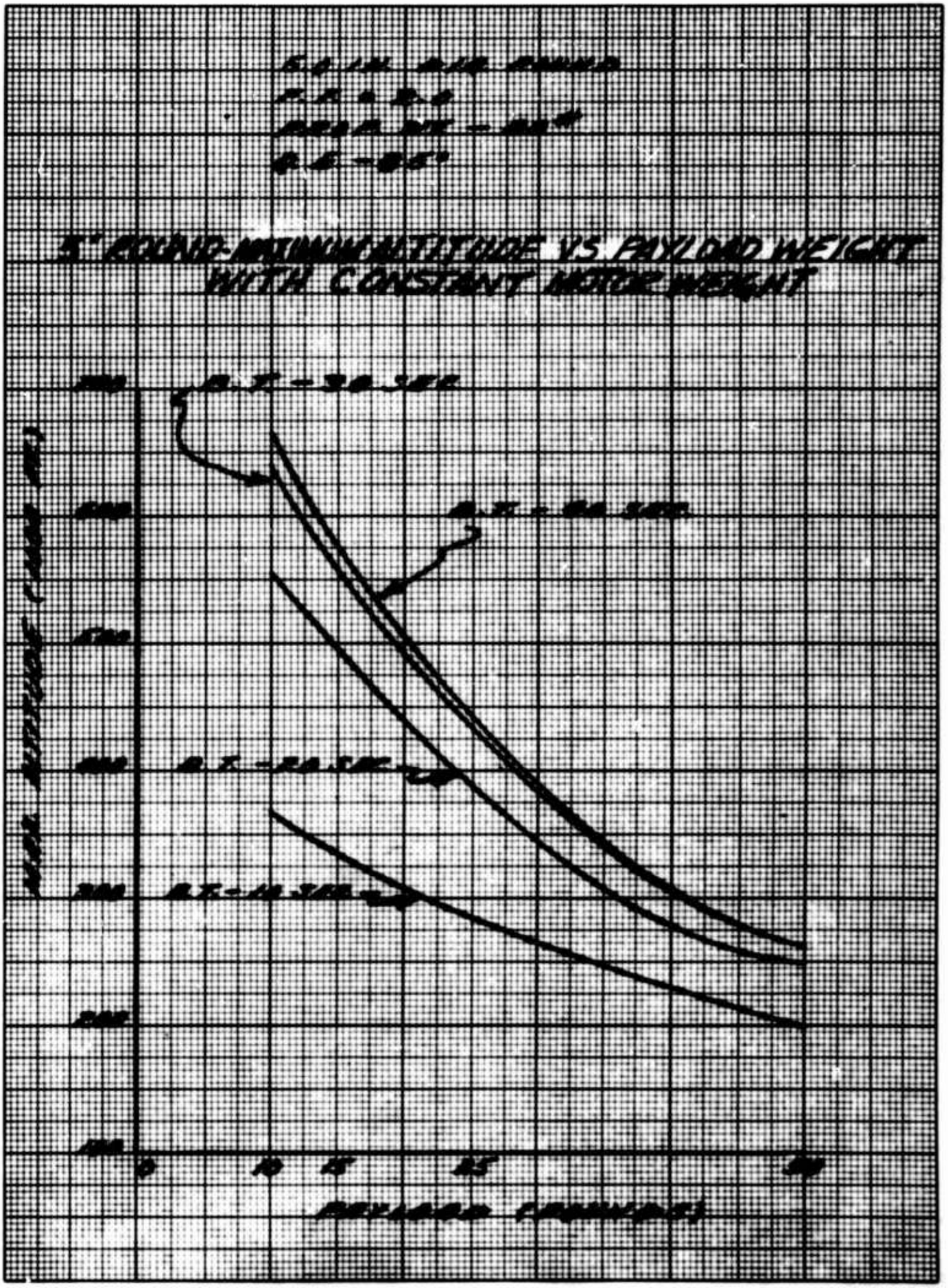

5" ROCKET-MAXIMUM ALTITUDE VS PAYLOAD WEIGHT
WITH CONSTANT MOTOR WEIGHT

FIG. 7

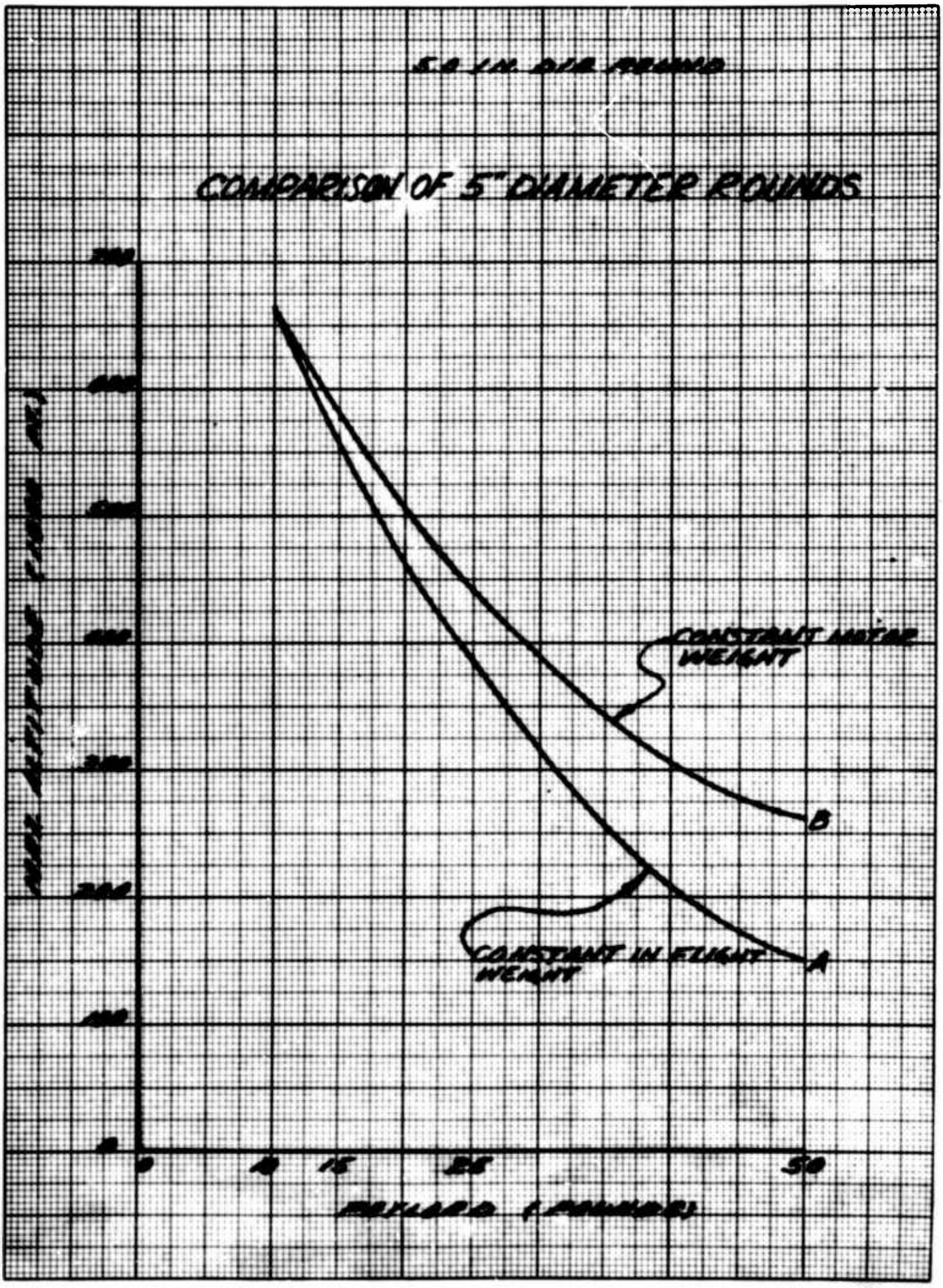

5.0 IN. DIA. ROUNDS
COMPARISON OF 5" DIAMETER ROUNDS
CONSTANT MUZZLE WEIGHT
CONSTANT IN FLIGHT WEIGHT
B
A
0
10
15
25
50

FIG. 8

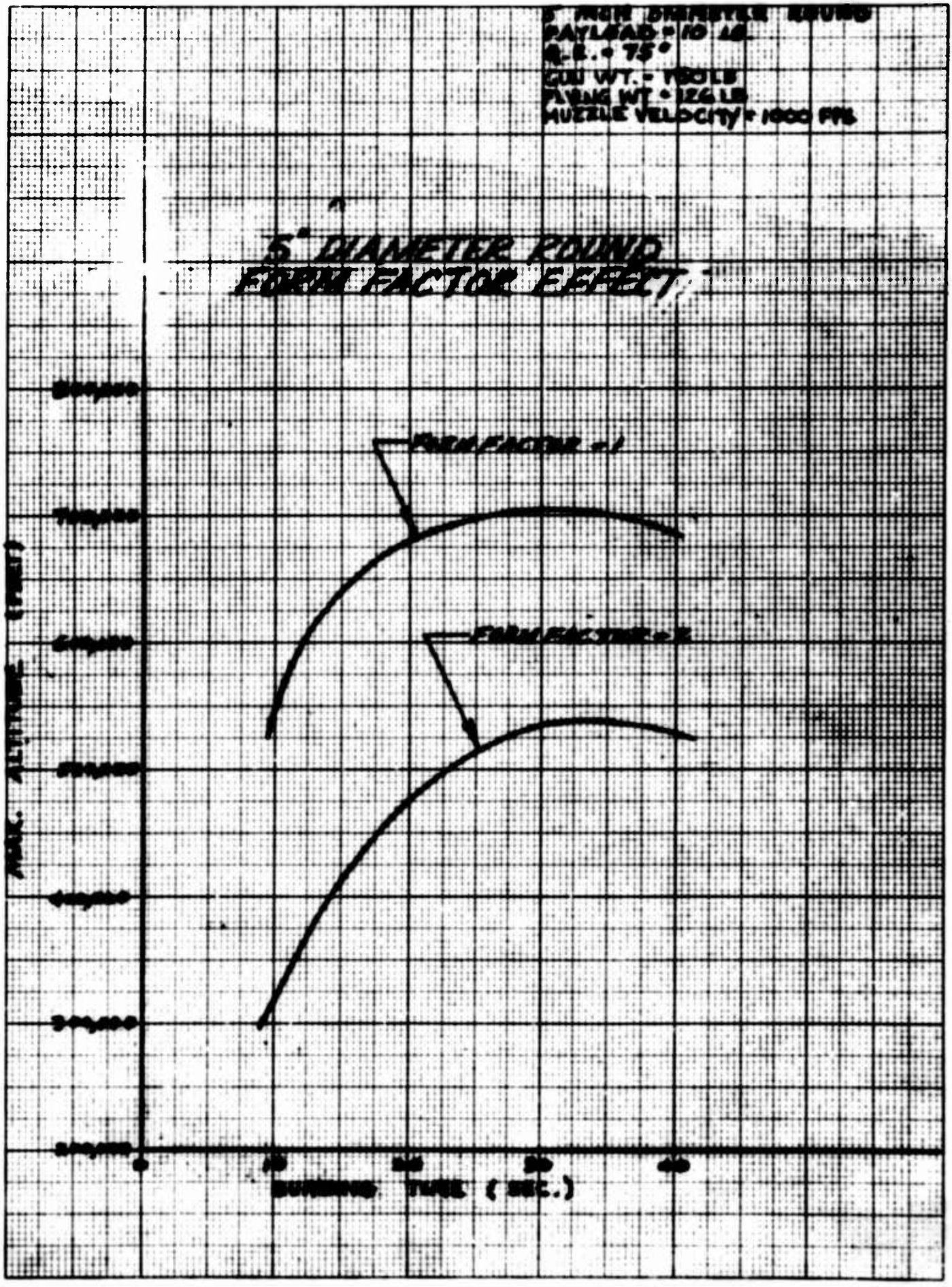

5" DIAMETER ROUND
FORM FACTOR SHEET
PAYLOAD = 10 LB
GUN WT. = 1900 LB
FLYING WT. = 126 LB
MUZZLE VELOCITY = 1000 FPS
FORM FACTOR = 1
FORM FACTOR = .8
ALTITUDE (FEET)
BURNING TIME (SEC.)

FIG. 9

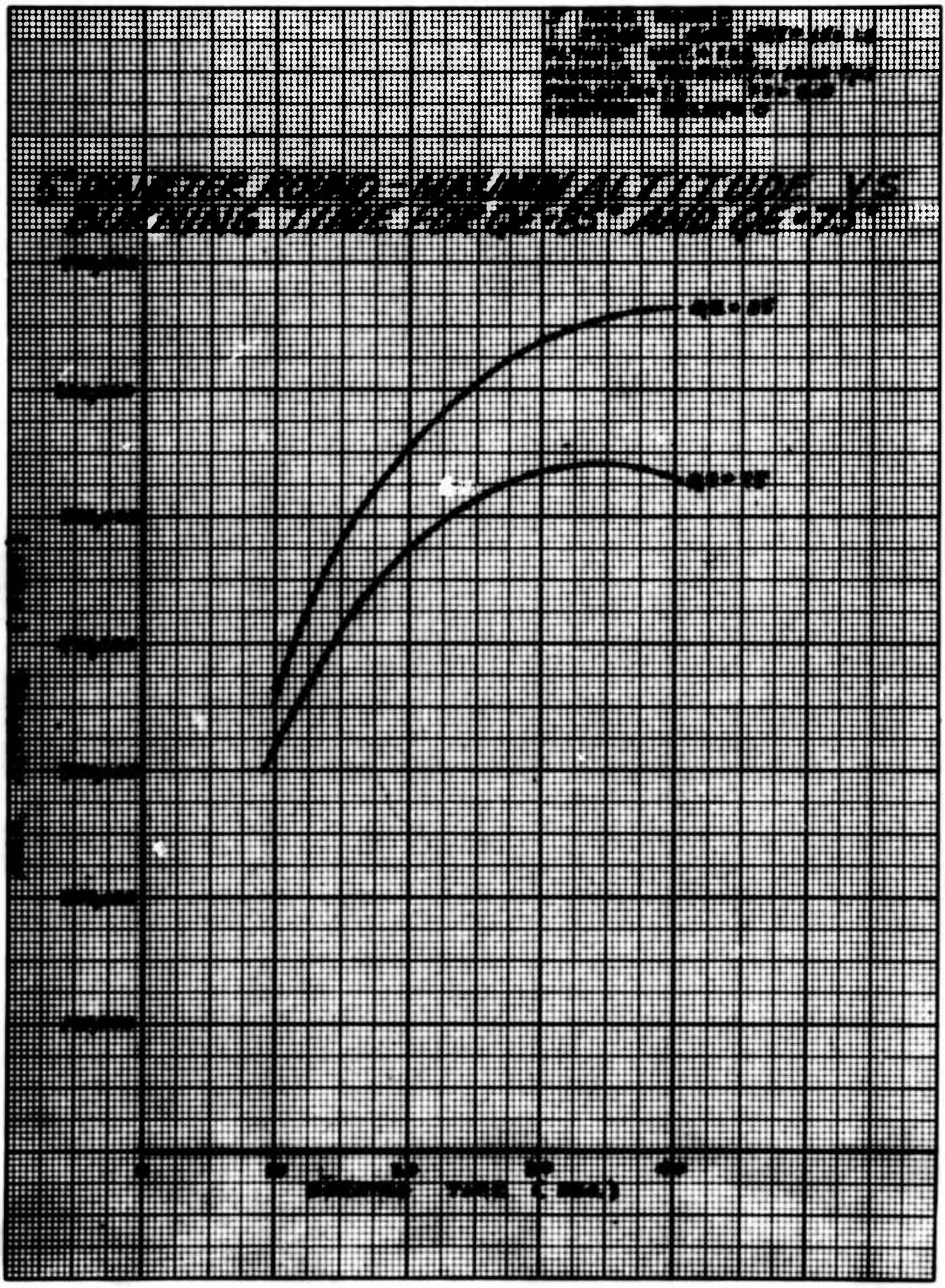


FIG. 10

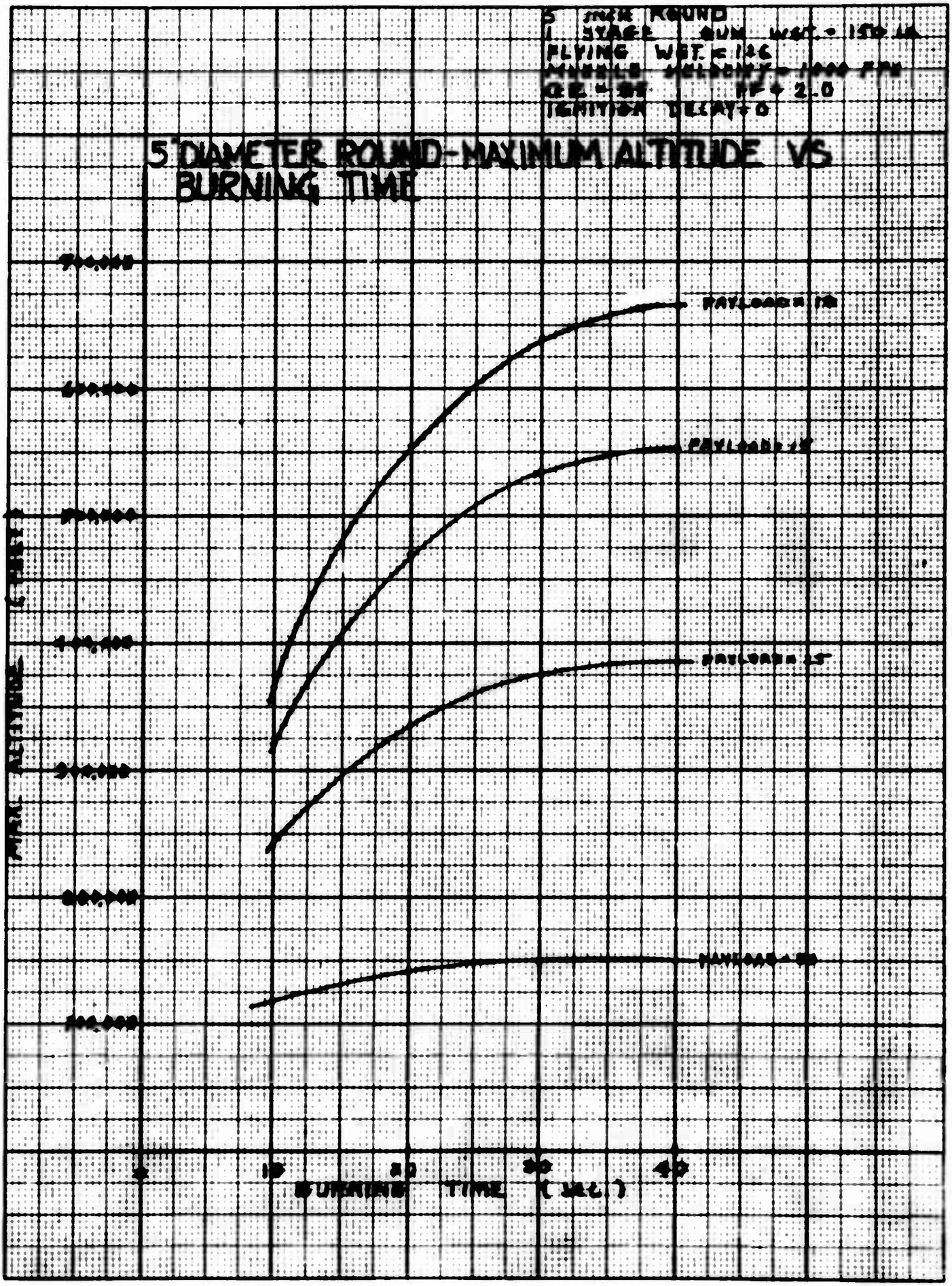

5" SIZE ROUND
1 STAGE
FLYING WGT. = 126
IGNITION DELAY = 0
5" DIAMETER ROUND - MAXIMUM ALTITUDE VS BURNING TIME
PAYLOAD = 10
PAYLOAD = 15
PAYLOAD = 25
PAYLOAD = 50
MAX. ALTITUDE (FEET)
BURNING TIME (SEC.)

FIG. 11

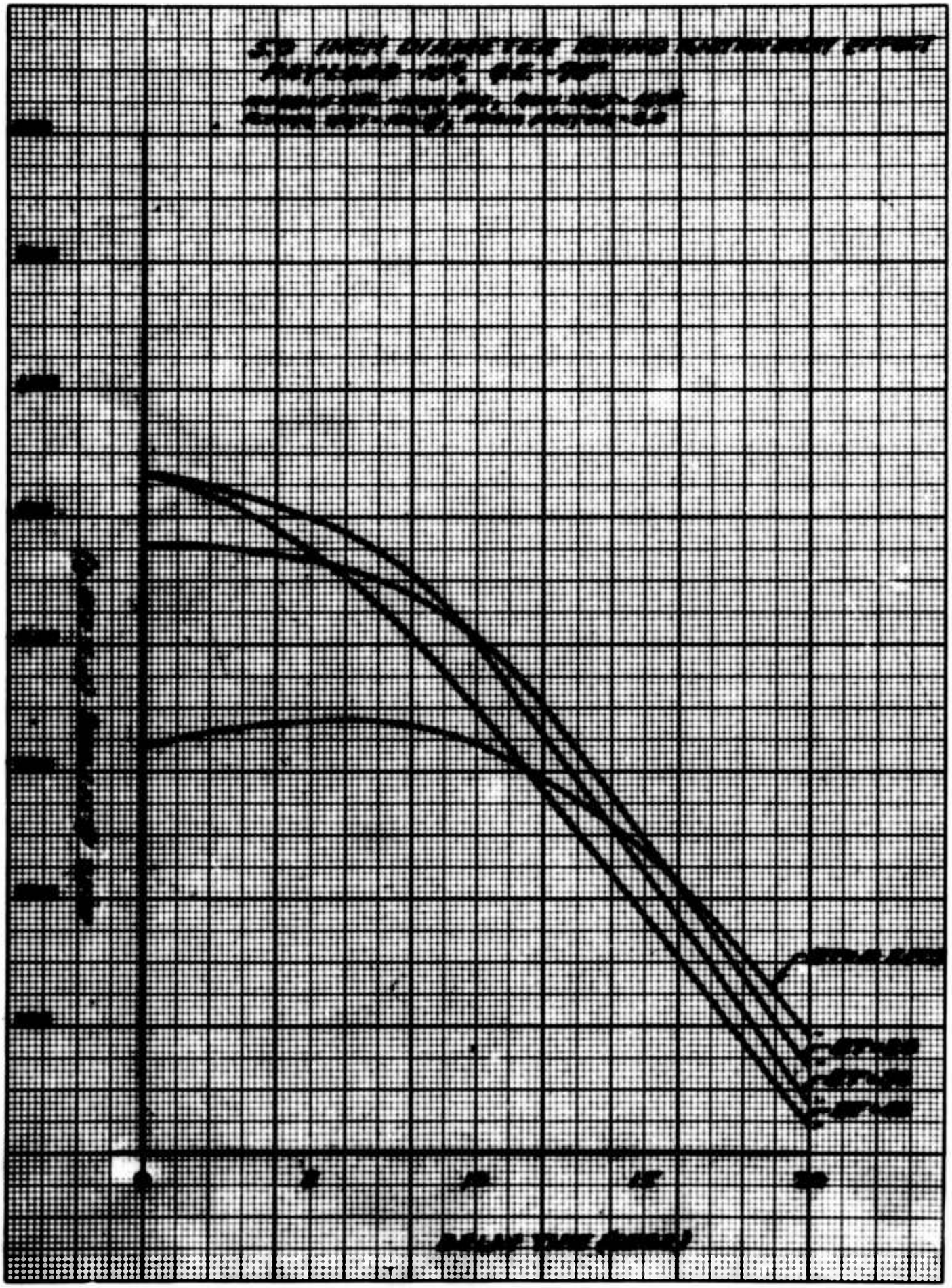


FIG. 12

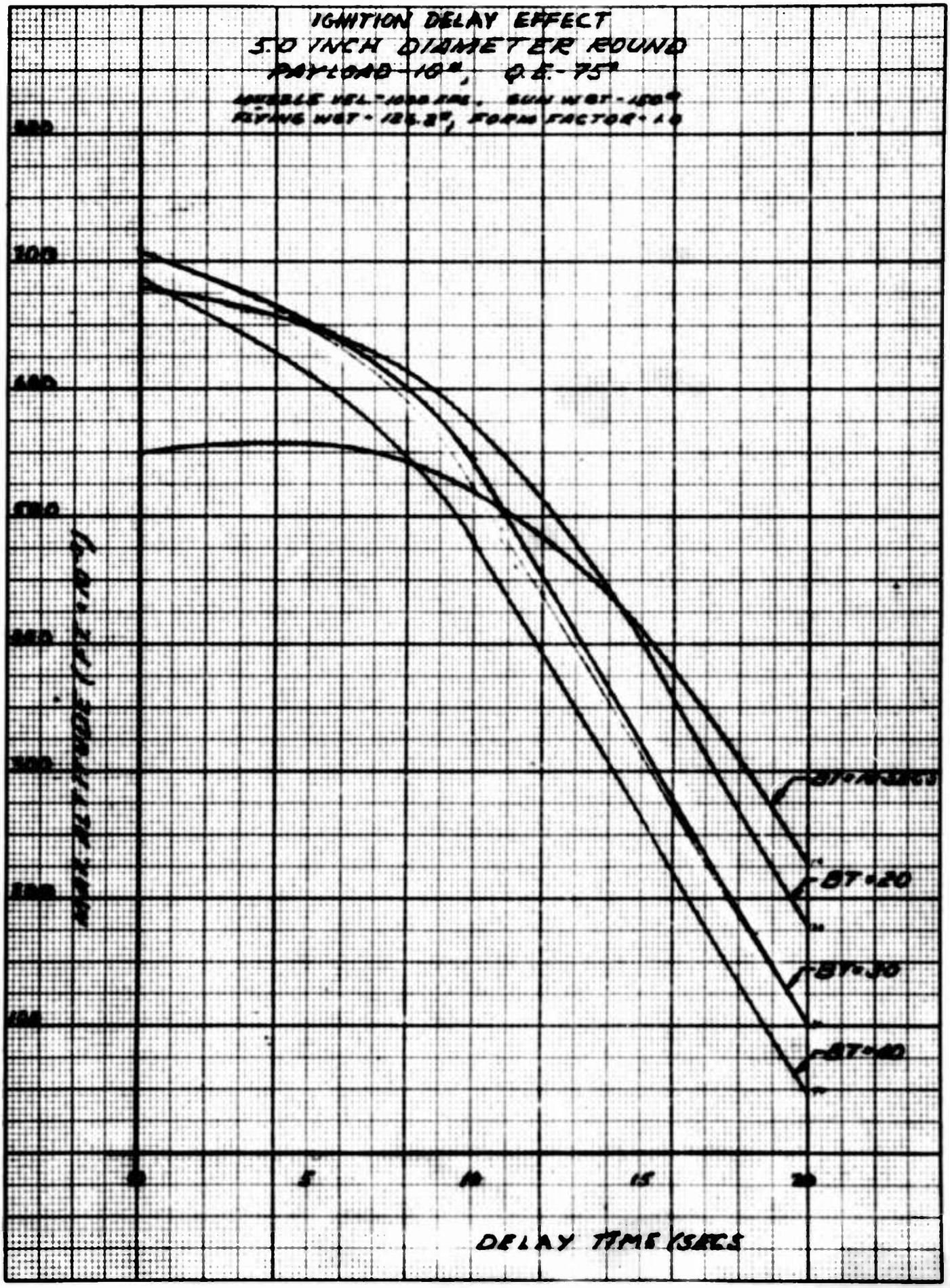

IGNITION DELAY EFFECT
5.0 INCH DIAMETER ROUND
PAYLOAD 16#, Q.E. 75%
DELAY TIME (SECS)
DT=20
DT=30
DT=40

FIG. 13

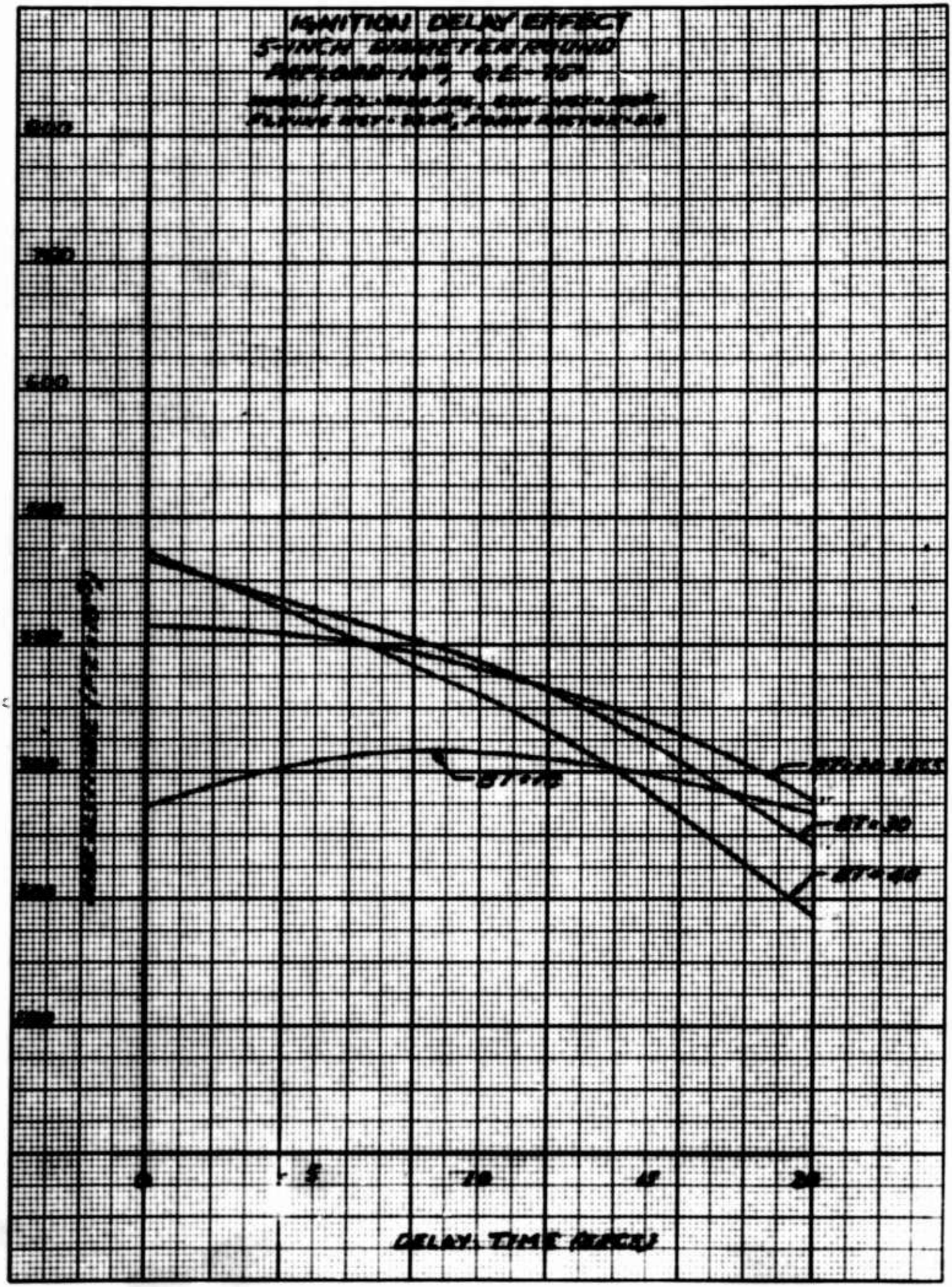


FIG. 14

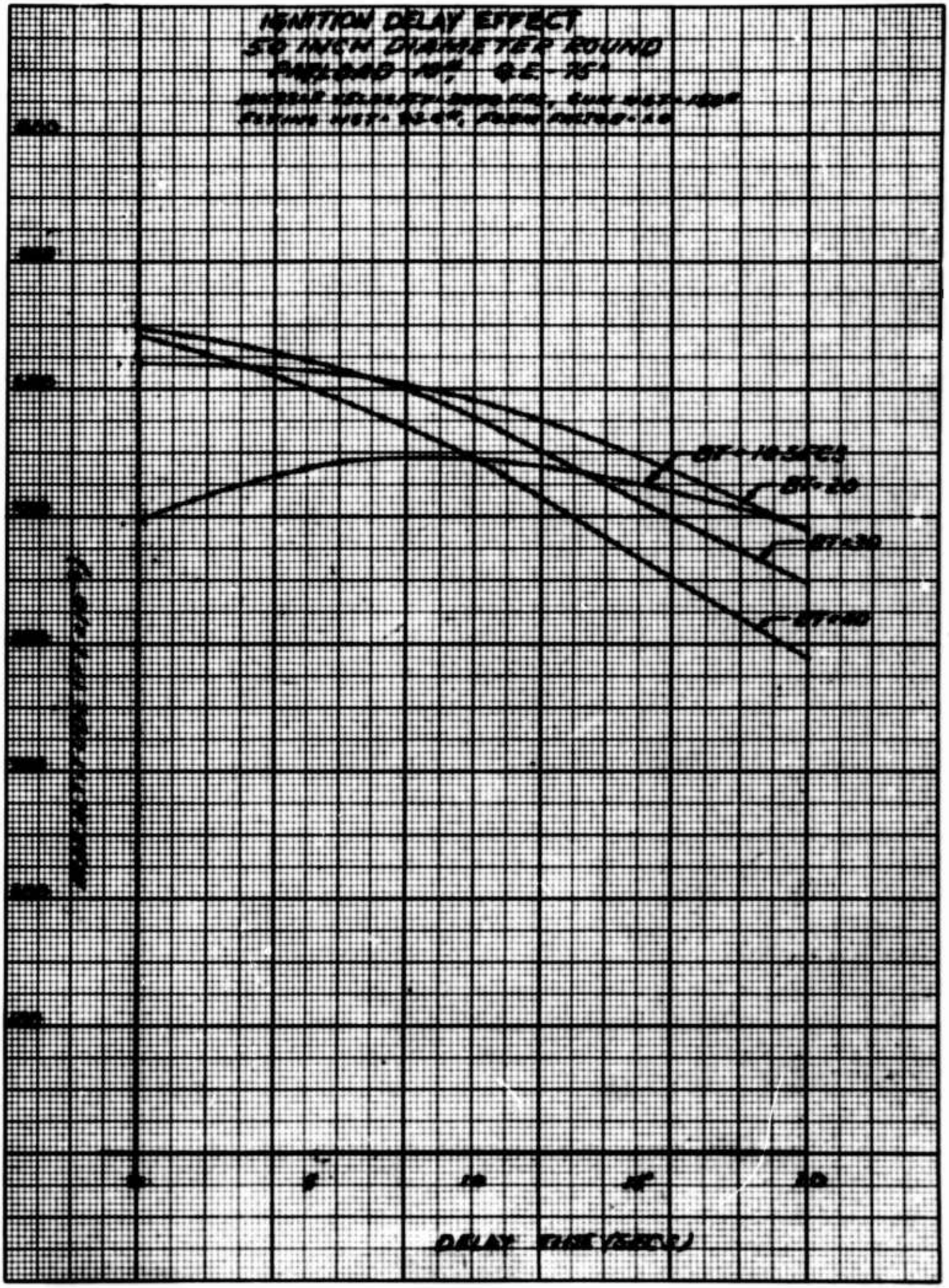


FIG. 15

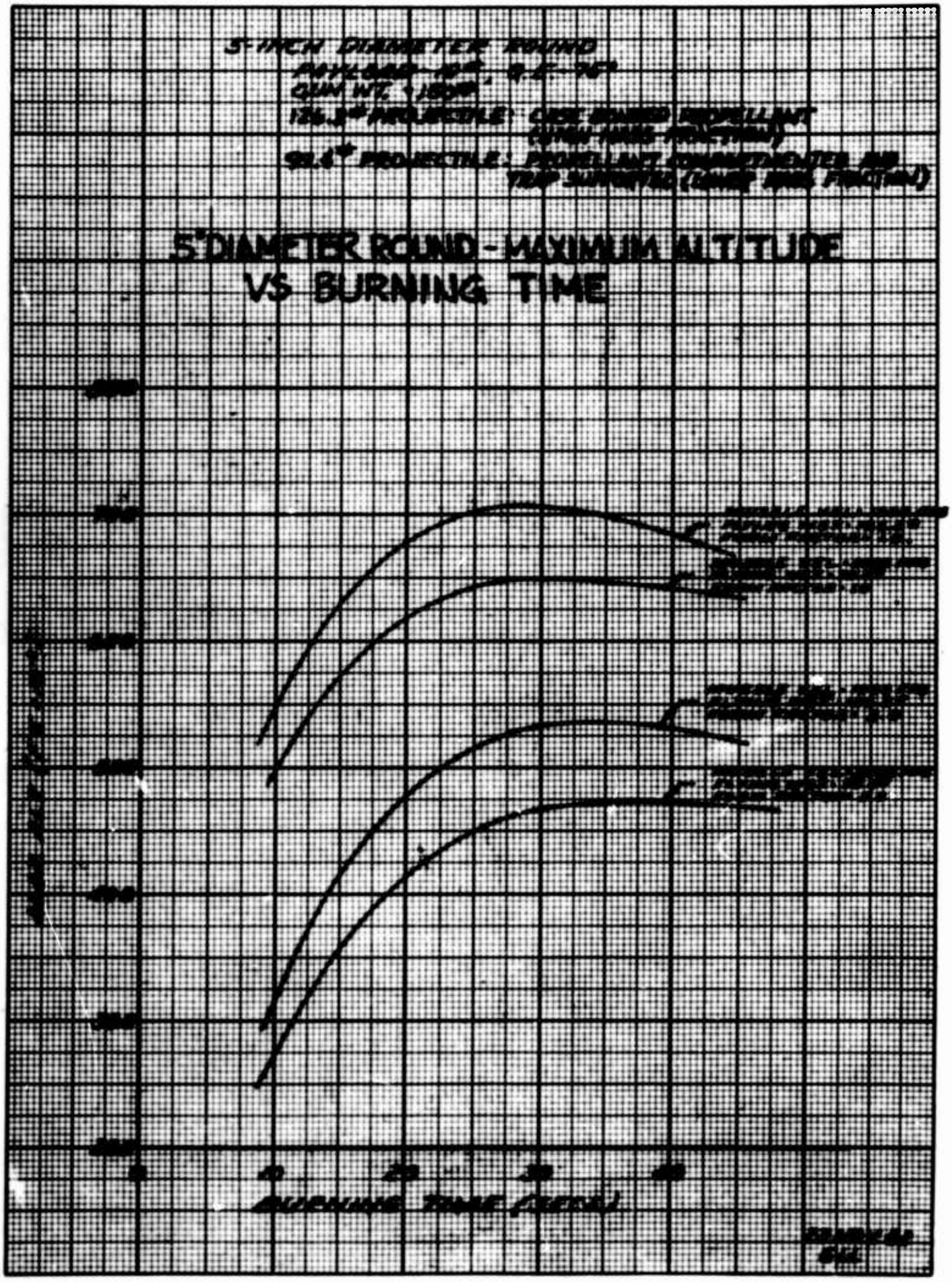


FIG. 16

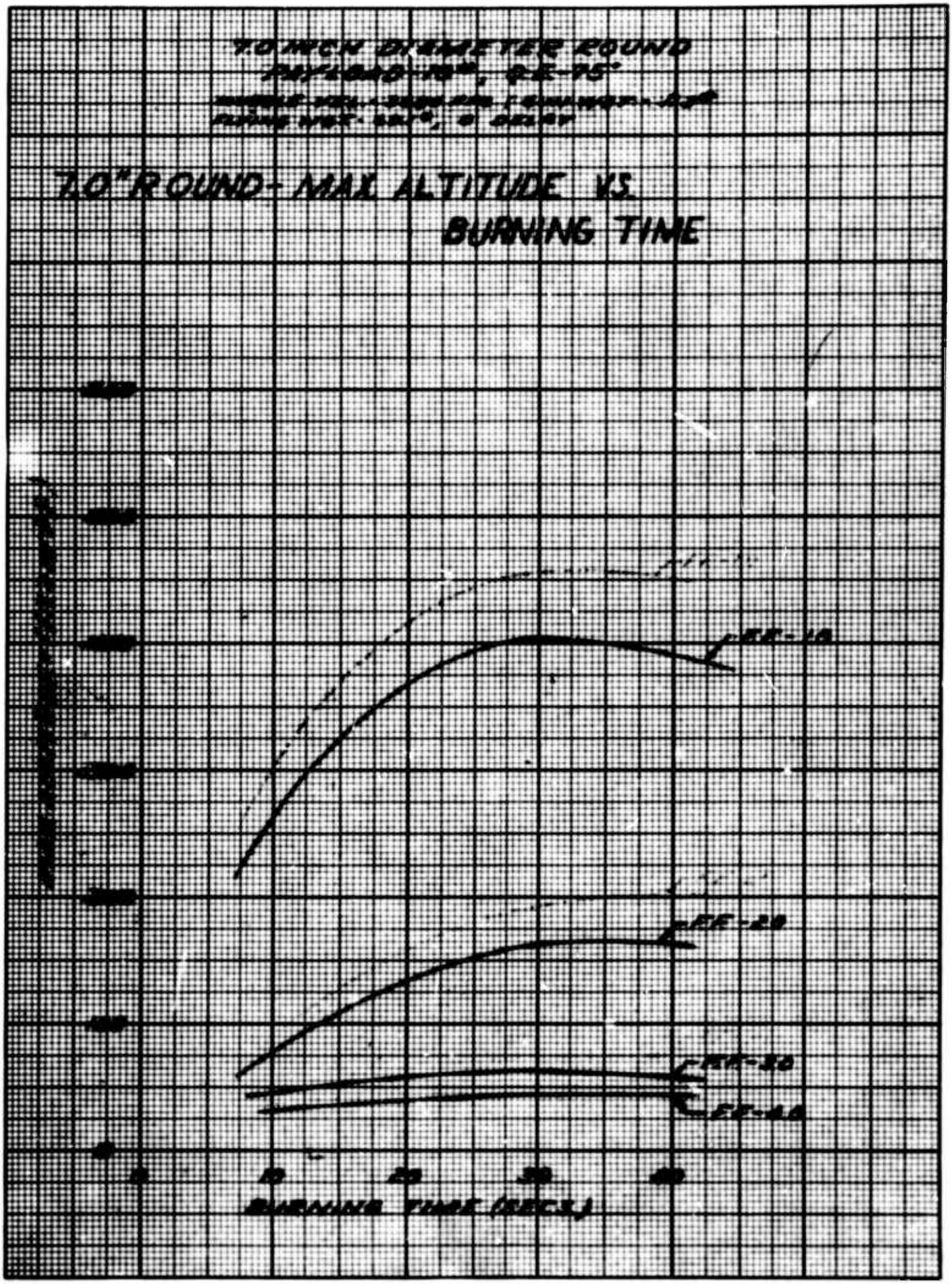

7.0"R ROUND - MAX ALTITUDE VS.
BURNING TIME
EFF-10
EFF-20
EFF-30
EFF-40
BURNING TIME (SEC.)

FIG. 17

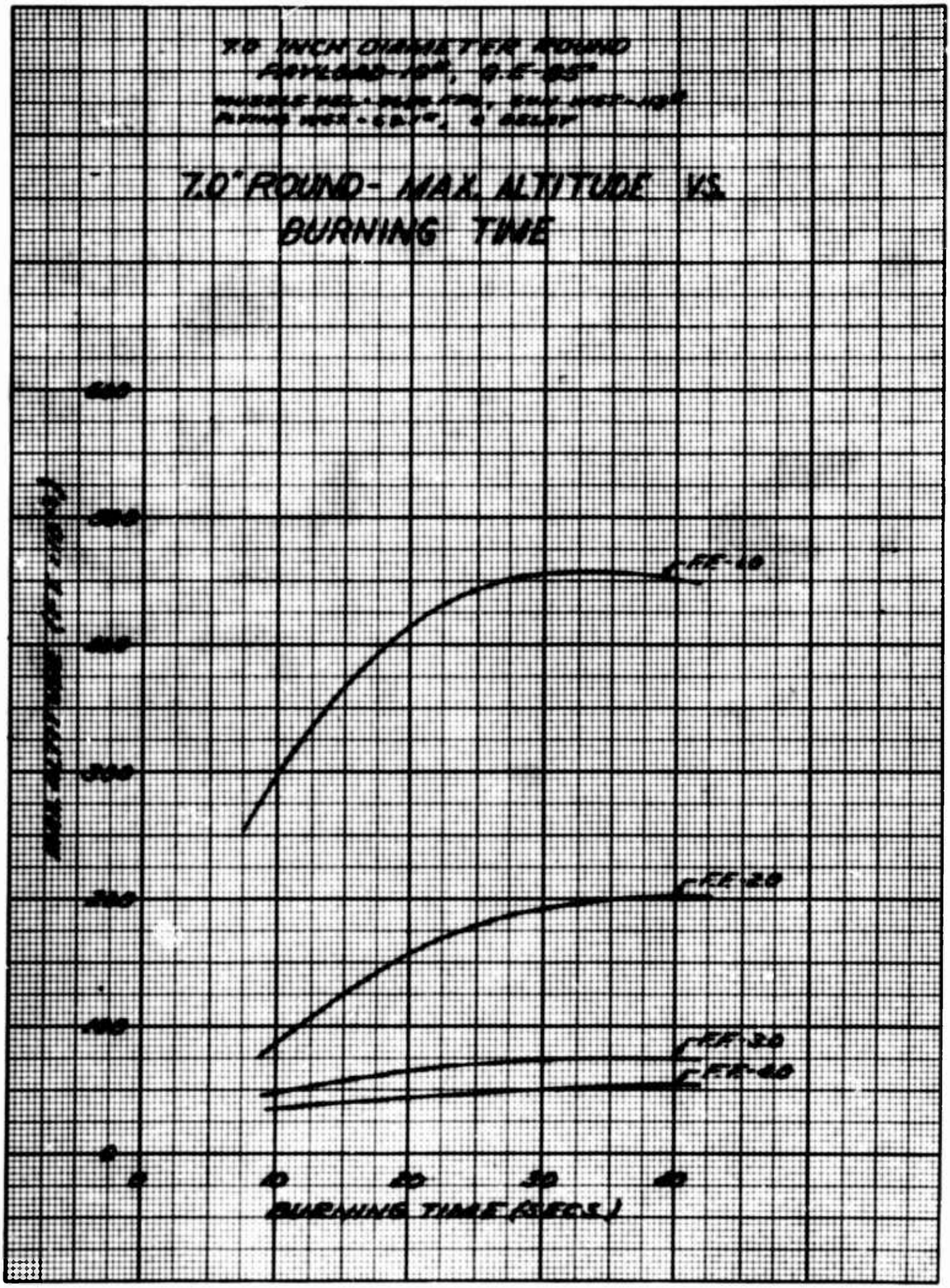

7.0" ROUND - MAX. ALTITUDE VS.
BURNING TIME
FF-40
FF-20
FF-30
FF-40
BURNING TIME (SECS.)

FIG. 18

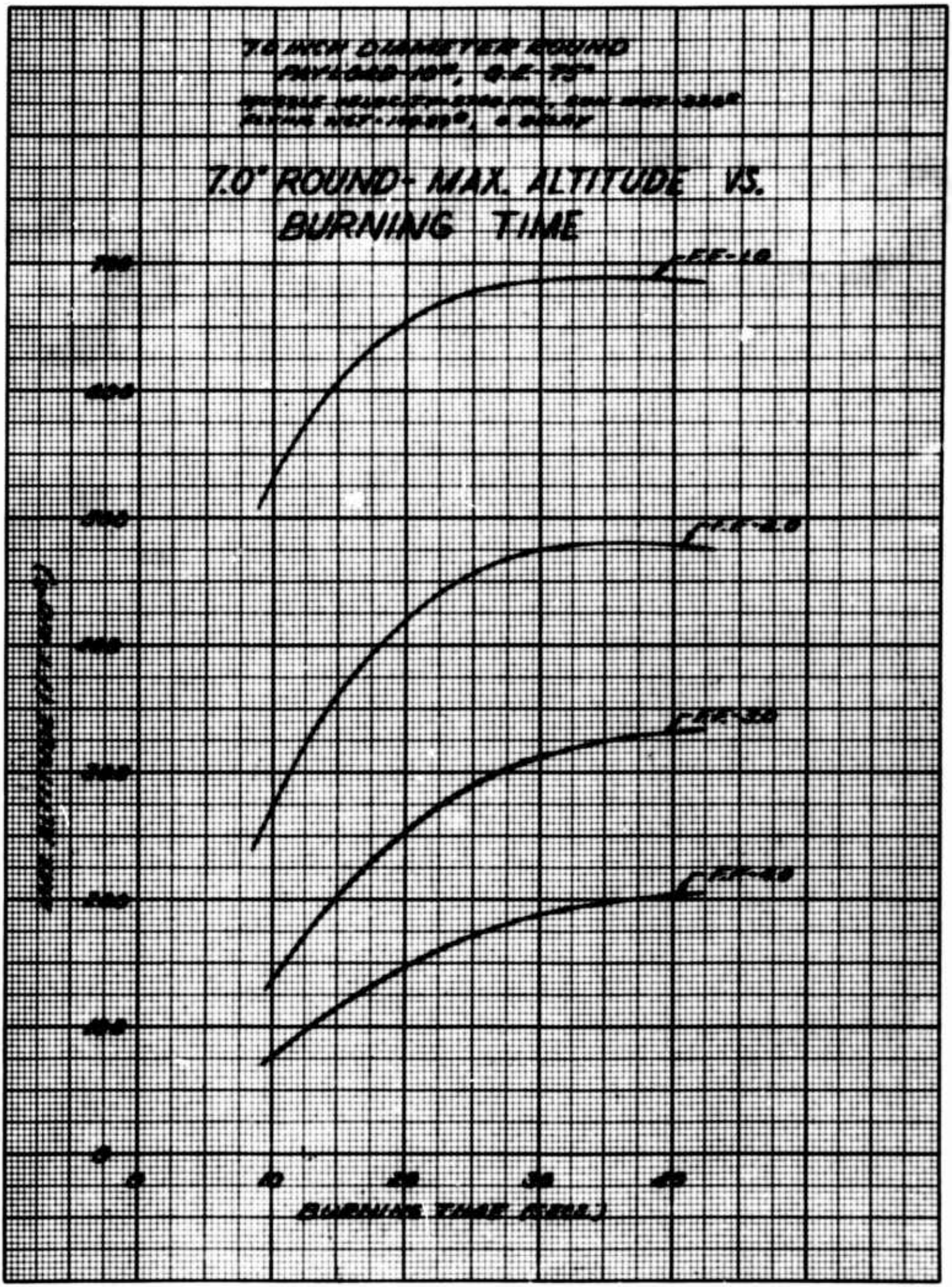

7.0" ROUND - MAX. ALTITUDE VS.
BURNING TIME
EE-10
F-E-20
FF-30
FF-40
BURNING TIME (SEC.)

FIG. 19

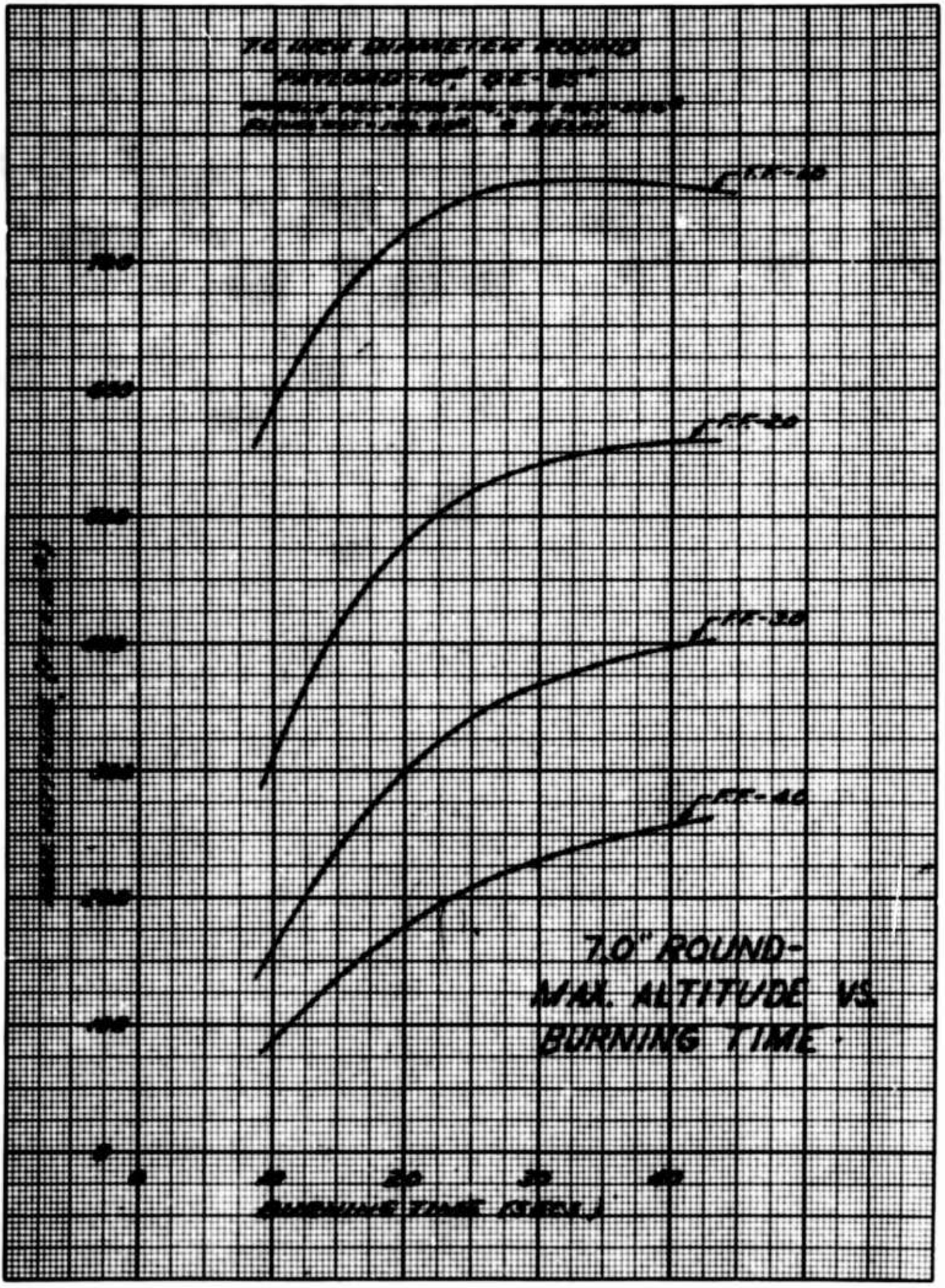


FIG. 20

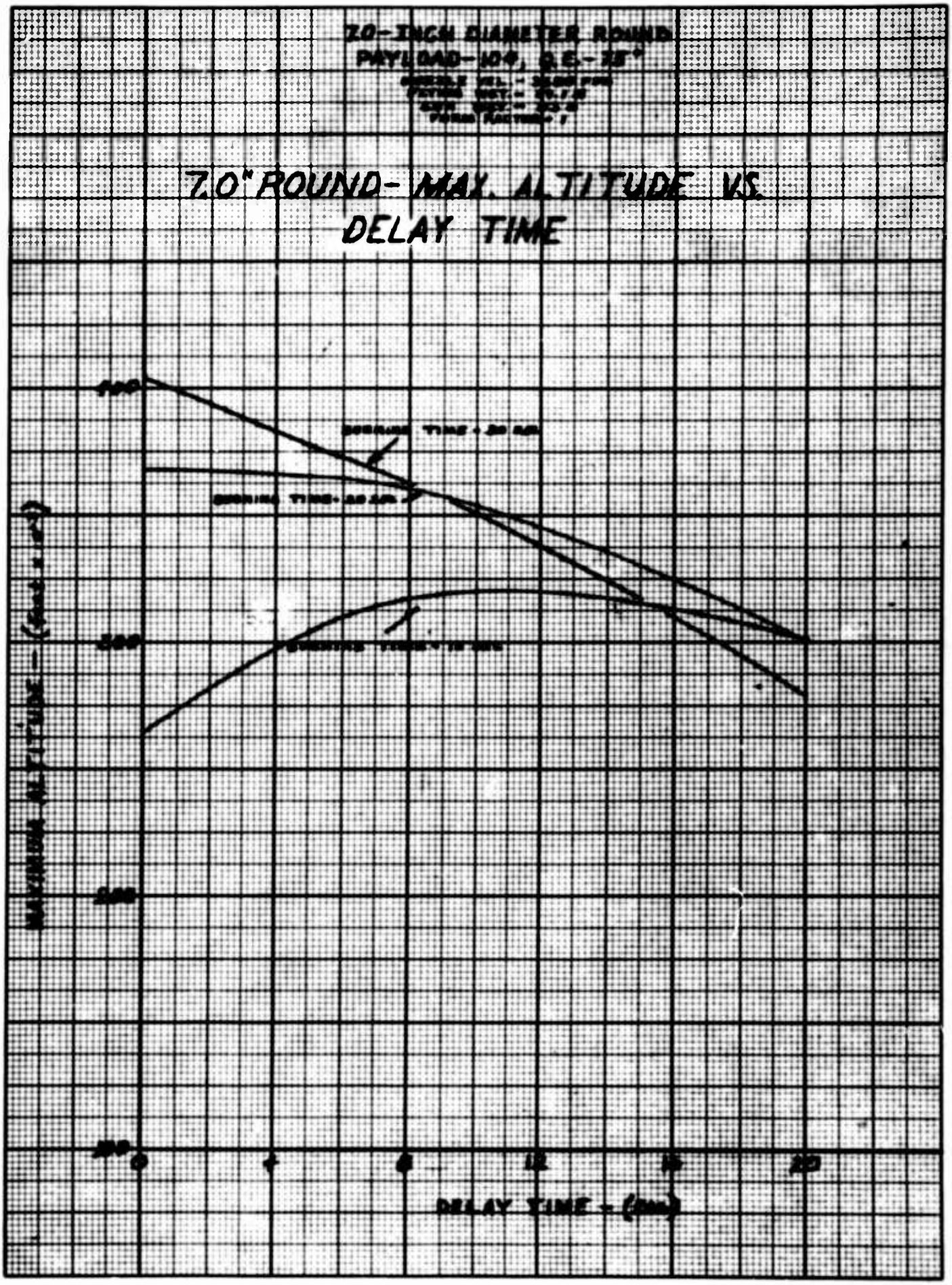

7.0-INCH DIAMETER ROUND
PAYLOAD-10#, C.E.-15°
7.0" ROUND- MAX. ALTITUDE VS.
DELAY TIME
MAXIMUM ALTITUDE - (Feet)
DELAY TIME - (Sec)
0
4
8
12
16
20

FIG. 21

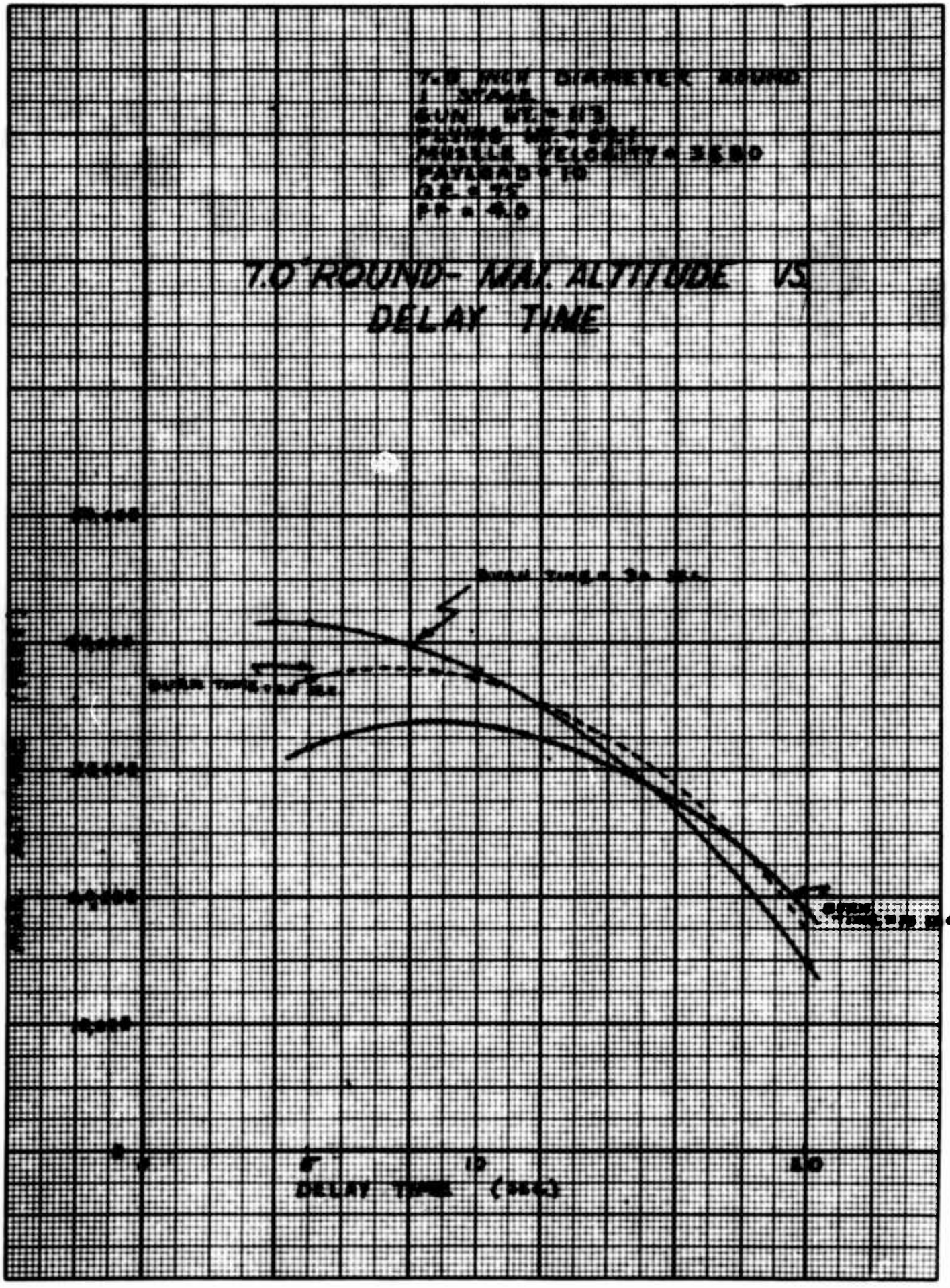


FIG. 22

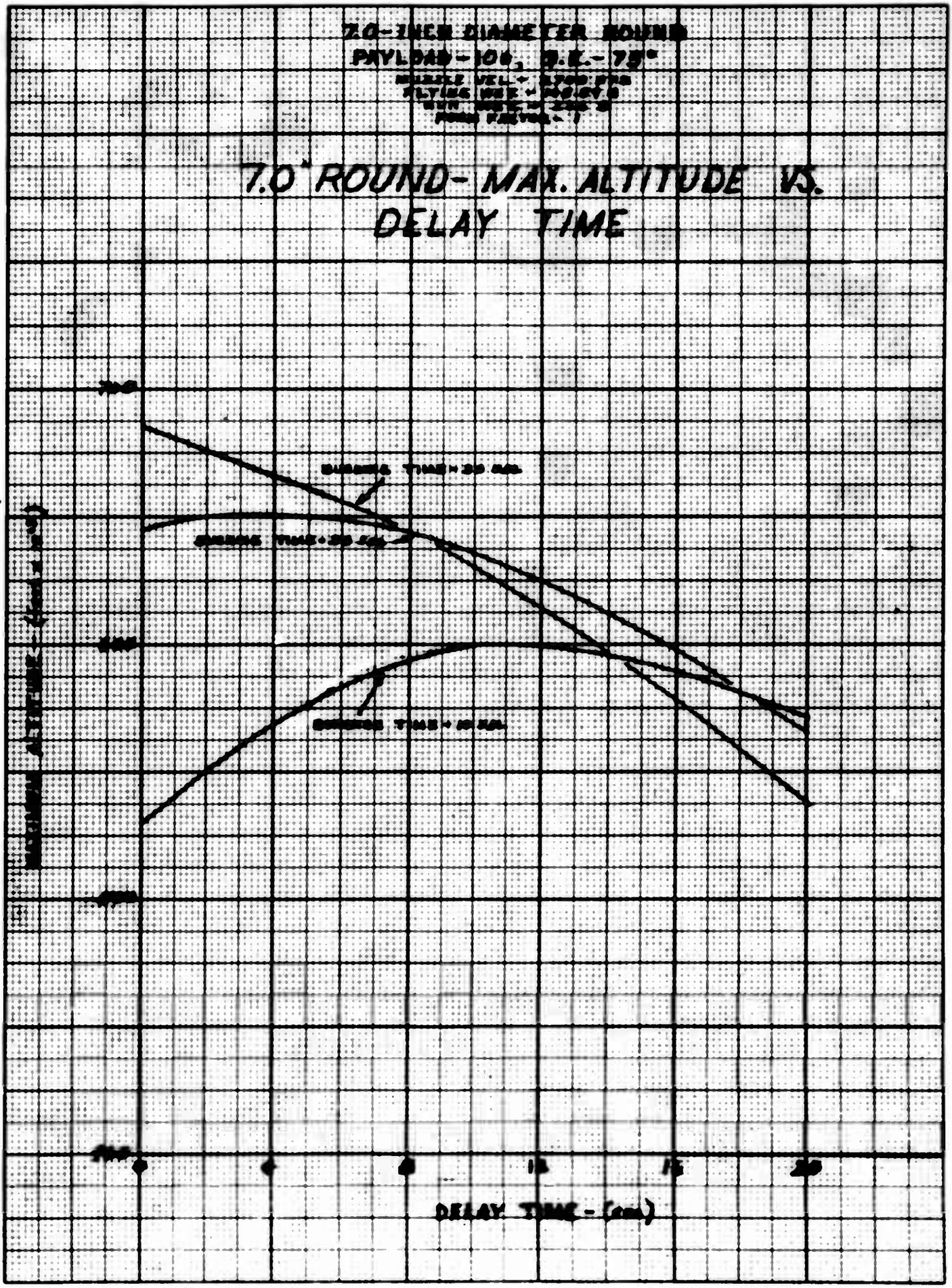

7.0-INCH DIAMETER ROUND
7.0" ROUND- MAX. ALTITUDE VS.
DELAY TIME
DELAY TIME - (sec)

FIG. 23

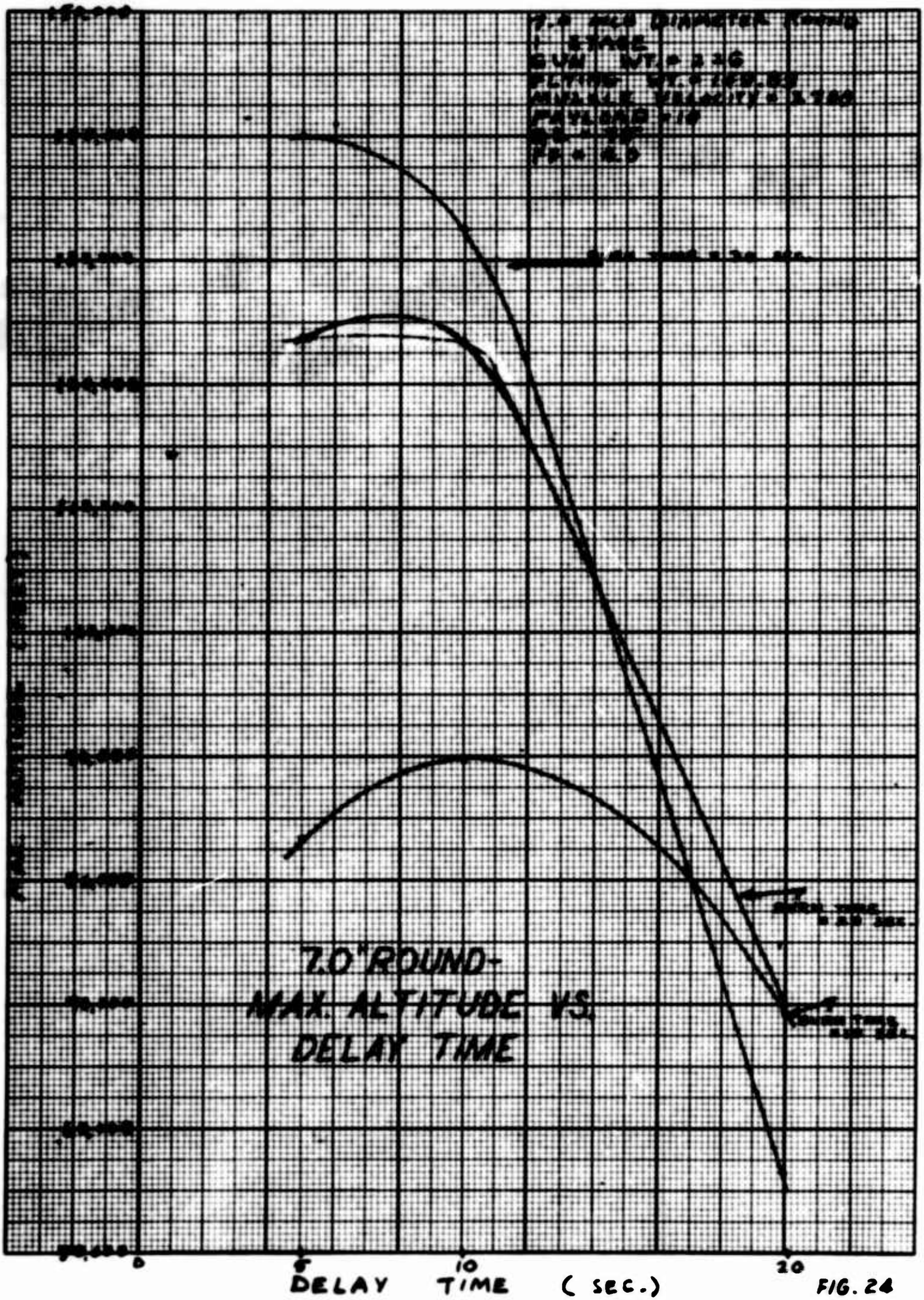


FIG. 24

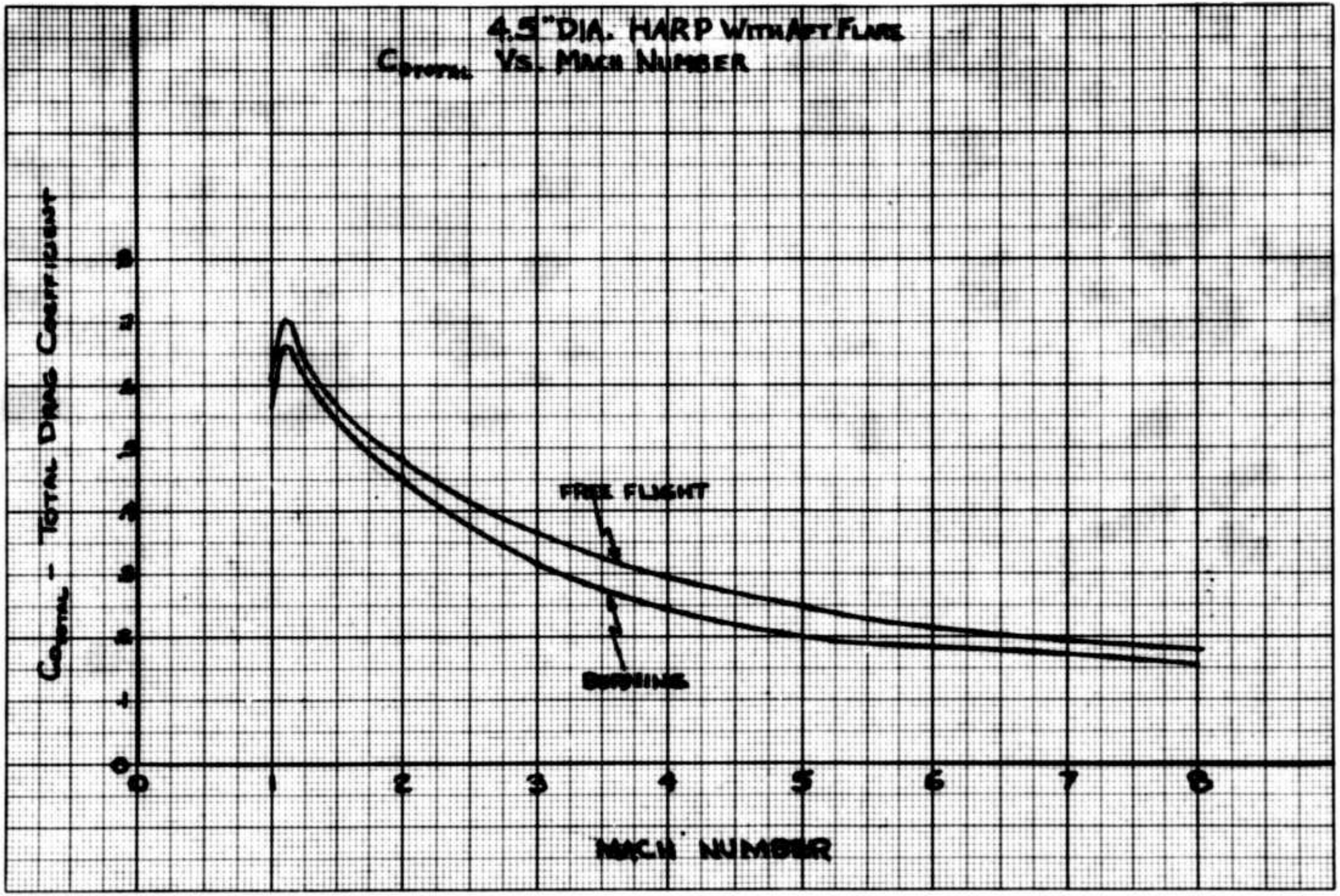

4.5" DIA. HARP WITH AFT FLARE
$C_{D_{TOTAL}}$ VS. MACH NUMBER
$C_{D_{TOTAL}}$ - TOTAL DRAG COEFFICIENT
FREE FLIGHT
BURNING
MACH NUMBER
0
1
2
3
4
5
6
7
8

FIG. 25

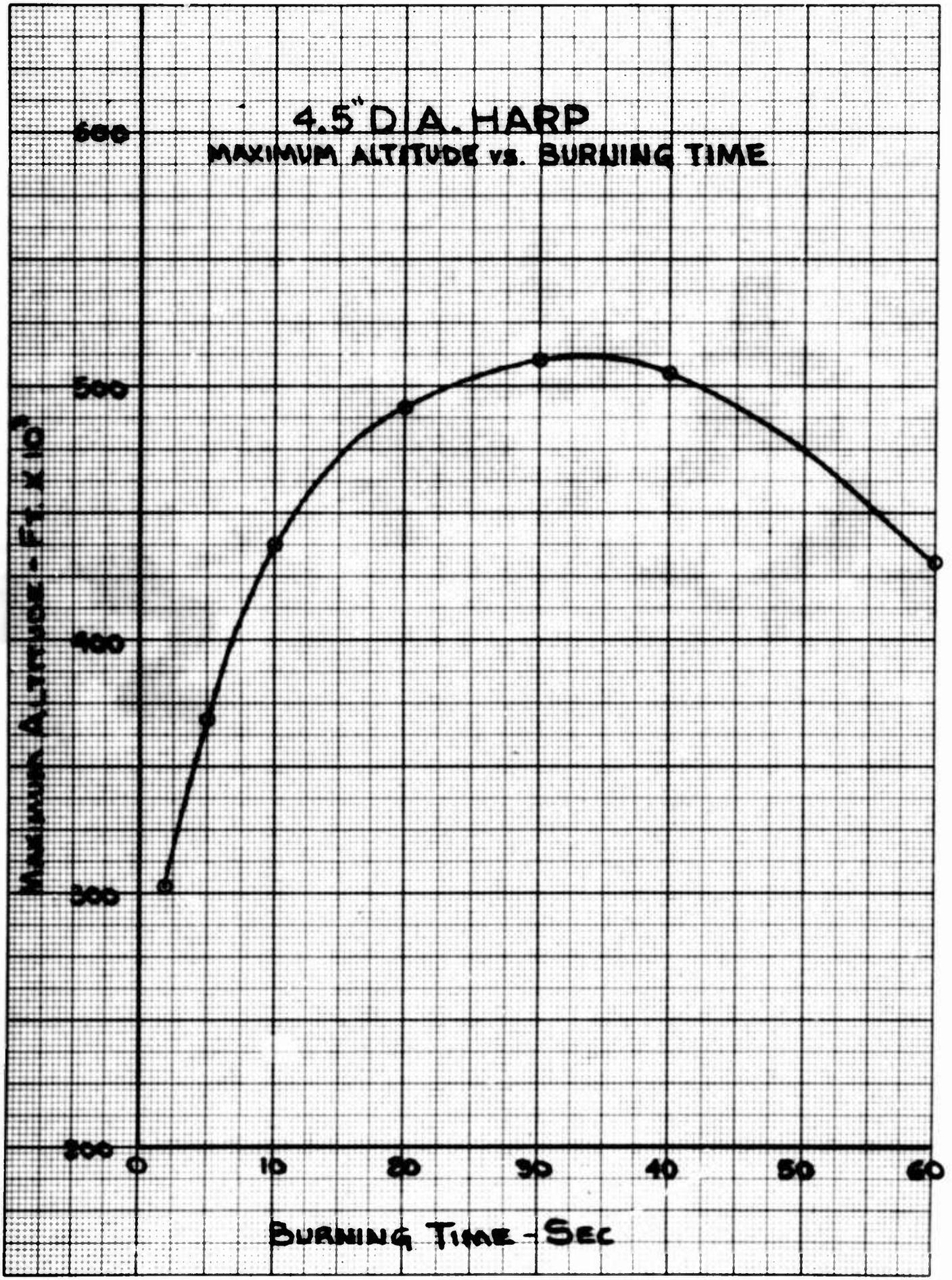

4.5" D.A. HARP
MAXIMUM ALTITUDE vs. BURNING TIME
600
500
400
300
200
MAXIMUM ALTITUDE - FT. X 10³
0
10
20
30
40
50
60
BURNING TIME - SEC

FIG. 26

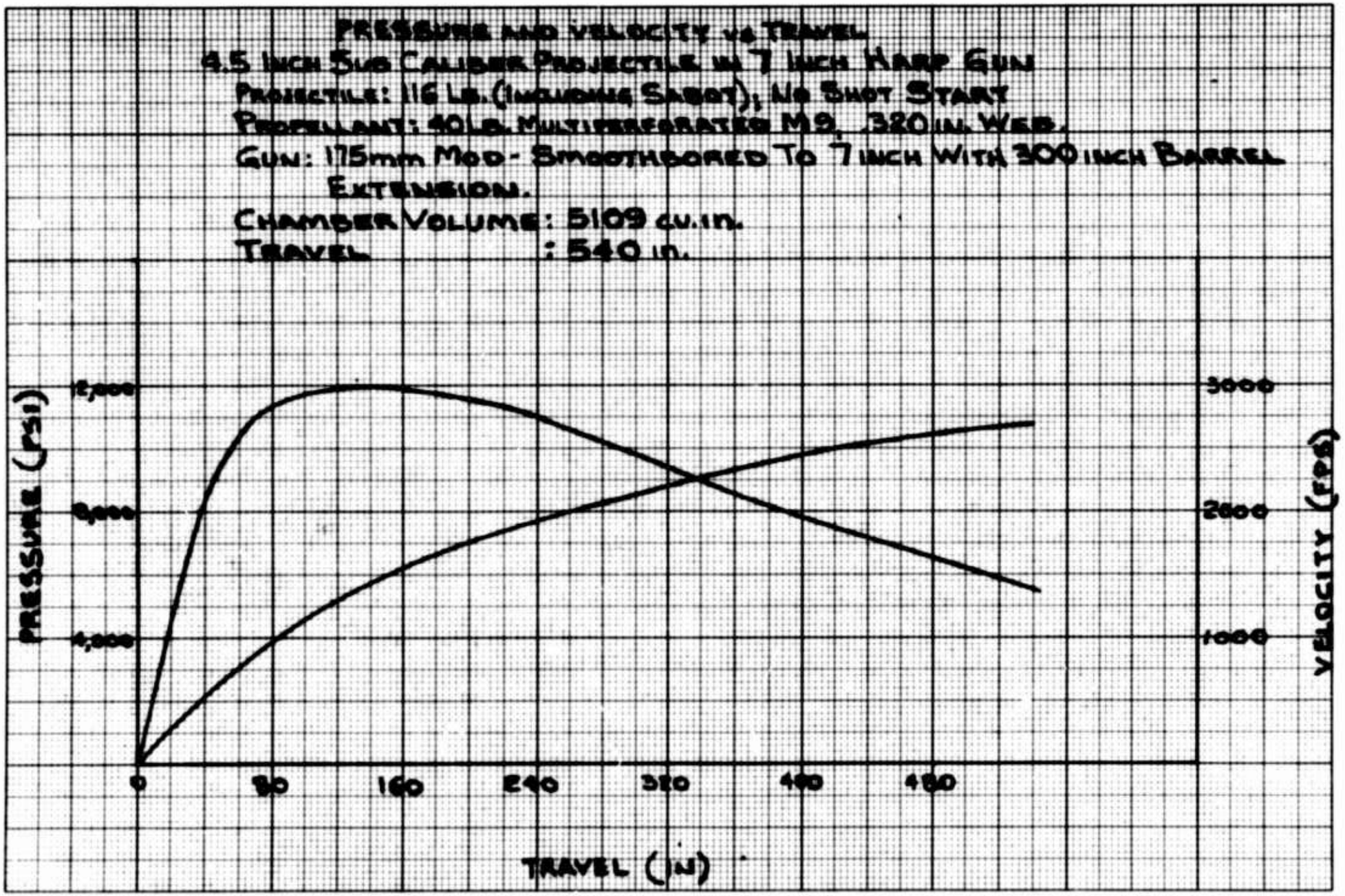

PRESSURE AND VELOCITY VS TRAVEL
4.5 INCH SUB CALIBER PROJECTILE IN 7 INCH HARP GUN
PROJECTILE: 116 LB. (INCLUDING SABOT); NO SHOT START
PROPELLANT: 40 LB. MULTIPERFORATED M9, .320 IN. WEB.
GUN: 175mm M60 - SMOOTHBORED TO 7 INCH WITH 300 INCH BARREL EXTENSION.
CHAMBER VOLUME: 5109 CU. IN.
TRAVEL : 540 IN.
PRESSURE (PSI)
2,000
3,000
4,000
VELOCITY (FPS)
3000
2000
1000
0
80
160
240
320
400
480
TRAVEL (IN)

FIG. 26a

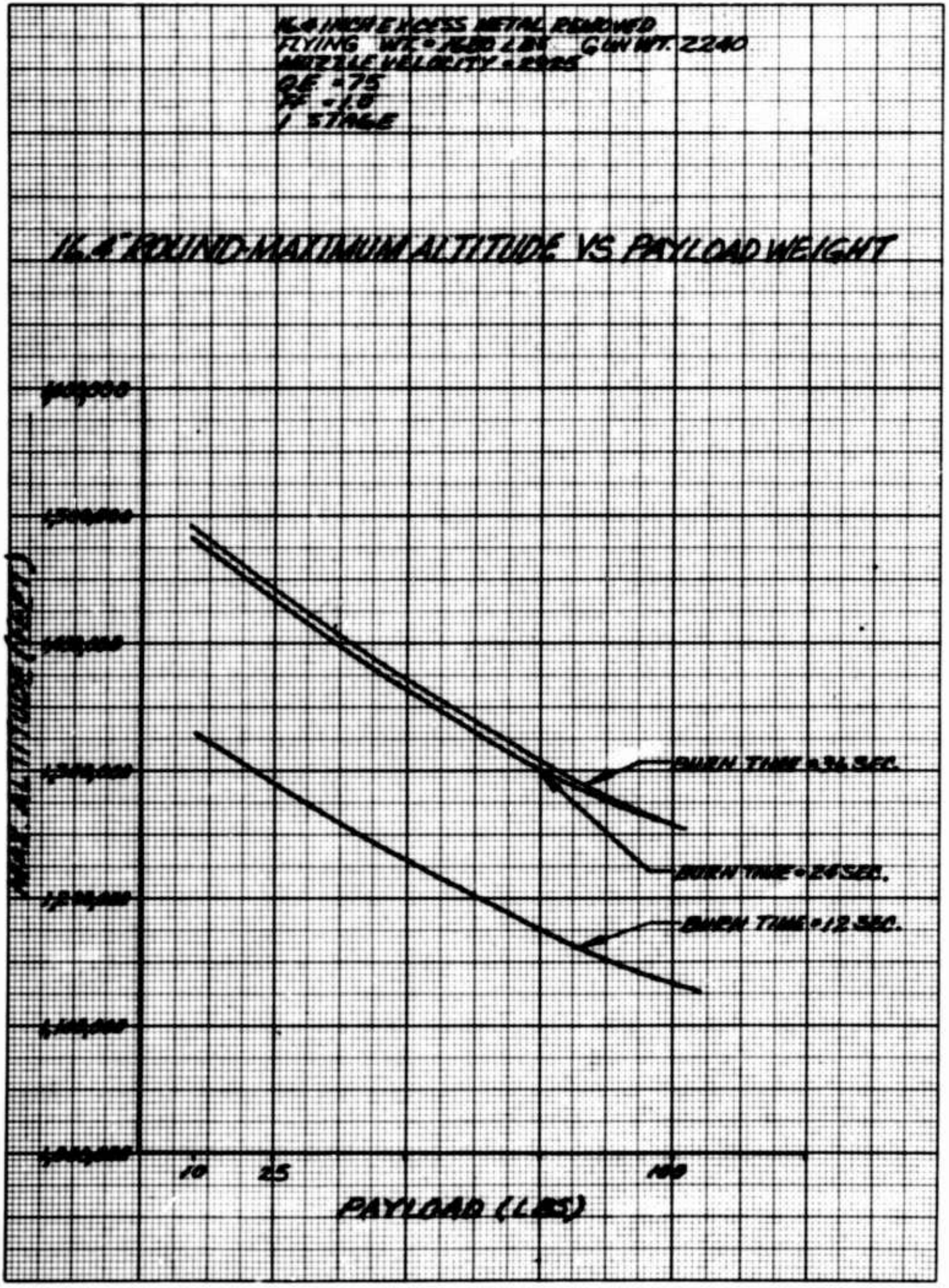

4.4 INCH EXCESS METAL REMOVED
FLYING WT. = 1680 LBS. GLW WT. 2240
MUZZLE VELOCITY = 2985
CE = .75
CF = .15
1 STAGE
4.4" ROUND-MAXIMUM ALTITUDE VS. PAYLOAD WEIGHT
BURN TIME = 34 SEC.
BURN TIME = 26 SEC.
BURN TIME = 12 SEC.
10
25
PAYLOAD (LBS)

FIG. 27

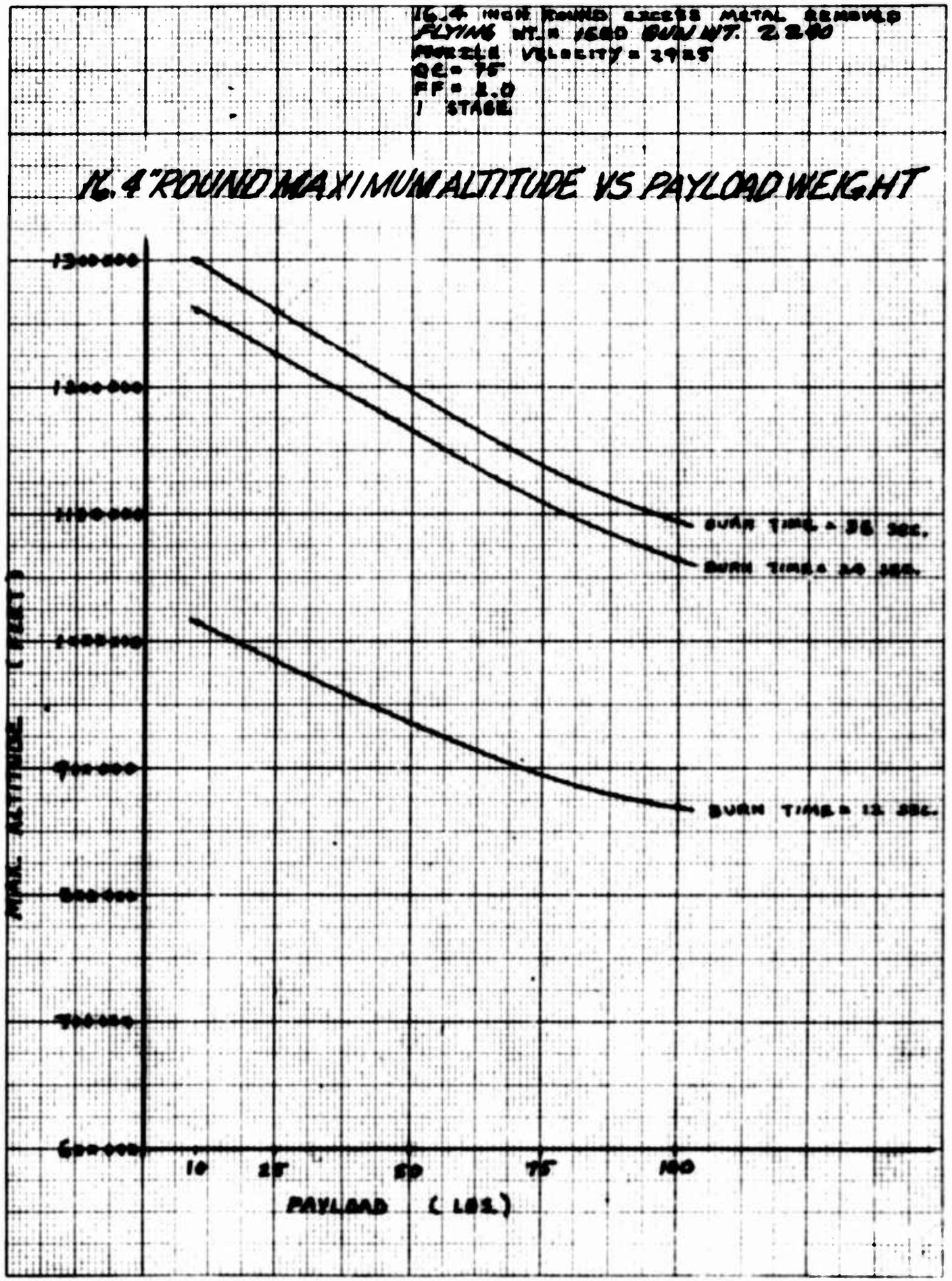

16.4 INCH ROUND EXCESS METAL REMOVED
FLYING WT. = 1600 BURN WT. 2,200
MUZZLE VELOCITY = 2925
CC = 75
FF = 2.0
1 STAGE
16.4" ROUND MAXIMUM ALTITUDE VS PAYLOAD WEIGHT
BURN TIME = 35 SEC.
BURN TIME = 24 SEC.
BURN TIME = 12 SEC.
MAX. ALTITUDE (FEET)
10
25
50
75
100
PAYLOAD (LBS.)

FIG. 28

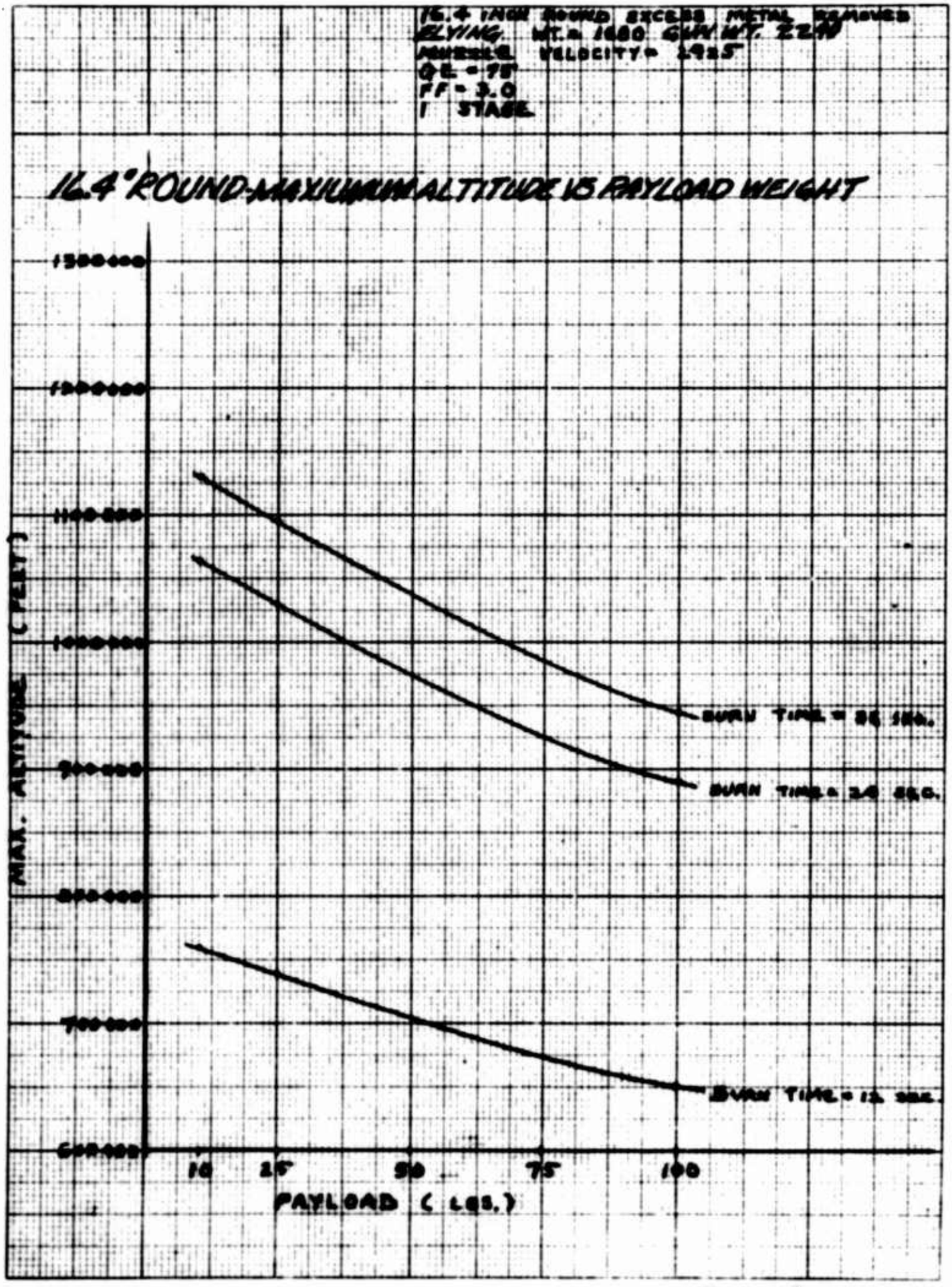

16.4 INCH ROUND EXCESS METAL REMOVED
FLYING WT. = 1680 GUN WT. 2270
MUZZLE VELOCITY = 2925'
QE = .78
FF = 3.0
1 STAGE
16.4" ROUND-MAXIMUM ALTITUDE IS PAYLOAD WEIGHT
MAX. ALTITUDE (FEET)
BURN TIME = 36 SEC.
BURN TIME = 24 SEC.
BURN TIME = 12 SEC.
10
25
50
75
100
PAYLOAD (LBS.)

FIG. 29

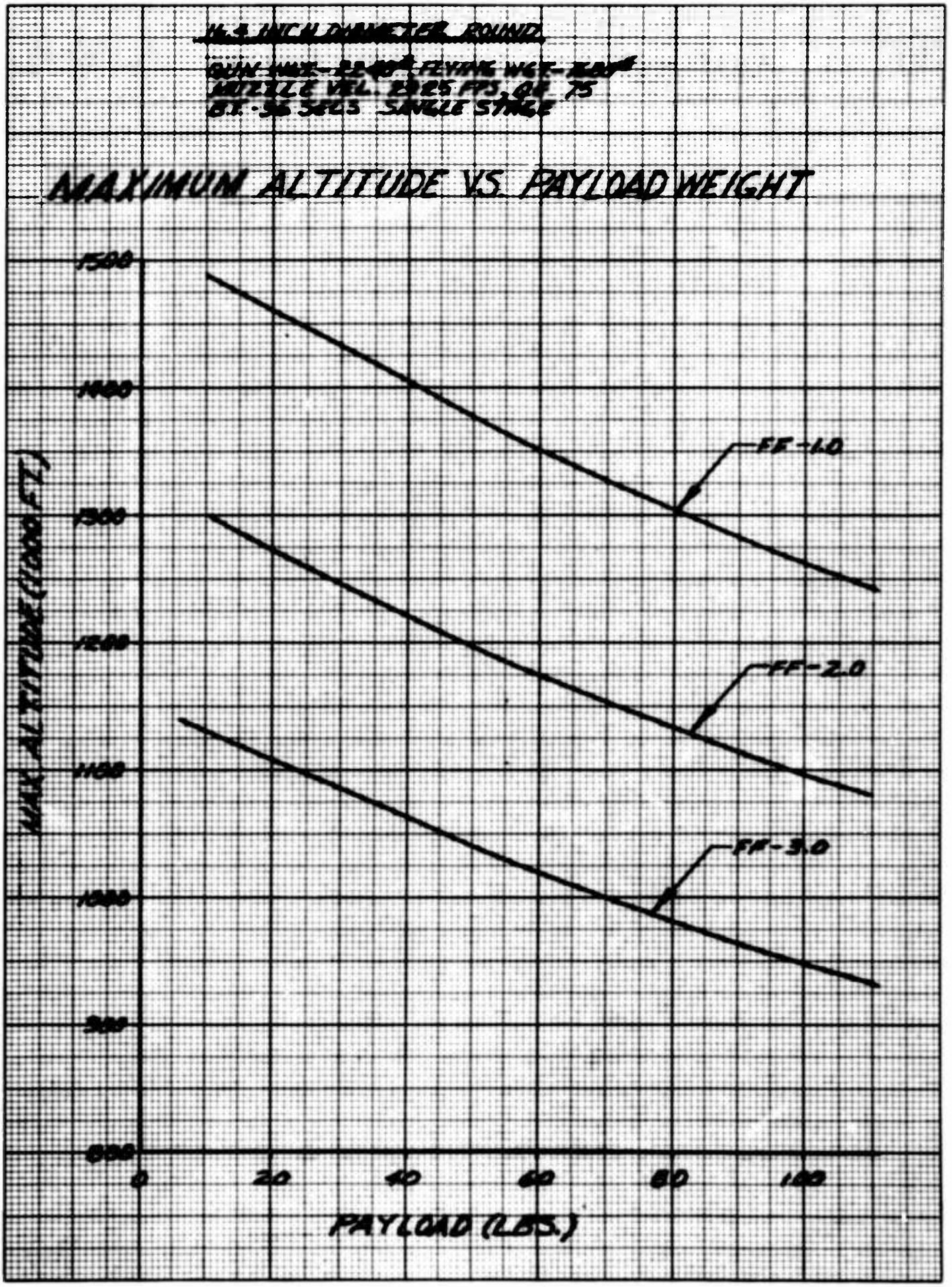

4.5 INCH DIAMETER ROUND
MAXIMUM ALTITUDE VS. PAYLOAD WEIGHT
FF-1.0
FF-2.0
FF-3.0
MAX. ALTITUDE (FT. ABOVE SEA LEVEL)
1500
1400
1300
1200
1100
1000
900
800
0
20
40
60
80
100
PAYLOAD (LBS.)

FIG. 30

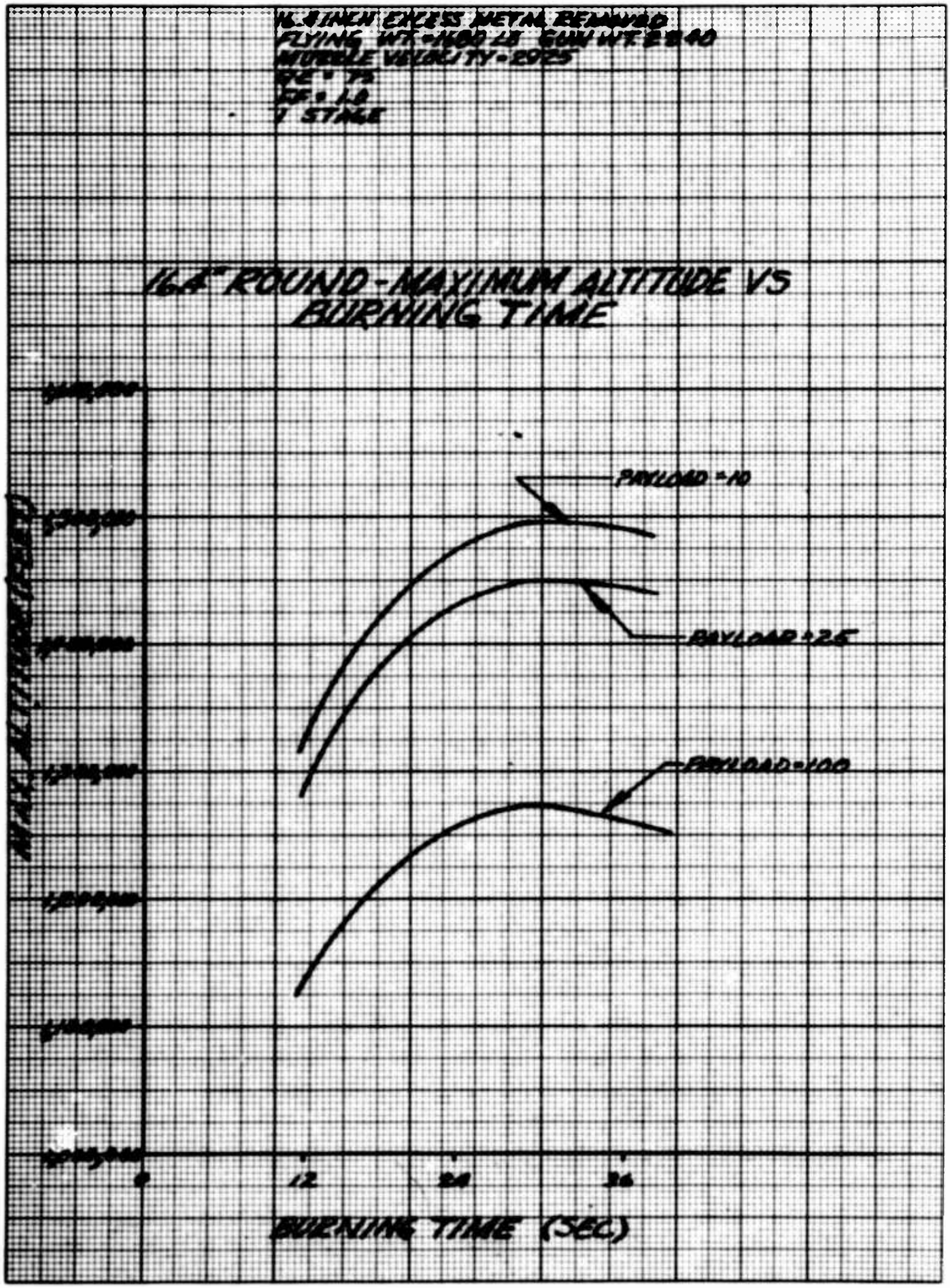

16.8 INCH EXCESS METAL REMOVED
FLYING WT-1600 LB GUM WT 2240
MUZZLE VELOCITY-2025
CE-.75
CF-1.0
1 STAGE
164" ROUND-MAXIMUM ALTITUDE VS BURNING TIME
PAYLOAD=10
PAYLOAD=25
PAYLOAD=100
12
24
36
BURNING TIME (SEC)

FIG. 31

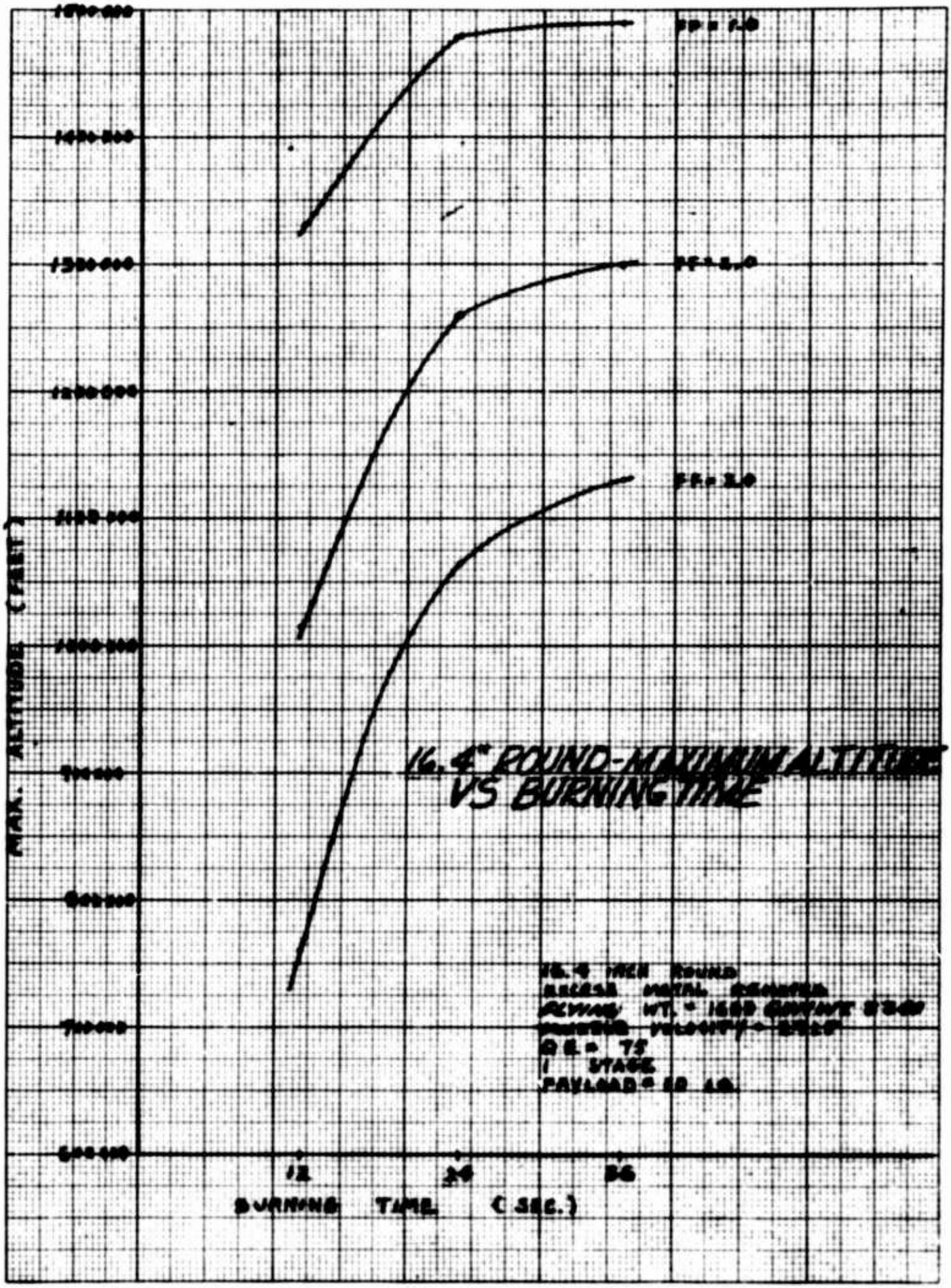

MAX. ALTITUDE (FEET)
16.4" ROUND-MAXIMUM ALTITUDE VS BURNING TIME
BURNING TIME (SEC.)

FIG. 32

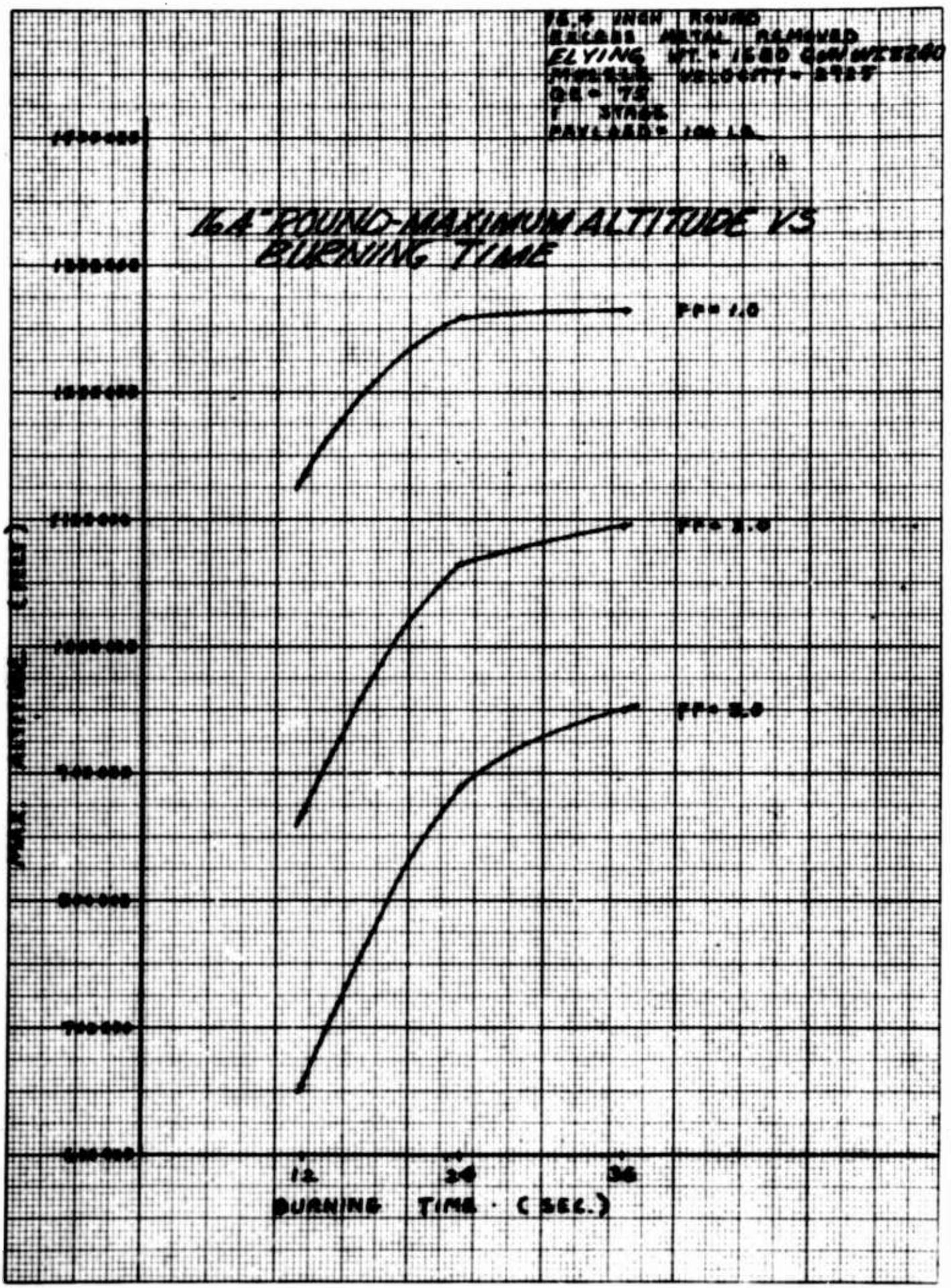

16.4" ROUND-MAXIMUM ALTITUDE VS BURNING TIME
FF= 1.0
FF= 1.5
FF= 2.0
12
24
36
BURNING TIME - (SEC.)

FIG. 33

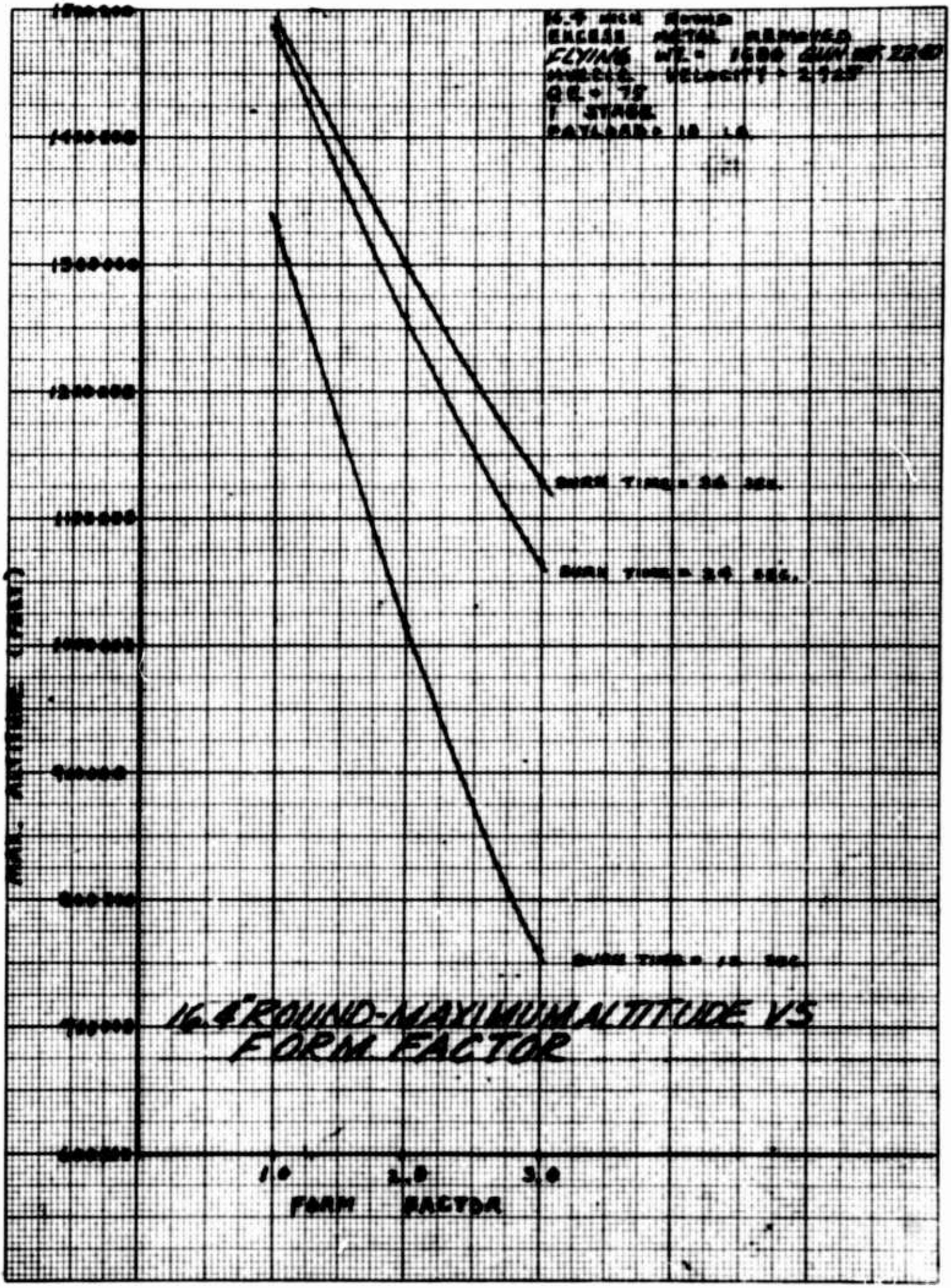

16.4" ROUND-MAXIMUM ALTITUDE VS FORM FACTOR
FORM FACTOR
1.0
2.0
3.0

FIG. 34

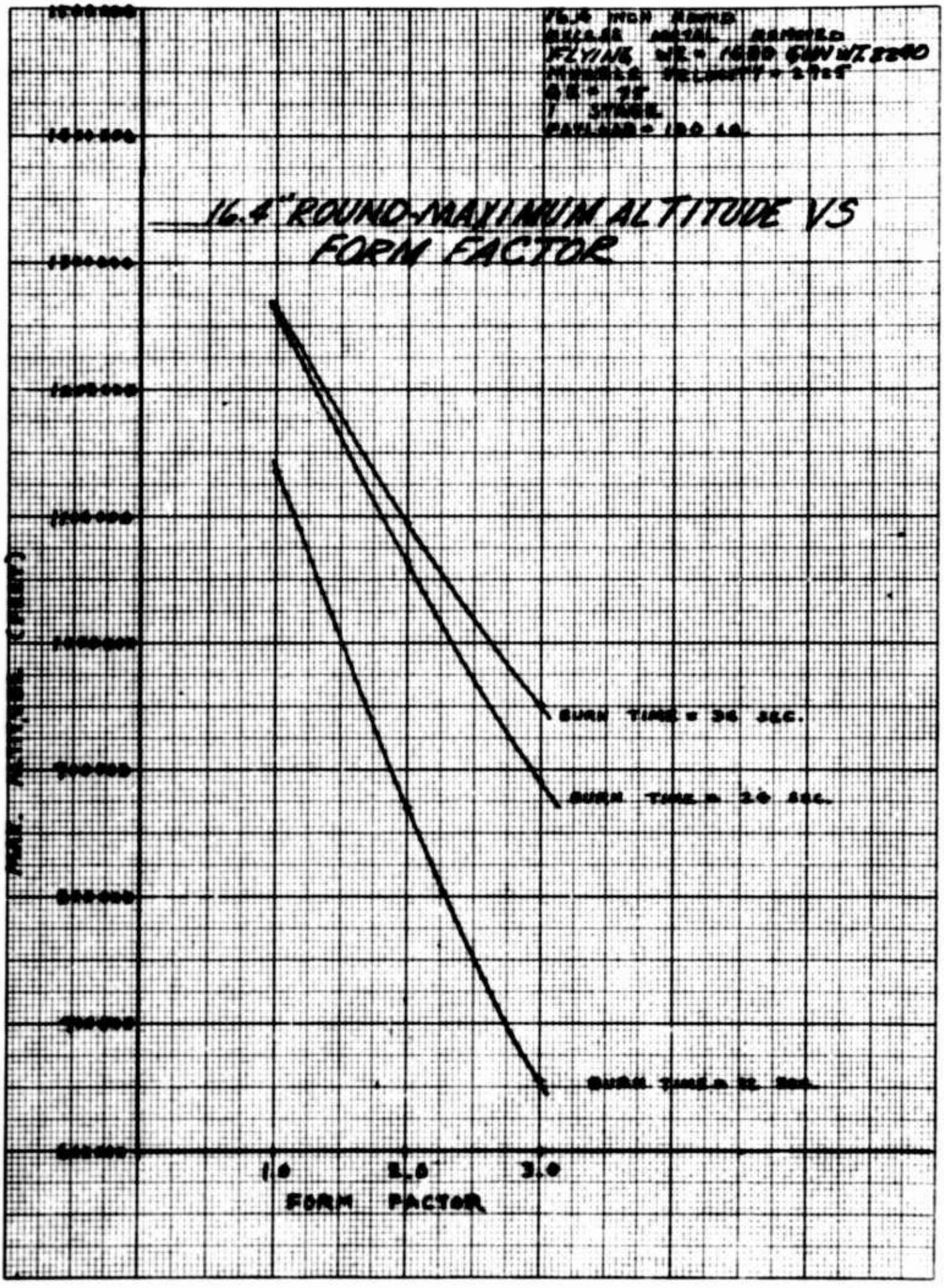

16.4" ROUND-MAXIMUM ALTITUDE VS FORM FACTOR
BURN TIME = 36 SEC.
1.0
2.0
3.0
FORM FACTOR

FIG. 35

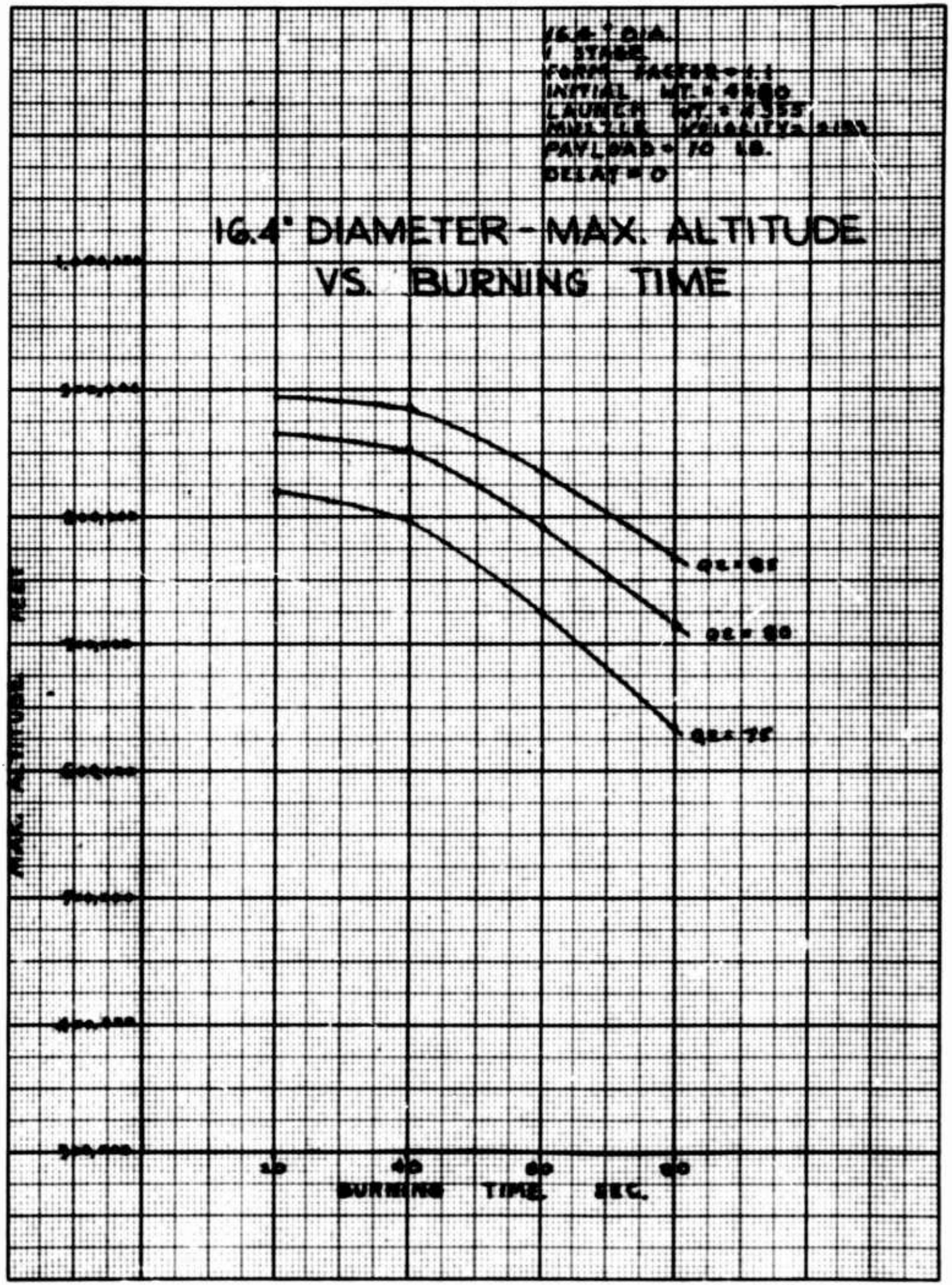

16.4" DIA.
PAYLOAD = 70 LB.
16.4" DIAMETER - MAX. ALTITUDE
VS. BURNING TIME
BURNING TIME SEC.

FIGURE 36

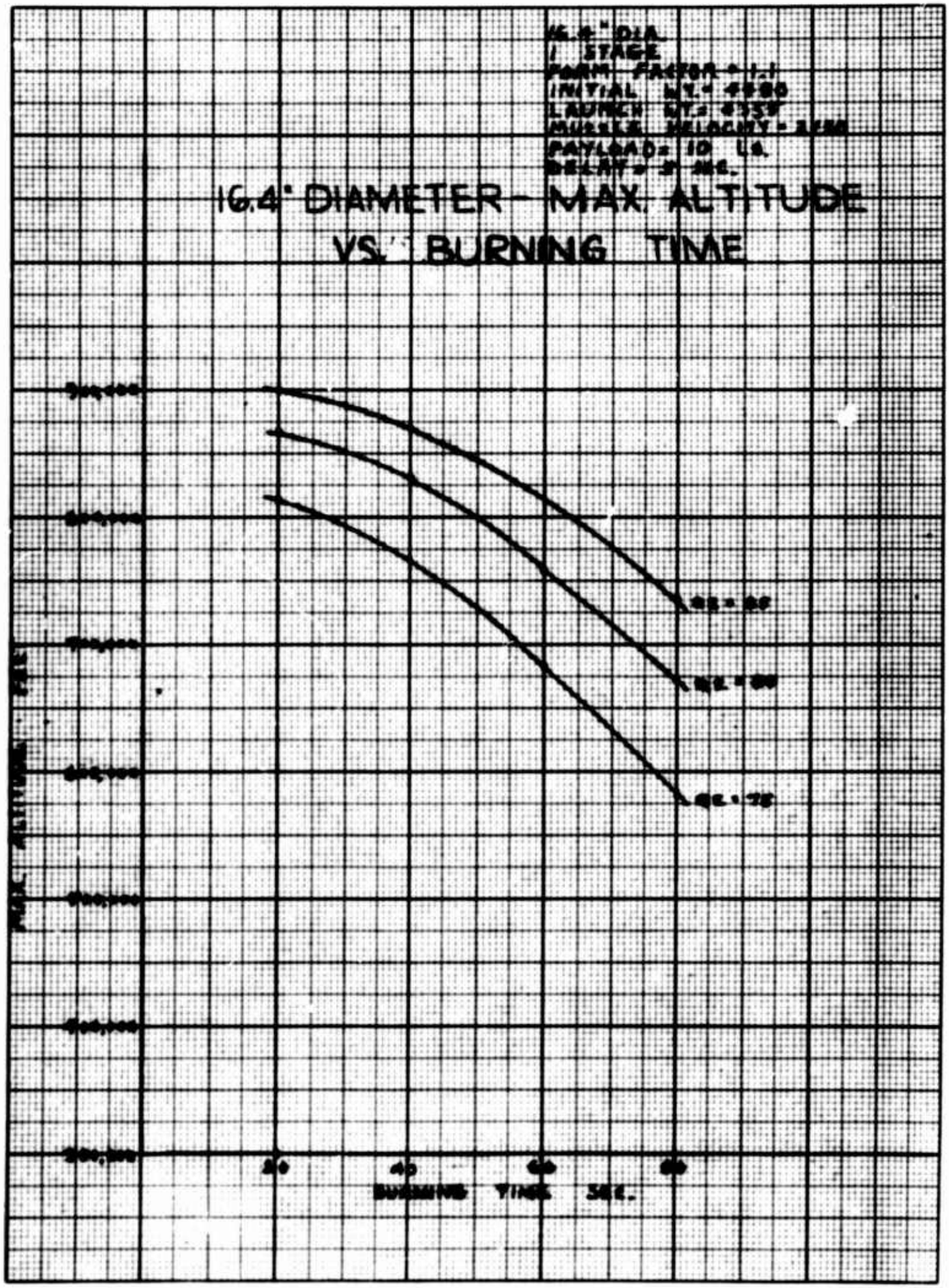

16.4" DIA.
1 STAGE
INITIAL WT.= 4980
LAUNCH WT.= 4339
PAYLOAD= 10 LB.
DELAY = 3 SEC.
16.4" DIAMETER - MAX. ALTITUDE
VS. BURNING TIME
BURNING TIME SEC.

FIGURE 37

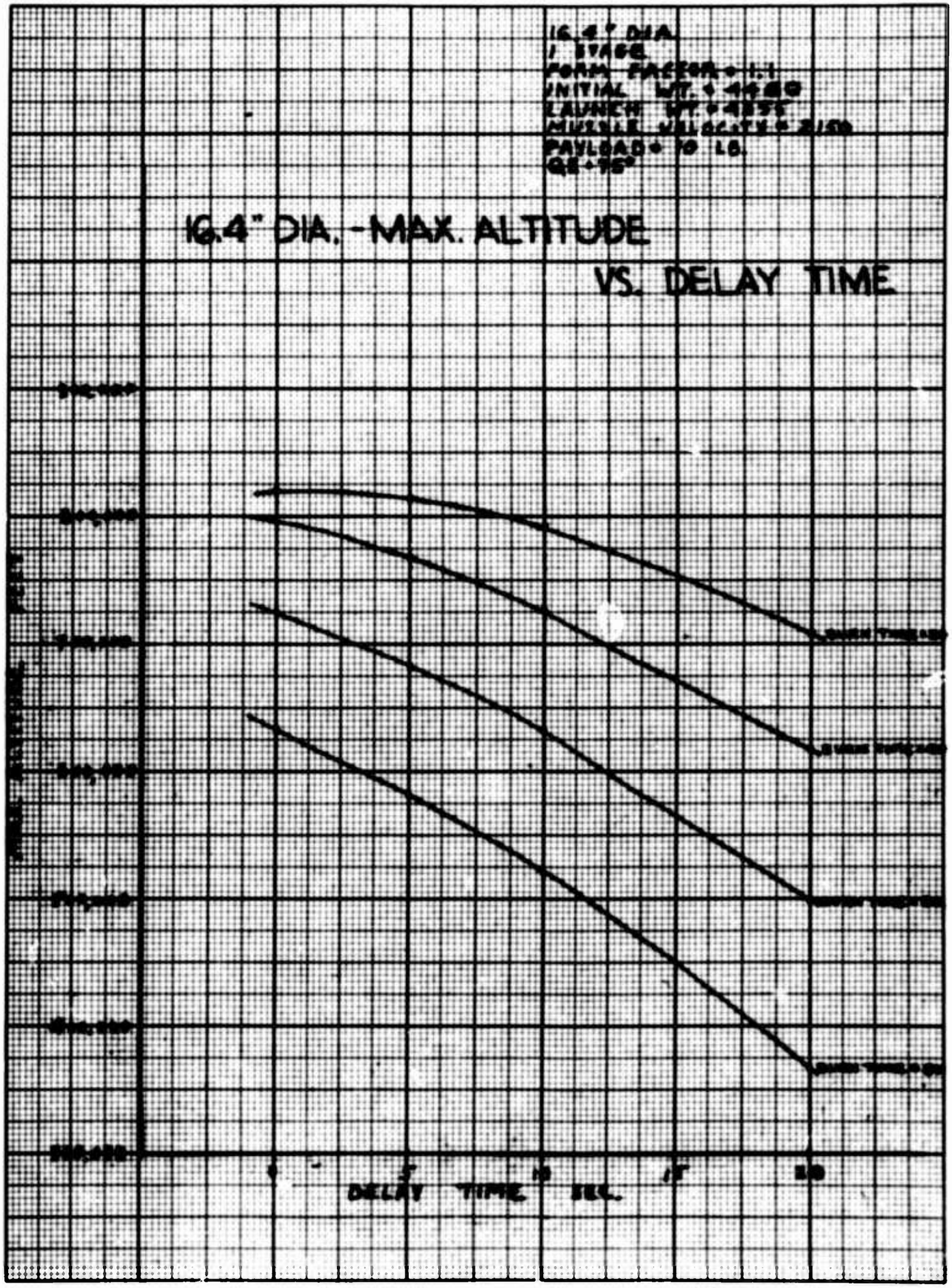

16.4" DIA.
1 STAGE
FORM FACTOR = 1.1
INITIAL WT. = 4480
LAUNCH WT. = 4155
PAYLOAD = 10 LB.
QE = 15°
16.4" DIA. - MAX. ALTITUDE
VS. DELAY TIME
DELAY TIME SEC.

FIGURE 38

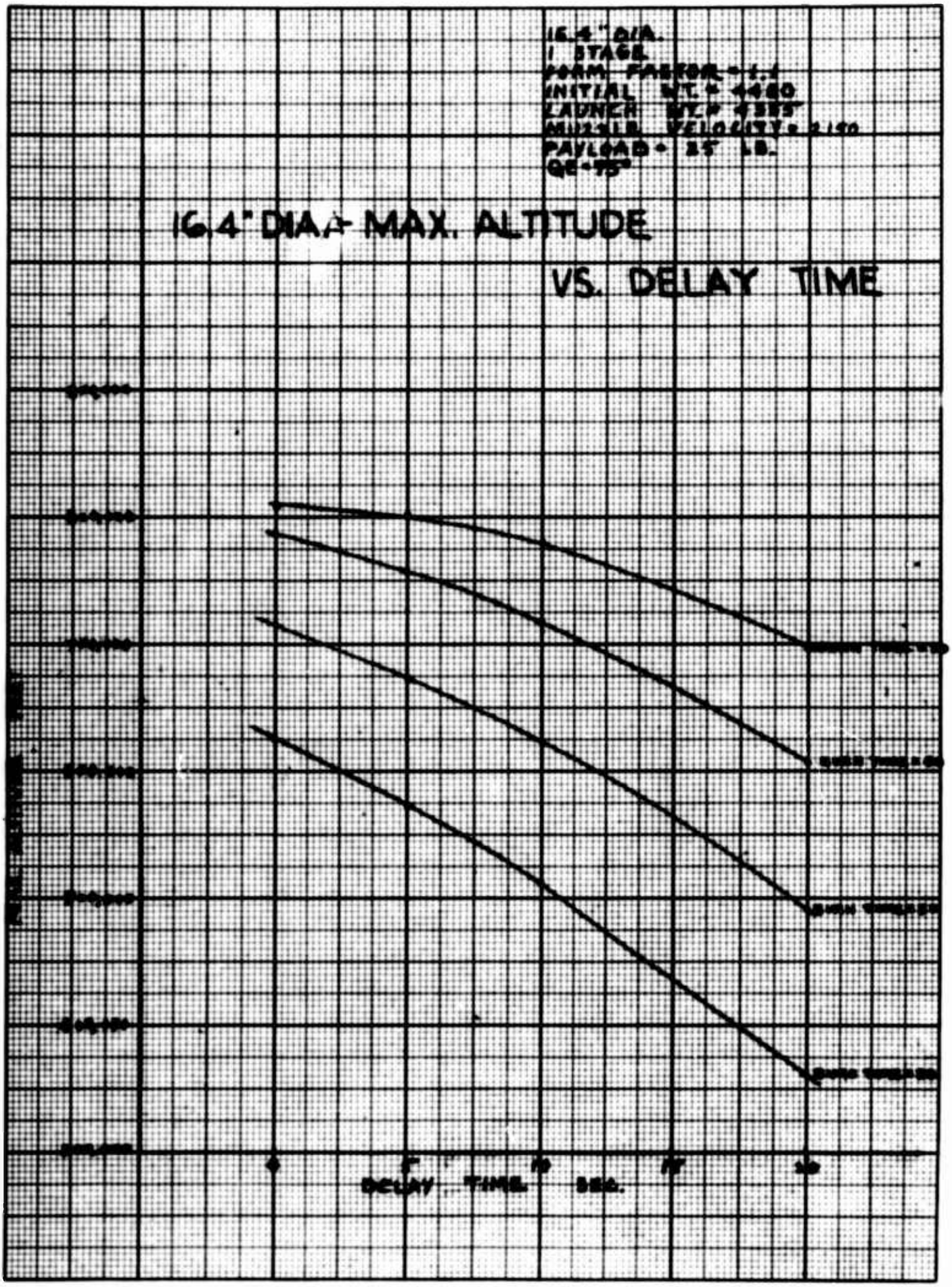

16.4" O/A.
1 STAGE
INITIAL WT. = 4480
PAYLOAD = 25 LB.
QE = 75°
16.4" DIA. - MAX. ALTITUDE
VS. DELAY TIME
DELAY TIME - SEC.

FIGURE 39

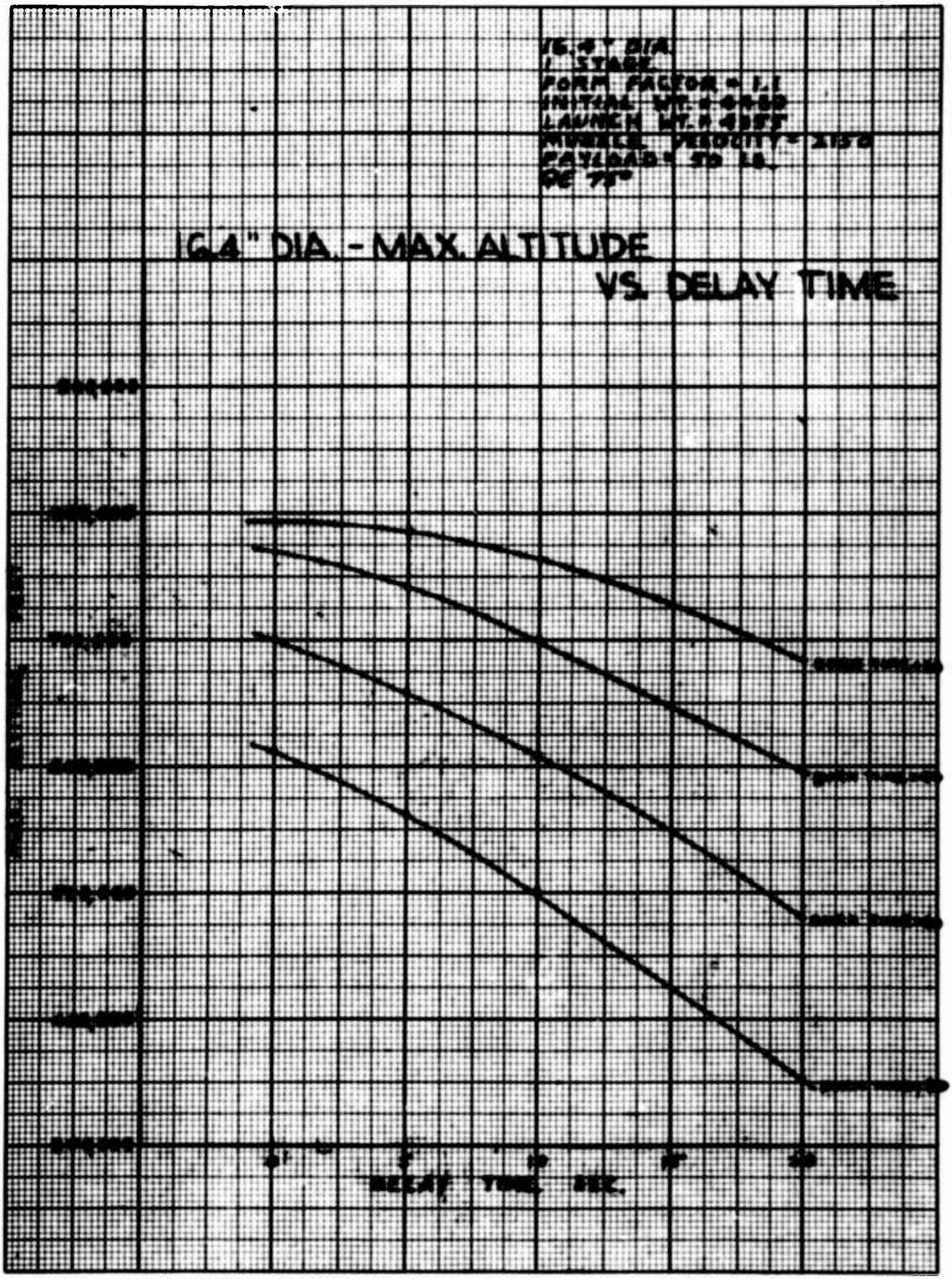

16.4" DIA.
1 STAGE
FORM FACTOR = 1.1
INITIAL WT. = 6900
LAUNCH WT. = 4857
MUZZLE VELOCITY = 2150
PAYLOAD = 50 LB.
@ 75°
16.4" DIA. - MAX. ALTITUDE
VS. DELAY TIME
DELAY TIME SEC.

FIGURE 40

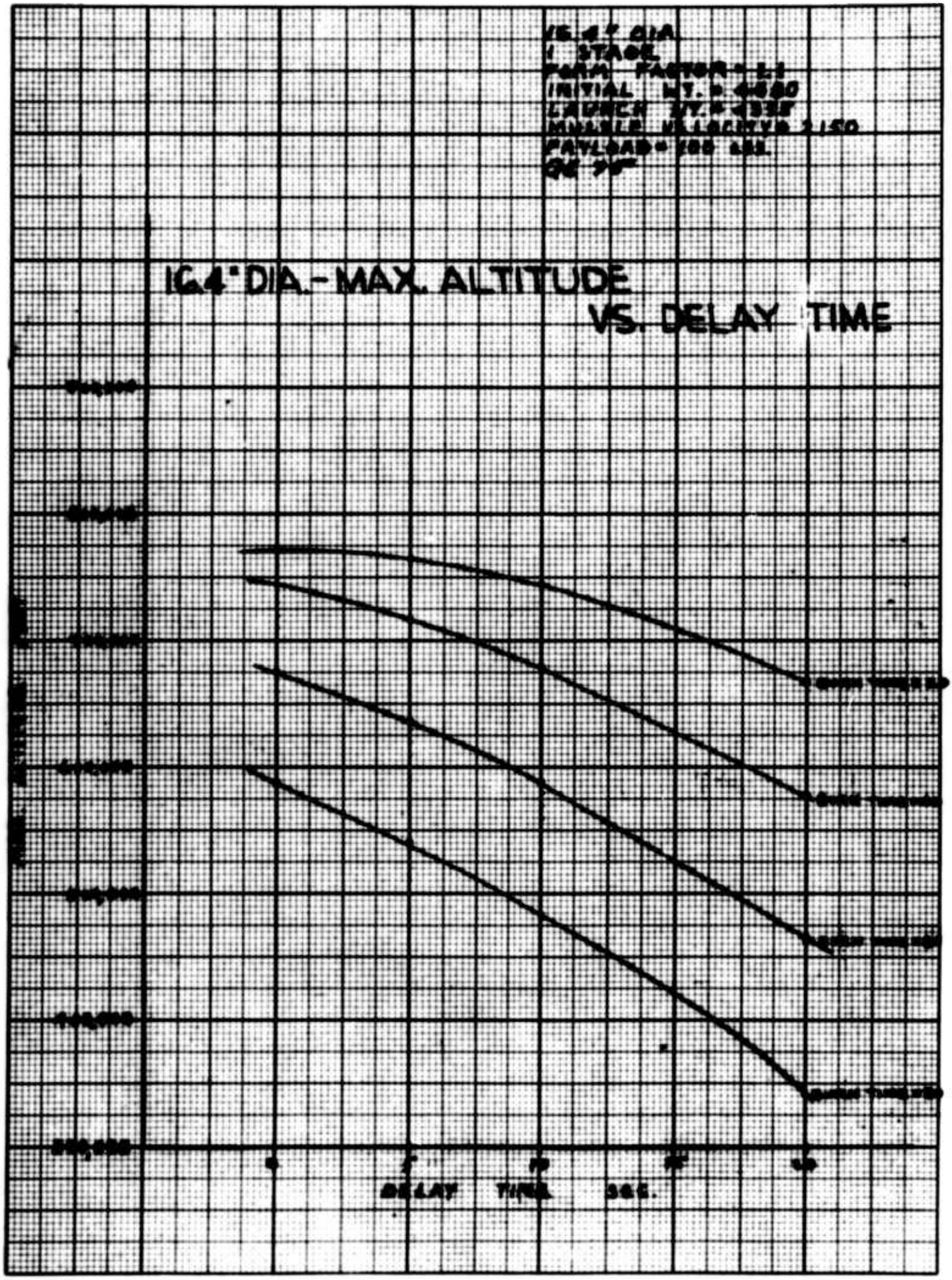

16.4" DIA
1 STAGE
FORM FACTOR = .51
INITIAL WT. = 4980
LAUNCH EFF. = .038
MOTOR I.D. = 16.4 I.D. 2.150
PAYLOAD = 100 LBS.
CG 39"
16.4" DIA.- MAX. ALTITUDE
VS. DELAY TIME
DELAY TIME SEC.

FIGURE 41

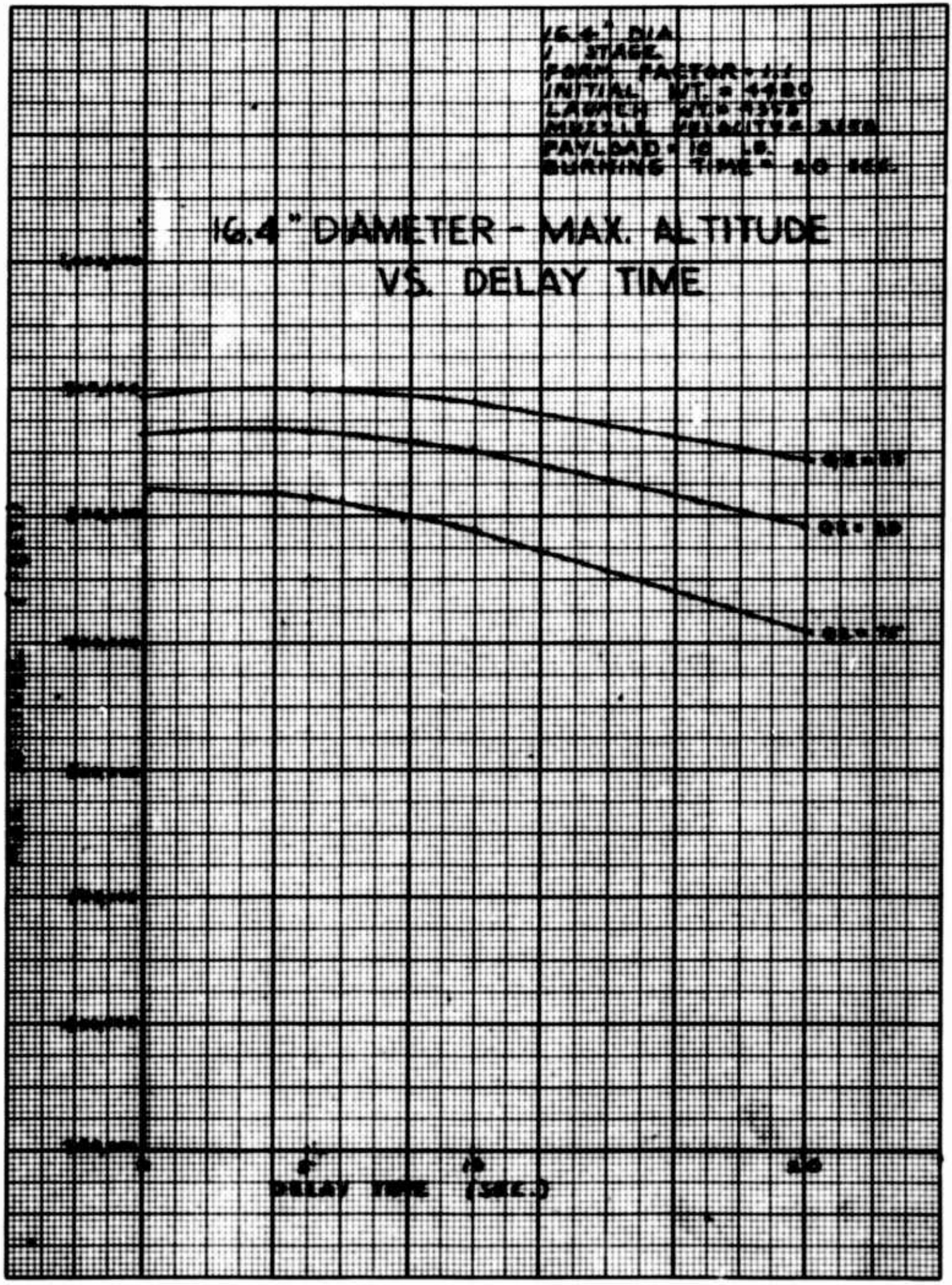
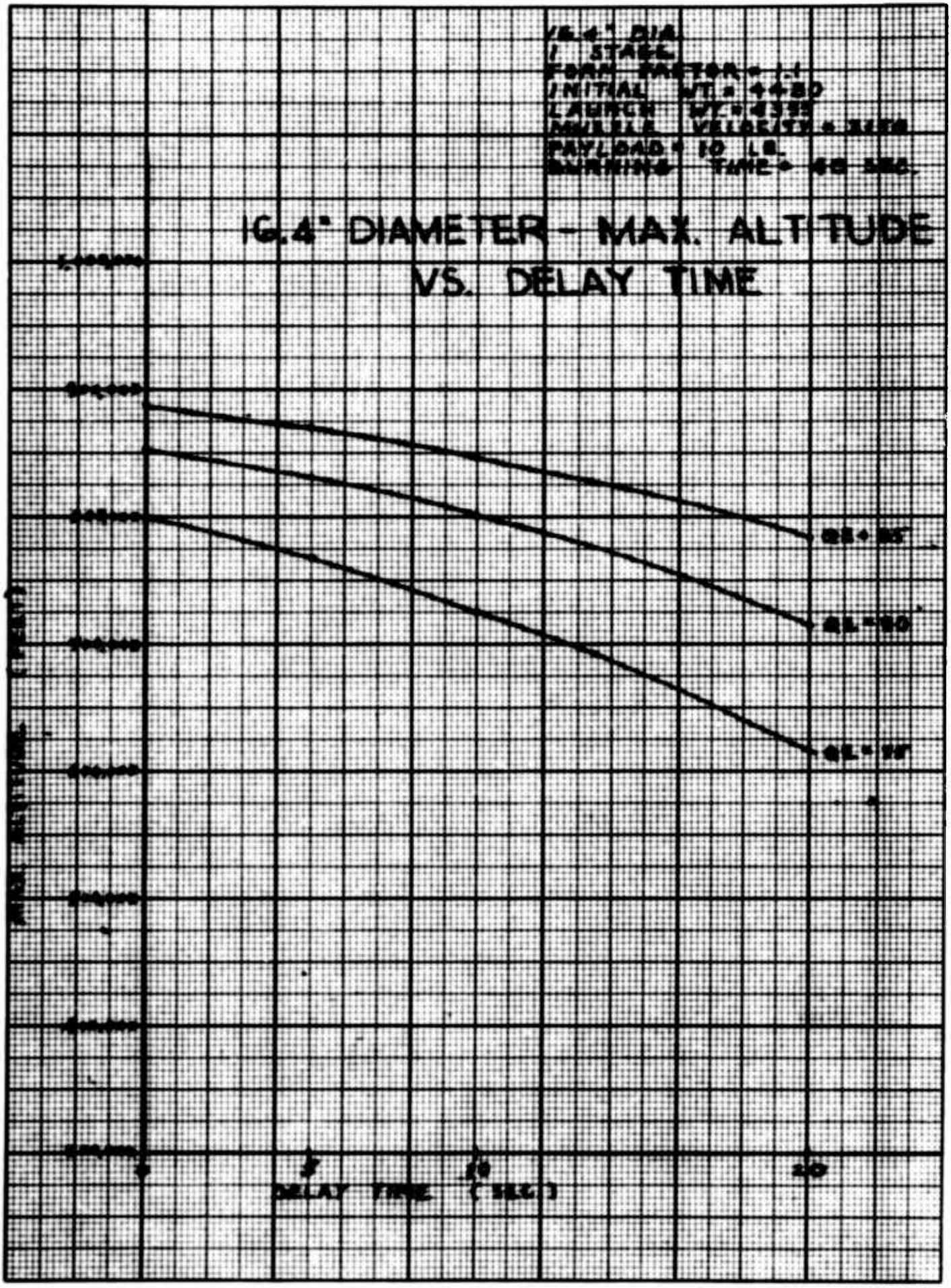

16.4" DIA
1 STAGE
FORM FACTOR =
INITIAL WT. = 4180
LAUNCH WT. = 4375
PAYLOAD = 16 LB.
BURNING TIME = 20 SEC.
16.4" DIAMETER - MAX. ALTITUDE
VS. DELAY TIME
DELAY TIME (SEC.)

FIGURE 42



6.4" DIAMETER - MAX. ALTITUDE VS. DELAY TIME

FIGURE 43

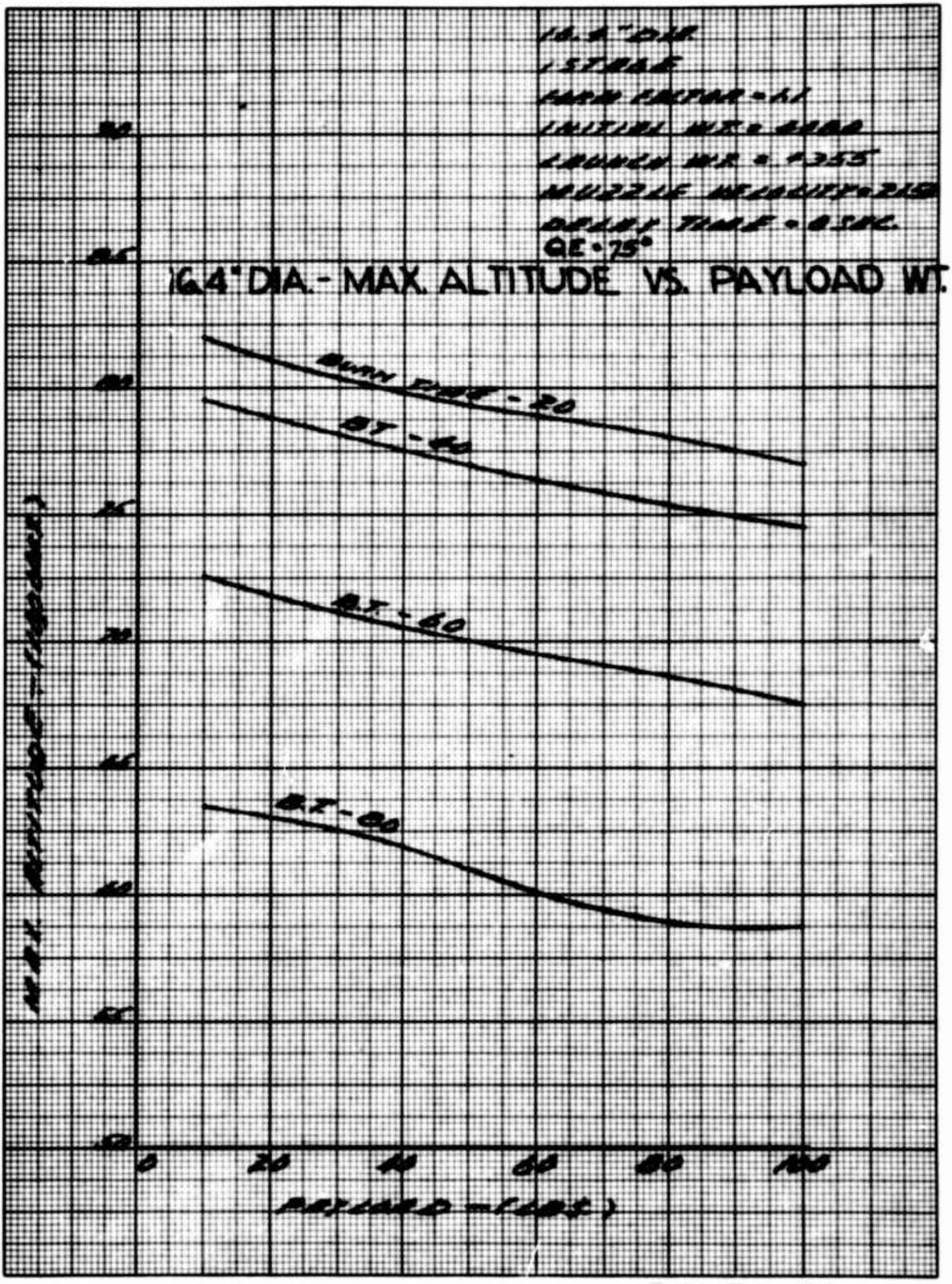

16.4" DIA
1 STAGE
BURN FACTOR - .11
INITIAL WT. = 4480
LAUNCH WT. = 1355
PROPELLANT WEIGHT = 215
DELAY TIME = 0 SEC.
QE = 75°
16.4" DIA. - MAX. ALTITUDE VS. PAYLOAD WT.
BURN RATE - .20
BT - 40
BT - 40
BT - 80
0
20
40
60
80
100

FIGURE 44

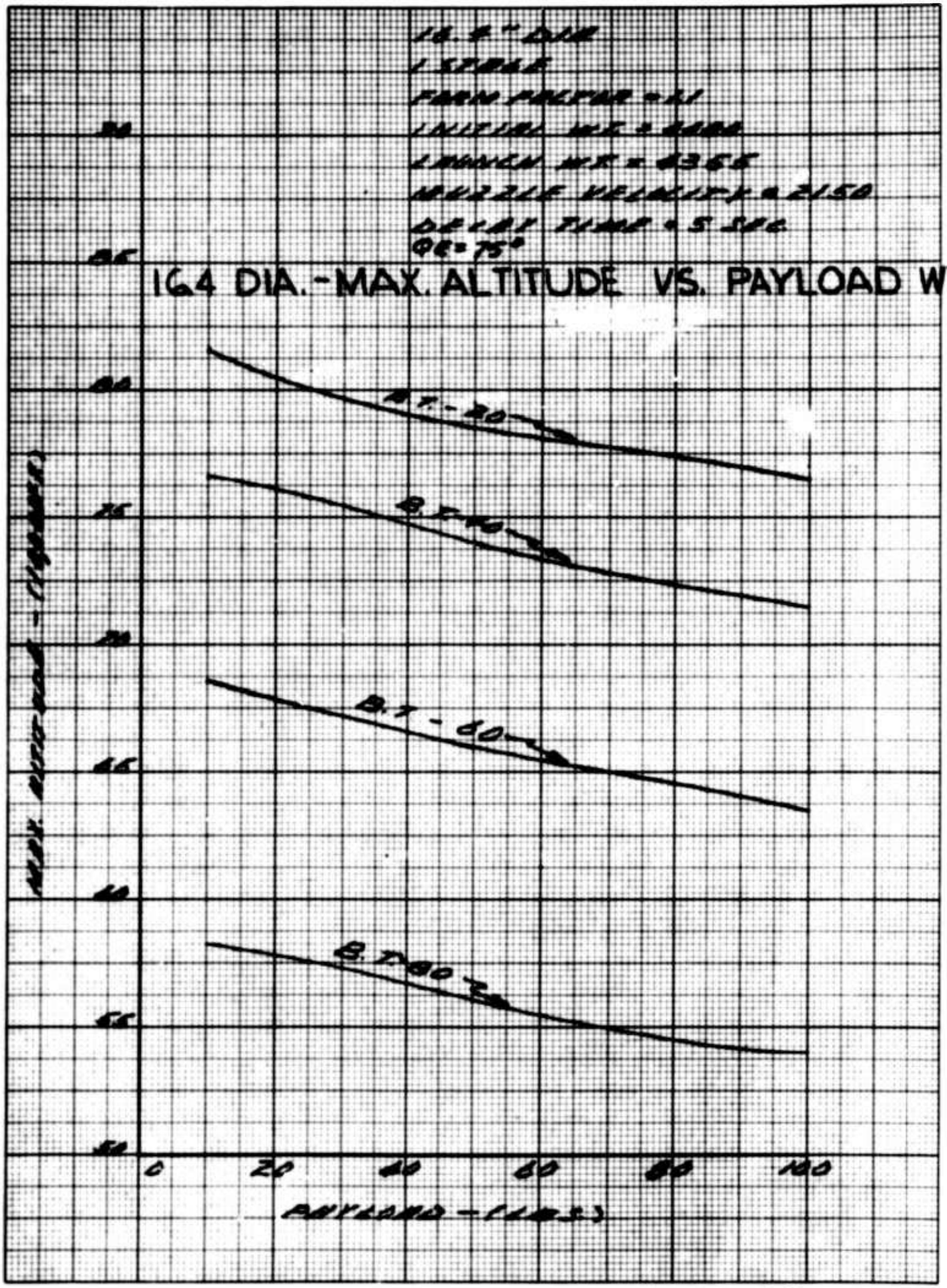

164 DIA.-MAX. ALTITUDE VS. PAYLOAD WT.
A.T. - 20
A.T. - 40
A.T. - 60
A.T. 80
0
20
40
60
80
100

FIGURE 45

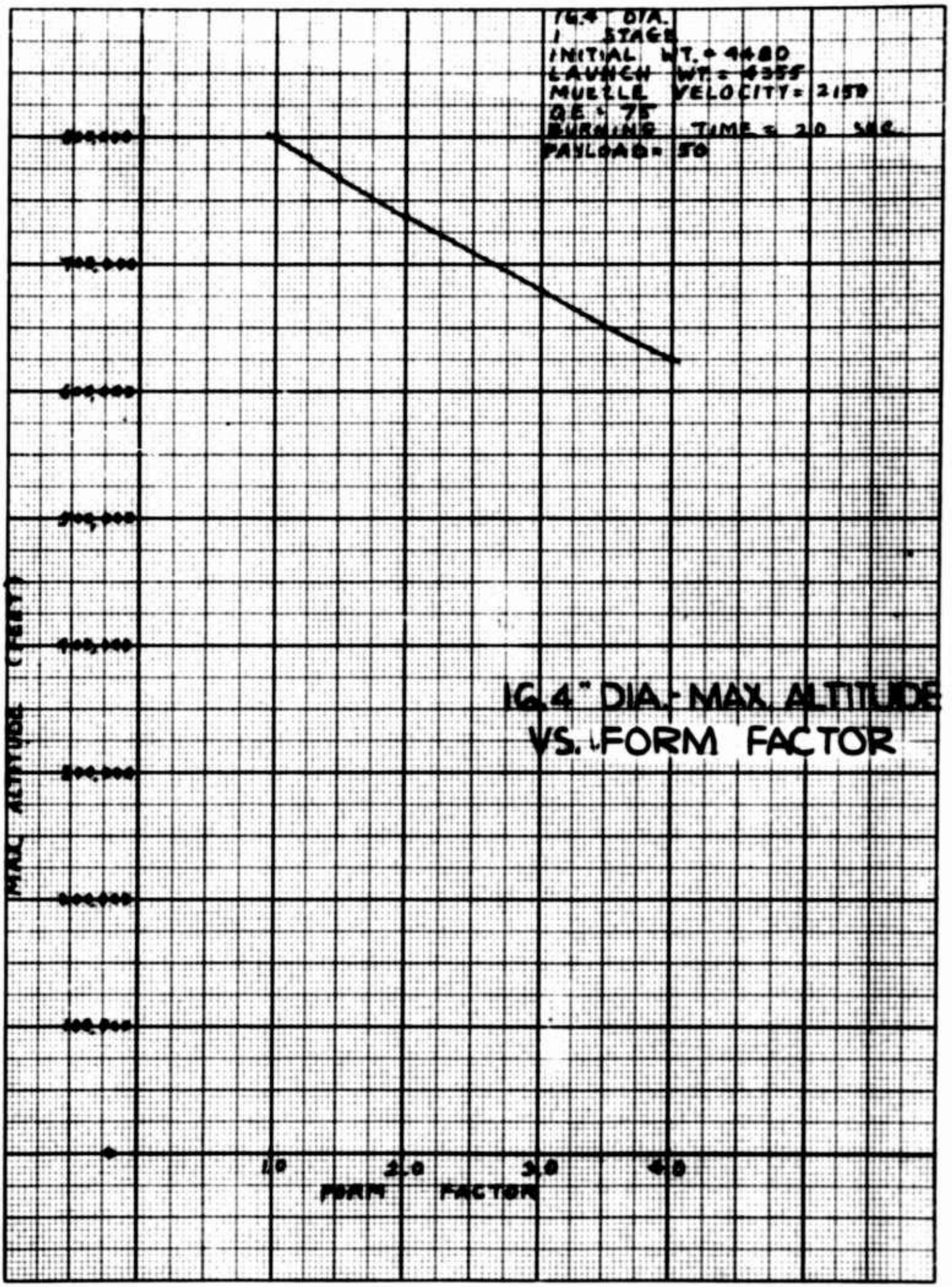

16.4 DIA.
1 STAGE
INITIAL WT. = 4480
LAUNCH WT. = 4355
MUZZLE VELOCITY = 2150
C.E. = 75
BURNING TIME = 2.0 SEC.
PAYLOAD = 50
MAX. ALTITUDE (FEET)
FORM FACTOR
1.0
2.0
3.0
4.0
16.4" DIA. - MAX. ALTITUDE VS. FORM FACTOR

FIGURE 46

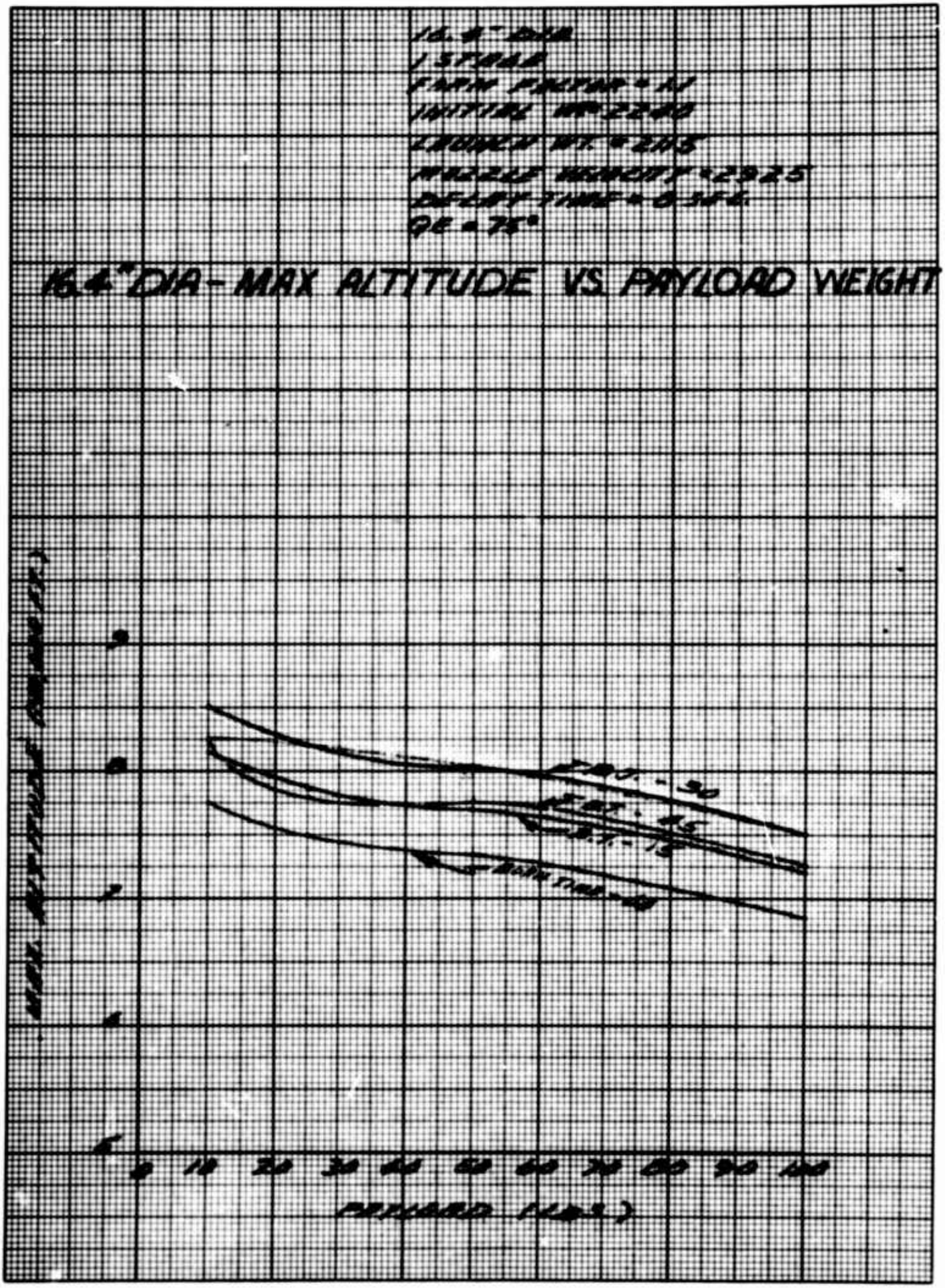


FIG. 47

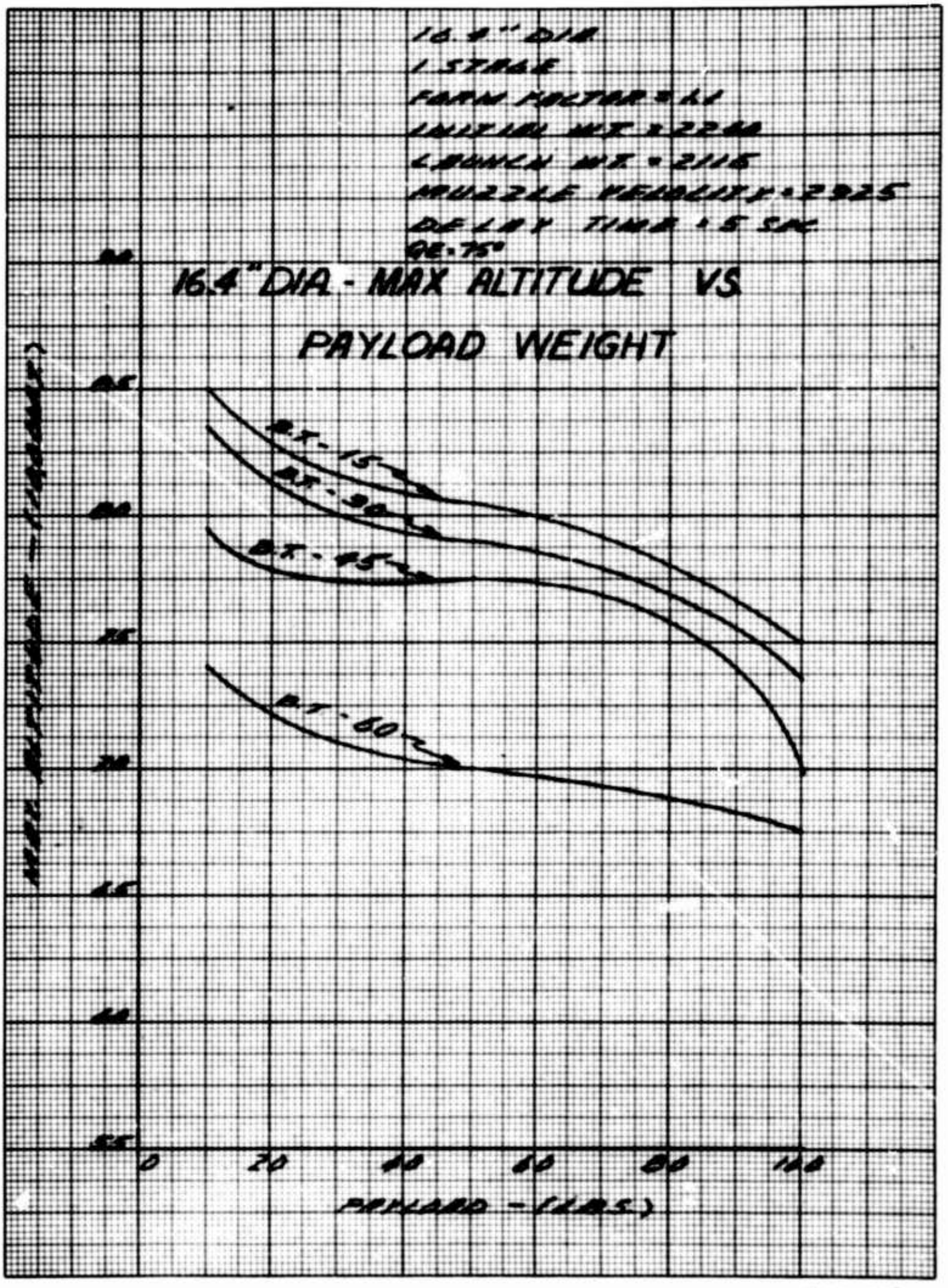

16.4" DIA
1 STAGE
PAYLOAD WEIGHT = LV
IGNITION WT = 2248
LAUNCH WT = 2118
NOZZLE EFFICIENCY = .2925
DELAY TIME = .5 SEC
QE = 75°
16.4" DIA - MAX ALTITUDE VS
PAYLOAD WEIGHT
BT - 15
BT - 30
BT - 45
BT - 60
MAX ALTITUDE - (THOUSANDS)
PAYLOAD - (LBS.)
0
20
40
60
80
100

FIG. 48

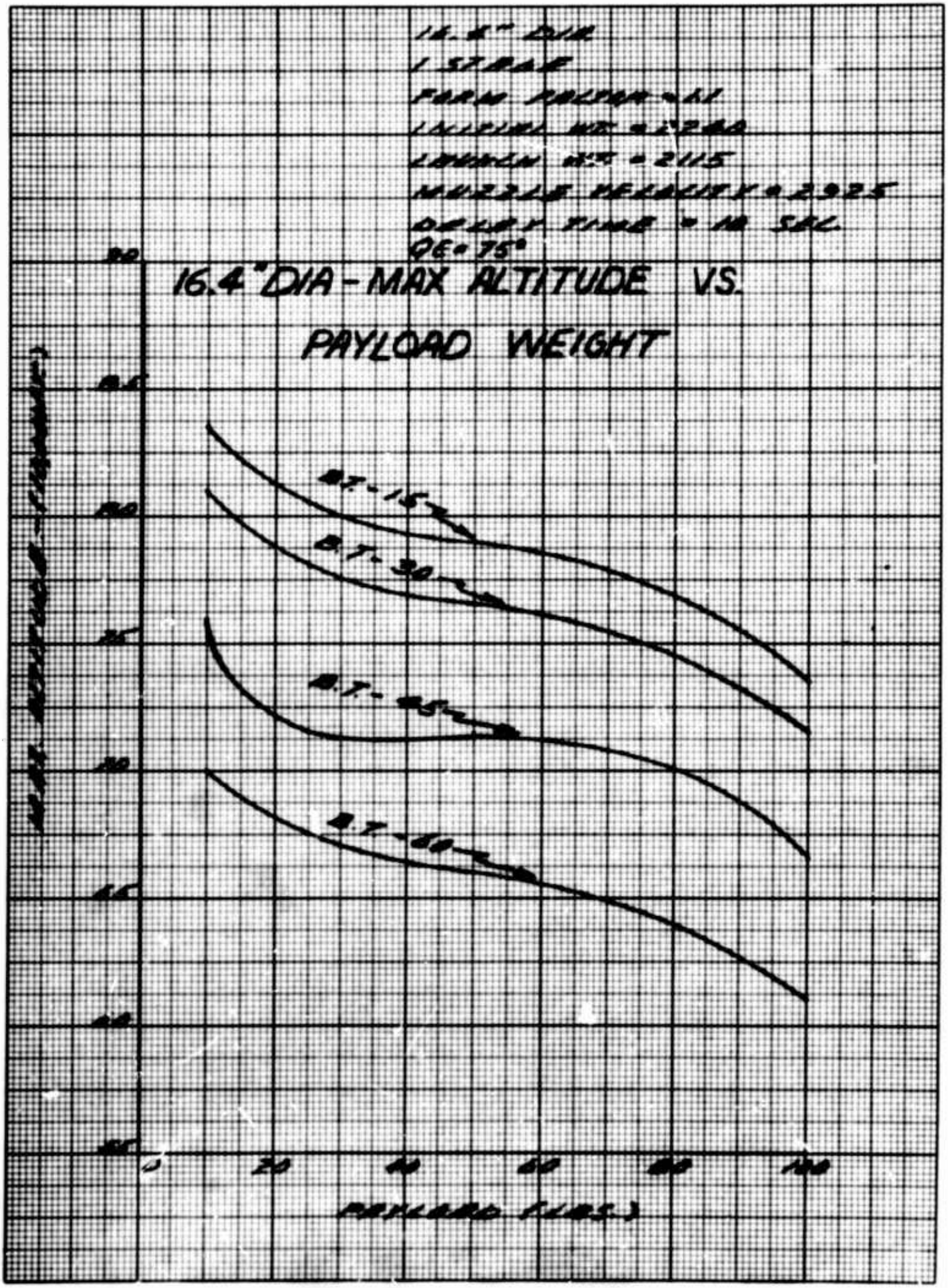

16.4" DIA - MAX ALTITUDE VS.
PAYLOAD WEIGHT
W.T. - 15
W.T. - 30
W.T. - 45
W.T. - 60
0
20
40
60
80
100

FIG. 49

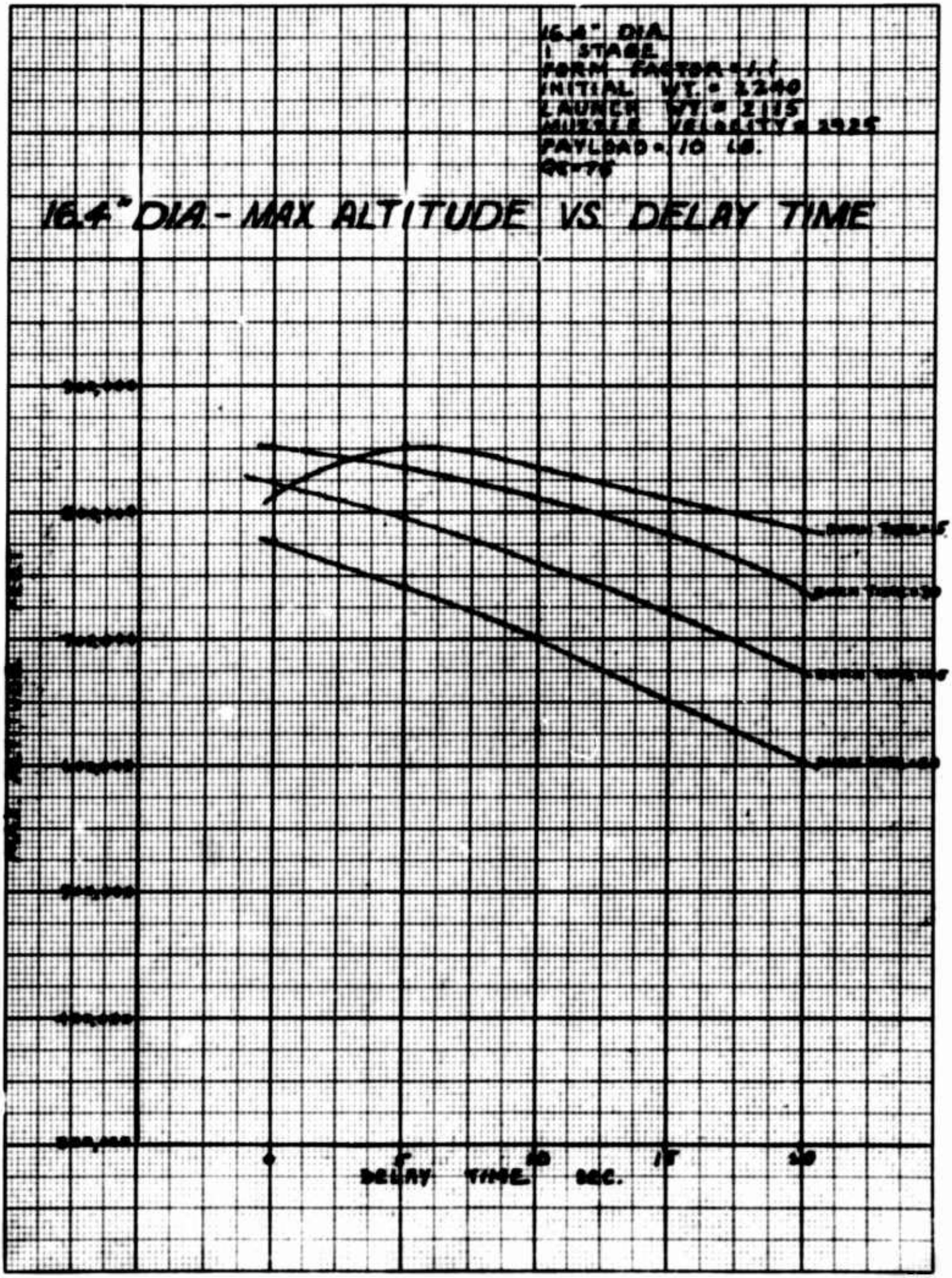

16.4" DIA.
1 STAGE
FORM FACTOR = 1/1
INITIAL WT. = 1240
LAUNCH WT. = 2135
MUZZLE VELOCITY = 1925
PAYLOAD = 10 LB.
QE-76
16.4" DIA. - MAX ALTITUDE VS. DELAY TIME
DELAY TIME SEC.

FIG. 50

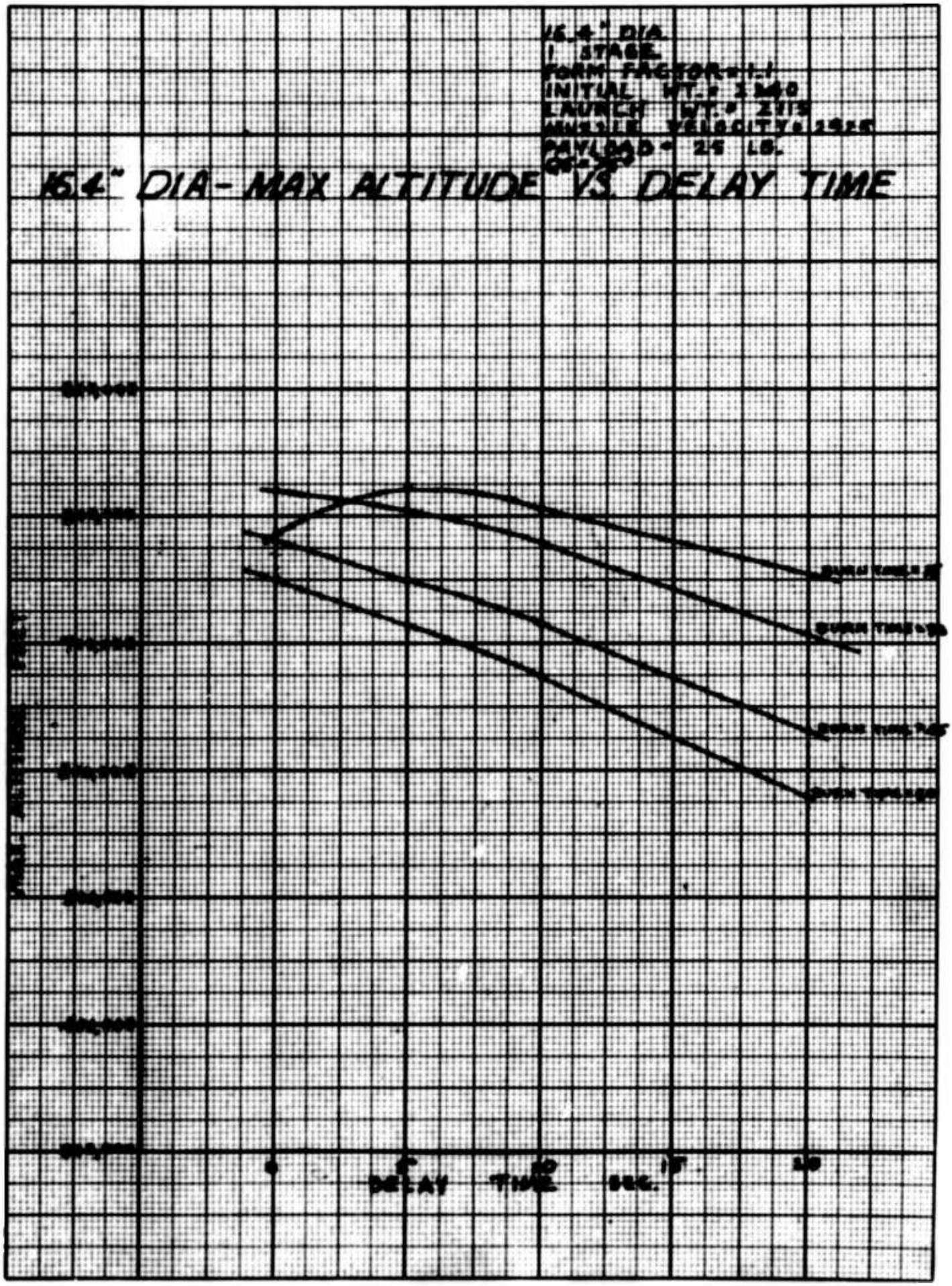

16.4" DIA.
I STAGE
FORM FACTOR = 1.1
INITIAL WT. = 3340
LAUNCH WT. = 2175
MUZZLE VELOCITY = 1925
PAYLOAD = 24 LB.
CD = .5
16.4" DIA - MAX ALTITUDE V.S. DELAY TIME
DELAY TIME SEC.

FIG. 51

16.4" DIA.
1 STAGE
FORM FACTOR = 1.1
INITIAL WT. = 2240
LAUNCH WT. = 2115
MUZZLE VELOCITY = 2925
PAYLOAD = 50 LB.
QE = 75°

16.4" DIA. - MAX ALTITUDE VS. DELAY TIME

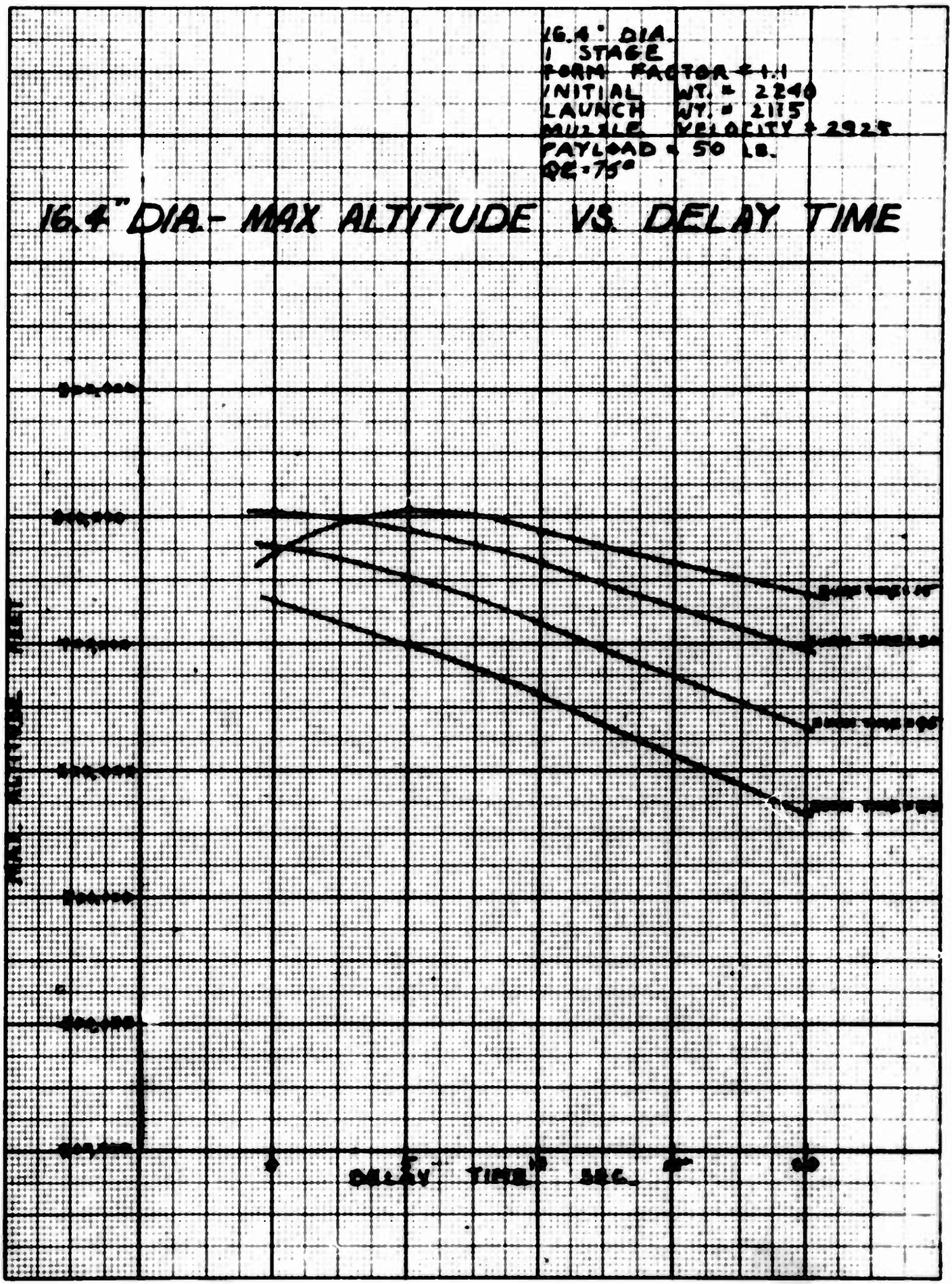


FIG. 52

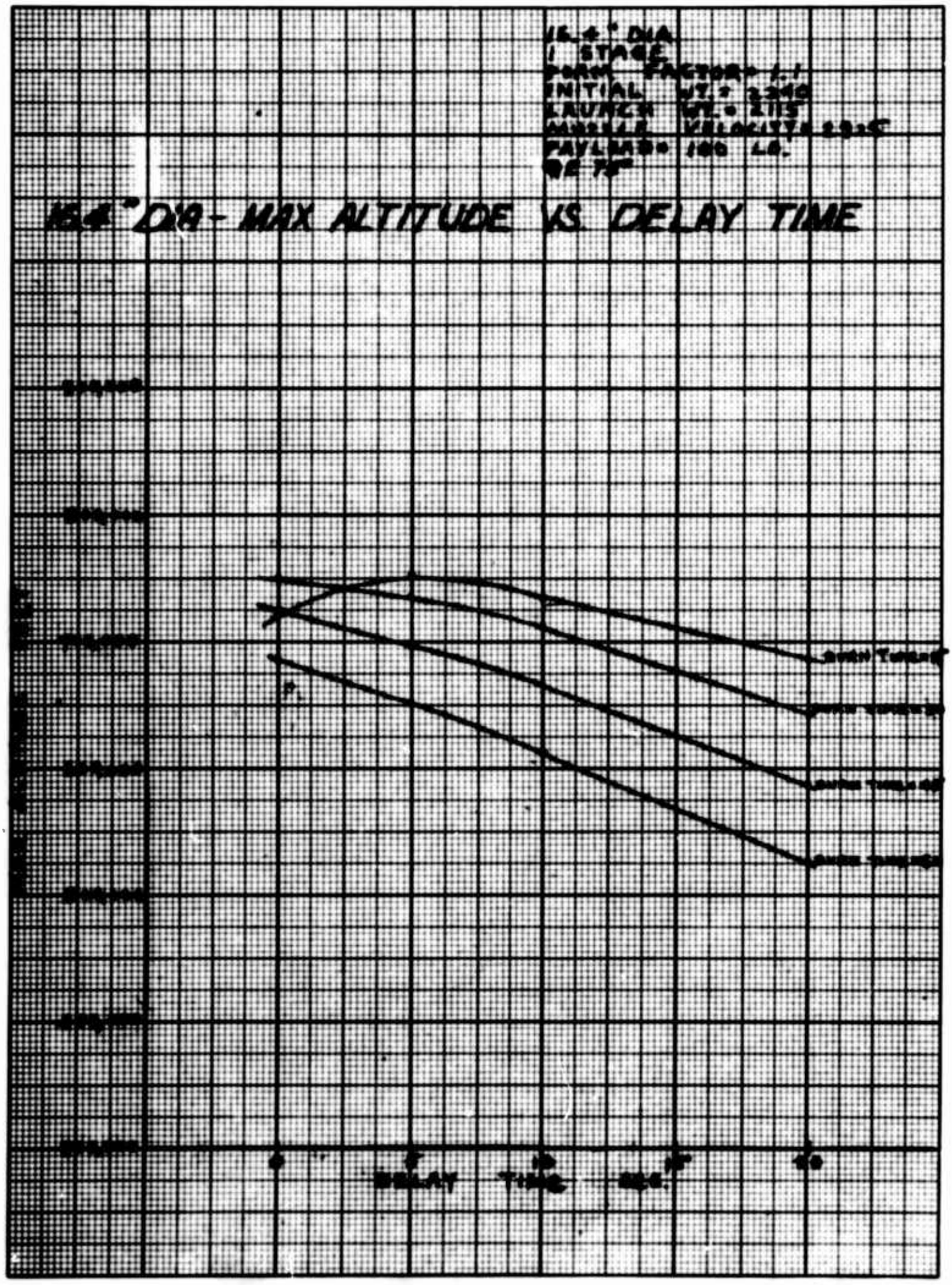

15.4" DIA
1 STAGE
INITIAL WT. = 3240
LAUNCH WT. = 2115
PAYLOAD = 100 LB.
15.4" DIA - MAX ALTITUDE VS. DELAY TIME
DELAY TIME

FIG 53

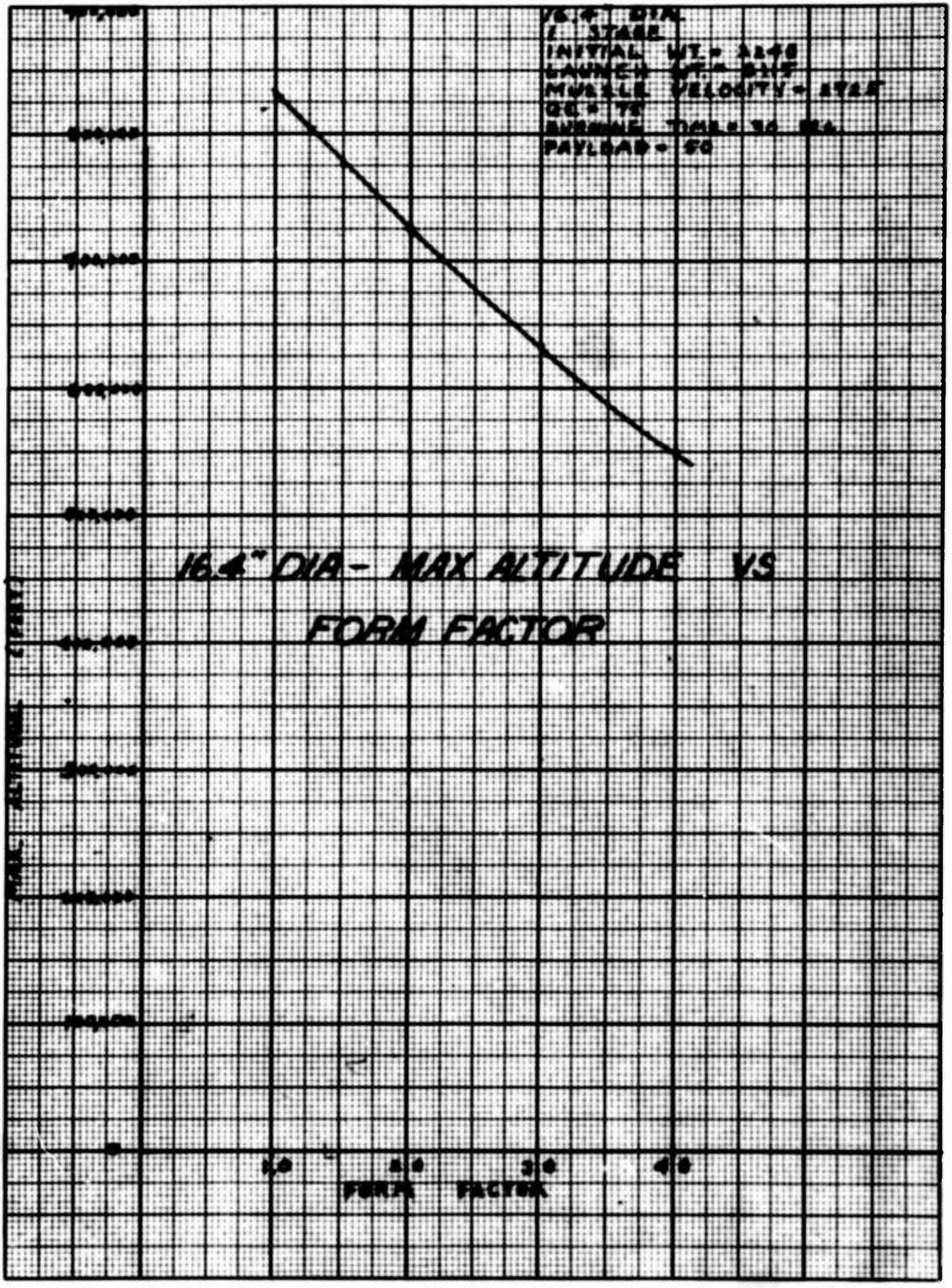

16.4" DIA
2 STAGE
PAYLOAD = 50
16.4" DIA - MAX ALTITUDE VS
FORM FACTOR
1.0
2.0
3.0
4.0
FORM FACTOR

FIG. 54

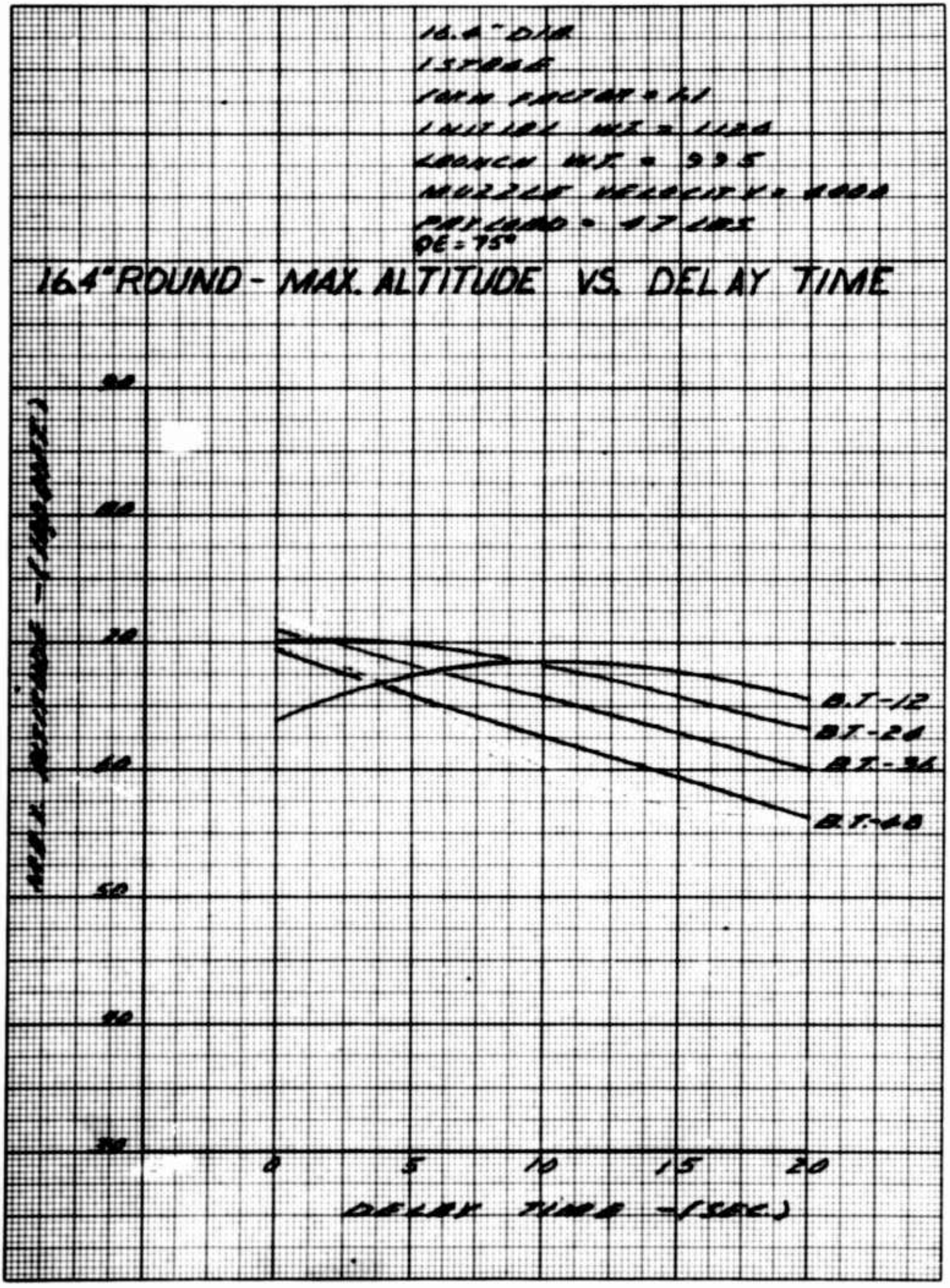

16.4" DIA
ISP 244
PROP FRACTION = .41
INITIAL WT = 1184
LAUNCH WT = 995
MUZZLE VELOCITY = 4000
PAYLOAD = 17 LBS
QE = 75°
16.4" ROUND - MAX. ALTITUDE VS. DELAY TIME
B.T.-12
B.T.-24
B.T.-36
B.T.-48
0
5
10
15
20

FIG. 55

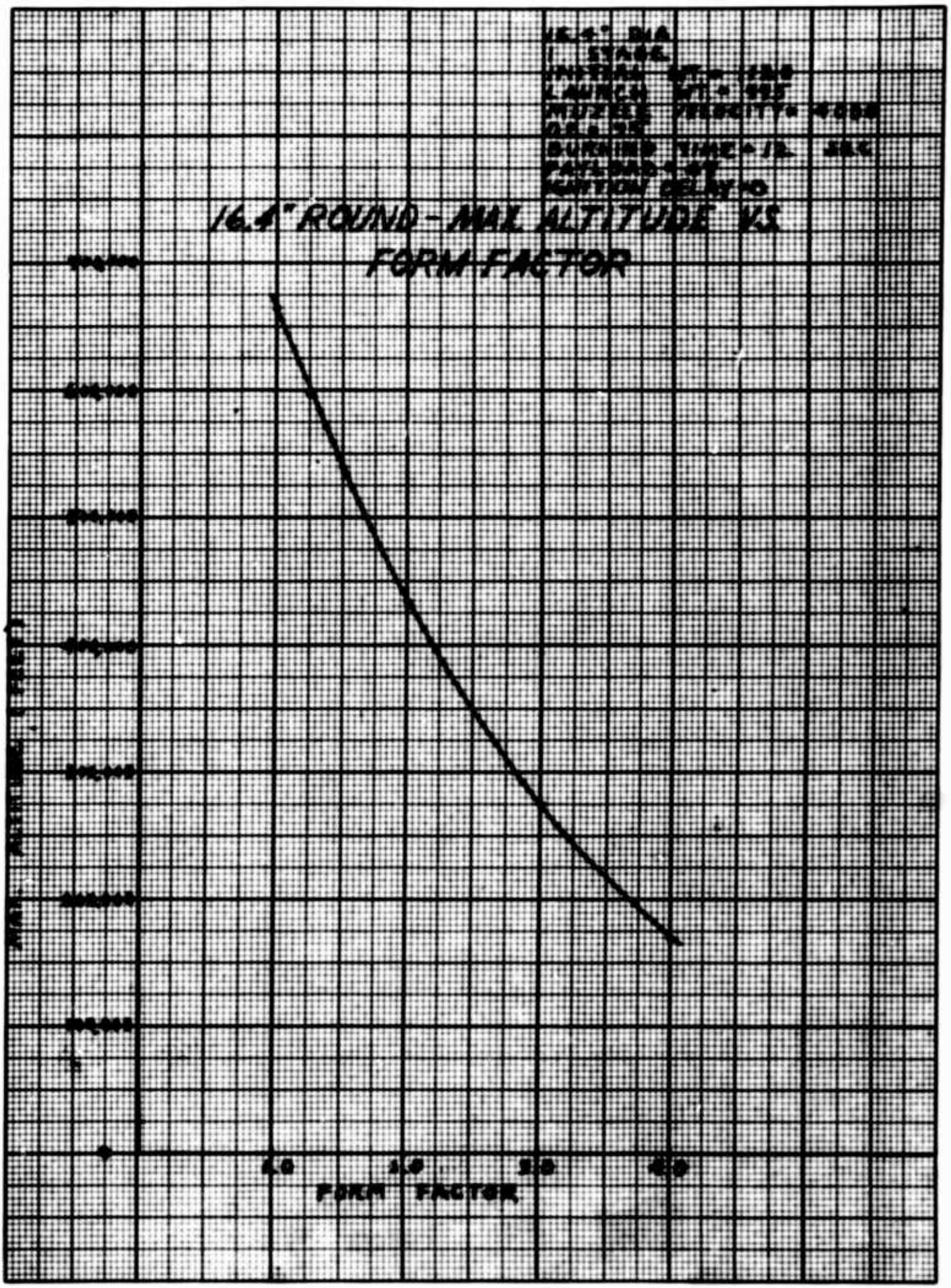


FIG. 56

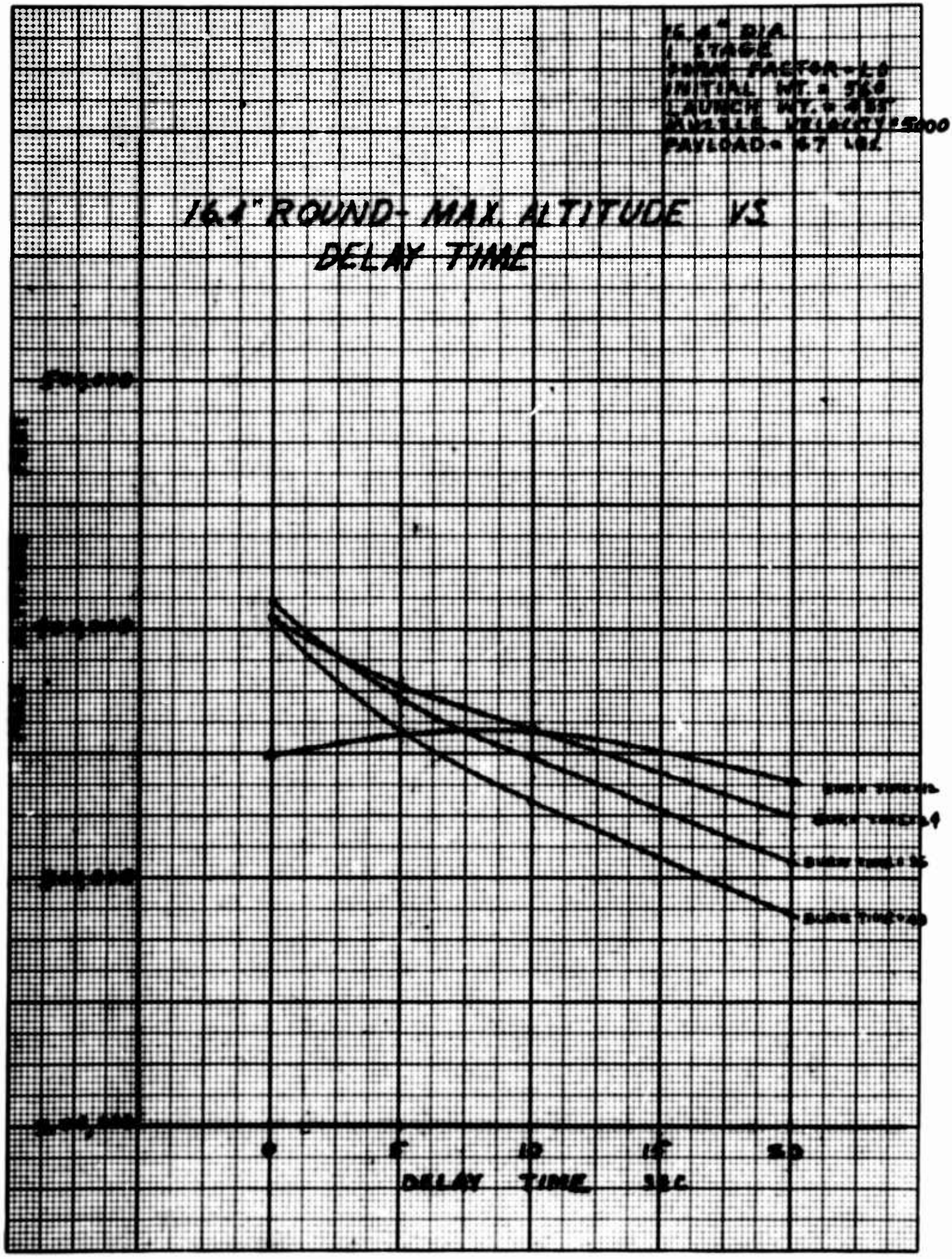


FIG. 57

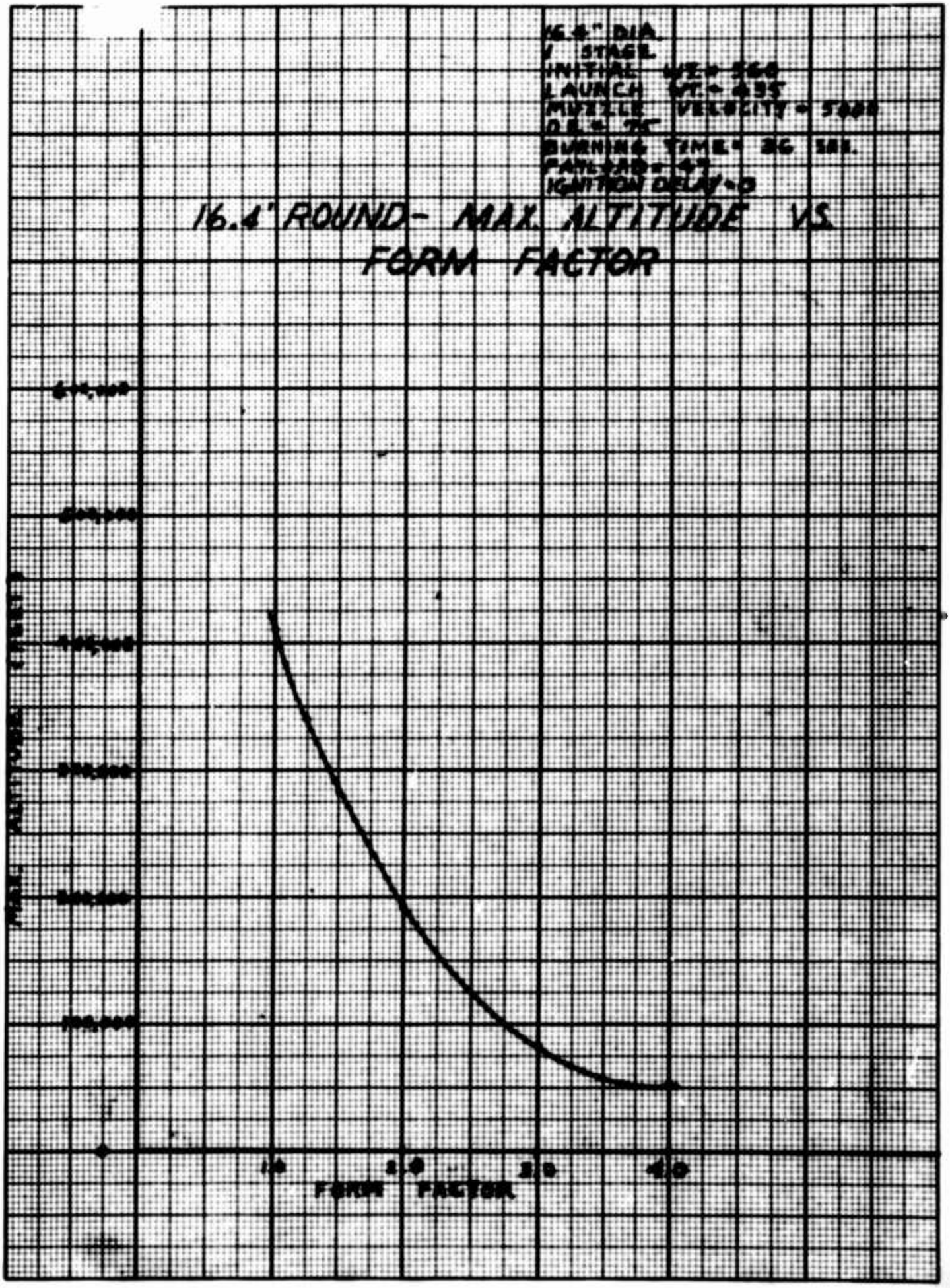

16.4" DIA.
1 STAGE
INITIAL WT. = 560
LAUNCH WT. = 435
MUZZLE VELOCITY = 5000
D.E. = 75%
BURNING TIME = 36 SEC.
FAIRING = 0
IGNITION DELAY = 0
16.4" ROUND - MAX. ALTITUDE VS. FORM FACTOR
FORM FACTOR

FIG. 58

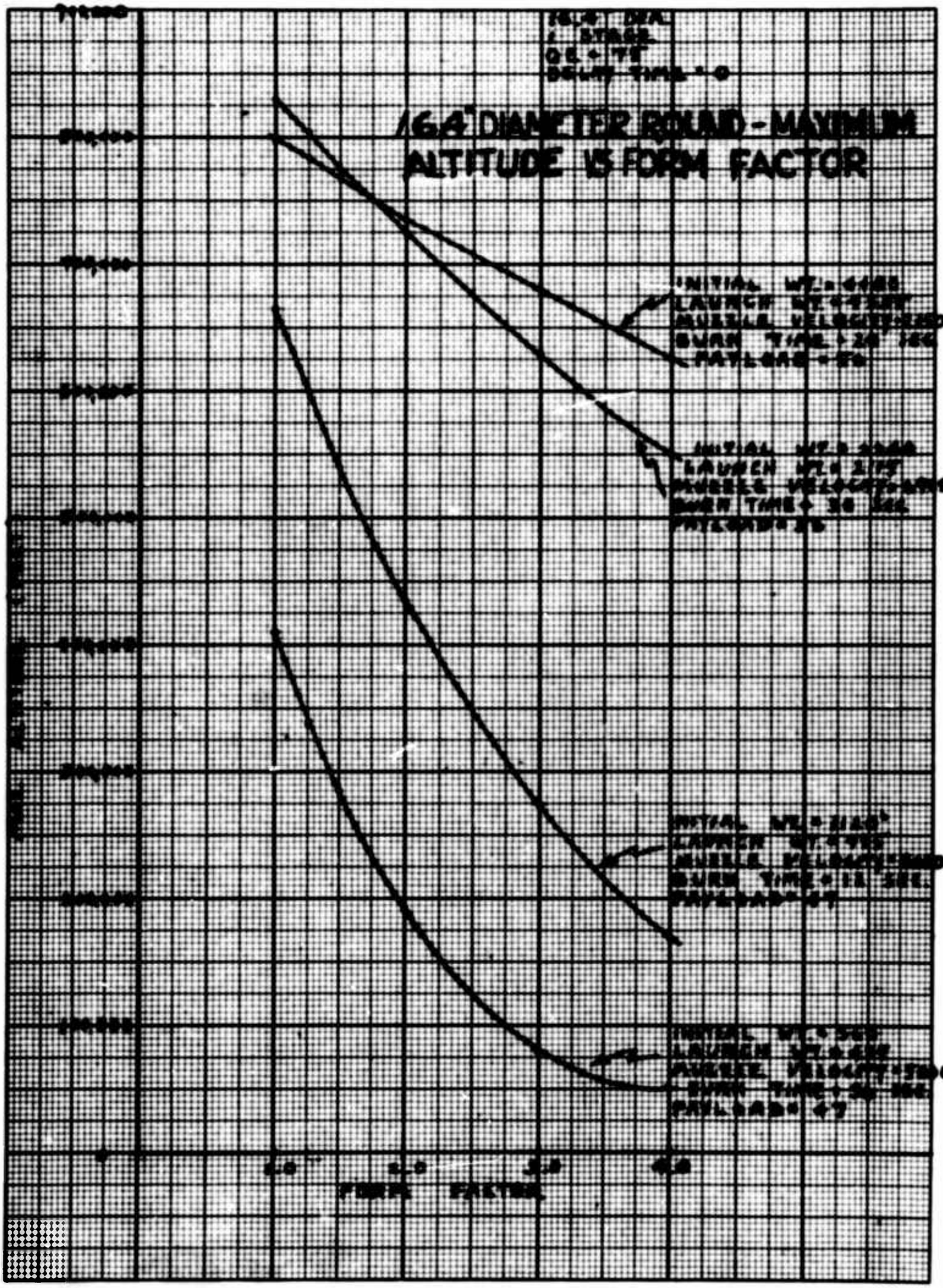


FIG 59

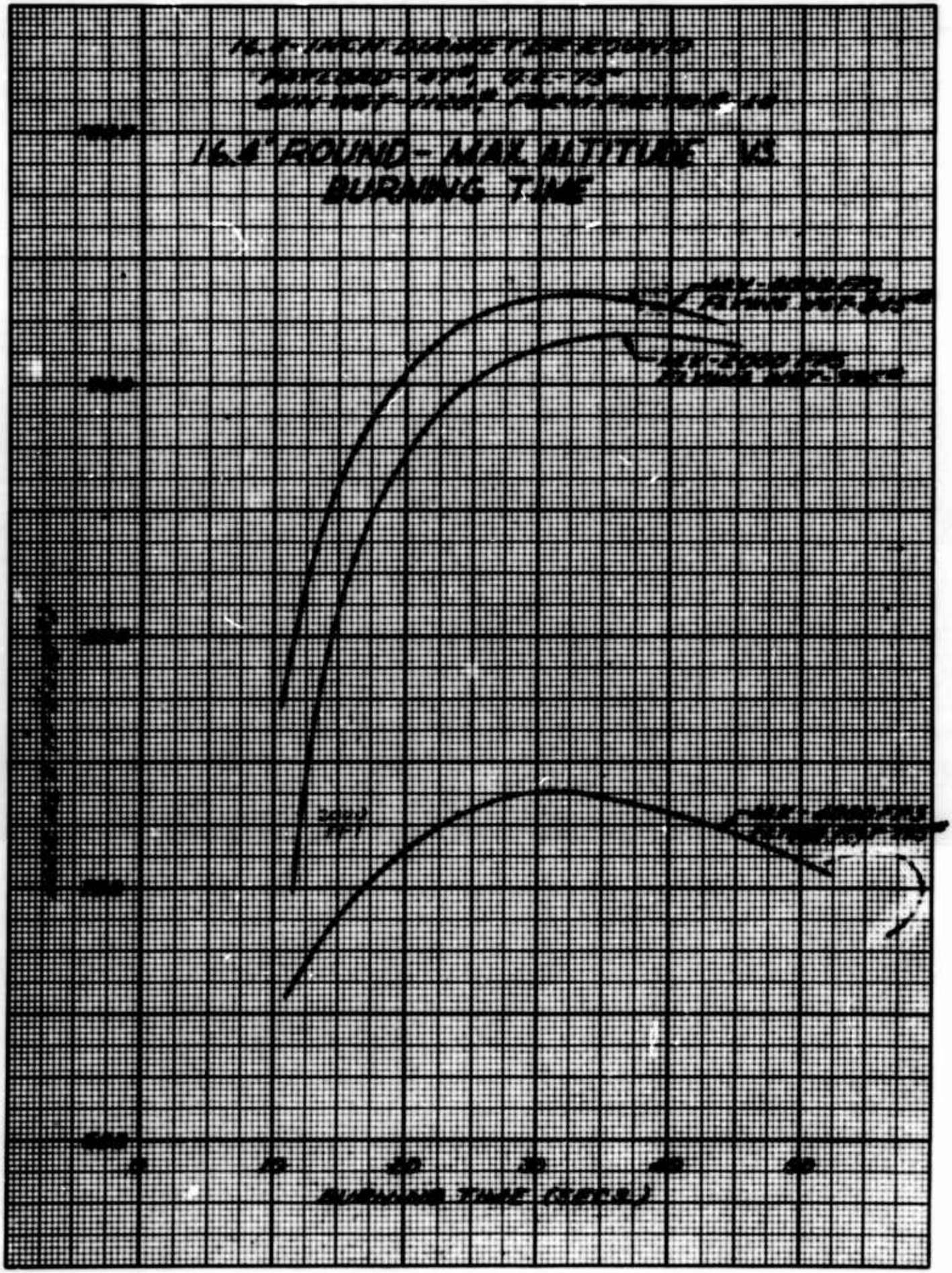


FIG. 60

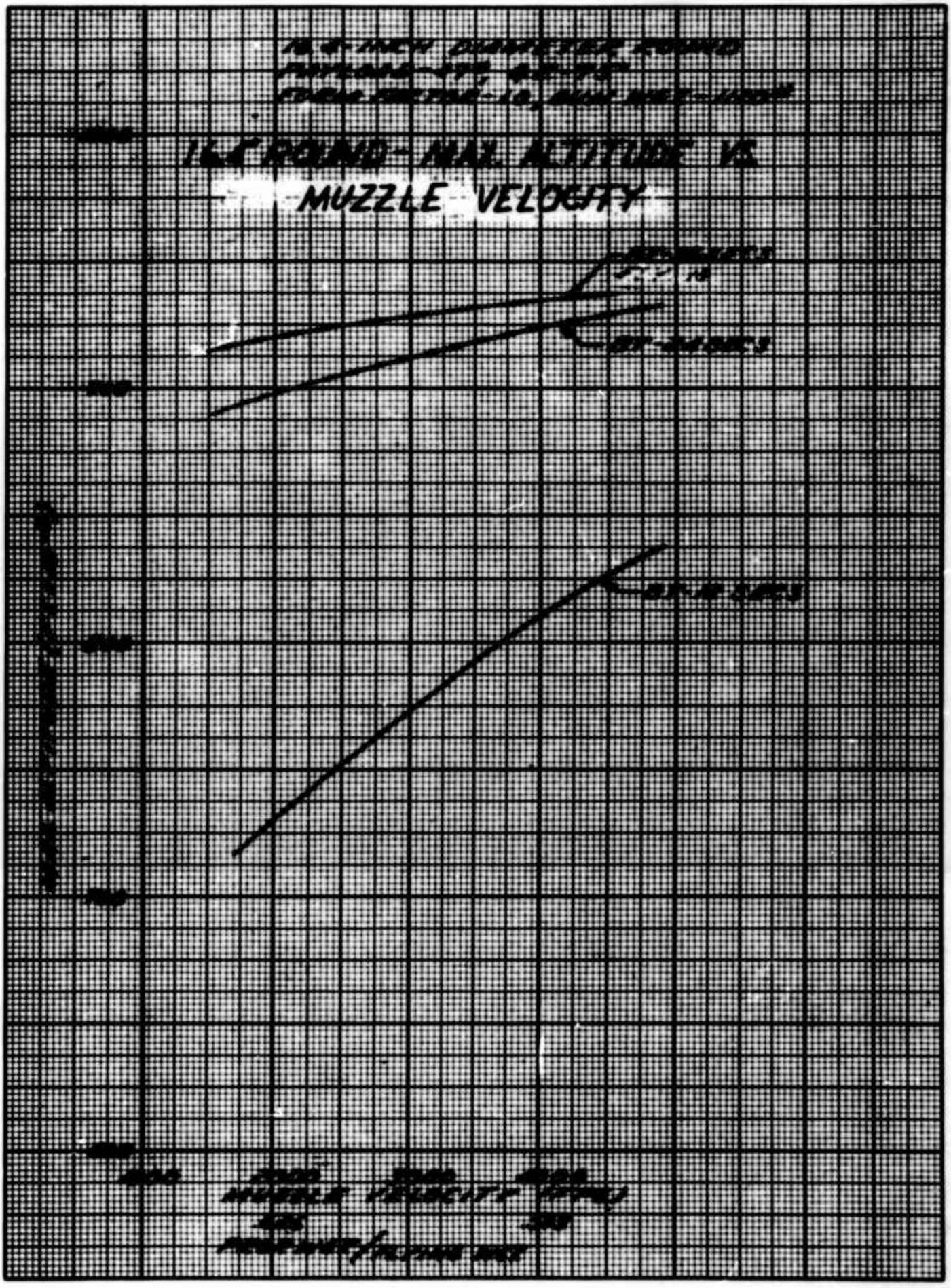


FIG. 61

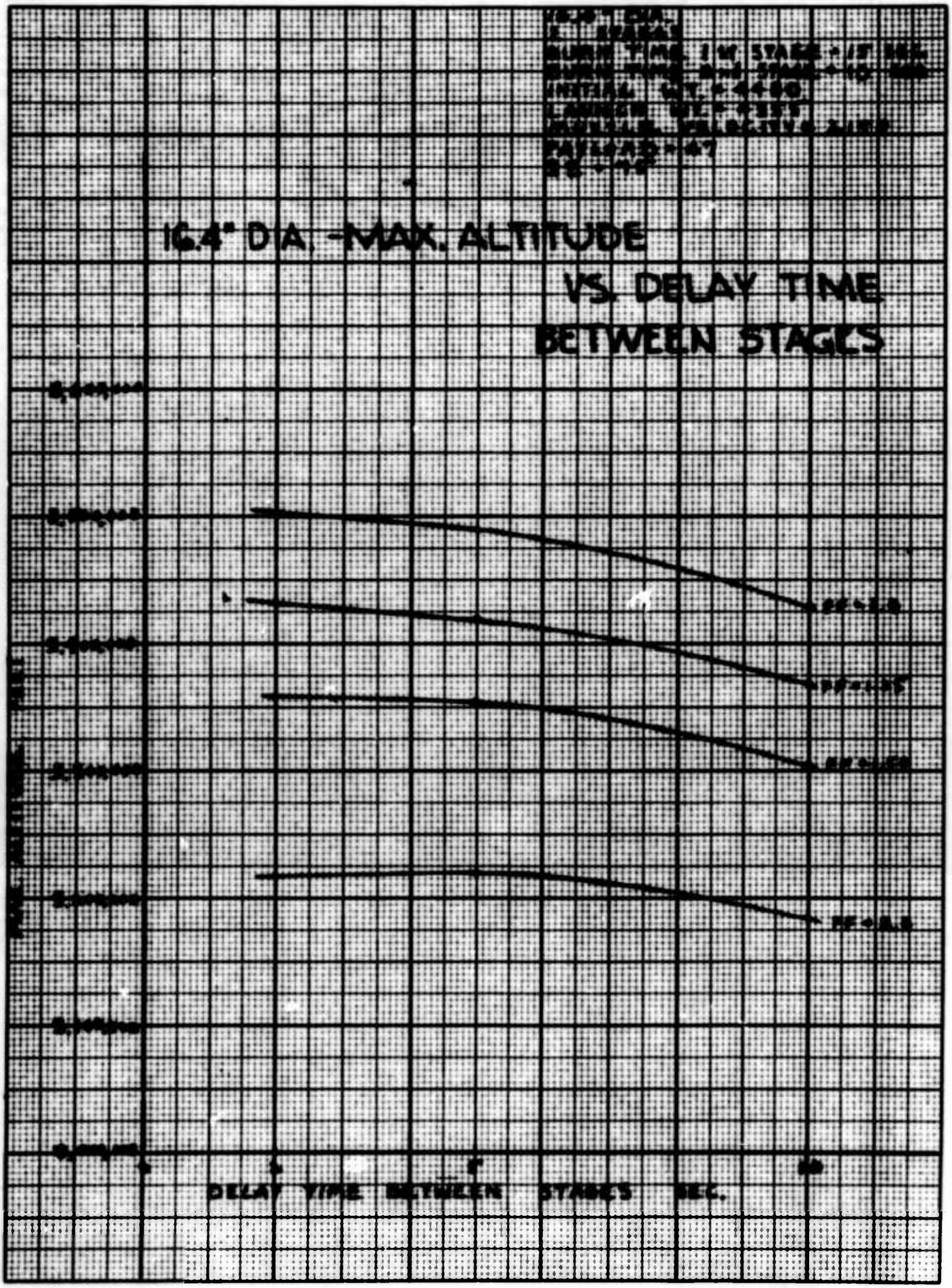

16.4" DIA. - MAX. ALTITUDE
VS. DELAY TIME
BETWEEN STAGES
DELAY TIME BETWEEN STAGES SEC.

FIGURE 62

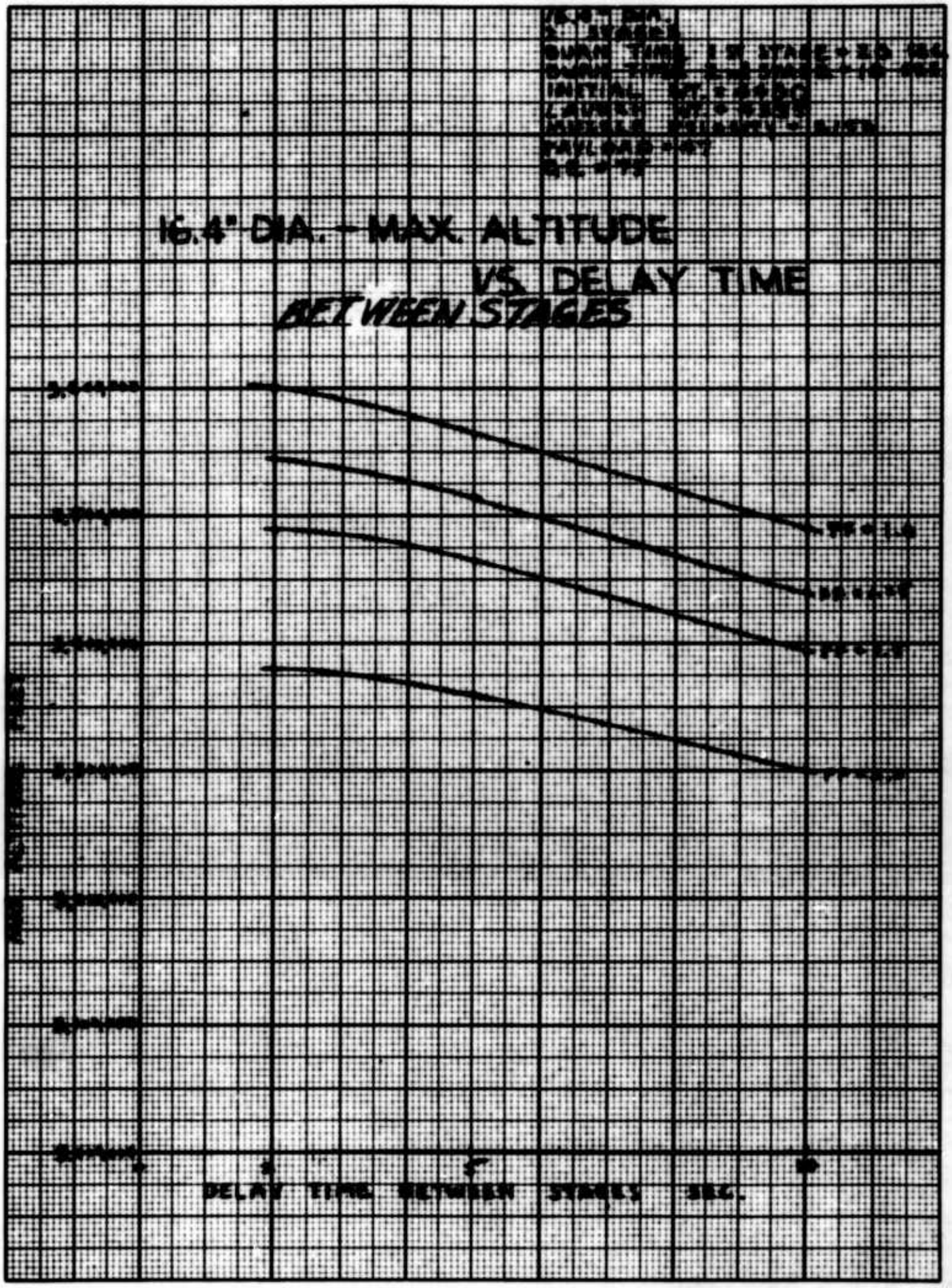

16.4" DIA. - MAX. ALTITUDE
VS. DELAY TIME
BETWEEN STAGES
DELAY TIME BETWEEN STAGES SEC.

FIGURE 63

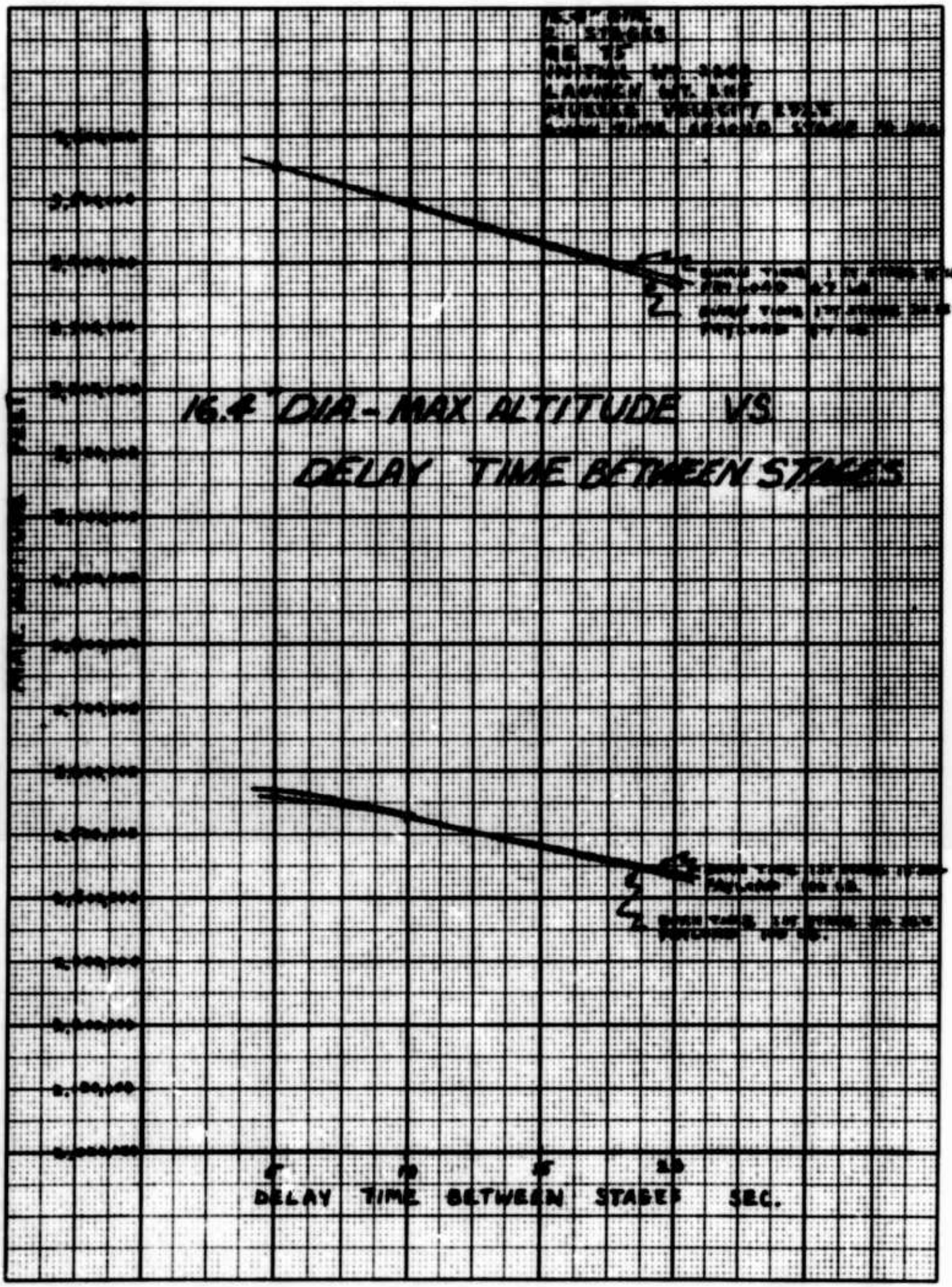

16.4 DIA-MAX ALTITUDE VS
DELAY TIME BETWEEN STAGES
DELAY TIME BETWEEN STAGES SEC.

FIG. 64

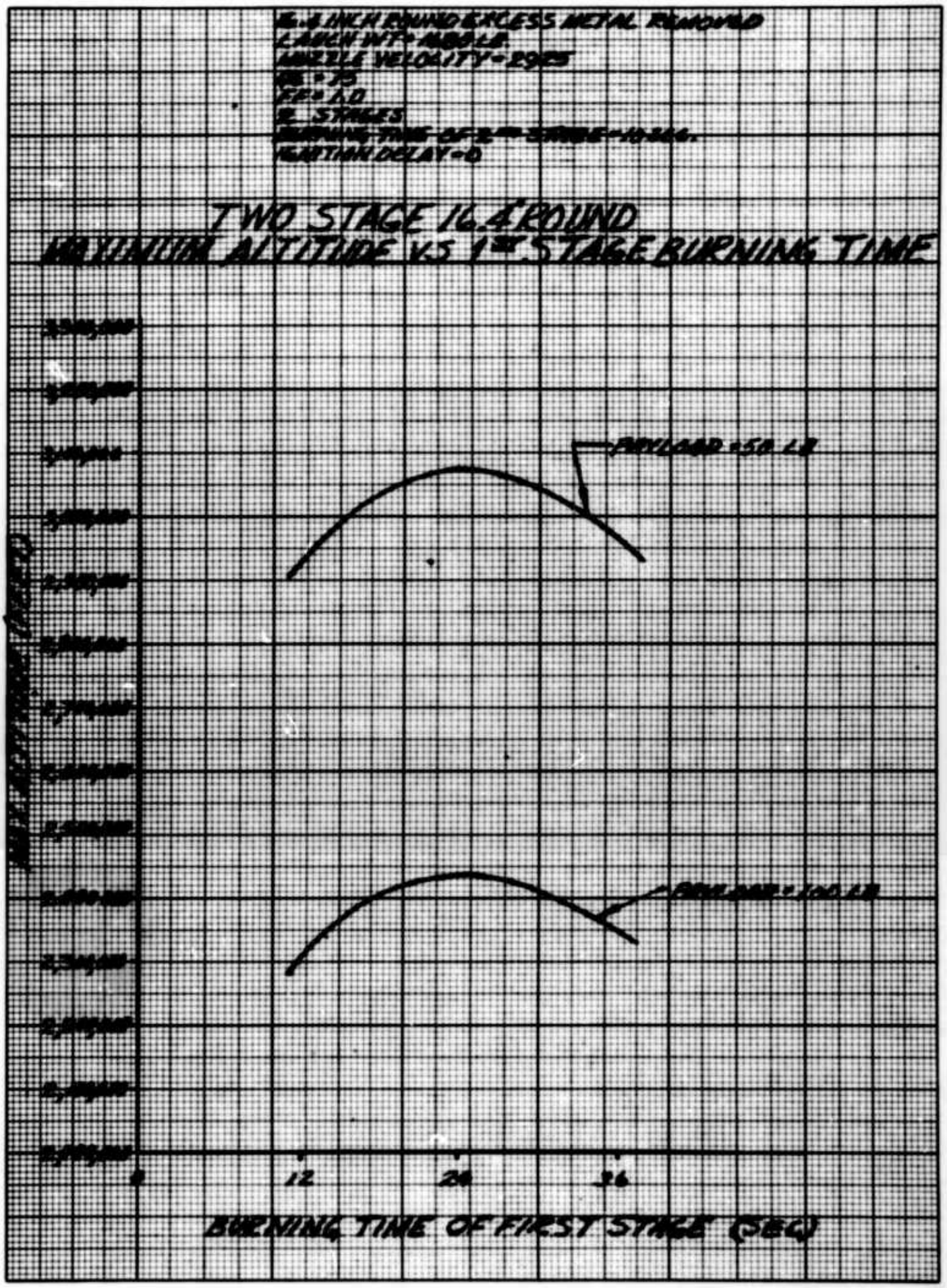

16.4 INCH ROUND EXCESS METAL REMOVED
LAUNCH ANGLE
NOZZLE VELOCITY - 2925
CD = .75
EE = 1.0
2 STAGES
IGNITION DELAY = 0
TWO STAGE 16.4 ROUND
MAXIMUM ALTITUDE VS 1ST STAGE BURNING TIME
PAYLOAD = 50 LB
PAYLOAD = 100 LB
12
24
36
BURNING TIME OF FIRST STAGE (SEC)

FIG. 67

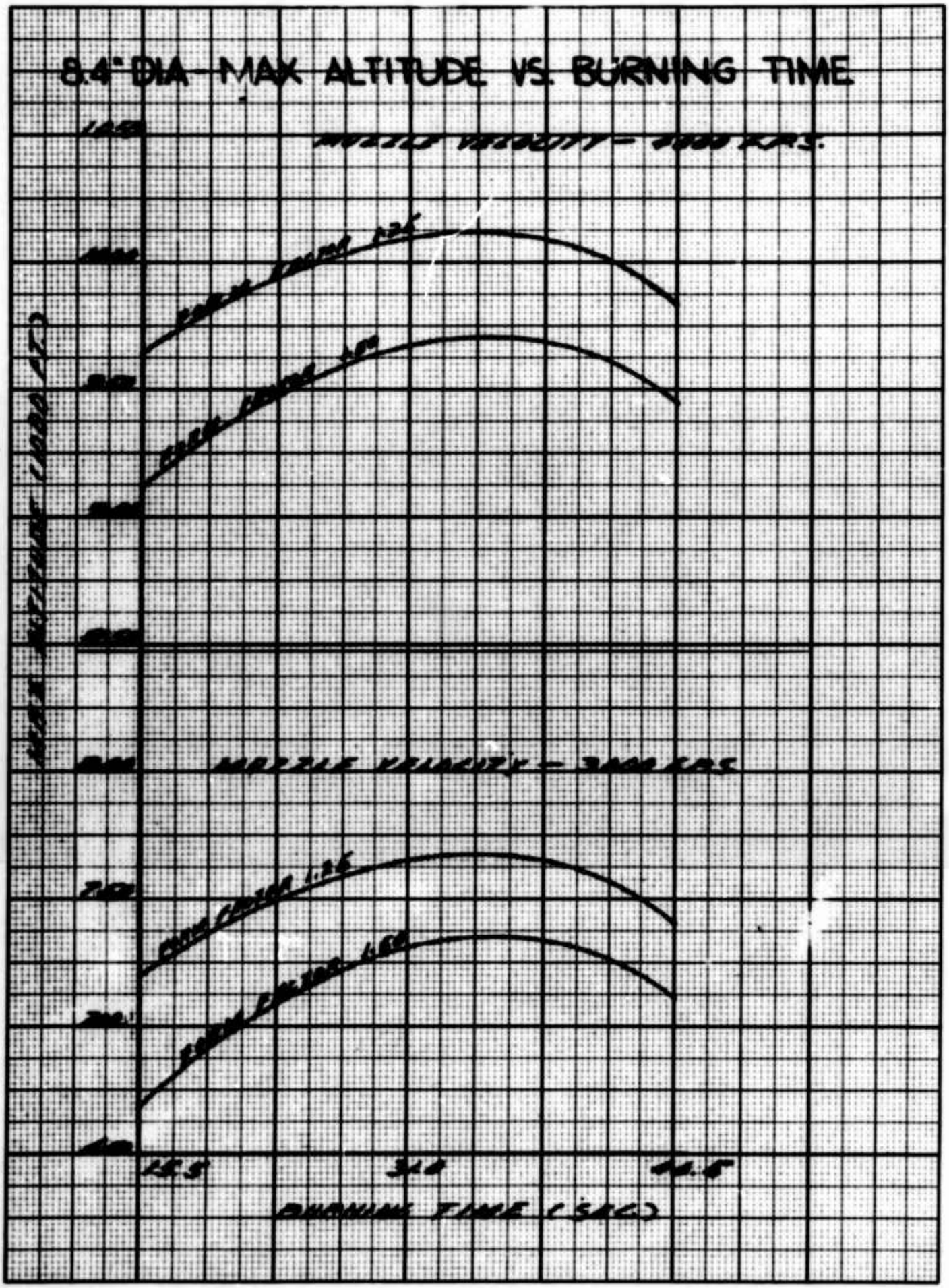

8.4" DIA - MAX ALTITUDE VS. BURNING TIME
MAXIMUM ALTITUDE (1000 FT)
BURNING TIME (SEC)

FIGURE 68

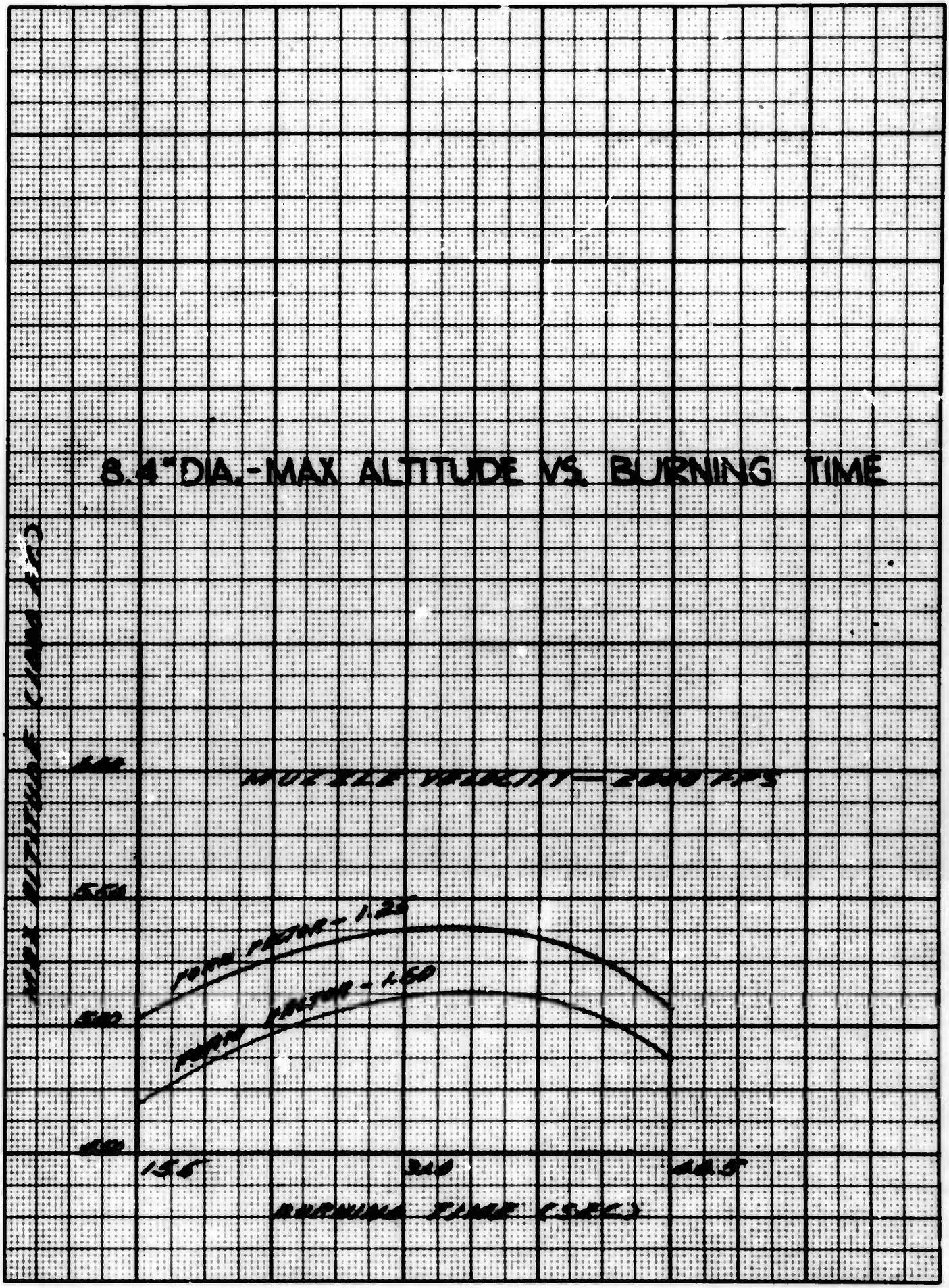
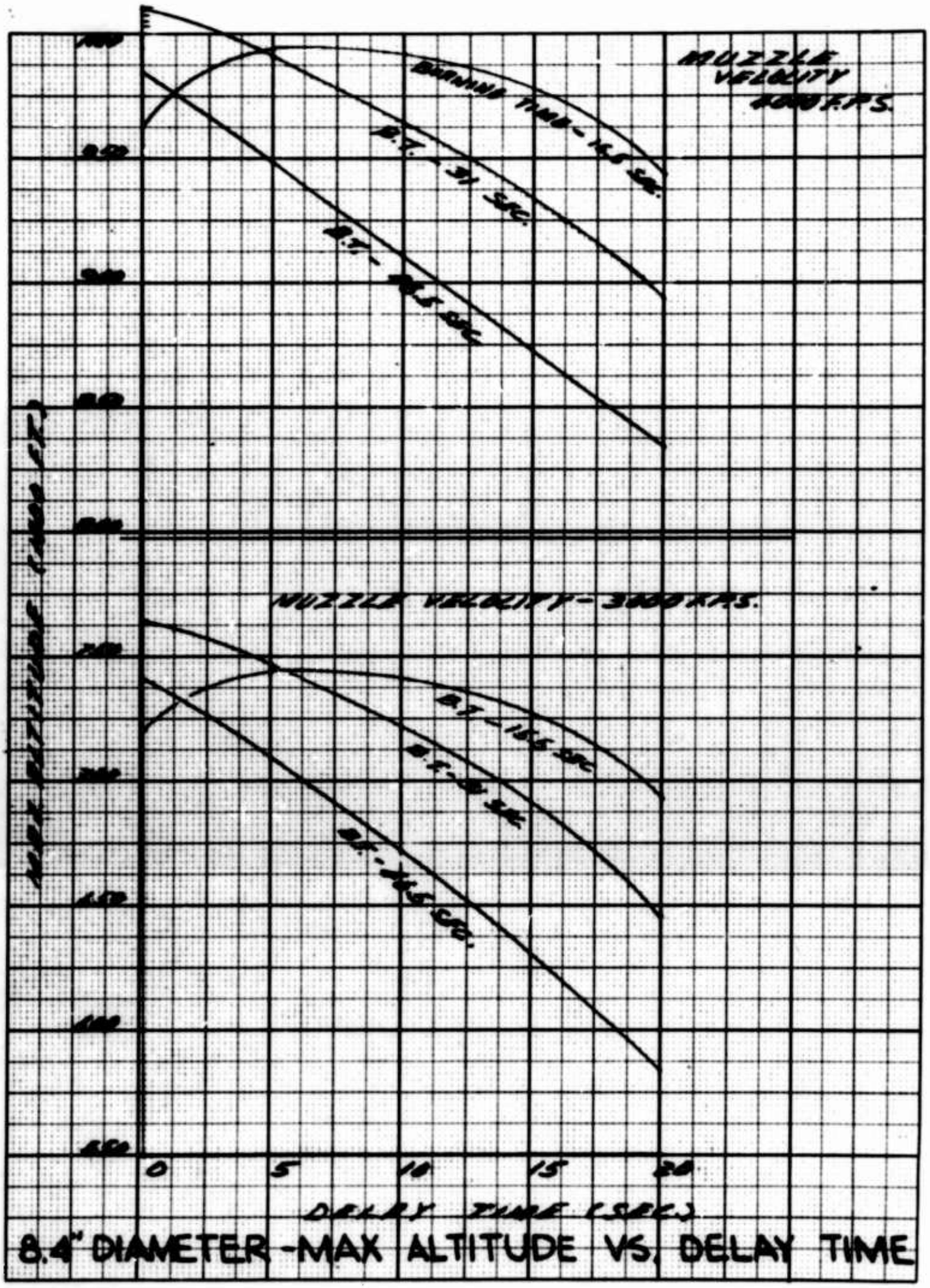

8.4" DIA. - MAX ALTITUDE VS. BURNING TIME
MAXIMUM ALTITUDE (FT)
MAXIMUM VELOCITY = 2500 FPS
PROPELLANT PRESSURE - 1.25
PROPELLANT PRESSURE - 1.50
1.5
3.0
4.5
BURNING TIME (SEC.)

FIGURE 69



8.4" DIAMETER - MAX ALTITUDE VS. DELAY TIME

FIGURE 70

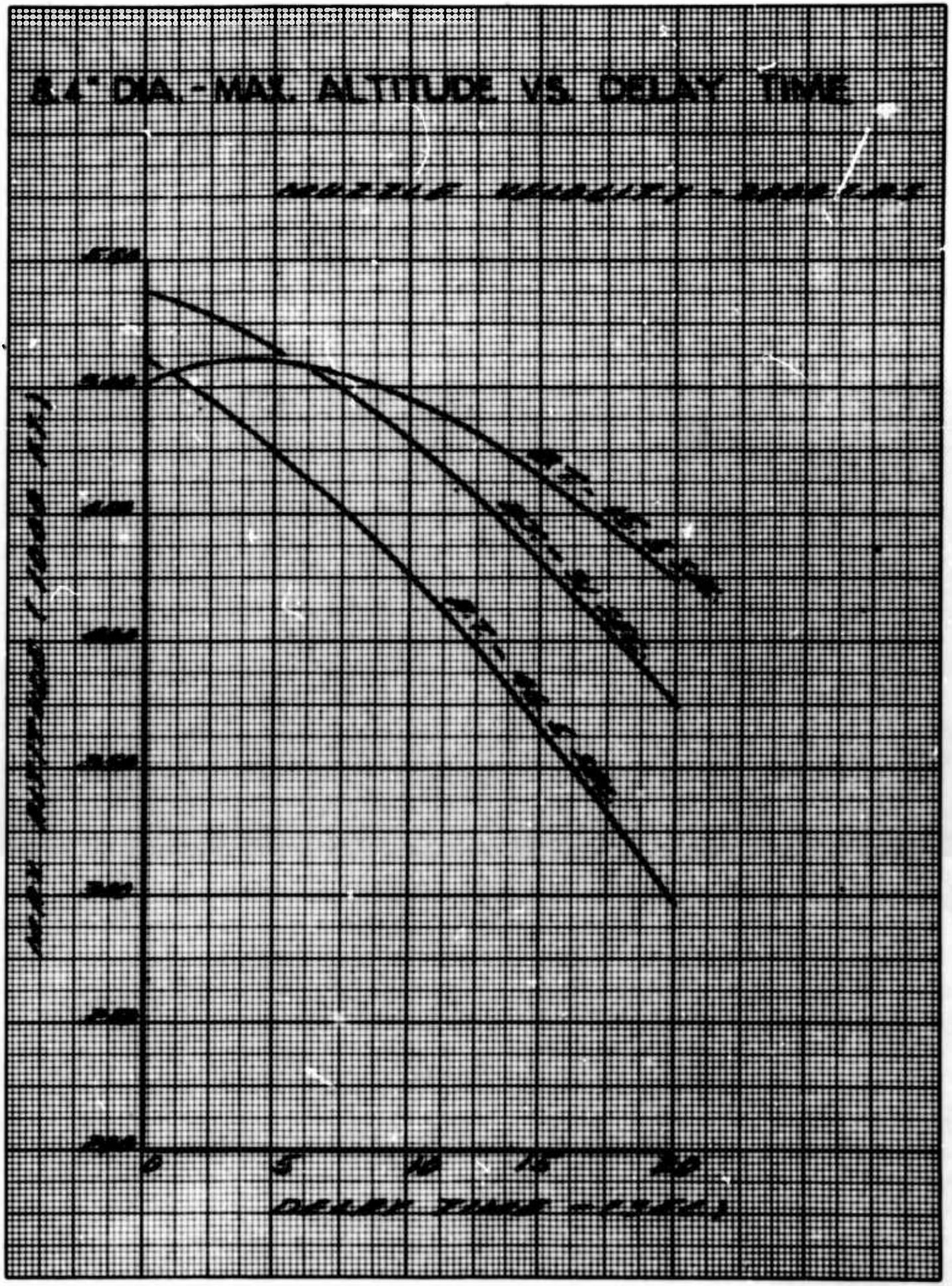


FIGURE 71

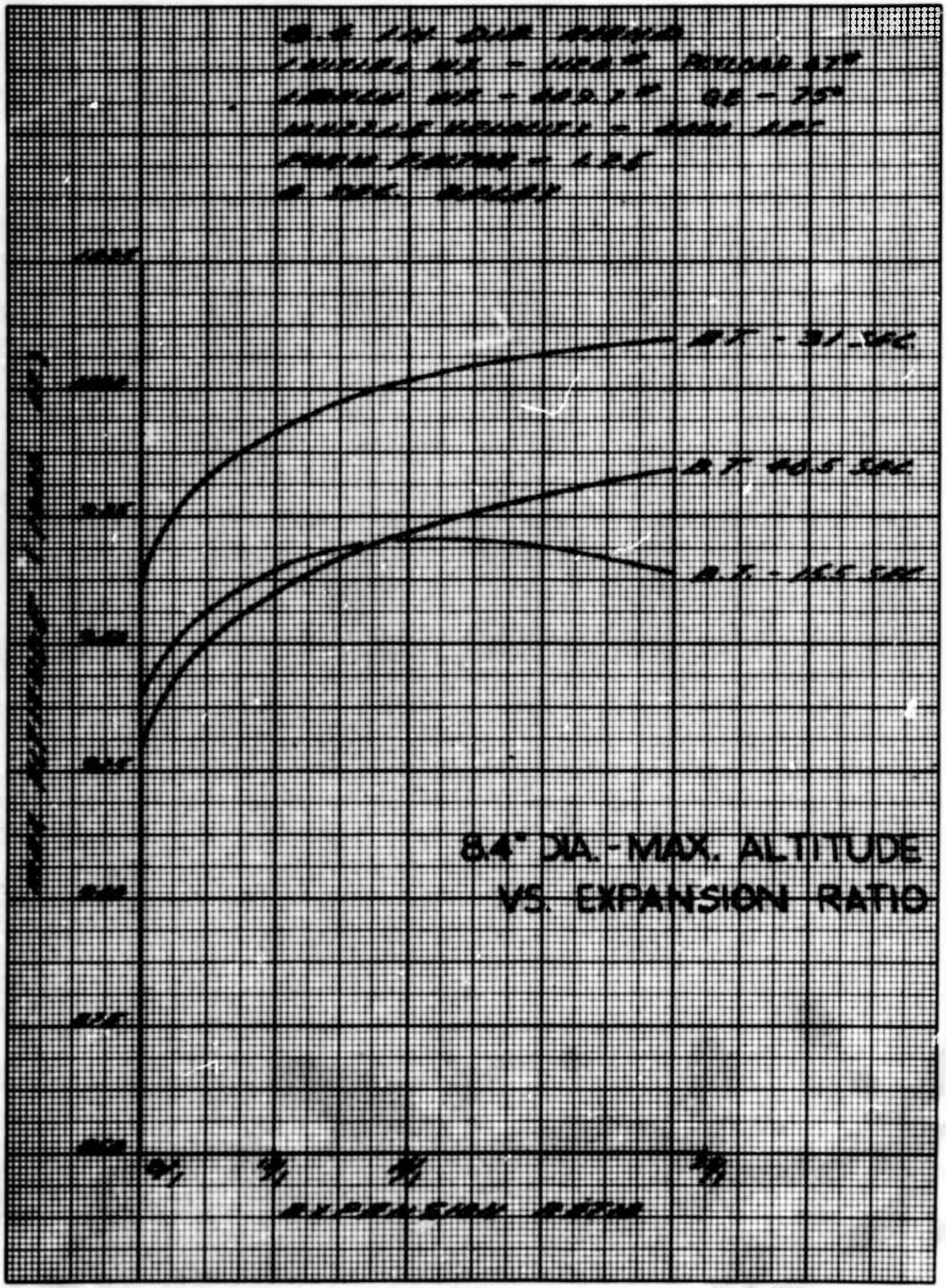


FIGURE 72

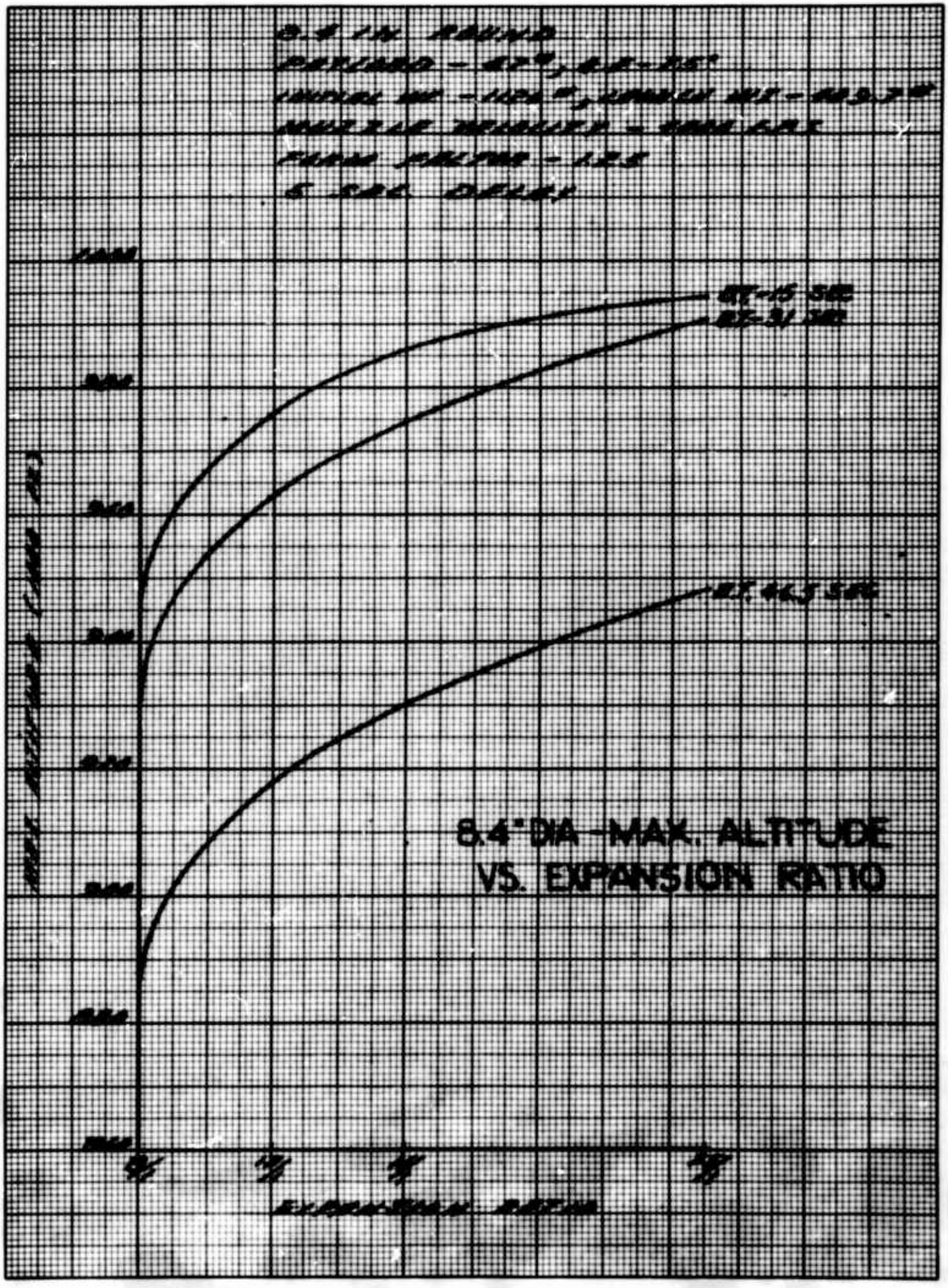


FIGURE 73

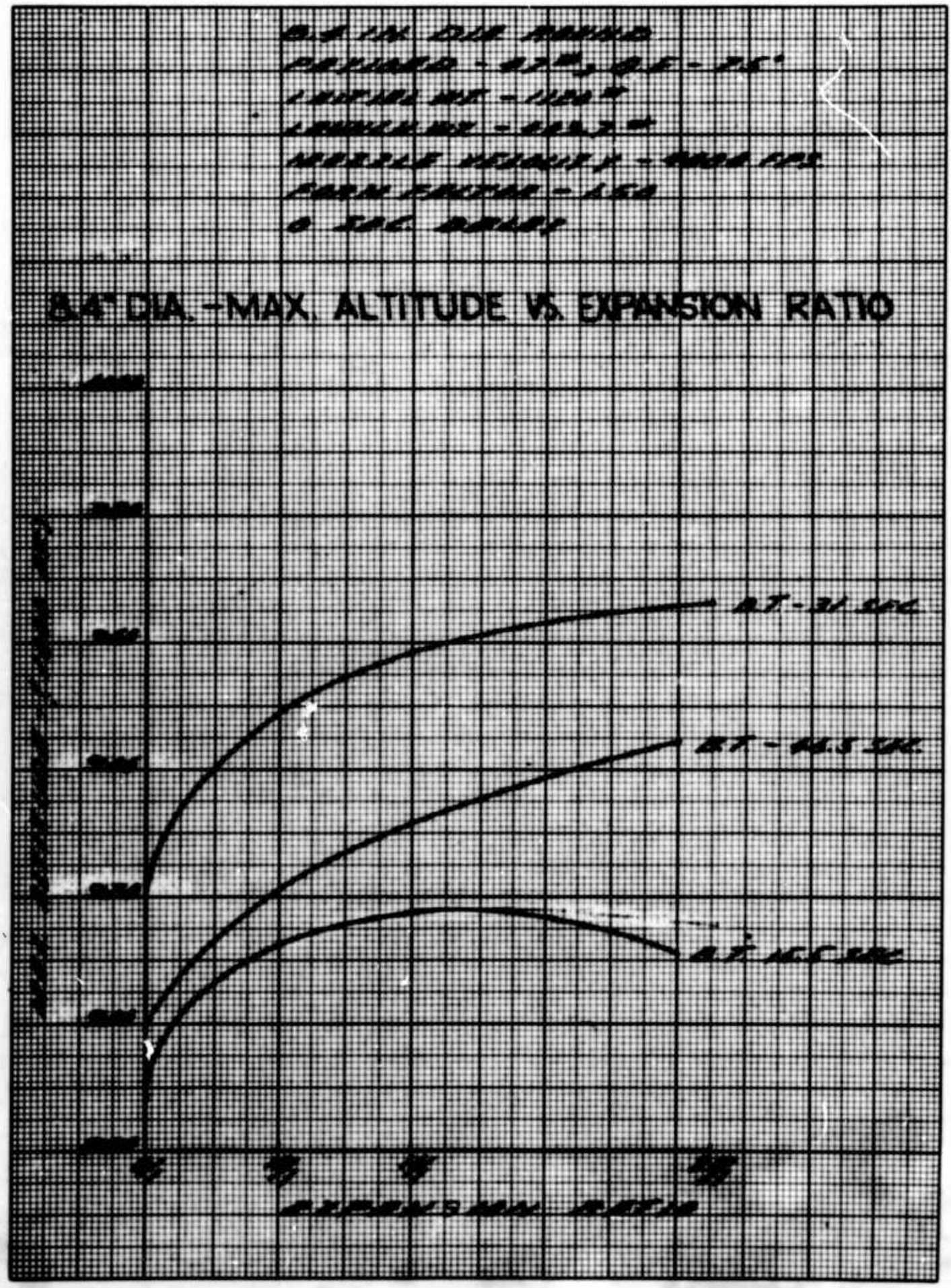


FIGURE 74

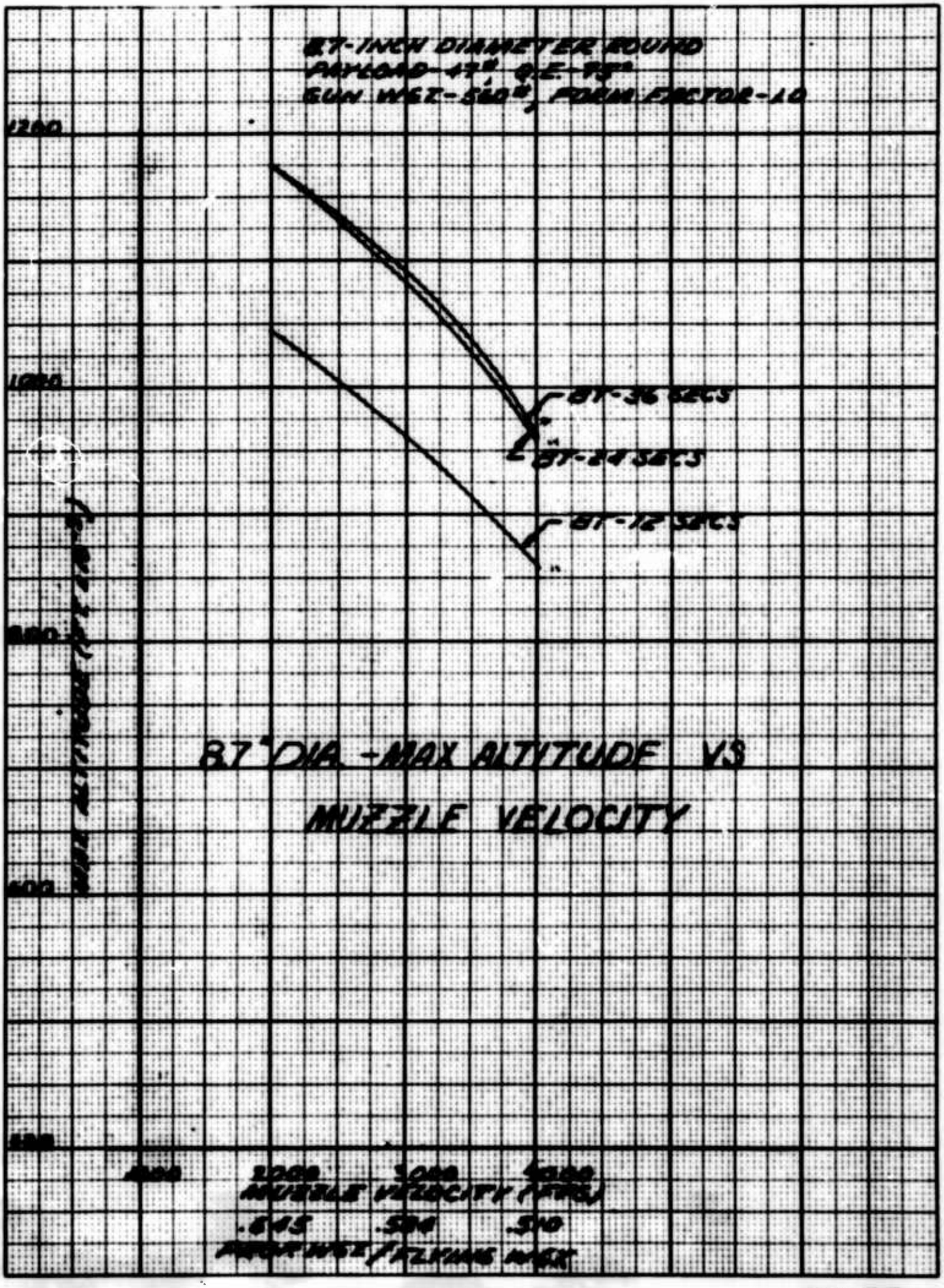

87-INCH DIAMETER ROUND
PAYLOAD-47# Q.E. 95°
GUN WGT-560# FORM FACTOR-1.0
87-36 SECS
87-24 SECS
87-12 SECS
87" DIA - MAX ALTITUDE VS
MUZZLE VELOCITY
MUZZLE VELOCITY (FPS)
.615
.504
.510

FIG. 75

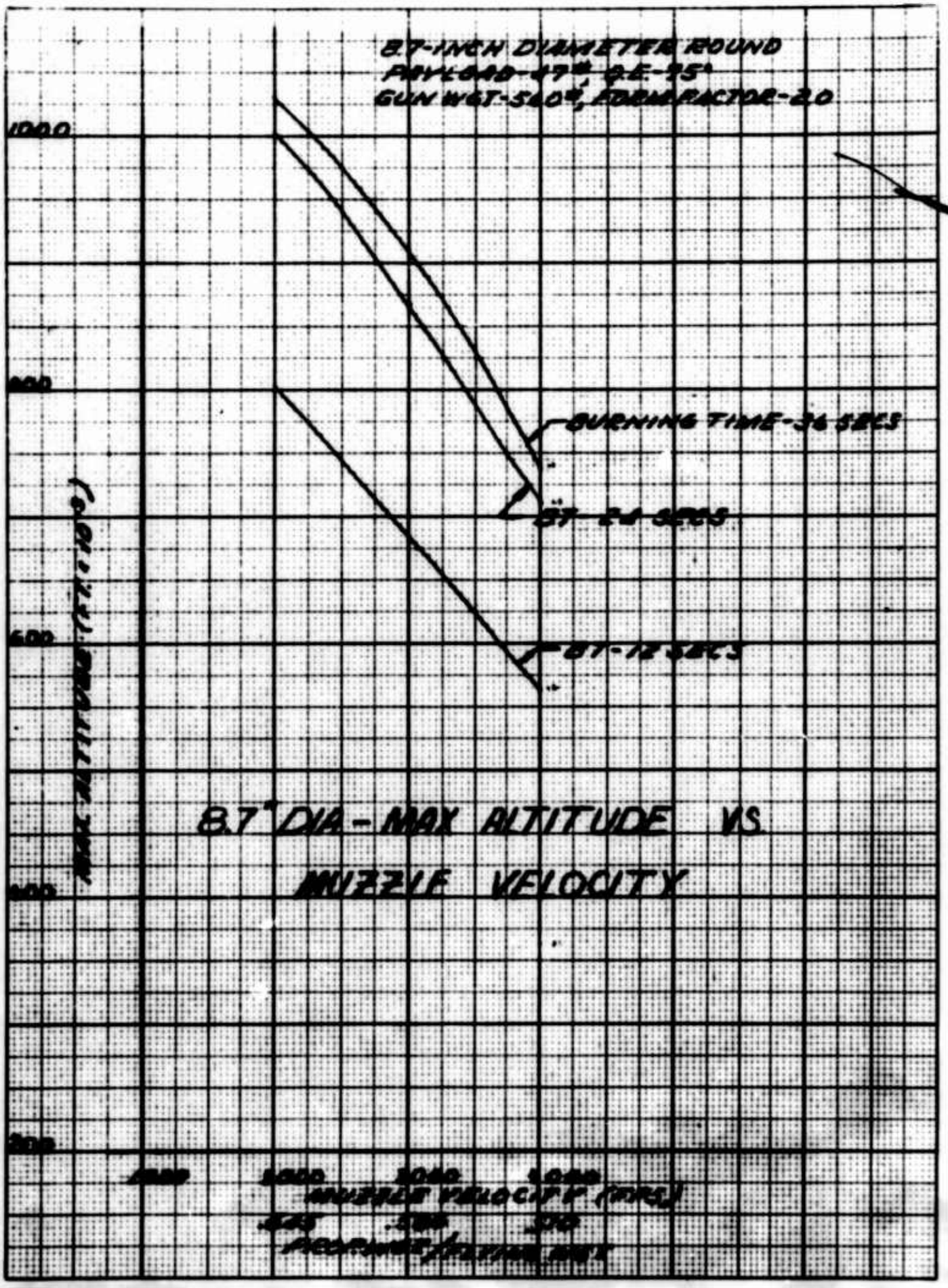

8.7-INCH DIAMETER ROUND
PAYLOAD-47#, B.E.-95
GUN WGT-560#, ADAM RACTOR-2.0
BURNING TIME-36 SECS
37-24 SECS
37-12 SECS
MAX ALTITUDE (FEET)
1000
800
600
400
200
8.7" DIA - MAX ALTITUDE VS
MUZZLE VELOCITY
MUZZLE VELOCITY (FPS)

FIG. 76

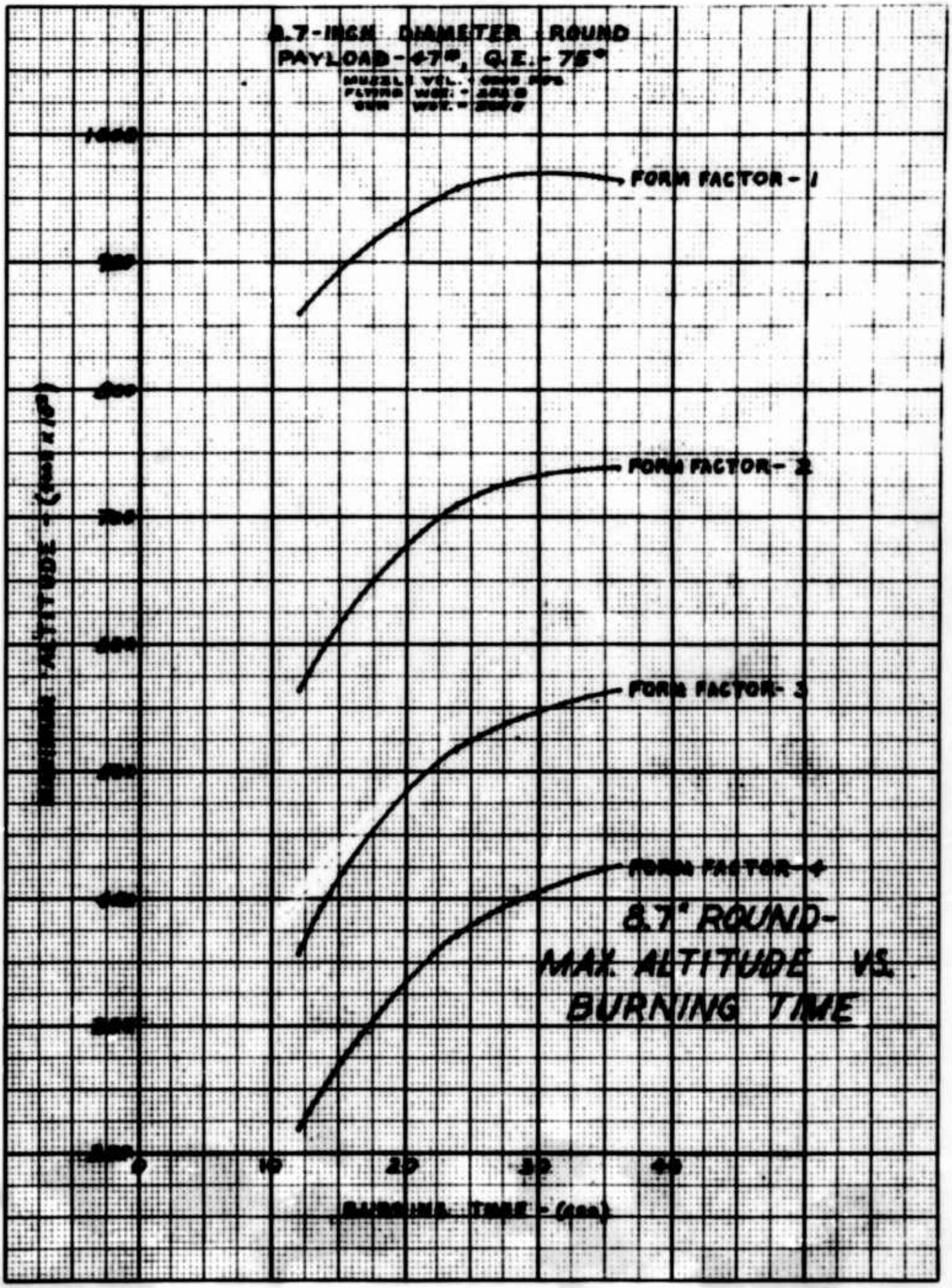

8.7-INCH DIAMETER ROUND
PAYLOAD - 47#, Q.E. - 75°
FORM FACTOR - 1
FORM FACTOR - 2
FORM FACTOR - 3
FORM FACTOR - 4
8.7" ROUND -
MAX. ALTITUDE VS.
BURNING TIME
0
10
20
30
40

FIG. 77

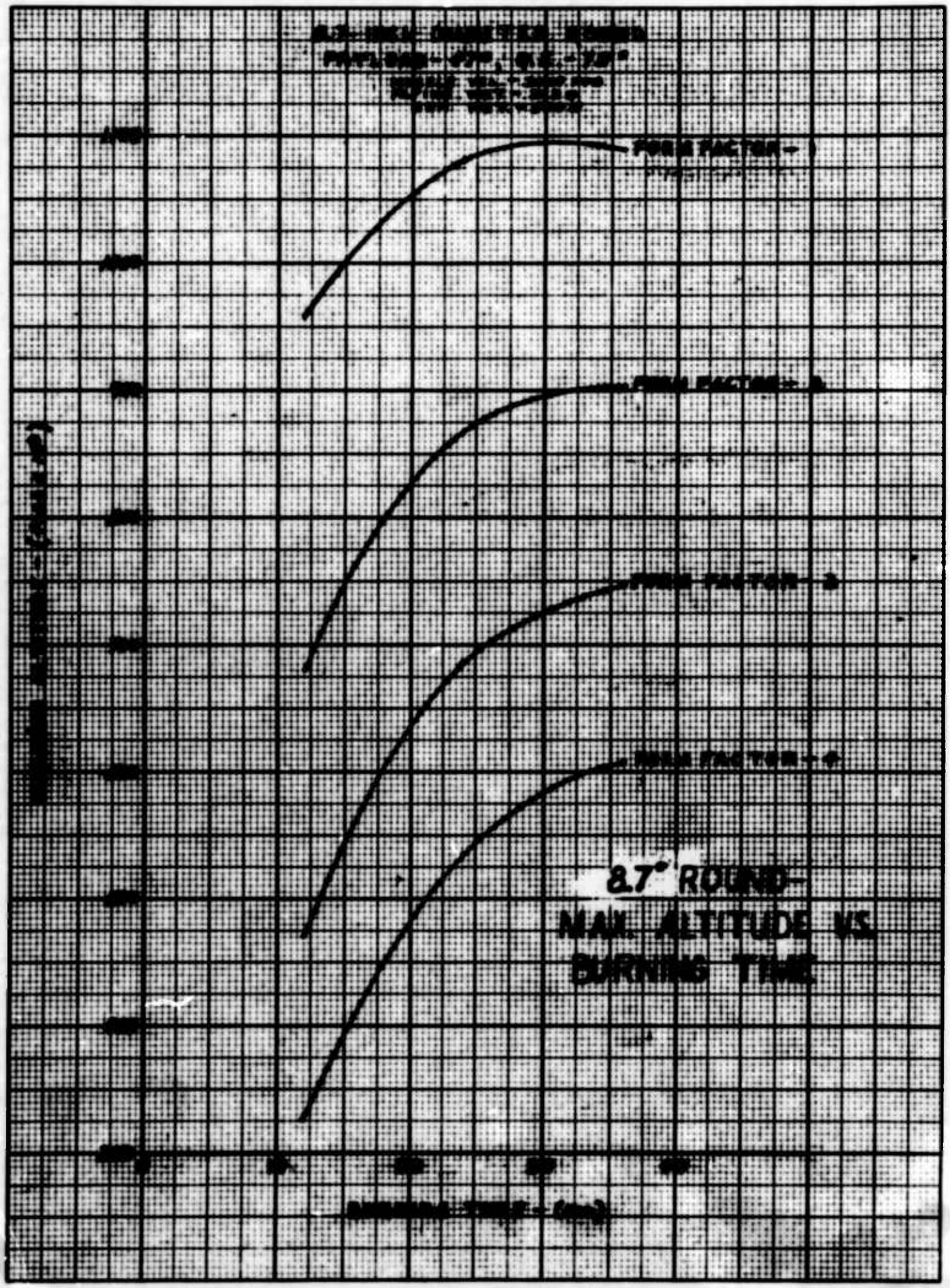
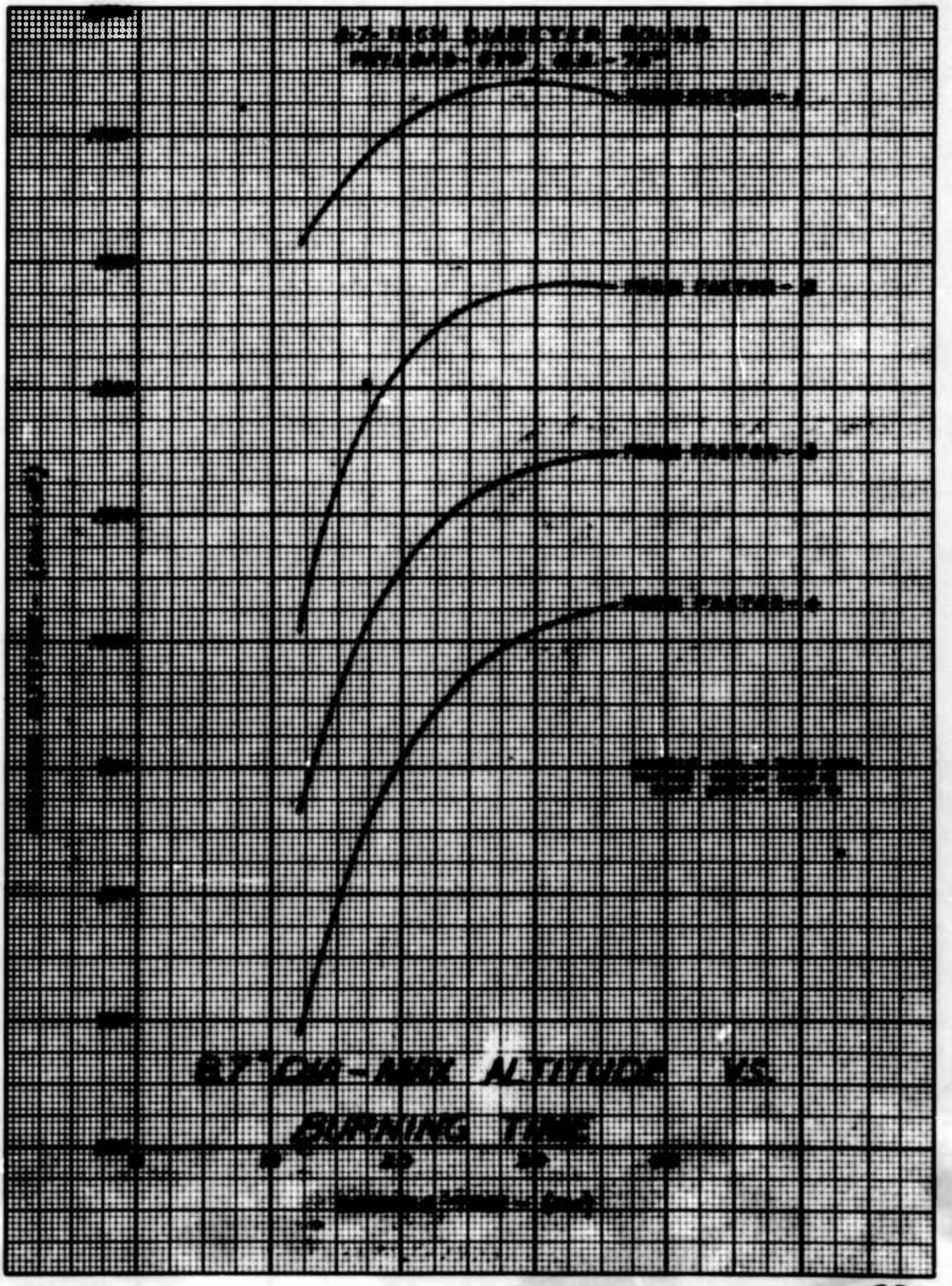
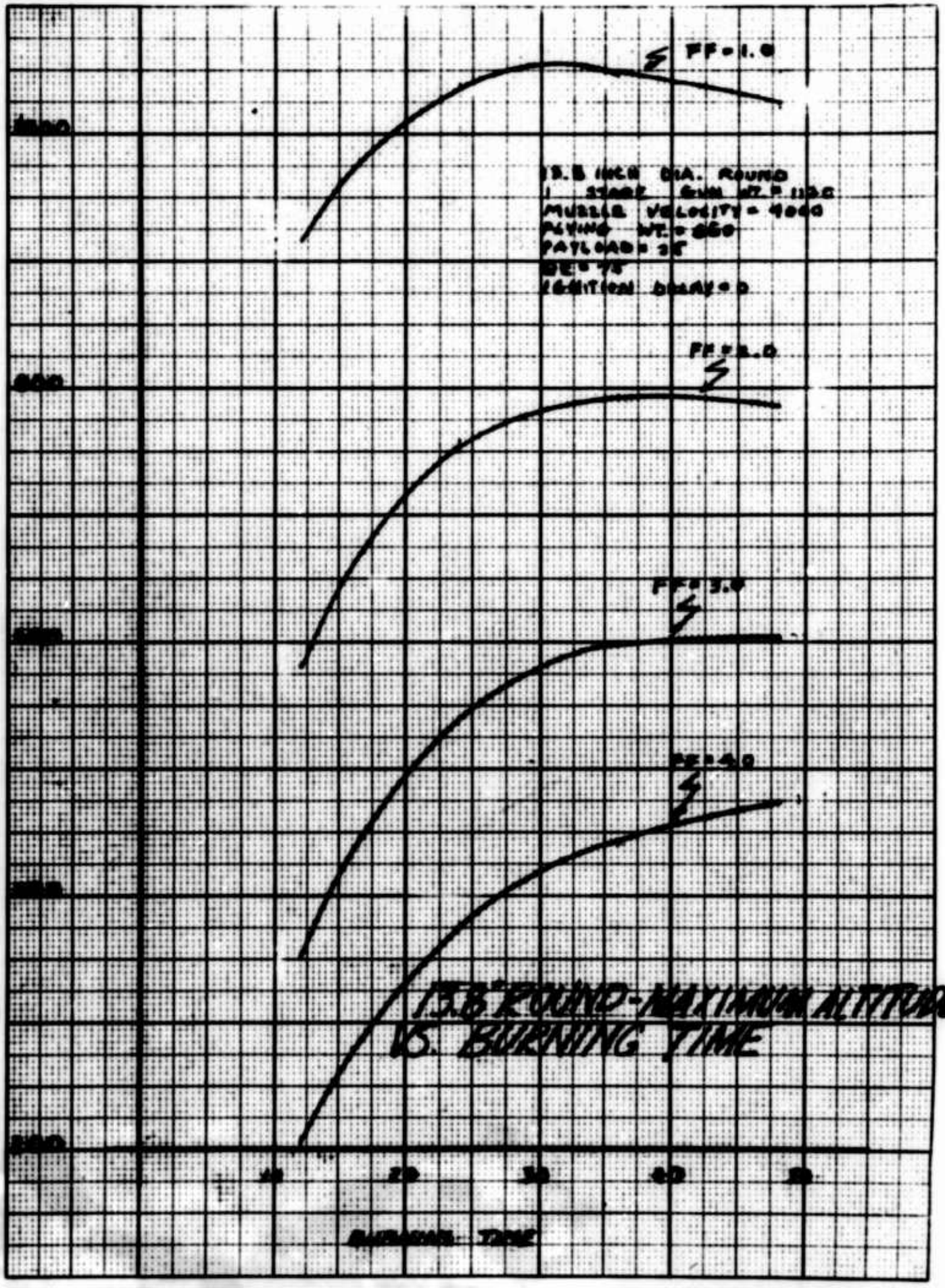


FIG. 78



F16. 80



13.5 ROUND - MAXIMUM ALTITUDE VS. BURNING TIME

FIG. 81

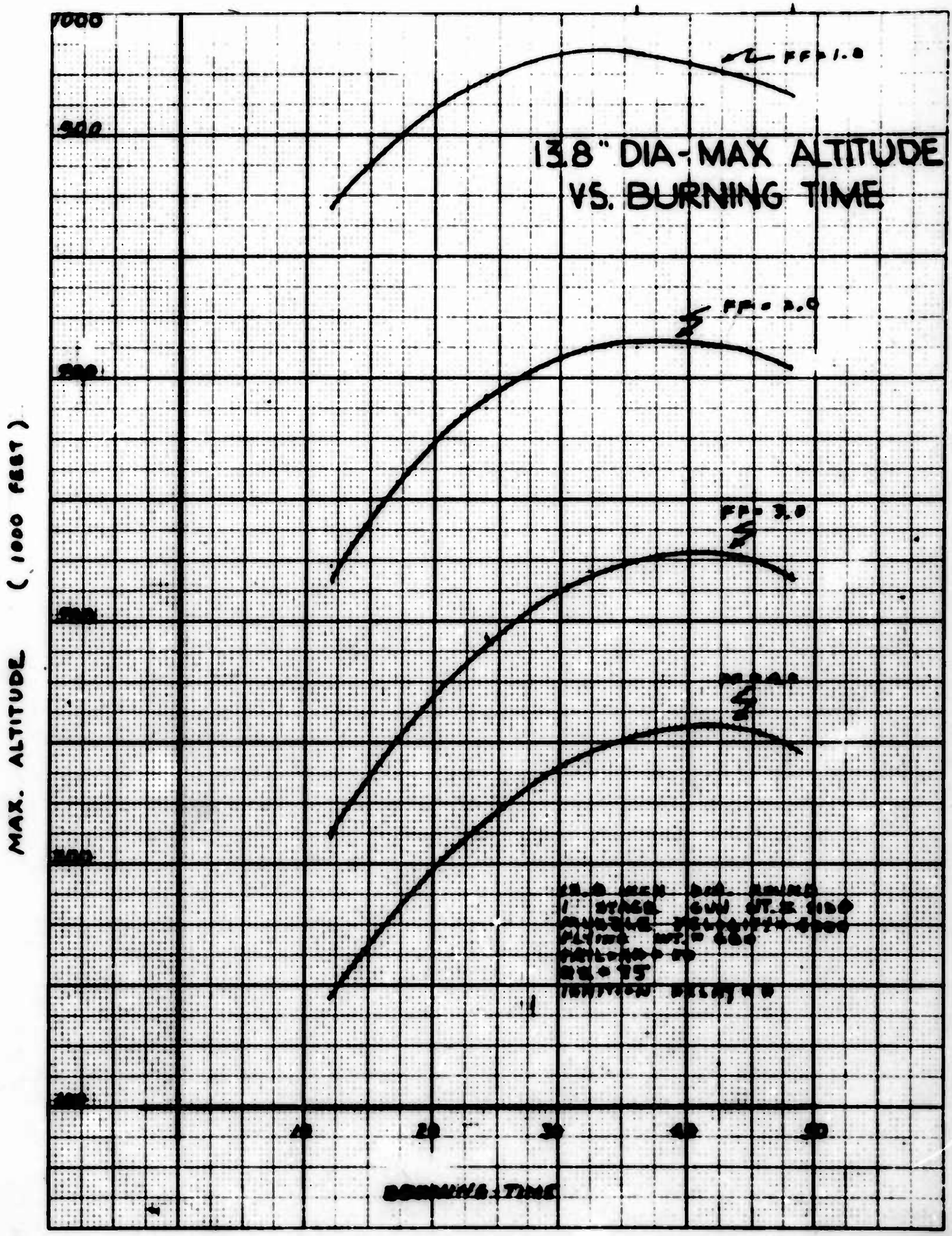

13.8" DIA - MAX ALTITUDE
VS. BURNING TIME
MAX. ALTITUDE (1000 FEET)
BURNING TIME

FIGURE 82

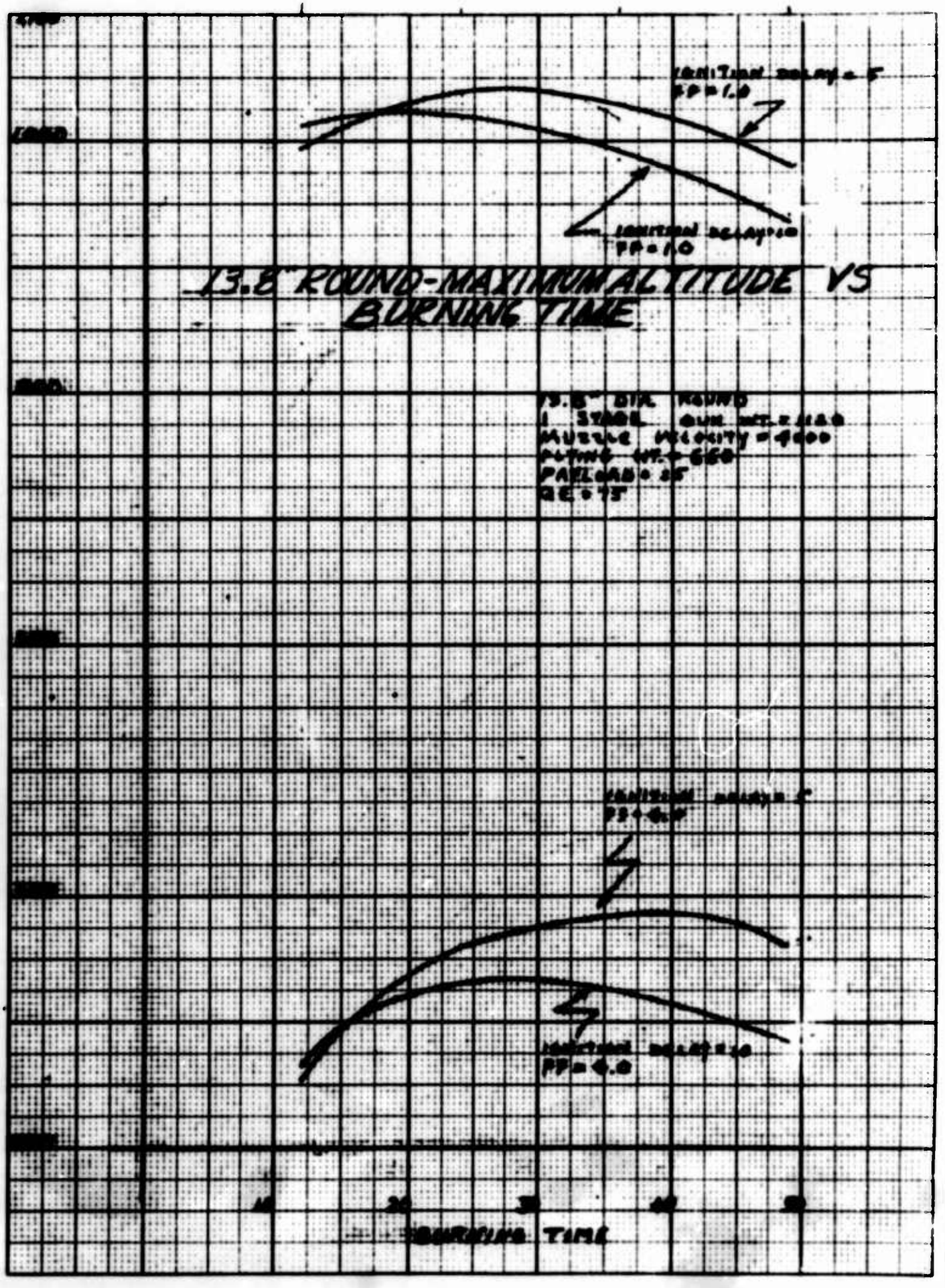

13.6" ROUND-MAXIMUM ALTITUDE VS BURNING TIME
MAX. ALTITUDE (1000 FEET)
BURNING TIME

FIG. 83

FIG. 84

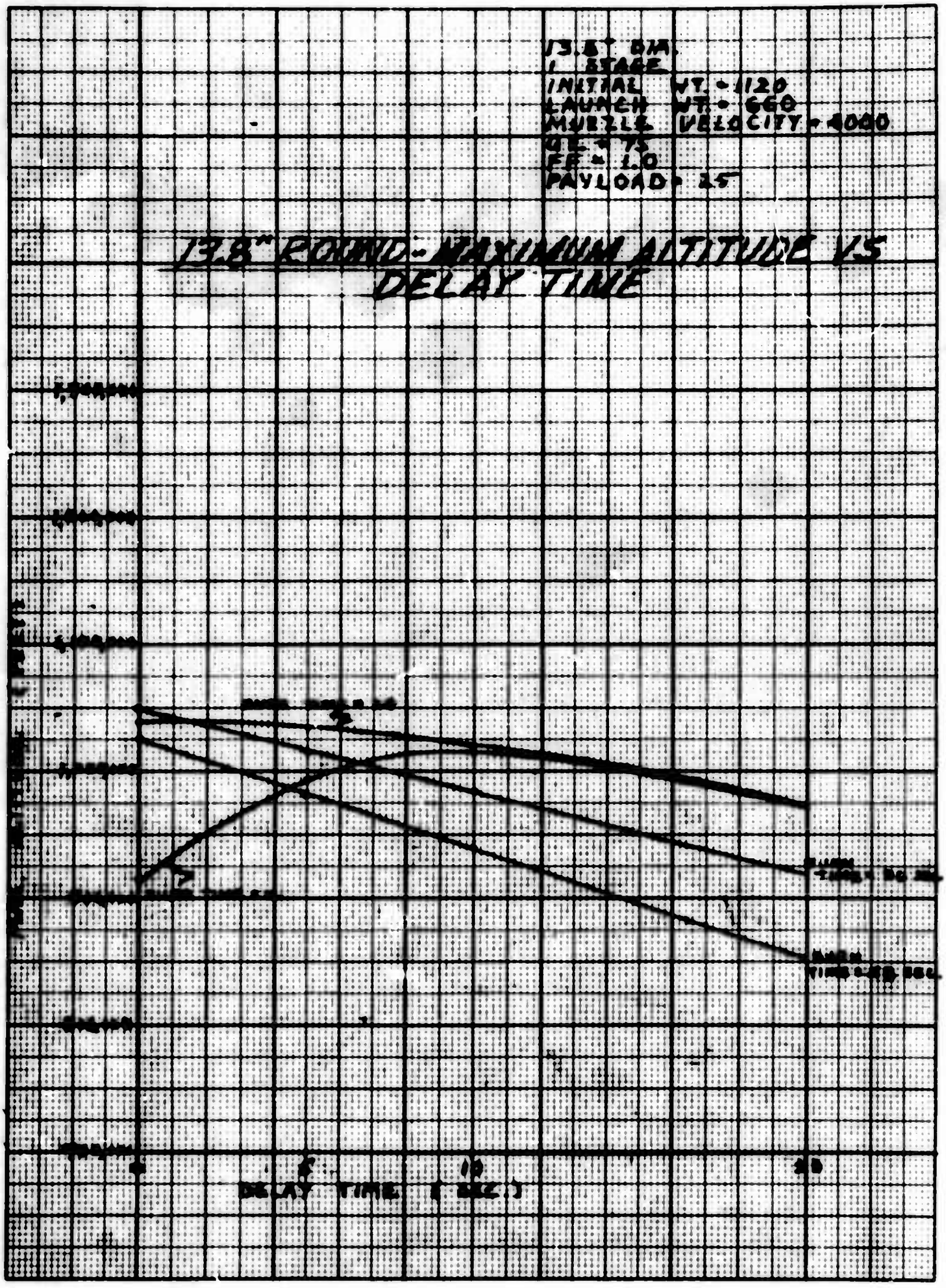

13.8 CM.
1 STAGE
INITIAL WT. = 1120
LAUNCH WT. = 660
MUZZLE VELOCITY = 4000
CE. = .75
FF = 1.0
PAYLOAD = 25
13.8" ROUND - MAXIMUM ALTITUDE VS DELAY TIME
DELAY TIME (SEC.)

FIG. 85

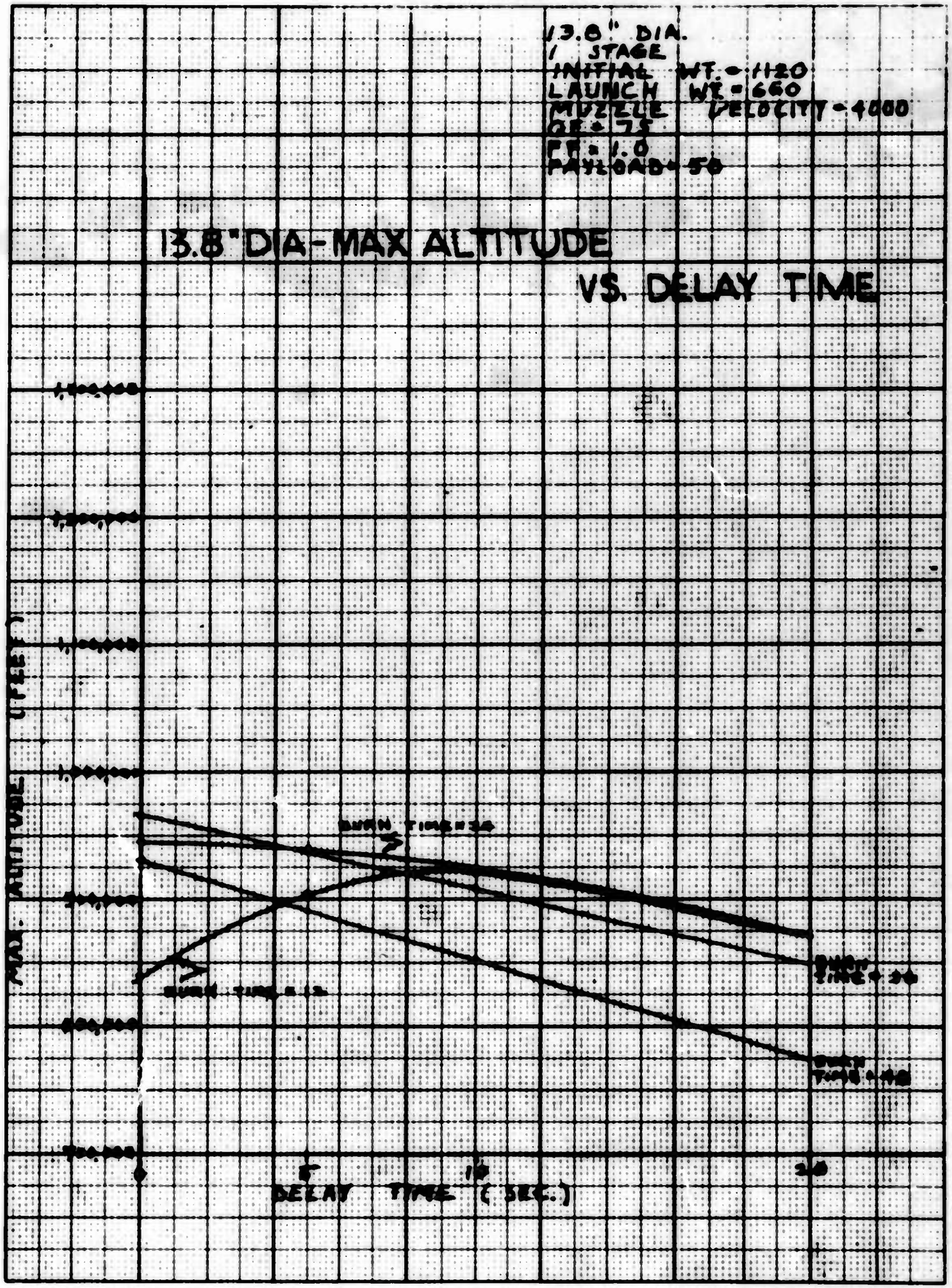
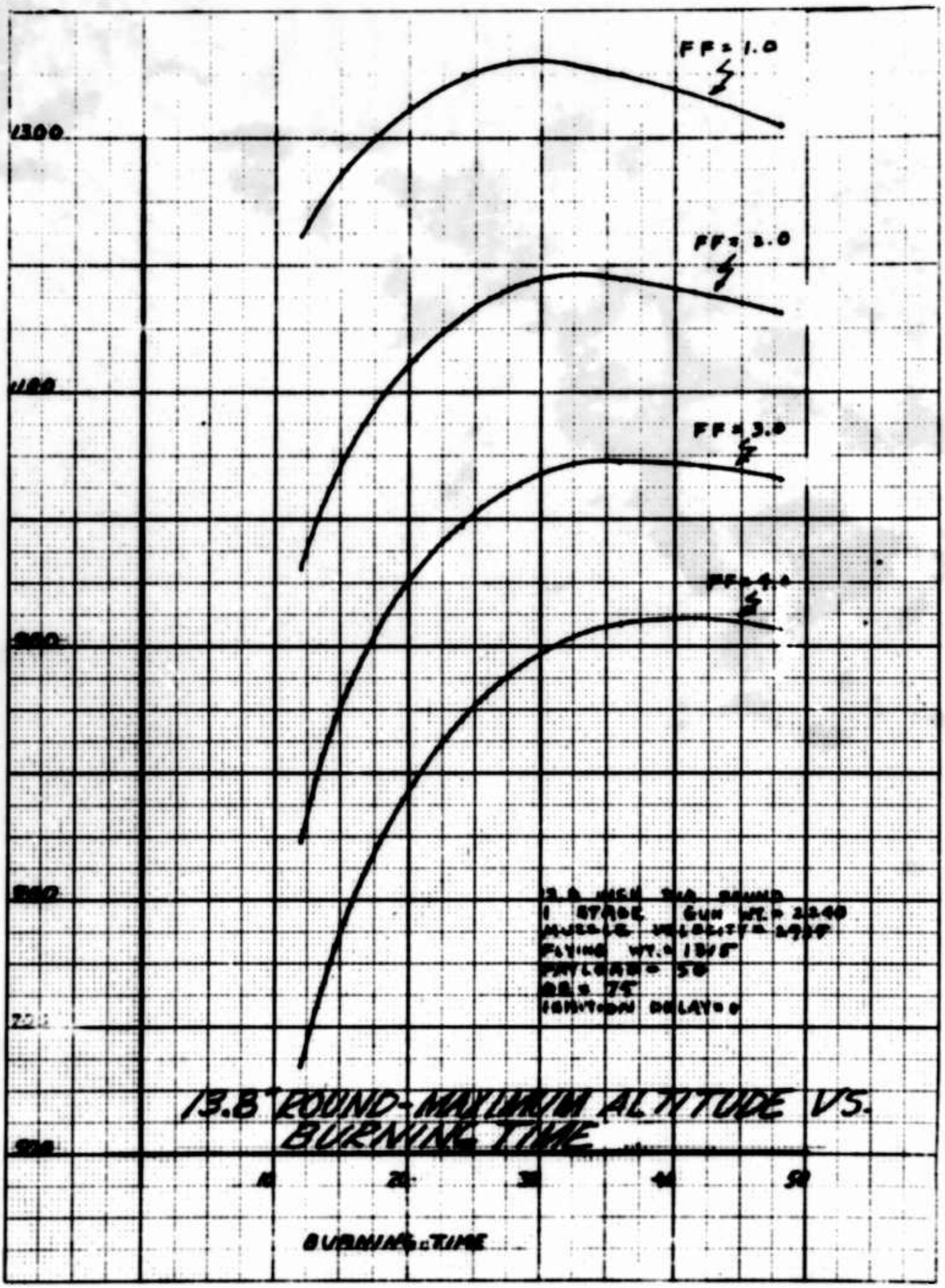

13.8" DIA.
1 STAGE
INITIAL WT. = 1120
LAUNCH WT. = 660
MUZZLE VELOCITY = 4000
CE = .75
FF = 1.0
PAYLOAD = 50
13.8" DIA - MAX ALTITUDE
VS. DELAY TIME
MAX. ALTITUDE (FEET)
DELAY TIME (SEC.)

FIGURE 86



13.8 ROUND-MAXIMUM ALTITUDE VS. BURNING TIME

FIG. 87

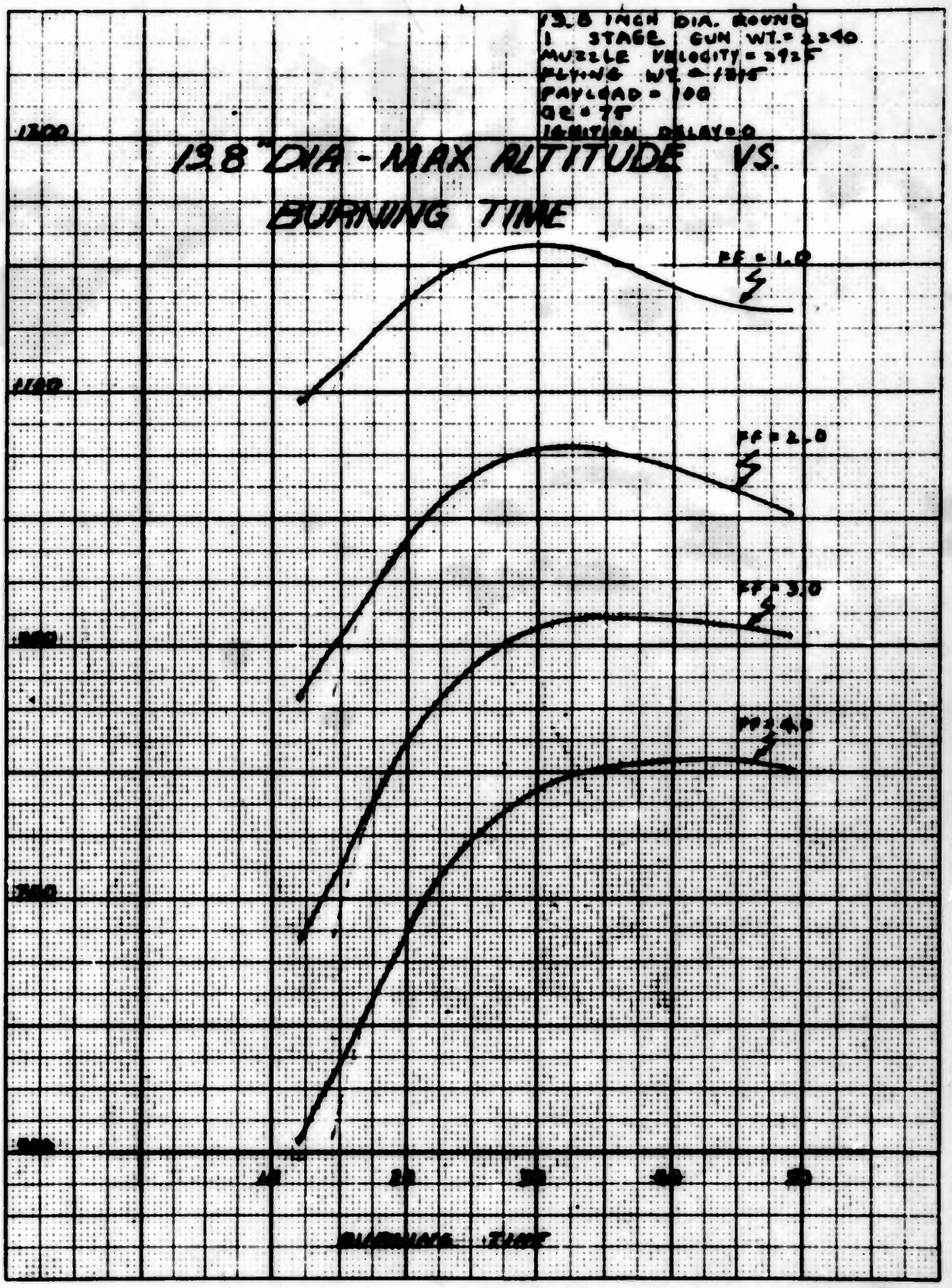

13.8 INCH DIA. ROUND
1 STAGE GUN WT. = 2240
MUZZLE VELOCITY = 2925
FLYING WT. = 1815
PAYLOAD = 100
QE = 75°
IGNITION DELAY = 0
13.8" DIA - MAX ALTITUDE VS.
BURNING TIME
FF = 1.0
FF = 2.0
FF = 3.0
FF = 4.0
MAX. ALTITUDE (1000 FEET)
BURNING TIME

FIG 88

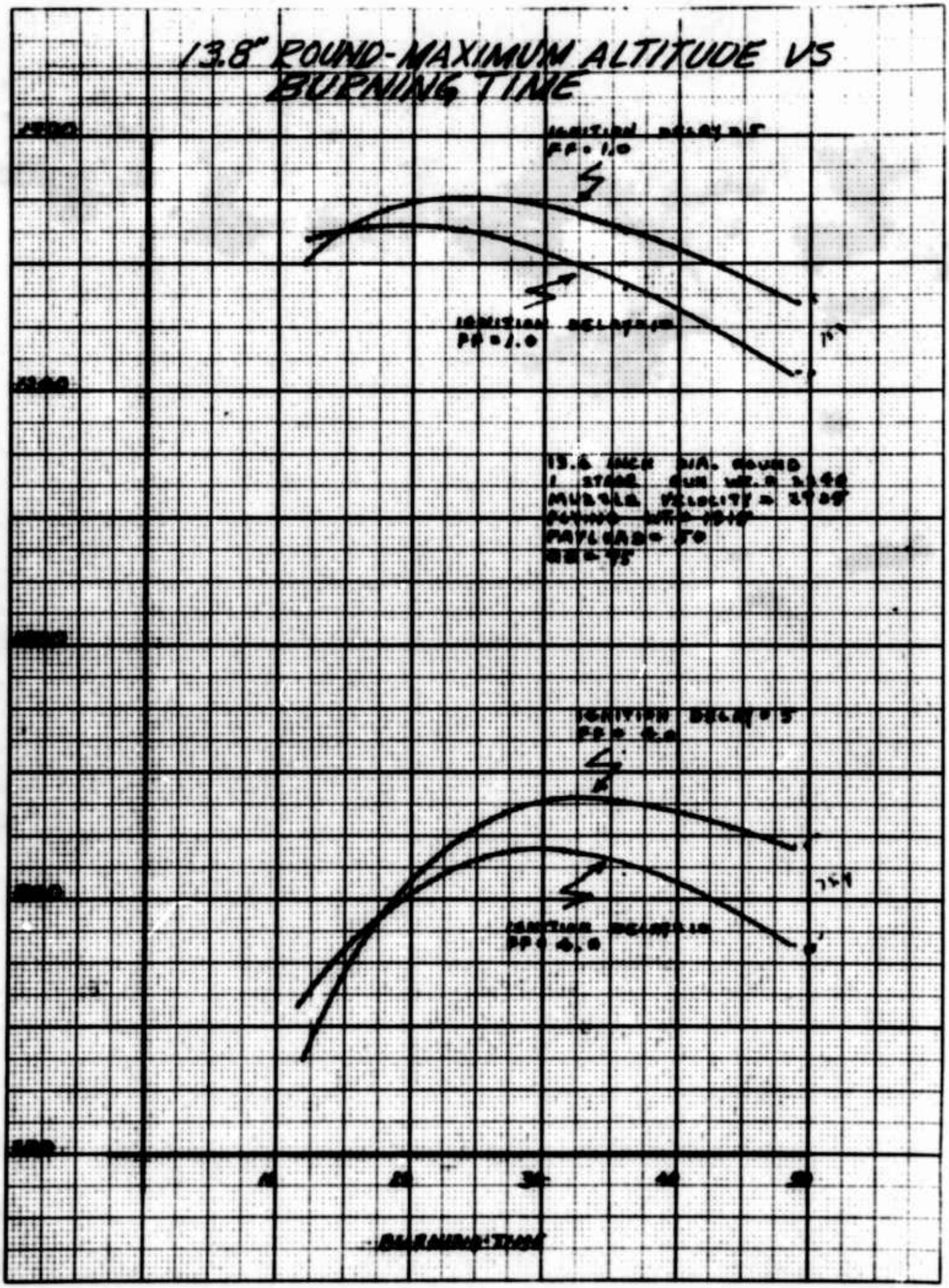

13.8" ROUND-MAXIMUM ALTITUDE VS BURNING TIME
MAX. ALTITUDE (1000 FEET)

FIG. 89

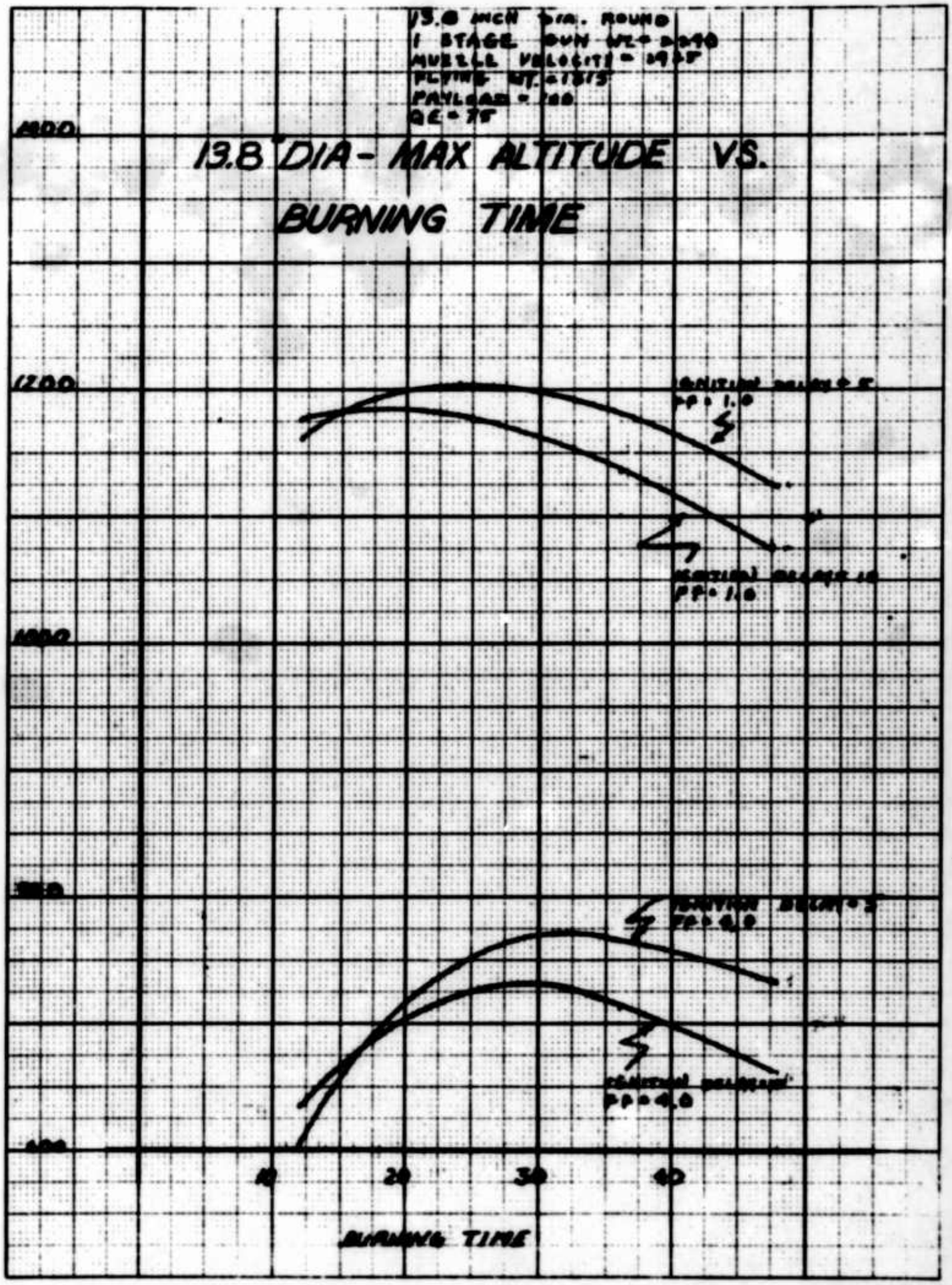

13.8 INCH DIA. ROUND
1 STAGE GUN WT. = 2,240
MUZZLE VELOCITY = 1925
FLYING WT. = 1315
PAYLOAD = 100
QE = 75°
13.8 DIA - MAX ALTITUDE VS.
BURNING TIME
MAX. ALTITUDE (1000 FEET)
BURNING TIME
10
20
30
40

FIG. 90

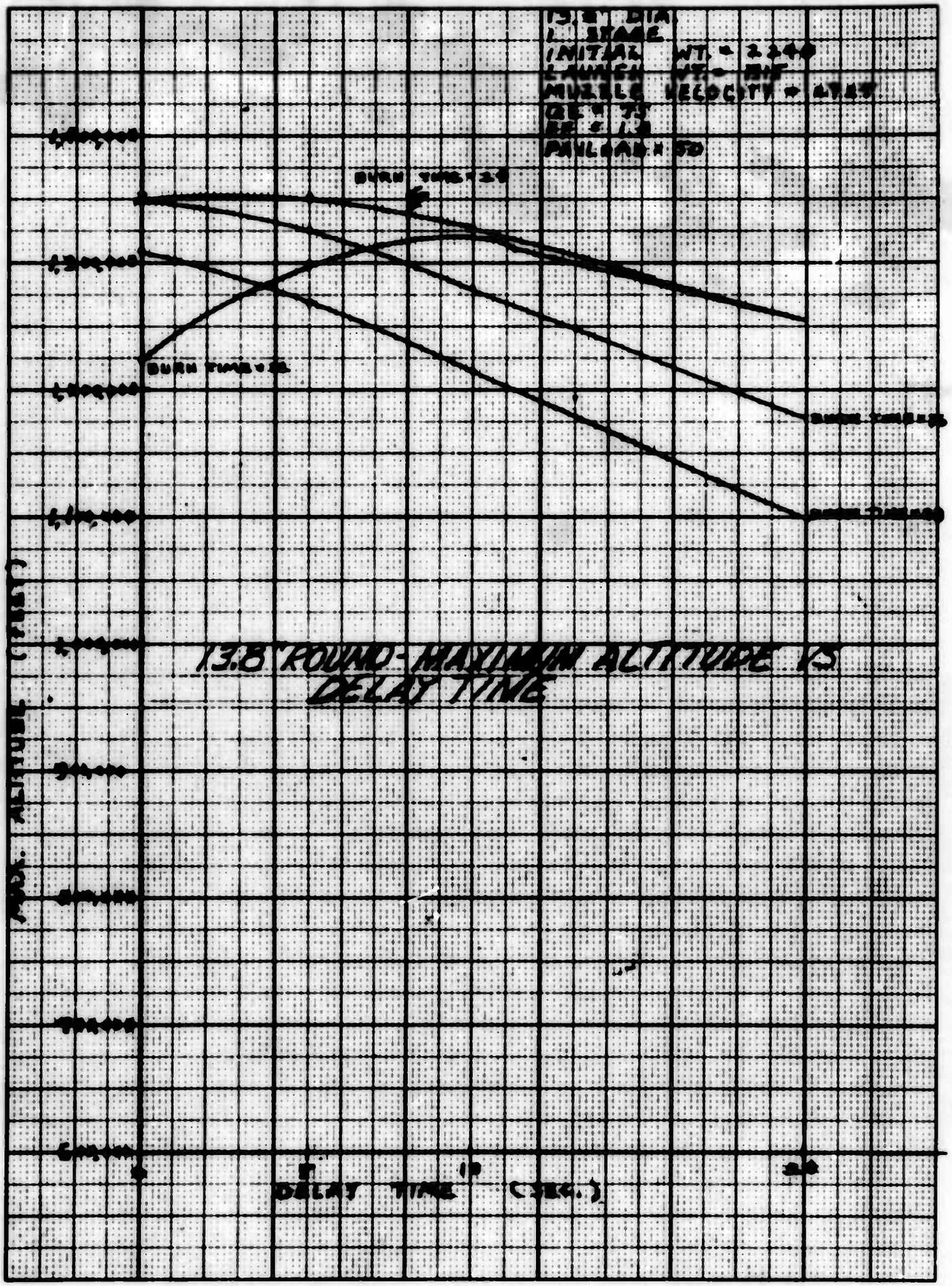

13.8 DIA
1 STAGE
INITIAL WT = 2240
MUZZLE VELOCITY = 4765
CD = .75
PAYLOAD = 50
BURN TIME = 24
BURN TIME = 28
BURN TIME = 32
BURN TIME = 36
13.8 ROUND - MAXIMUM ALTITUDE VS DELAY TIME
MAX. ALTITUDE (FEET)
DELAY TIME (SEC.)

FIG. 91

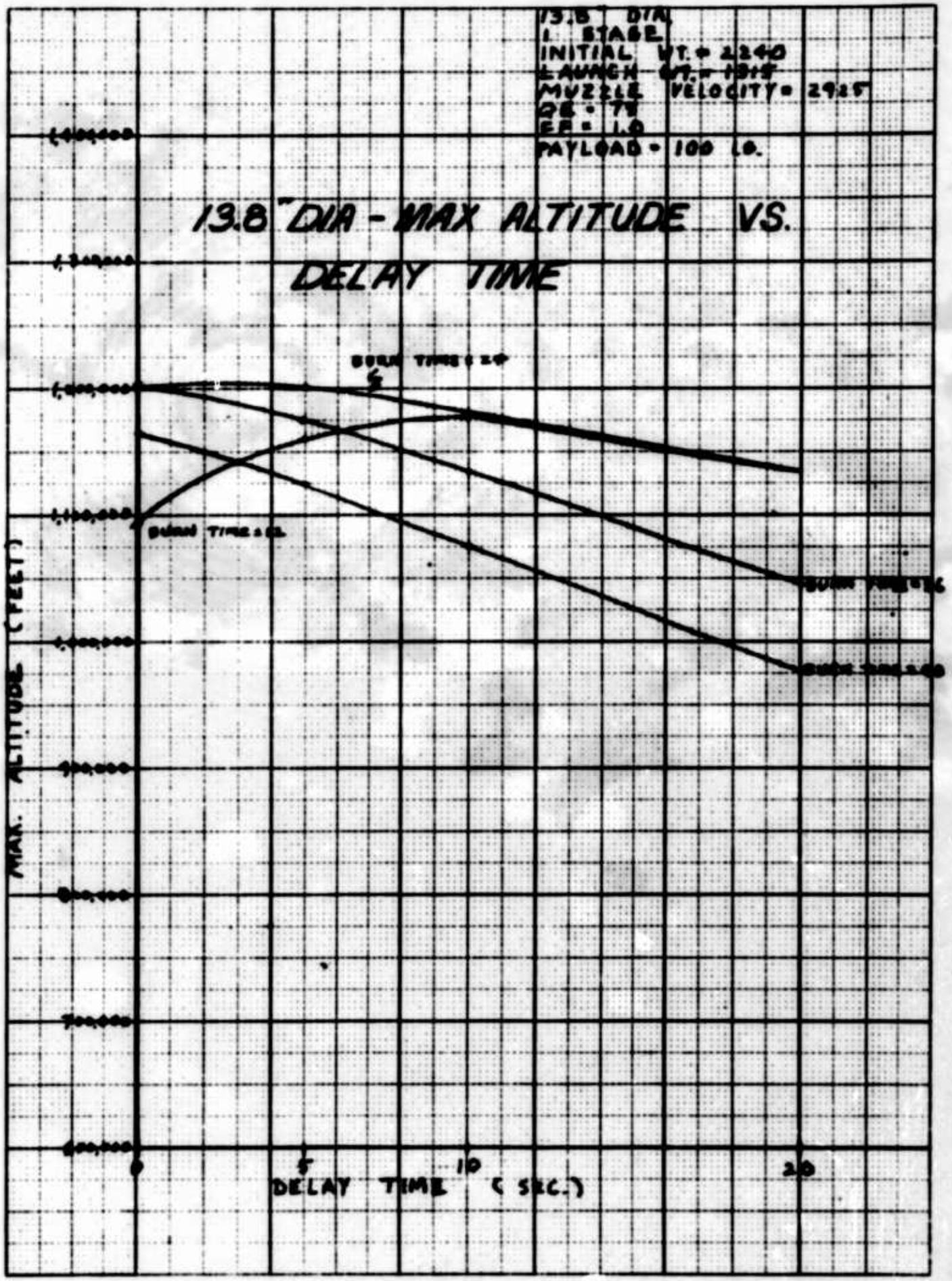

13.8 DIA
1 STAGE
INITIAL WT. = 2240
LAUNCH WT. = 1918
MUZZLE VELOCITY = 2925
OE = 7°
EF = 1.0
PAYLOAD = 100 LB.
13.8" DIA - MAX ALTITUDE VS. DELAY TIME
BURN TIME = 20
BURN TIME = 12
MAX. ALTITUDE (FEET)
DELAY TIME (SEC.)
0
5
10
20

FIG. 92

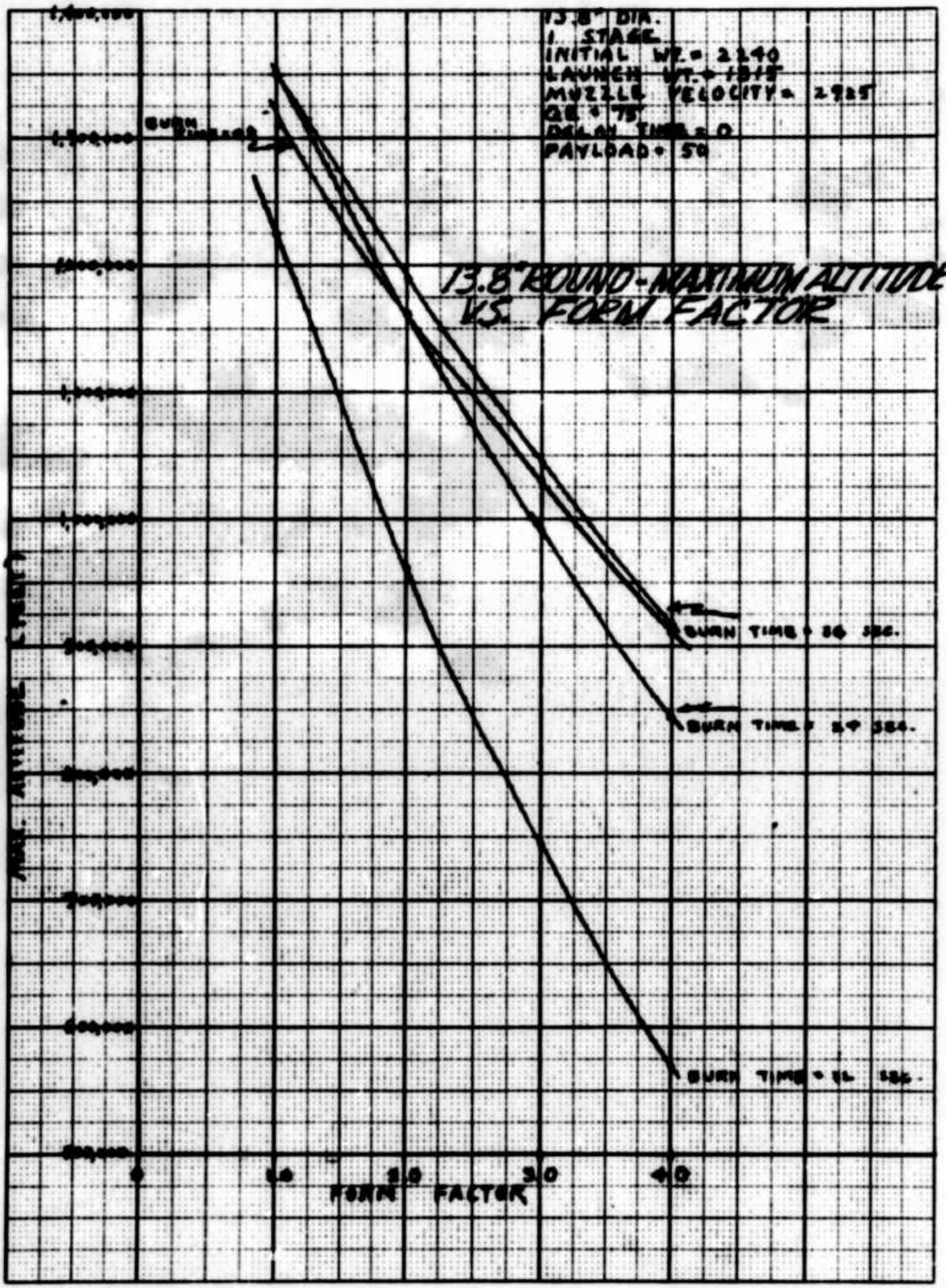

13.8" DIA.
1 STAGE
INITIAL WT. = 2240
LAUNCH WT. = 1815
MUZZLE VELOCITY = 2925
QE = 75°
DELAY TIME = 0
PAYLOAD = 50
13.8" ROUND - MAXIMUM ALTITUDE VS. FORM FACTOR
BURN TIME = 84 SEC.
BURN TIME = 54 SEC.
BURN TIME = 24 SEC.
FORM FACTOR
1.0
2.0
3.0
4.0

FIG. 93

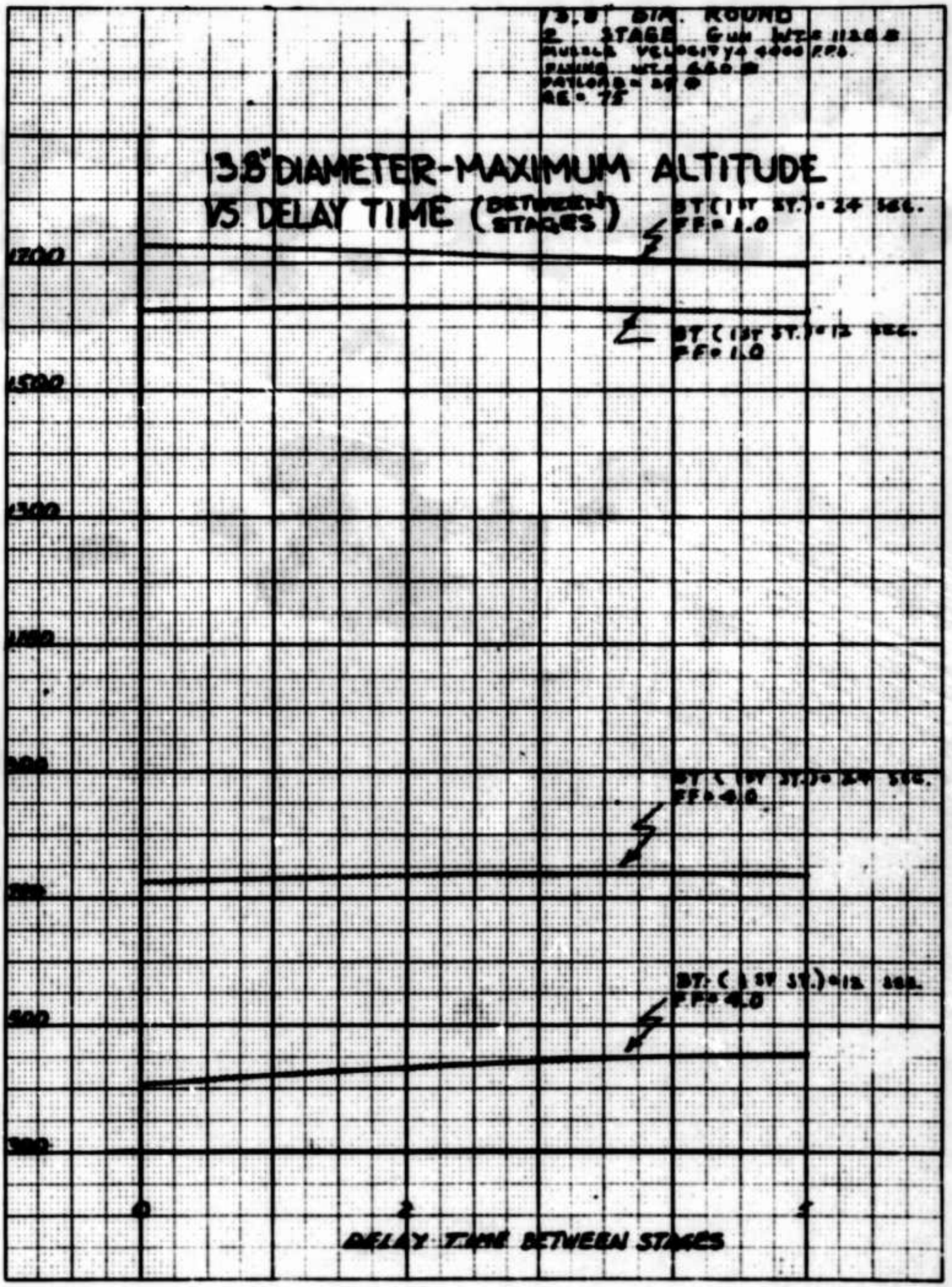

3.8" DIA. ROUND
2 STAGE
3.8" DIAMETER-MAXIMUM ALTITUDE
VS. DELAY TIME (BETWEEN STAGES)
BT. (1ST ST.) = .24 SEC.
FF = 1.0
BT. (1ST ST.) = .12 SEC.
FF = 1.0
FF = 4.0
FF = 4.0
MAX. ALTITUDE (1000 FEET)
DELAY TIME BETWEEN STAGES

FIG 94

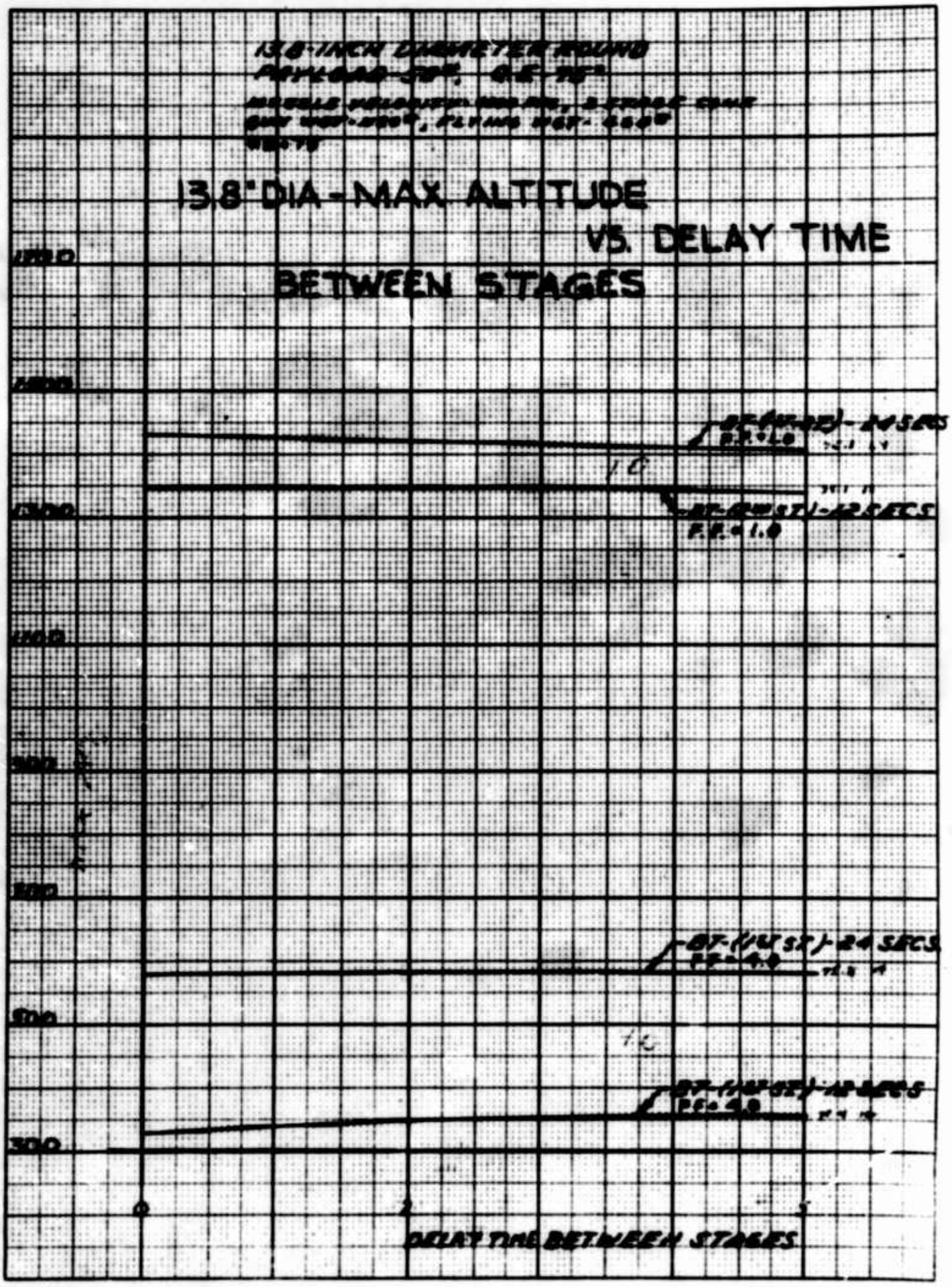

13.8"DIA - MAX. ALTITUDE
VS. DELAY TIME
BETWEEN STAGES
MAX. ALTITUDE (1000 FEET)
DELAY TIME BETWEEN STAGES

FIGURE 95

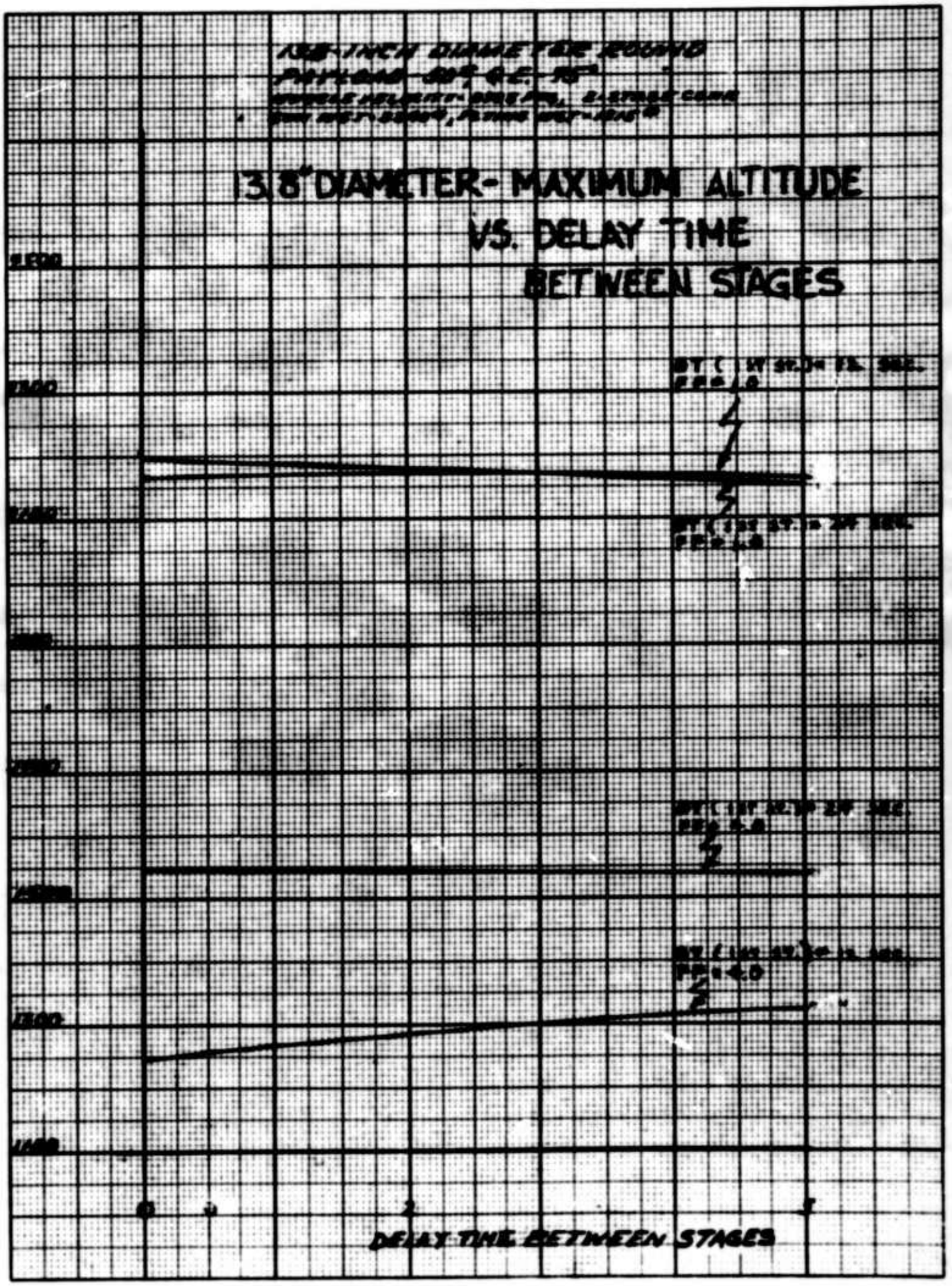

13.8" DIAMETER- MAXIMUM ALTITUDE
VS. DELAY TIME
BETWEEN STAGES
MAX. ALTITUDE (1000 FEET)
DELAY TIME BETWEEN STAGES

FIG 96

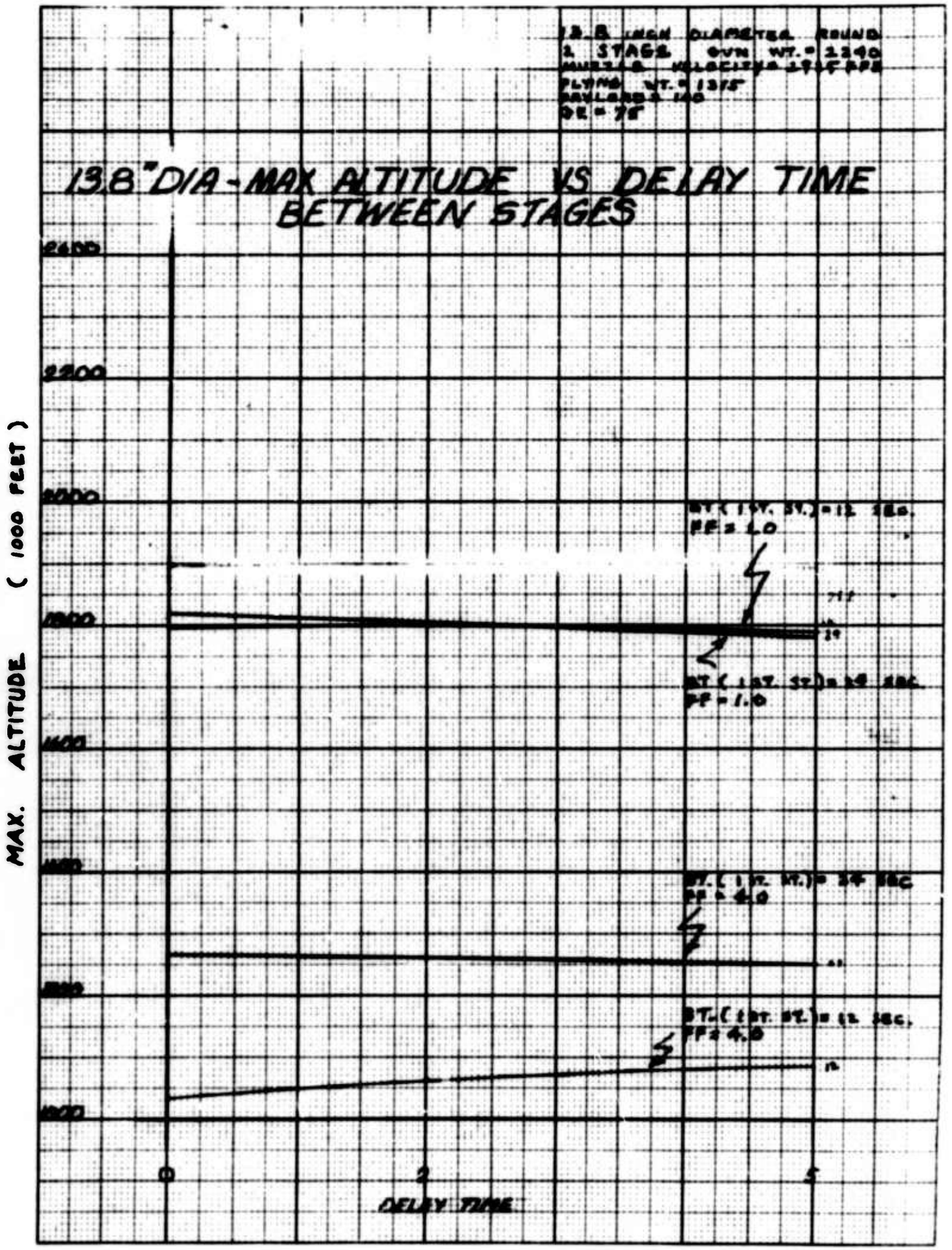

13.8 INCH DIAMETER ROUND
2 STAGE GUN WT. = 2340
FLYING WT. = 1315
DIA = 13.8"
13.8" DIA - MAX ALTITUDE VS DELAY TIME BETWEEN STAGES
MAX. ALTITUDE (1000 FEET)
2400
2200
2000
1800
1600
1400
1200
1000
DT (1ST. ST.) = 12 SEC.
FF = 1.0
DT (1ST. ST.) = 24 SEC.
FF = 1.0
DT (1ST. ST.) = 24 SEC.
FF = 4.0
DT (1ST. ST.) = 12 SEC.
FF = 4.0
0
2
5
DELAY TIME

FIG. 97

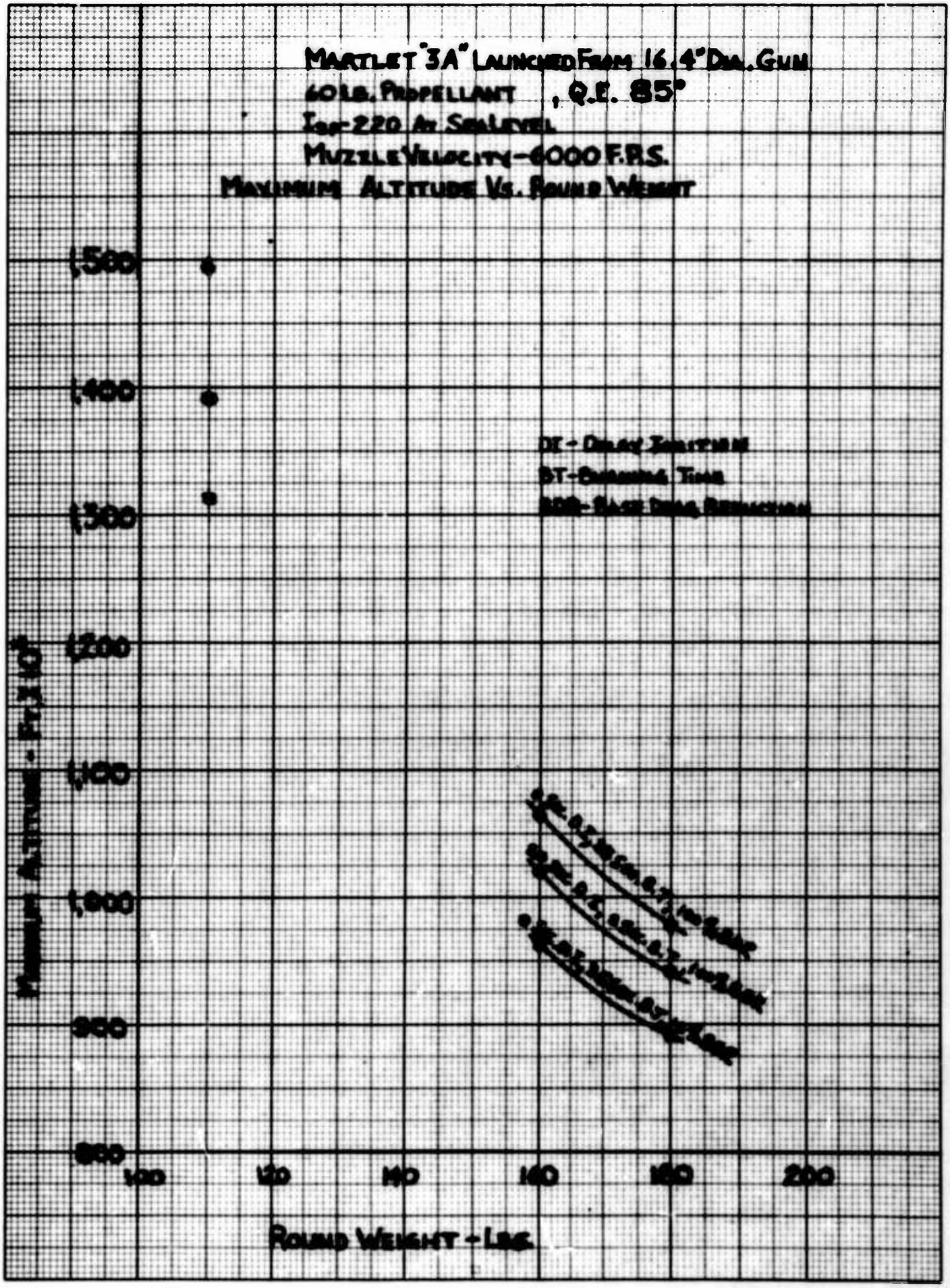

MARTLET "3A" LAUNCHED FROM 16.4" DIA. GUN
60 LB. PROPELLANT , Q.E. 85°
ISP 220 AT SEA LEVEL
MUZZLE VELOCITY - 6000 F.P.S.
MAXIMUM ALTITUDE VS. ROUND WEIGHT
DT - DELAY TIME
BT - BURNING TIME
MAXIMUM ALTITUDE - FEET
ROUND WEIGHT - LBS.

FIG. 98

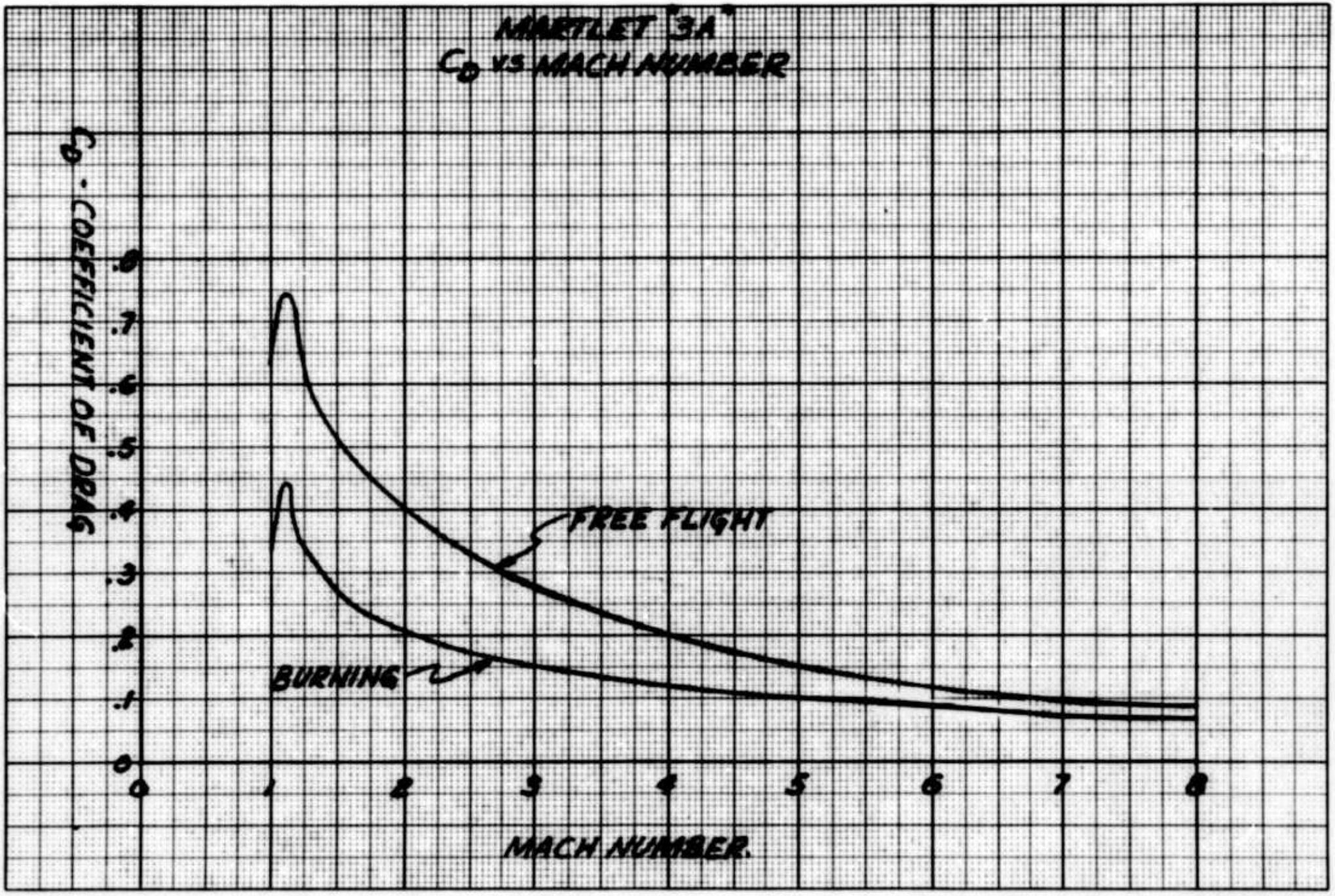

MARTLET 3A
C_D VS MACH NUMBER
C_D - COEFFICIENT OF DRAG
.8
.7
.6
.5
.4
.3
.2
.1
0
0
1
2
3
4
5
6
7
8
FREE FLIGHT
BURNING
MACH NUMBER.

FIG. 99