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TR-1193
September 15, 1972

**JOHN F. KENNEDY
SPACE CENTER**

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DESIGN STUDY OF ARRESTING GEAR SYSTEM FOR RECOVERY OF SPACE SHUTTLE ORBITERS

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JOHN F. KENNEDY SPACE CENTER, NASA

TR-1193

DESIGN STUDY OF ARRESTING GEAR SYSTEM FOR RECOVERY OF SPACE SHUTTLE ORBITERS

This study was performed at the Naval Air Engineering Center, Philadelphia, Pennsylvania, 19112 by a field activity of the U. S. Naval Air Systems Command.

The study was authorized and funded by NASA Defense Purchase Request No. CC-15969A, dated 23 Feb. 1972.

Mr. Preston E. Beck, Space Shuttle Task Group, SP-A, Kennedy Space Center, Florida, 32899 was the NASA coordinator and technical representative for the study. The NASA study team included:

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Mr. D. Bourque, MSC (EK)

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TABLE OF CONTENTS

LIST OF TABLES

REFERENCES

A. TR-1135, December 1, 1971.
Space Shuttle Recovery Requirements
(Facility/Flight Hardware Interface)
Preston E. Beck, KSC Shuttle Task Group
Kennedy Space Center (NASA), Florida 32899

B. TR-1125, August 1, 1971
Feasibility of Arrestment of Space Shuttle Vehicles After Landing
Preston E. Beck, KSC Shuttle Task Group
Kennedy Space Center (NASA), Florida 32899

1.0 INTRODUCTION

The National Aeronautics and Space Administration (NASA) is engaged in the development of a reusable space shuttle that can be used for a series of missions instead of the single operation presently being performed. Reusability of the shuttle orbiter is based upon landing the vehicles on a runway similar to that used by conventional aircraft on the completion of each mission. Because of the limited number of shuttle orbiters, cost, and crew safety, the use of emergency arrestment techniques is being considered as a backup system to preclude runway overrun accidents involving the shuttle orbiter in much the same manner as emergency arresting systems are being employed by military aircraft.

Present concepts of the orbiter design (not presently fixed) indicate the vehicle size, weight, and speed are significantly greater than any current type of military aircraft using an arresting system(s), and exceed, by far, the capabilities of existing test facilities. This technical report presents a plan for the design, manufacture, development, test, and production of an emergency arrestment system for the recovery of shuttle orbiters and also includes time and cost estimates for such a system. Due to system testing being a major cost area several optional test programs are discussed.

2.0 ASSUMPTIONS

2.1 The first step of the study was fixing operational requirements of the shuttle orbiters so that arresting gear design criteria could be established. While these requirements are subject to change as the orbiter design is finalized, it was assumed that:

a. The degree of the changes in the landing velocities and weights will be small and the resulting effects on study results will be minor.

b. The design of the system should be based on the maximum energy engaging conditions contained in item c. This procedure does not significantly affect overall cost of the program and precludes designing a system that might prove to be inadequate at some future date. Details of the design optimization are contained in Appendix A.

c. Parameters for determining the most suitable type and size of energy absorber for this application and in sizing of the purchase member, storage, and drive components are as follows:

(1) Maximum vehicle weight and corresponding maximum velocity:

(a) Orbiter Mode; landing, 195,000 lbs., 180 knots.

(b) Ferry Mode; aborted takeoff, 220,000 lbs., 220 knots.

(c) Ferry Mode; future growth, 275,000 lbs., 220 knots.

(2) Minimum vehicle weight; 150,000 lbs.

(3) Vehicle deceleration limits; minimized insofar as practical, one to two g's preferred.

(4) Arresting gear runout limit; a maximum of approximately 2,000 feet preferred, to be determined by arresting gear design.

d. Parameters affecting design of engaging system, installation, configuration, and ancillary equipment are as follows:

(1) Mode of Operation; emergency, backup system only.

(2) Mode of Engagement; subject of tradeoff study, three methods considered:

(a) Hook/Pendant.

(b) Barricade.

(c) Landing Gear Entanglement.

(3) System Recycle Time; since booster recovery is not planned, cycle time is not critical; approximately one hour to clear runway for use is acceptable.

(4) Retraction Power Source; electricity will be made available and is preferred.

(5) Runway Width; 200 ft. minimum, 400 ft. maximum.

(6) Other Installation Requirements; consistent with standard Navy installation.

(7) Range of Environmental Conditions; California and Florida.

(8) Off-Center Engaging Distance; to be demonstrated by test, 1/4 runway span for design and test purposes.

(9) Bi-Directional Capability Requirement; none, no approach end engagements planned.

(10) Size and Weight Limits (Components); compatible with cargo compartment of C-5A aircraft.

(11) Test Requirement; system must absorb specified kinetic energy and maintain a minimum safety factor of 1.2 on any component.

(12) Estimated Date First System Required on Site; available schedules indicate initial flight test of orbiter will occur approximately in December 1975.

(13) Total Number of Systems (To be Procured); five to eight.

3.0 DISCUSSION

The United States Navy has employed arresting gear systems as a primary method of restraining and stopping aircraft following the landing since 1911. The Navy has gained valuable and quite extensive experience with arresting gear systems, with particular emphasis being placed on the experience attained since 1942. The arresting gear systems developed by the Navy have exhibited an exceptionally high rate of reliability as shown in Tables 1 and 2.

Statistical data gathered over an extended period of time indicates that the tail hook arresting gear system method has experienced the highest degree of reliability as compared to other types of systems such as; net and landing gear entanglement systems. Installation of a landing gear hook on aircraft or orbiters (Reference A) increases the overall vehicle weight as a result of greater strength requirements in the flight hardware. The Navy accepts the increased weight penalty in preference to a compromise in reliability since any significant number of arrestment failures during landing operations is totally unacceptable.

Realizing that several types of aircraft can use the same arresting equipment the Navy manrates the flight hardware and the arresting gear system prior to the system becoming operational. Qualification testing of the system includes dead load testing to the highest energy level and actual engagements under test conditions using the flight vehicle(s) that will employ the system operationally. Full scale testing such as this has been found necessary, through experience, to ensure a high level of reliability.

The use of an arresting gear system in the Space Shuttle program is being considered for use as a backup system for wheel brakes, aerodynamic brakes, drag chutes, etc. Thus, this study considers acceptance of lower reliability levels as compared to those contained in Table 2 which will enable orbiter design engineers to consider the feasibility of little or no increase in weight penalties of the flight hardware and degree of limited qualifications of the arresting gear system.

If future experience indicates that an arresting gear system will be required on a routine basis it will become necessary to examine in detail the possibility/necessity of using a tail hook(s), and to determine if full scale testing requirements warrant the attendant facility costs as existing facilities lack the capacity to handle orbiter energy levels.

Table 1. M-21 Arresting Gear Arrestment History*

TOTAL M-21 Arrestments as of approximately 30 September 1970: 75,794 (Approx. No.)

Reported Unsuccessful Arrestments:

Tape Tucks	26	(Includes Unintentional Tucks at NATF Test Sites)
Other Tape Failures	6	(Estimated, Approx. 3 Reported)
Pendant Failures	10	(Estimated, Approx. 4 Reported)
Other Failures	15	(Estimated, Includes Hubs, Flanges, Connectors, Sheaves, etc.)
TOTAL	57	

$$\text{RELIABILITY} = \frac{75{,}794 - 57}{75{,}794} = \frac{75{,}737}{75{,}794} = .9993$$

*System described in KSC TR-1125

Table 2. Shorebased Arresting Gear Reliability

1	2	3	4	5	6***
Year	Total Engagements		All Systems		E-28 System Only No. of Unsuccessful Arrestments Due to Mechanical Failure After Engagement**
	All Shorebased Systems	** E-28 System Only	No. of Dropped Pendants After Engagement	No. of Hook Skips, Late Hooks & Drops	
1966	1811	0	2	4	0
1967	2621	593	0	5	0
1968	2961	712	0	6	0
1969	2853	1258	0	3	0
1970	2800	1395	2	3	0
TOTAL	13046	3958	4	21*	0

Reliability of Retaining Pendant After Hook Engagement:

$$1 - \frac{4}{13046} = .99969$$

Reliability of Engaging and Retaining Pendant Once Decision to Arrest has been Made:

$$1 - \frac{21}{13046} = .99839$$

Reliability of E-28 System to Make Successful Arrestment:

$$1 - \frac{0}{3950} = 1.00000$$

*Includes the four in Column 4.
**Became Operational in 1967.
***System Described in KSC TR-1125.

Appendices A through E contain study results relative to arresting gear systems as performed by the Navy; those results are as follows:

NOTE

For those who are not familiar with the terminology used, refer to Appendix A of Reference B for the necessary definitions.

APPENDIX A.	Presents information on a preliminary design for an orbiter arresting gear system.
APPENDIX B.	Presents results of a trade-off study of various engagement modes of the orbiter with the arresting gear system. Conclusions reached are presented in paragraph 4.0.
APPENDIX C.	Presents a description of a proposed arresting gear system for the orbiter.
APPENDIX D.	Presents testing, with the Navy analysis being based upon the concept of full scale testing. For the Space Shuttle application (backup system) consideration should also be given to scale model testing.
APPENDIX E.	Presents the costs and schedules of arresting gear for the orbiter. The costs should be very carefully examined as they include full scale test costs. The testing costs are the highest cost item and are far in excess of manufacturing costs.

4.0 RECOMMENDATIONS (U. S. Navy Reps.)

Recommendations made by Navy representatives relative to the use of arresting gear systems are contained in paragraphs 4.1 through 4.4.

4.1 RECOVERY SYSTEM

The recovery system should be designed for a maximum aircraft runout of 1800 feet. All major performance requirements will be satisfied by designing the system as specified in Appendices A and C of this report.

4.2 MODE OF ENGAGEMENT

a. Hook - pendant mode of engagement is recommended.

b. The increased risk of damage to the aircraft and crew associated with the barricade mode of engagement should not be accepted unless weight penalty cost considerations prohibit the installation of a hook system in the Space Shuttle orbiter.

c. Weight penalty is a cost factor only during orbiter operations of the Space Shuttle. For these operations, barricade engagements could be used, if required. However, it may be possible to use hook-pendant engagement during ferry mode operations of the shuttle if the hook system can be made removable.

d. Barricade engagement of the vehicle is preferred over landing gear entanglement if hook-pendant engagement is not possible for either orbiter or ferry operations.

4.3 TEST PROGRAM

a. A standard Navy type test program which would test the recovery system at maximum possible aircraft engaging energy is recommended.

b. If cost considerations do not permit conducting the standard program, either of two alternate test programs utilizing the existing jet car to provide an energy capacity of 280×10^6 ft-lbs is recommended.

4.4 ALTERNATE SITE RECOVERY SYSTEMS

a. Permanent or semimobile installations are required to avoid excessive delay in availability of the systems when needed.

b. Final selection of the type of installation should be deferred until the mode of engagement and number of alternate landing sites are determined.

5.0 RECOMMENDATIONS (NASA Tech. Reps.)

Recommendations made by NASA technical representatives relative to the use of arresting gear systems are as follows:

a. Orbiter design contractor investigate the feasibility/desireability of hook-pendant vs. barricade mode of engagement with emphasis on the safety factors.

b. Landing gear entanglement arresting system not to be considered.

c. Limit testing to existing facility capabilities through use of scale models.

d. Conduct program level study to establish requirements, if any, for the following:

(1) Permanent arresting gear installations at locations other than the operational sites.

(2) Portable arresting gear transportable by air to selected locales.

APPENDIX A
DESIGN AND PERFORMANCE ANALYSIS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

B

LIST OF TABLES

APPENDIX A

DESIGN AND PERFORMANCE ANALYSIS

1.0 INTRODUCTION

The objective of this analysis is to design the major components of the recovery system and predict how this system will perform under actual operating conditions.

1.1 PROCEDURE

The main components of the recovery system are designed to satisfy given performance requirements. Performance predictions of the system are obtained by mathematical model computer simulation techniques. The technique yields the theoretical response of a specified recovery system to the engagement of an aircraft. The dynamics of each major component of the system are described by a set of mathematical equations. These equations plus the mathematical descriptions of interactions between components and other rules of operation of the system are used to develop a computer program which simulates the performance of the actual system.

The initial conditions are known - at time equals zero the recovery system is at rest and the aircraft has a specified weight and speed. Time is advanced in very small steps (.001 sec.), during which the acceleration of all moving components is assumed to remain constant and equal to their particular values at the beginning of the time step. These new positions and velocities are then used to compute the loads developed and accelerations produced on the components. The new accelerations are then used for predictions in the next time step. Time thus continues until the arrestment is complete.

The technique yields excellent simulations of systems that can be accurately described mathematically, and for systems in which the change in acceleration is not large enough to introduce inaccuracies. Aircraft recovery systems such as the one designed for the NASA Space Shuttle are basically simple devices, but complete mathematical description of all components is not possible. Also, during the initial stages of the arrestment, the accelerations are changing violently. The technique has, however, been shown to yeild accurate simulations of other recovery systems, especially those similar in design to this proposed system, during both the dynamic and steady state regions of the arrestment. However, the technique has not yet been verified for the high kinetic energy conditions required for this design. For these reasons, the procedure used in this study is considered capable of producing performance results which permit a quantitative analysis in the steady state region of the arrestment, and at least a qualitative analysis in the early "dynamic" region of the arrestment.

Results of the computer simulation program are the histories of the positions, velocities, accelerations, loads, etc. of the aircraft and main components of the recovery system. The computer-generated performance is identical in form to the instrumented and recorded output of a full scale test program of the actual system. Hence, an analysis of the results of the computer simulation study is conducted in the same way as if the data were from actual tests.

Components of the recovery system are described by input data to the program, and are therefore easily varied. Proper sizing of each major component is accomplished so that the resultant system performs as required.

The study was conducted for hook-pendant mode of engagement only. Simulation programs for barricade and landing gear entanglement modes are still in a state of early development. Recovery systems which are identical except for the engaging member have been shown to perform very similarly, especially in the steady state region of the arrestment. Hence, present design procedure is to assume hook-pendant engagement and conduct the computer simulation study. All resulting components, except the pendant, are then incorporated into the final design. This technique yields performance predictions applicable to all engaging systems.

1.2 RECOVERY SYSTEM DESCRIPTION

1.2.1 OPERATION. Various aircraft recovery systems were considered. The one chosen as most capable of satisfying all design requirements is a tape stack rotary hydraulic system similar to the Navy Shorebased emergency gear. (Figure 1)

This recovery system is composed of an arresting engine on each side of the aircraft runway. An engine consists of a rotor and stator enclosed in a housing containing fluid. The rotor is connected by a shaft to a hub on which the purchase tape is wound. The free end of the tape of both engines is connected to a single pendant that stretches across the runway.

The aircraft employs the system by engaging the pendant with its hook. Tape is pulled off both hubs causing the hubs and rotors to revolve. Fluid resistance to the rotor's motion causes a retarding force to be generated in the purchase tape and pendant which opposes the motion of the aircraft. The kinetic energy of the aircraft is dissipated through this process. (Figure 2)

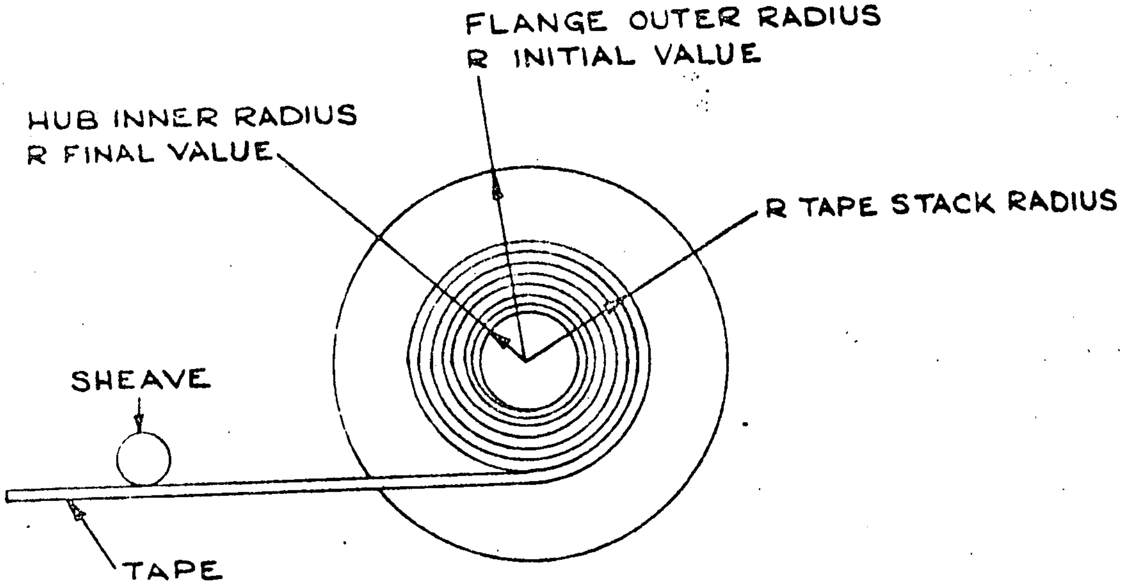

Figure 1. Tape Stack

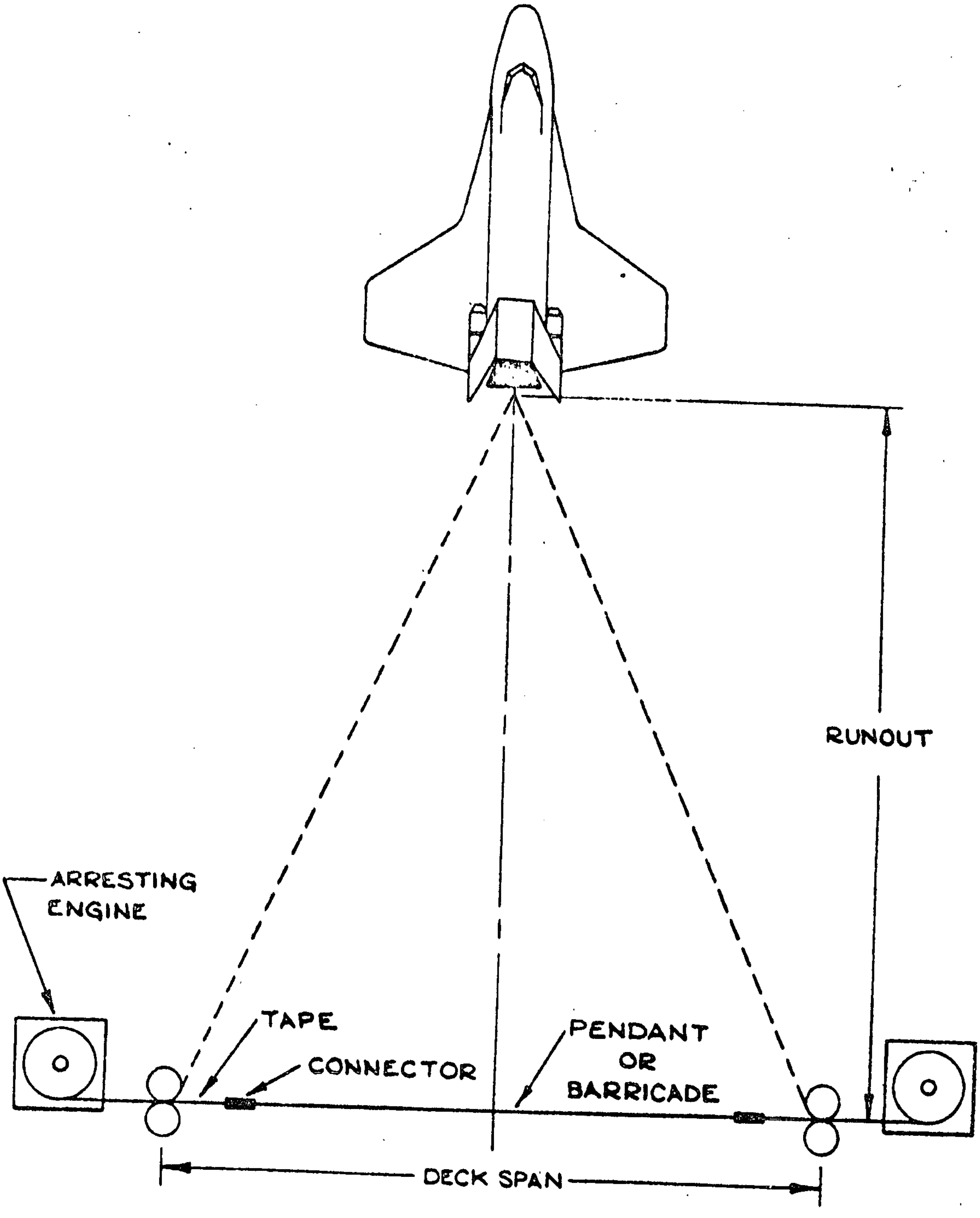

Figure 2. Deck Layout

1.2.2 COMPONENTS. Function and Mathematical Description.

a. Arresting Engine.

(1) Hydraulic energy absorber: converts the aircraft's kinetic energy into heat energy of the fluid.

(2) Rotational motion of the rotor generates a fluid flow field which retards the rotor's motion. The resistance to rotation, specified as a torque, is proportional to the speed of the rotor.

(3) Mathematical description of the arresting engine is provided by an expression relating the speed of the rotor and the torque developed. The mass moment of inertia of the rotor must also be specified. (Figure 3)

b. Tape Reel.

(1) Provides for purchase tape storage.

(2) Converts tape payout linear motion to rotary motion of tape stack, shaft and rotor.

(3) Converts torque imposed on the rotor to a linear tape tension load.

(4) Provides the means for maintaining a relatively constant tape tension load throughout the arrestment while torque and speed vary.

(5) Mathematical description of the tape reel is provided by programming, which calculates the change in outer radius of the tape stack and change in mass moment of inertia of the tape remaining on the reel throughout the arrestment. Data required to describe a specific tape reel is:

(a) Tape stack inner radius - hub radius.

(b) Tape length wound on the reel.

(c) Tape thickness.

(d) Tape mass density.

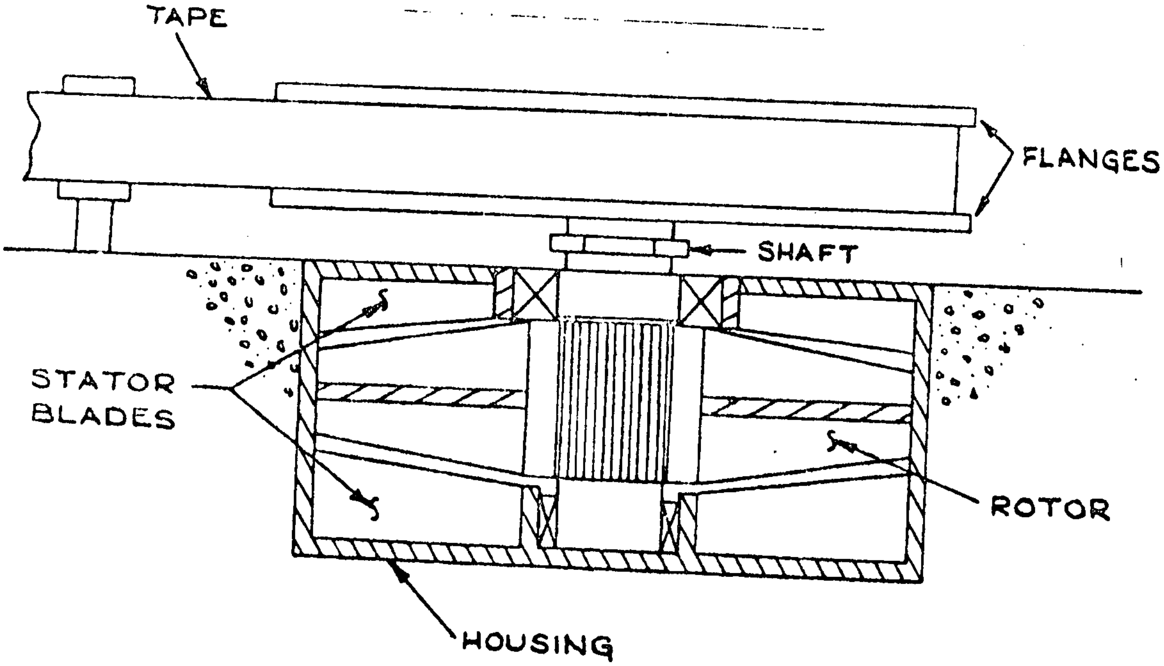

Figure 3. Arresting Engine

(6) Mass moment of inertia of the hub and flanges must also be specified.

See Figure 1.

c. Purchase Members - Pendant and Tape.

(1) Provide the connection between the aircraft and arresting engine.

(2) Mathematical description of the purchase members is provided by programming, which computes the elongation - load characteristics of these units. The mathematical model used for the pendant or tape is a spring and dashpot in parallel. The spring stiffness and damping coefficient are calculated for each size pendant and tape. Data required to describe a pendant or tape is:

(a) Mass density.

(b) Modulus of elasticity.

(c) Cross sectional size.

(3) Additional programming, required for mathematical description of the pendant and tape, calculates the response of these elastic members to the transverse impact imposed by the aircraft hook. The mathematical relationships of cable dynamics in an aircraft recovery system environment used to develop this model are detailed in reference a.

d. Other Moving Components. The mass or mass moment of inertia of all moving components of the recovery system must be specified in order to calculate the total effective mass accelerated by the aircraft. These components include the deck sheave, arresting engine shaft, tape-pendant connector, etc.

e. Positions and Locations. Mathematical description of the geometry of the recovery system must be provided. (Figure 2) Pendant length, deck span and position of tape reel relative to the deck sheave must be specified. The geometry used is two dimensional; the effects of positional considerations perpendicualr to the deck are assumed negligible.

f. The recovery system is assumed to be symmetrical. Only one-half of the system is programmed; the other side is assumed to respond exactly the same. This limits simulation to on-center arrestments.

1.2.3 COMPONENT DESIGN. Selection of Type.

a. The recovery system designed will be used in an emergency mode. Operations will be infrequent and scheduled well in advance. Hence, the system need not be designed for high cycle operations with components that have long service lives.

b. Arresting Engine. The small ratio of maximum to minimum aircraft weight (r = 275000/150000 = 1.8) indicates that a constant torque capacity unit will suffice. The design of this unit will be similar to that used in the Navy's E-28 system. A larger unit with greater torque and energy absorbing capacity will, however, be required. The growth potential of this type of energy absorber has been adequately demonstrated, providing the proper engine performance should involve no major design problems.

c. Tape. Nylon tape similar in design to the E-28 tape but larger and stronger will be used. Coating this tape to improve service life is not required.

d. Pendant. Two types of pendants will be investigated. They will both be of the non-rotating type of construction to minimize reduction in strength due to the tendency of a load carrying pendant to unwind.

(1) Steel Pendant - steel wire rope - (12 x 6)/(6 x 30) construction.

(2) Nylon Pendant - nylon rope - 2 in 1 braided construction - polyurethane coated.

e. Tape Reel. In order to reduce the total moving mass of the system, the tape reel will be designed with stationary flanges.

1.3 PERFORMANCE REQUIREMENTS

1.3.1 ENERGY CAPACITY. The recovery system must operate effectively over the following range of aircraft weights and speeds.

(a) Orbiter Mode.

Aircraft Weight = 150,000 to 195,000 lbs.

Engaging Speed - 0 to 180 knots.

Maximum Kinetic Energy = 280 x 10^6 ft.-lbs. (195K at 180 knots).

(b) Ferry Mode.

(1) Present Design.

Aircraft Weight = 150,000 to 220,000 lbs.

Engaged Speed - 0 to 220 knots.

NOTE: Maximum aborted take-off speed = 220 knots.

Maximum Kinetic Energy - 472 x 10^6ft. -lbs. (220K at 220 knots).

(2) Future Expected Weight Growth.

Possible maximum future growth in aircraft weight = 25%

Aircraft Weight = 220,000 (1.25) = 275,000 lbs.

Maximum Kinetic Energy = 590 x 10^6ft.-lbs. (275K at 220 knots.)

1.3.2 AIRCRAFT DECELERATION. Aircraft deceleration must be minimized. Maximum deceleration should be approximately 1g (1g = 32.2ft./sec.^2).

1.3.3 AIRCRAFT RUNOUT. Maximum aircraft runout should not exceed 2000 ft. This is a tentative limit which may be increased.

1.3.4 PENDANT and TAPE. Factors of Safety. Factors of safety should be maximized. A factor of safety of 2 based on the maximum steady state tension load and minimum breaking strength of the purchase member will be acceptable. Factors of safety, based on maximum dynamic region loads, that are slightly less than the steady state factors will be acceptable, if operational procedures provide that these components be discarded after being used once.

1.3.5 AIRCRAFT RUNWAYWIDTH. Nominal size will be 300 ft., but the recovery system should be compatible with runway widths 200 to 400 ft.

1.4 RESULTS

Details of component sizes and performance results of both System 1800 and System 2400 for various engaging conditions are presented in Tables 1 thru 4 and Figures 4 thru 20. The prefix S, as in S1800, denotes a system equipped with a steel pendant while the prefix N, as in N1800, denotes a nylon pendant.

1.4.1 SYSTEM 1800. A computer simulation design study was conducted to optimize performance for the maximum engaging conditions expected for the orbiter mode of operations. Optimum performance is defined as imposing the minimum retarding force on the aircraft while dissipating the kinetic energy within a fixed runout distance. Minimizing the loads and accelerations will minimize the size of the hook structure and result in the smallest weight addition to the aircraft. Minimizing this weight penalty is of prime importance for the space shuttle when operating as an orbiter.

This optimized system is designated System 1800.

Aircraft runout required is 1800 ft.

Maximum aircraft deceleration is approximately 1.0g's for an engaging speed of 180 knots with aircraft weights up to 195,000 lbs. Lower speeds will result in lower decelerations.

System 1800 incapable of safely arresting the higher speed and weight conditions associated with the ferry mode of operations, including the 25% future weight growth possibility.

Aircraft runout required is 1800 ft.

Maximum aircraft deceleration is approximately 1.5g's for an engaging speed of 220 knots and and aircraft weights up to 275,000 lbs. (Figure 4.)

1.4.2 SYSTEM 2400. A study was also conducted with emphasis on satisfying the deceleration requirements for maximum engaging conditions of ferry mode operations.

This system is called System 2400.

Aircraft runout required is 2400 ft.

Maximum aircraft deceleration is approximately 1.0g's for an engaging speed of 220 knots and aircraft weights up to 275,000 lbs. Lower speeds will result in lower decelerations.

System 2400 also provides also provides satisfactory performance with the orbiter mode maximum conditions.

Aircraft runout is 2400 ft.

Maximum aircraft deceleration is approximately 0.7g's for an engaging speed of 180 knots and aircraft weights up to 195,000 lbs. (Figure 5.)

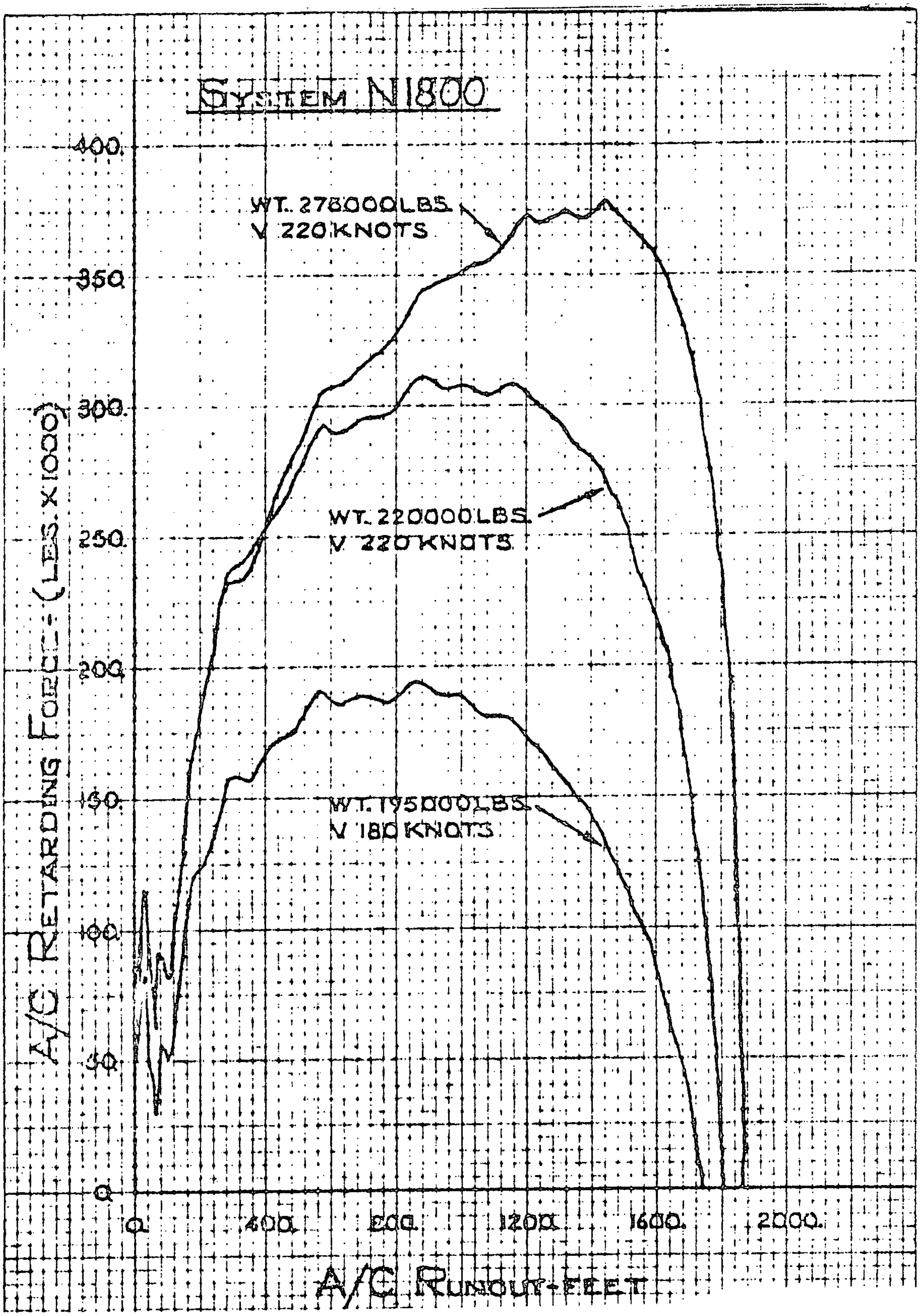

Figure 4. System N1800, AC Retarding Force/AC Runout-Feet

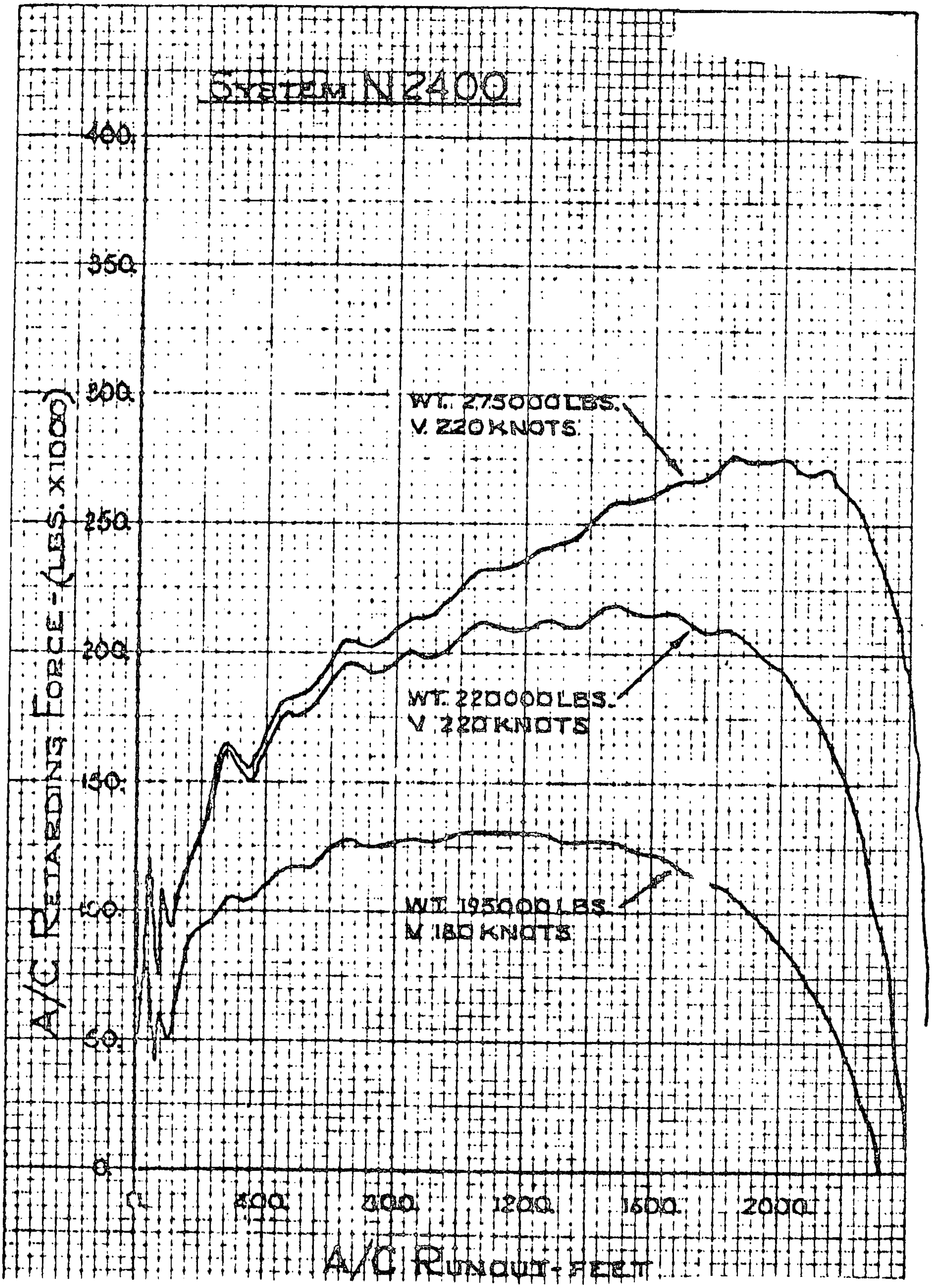

Figure 5. System N2400, AC Retarding Force/AC Runout-Feet

1.4.3 NYLON vs. STEEL PENDANT

a. Refer to Figures 6 thru 11 and Tables 1 thru 4.

b. The nylon pendant significantly reduces the aircraft retarding force and purchase member load oscillations in the dynamic region of the arrestment.

c. Peak loads, especially in the dynamic region, are lower with the nylon pendant.

d. Maximum pendant and tape loads occur in the steady state region of the arrestment with nylon pendants. Hence, a system with an adequate steady state factor of safety will have an adequate dynamic region safety factor.

e. Maximum pendant and tape loads generally occur in the dynamic region of the arrestment with steel pendant systems. This is caused by the stiffness and high weight of these pendants. A steel pendant strong enough to provide adequate safety factors in the steady state region may be so stiff and heavy that the larger loads produced in the dynamic region would result in inadequate safety factors in this region.

f. Nylon pendant system factor(s) of safety are greater than those for steel pendant systems in both the dynamic and steady state regions, for all design engaging conditions.

g. There is no need to change pendant or tape size to accommodate the different aircraft engaging conditions with a nylon pendant system. Steel pendant systems will, however, require changes in pendant size to accommodate the different aircraft weights. System S2400 will require changes in both pendant and tape. (Table 4)

h. In order to limit dynamic region loads with steel pendant systems, the deck span (distance between runway deck sheaves) must be at least 400 ft. Deck span with nylon pendant systems can be tailored to fit existing runway widths.

i. Conclusion. The nylon pendant is superior to the steel pendant for this application.

1.4.4 SYSTEM 1800 vs. SYSTEM 2400.

a. Refer to Figures 12 thru 20 and Tables 1 thru 4.

b. The main differences in performance previously mentioned, are:

	System 1800	System 2400
Runout	1800 ft.	2400 ft.
Max Deceleration Orbiter Mode	1.0g	0.7g
Max Deceleration Ferry Mode	1.5g	1.0g

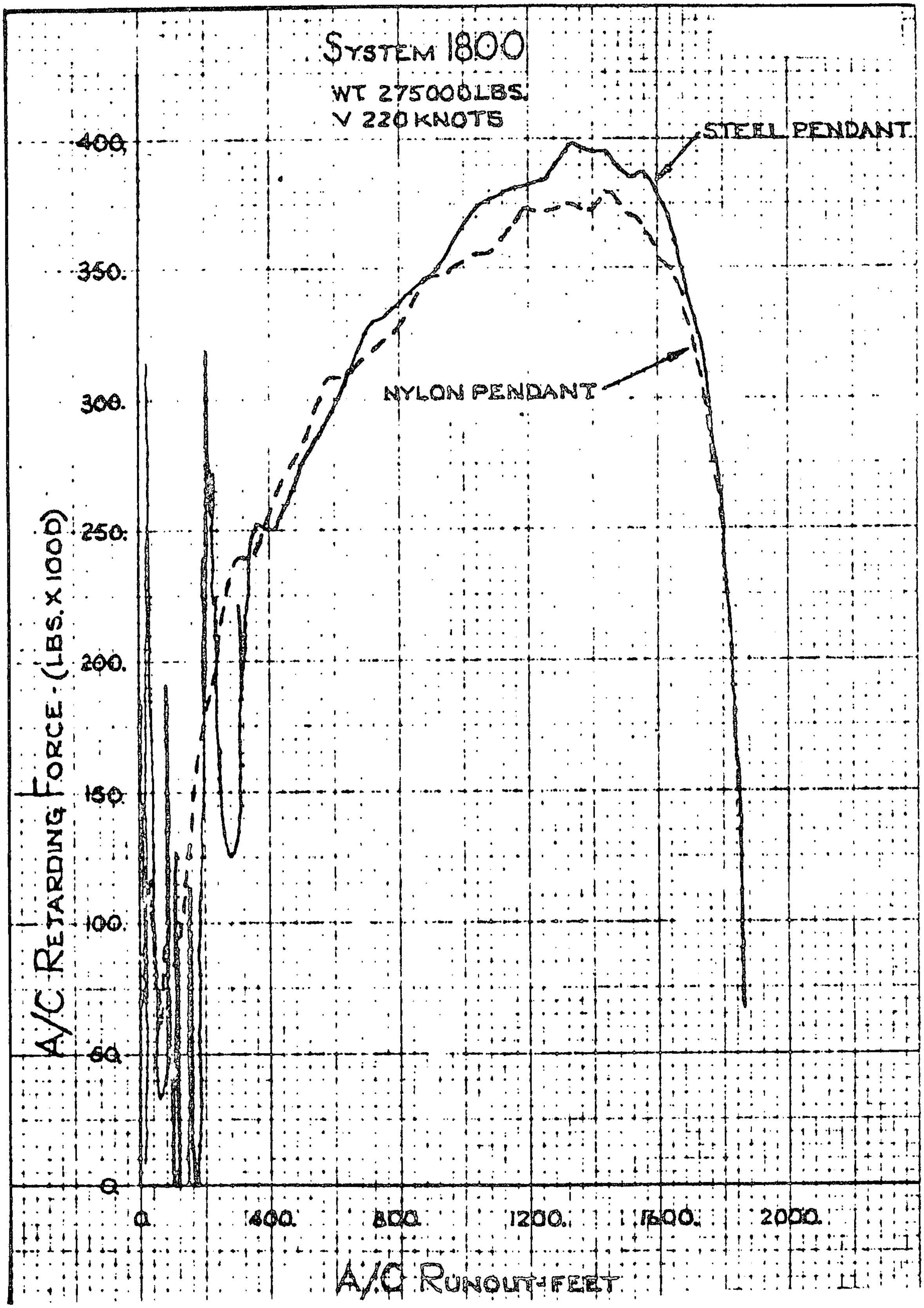

Figure 6. System 1800 (WT. 275,000 lbs. V 220 knots)
AC Retarding Force/AC Runout-Feet

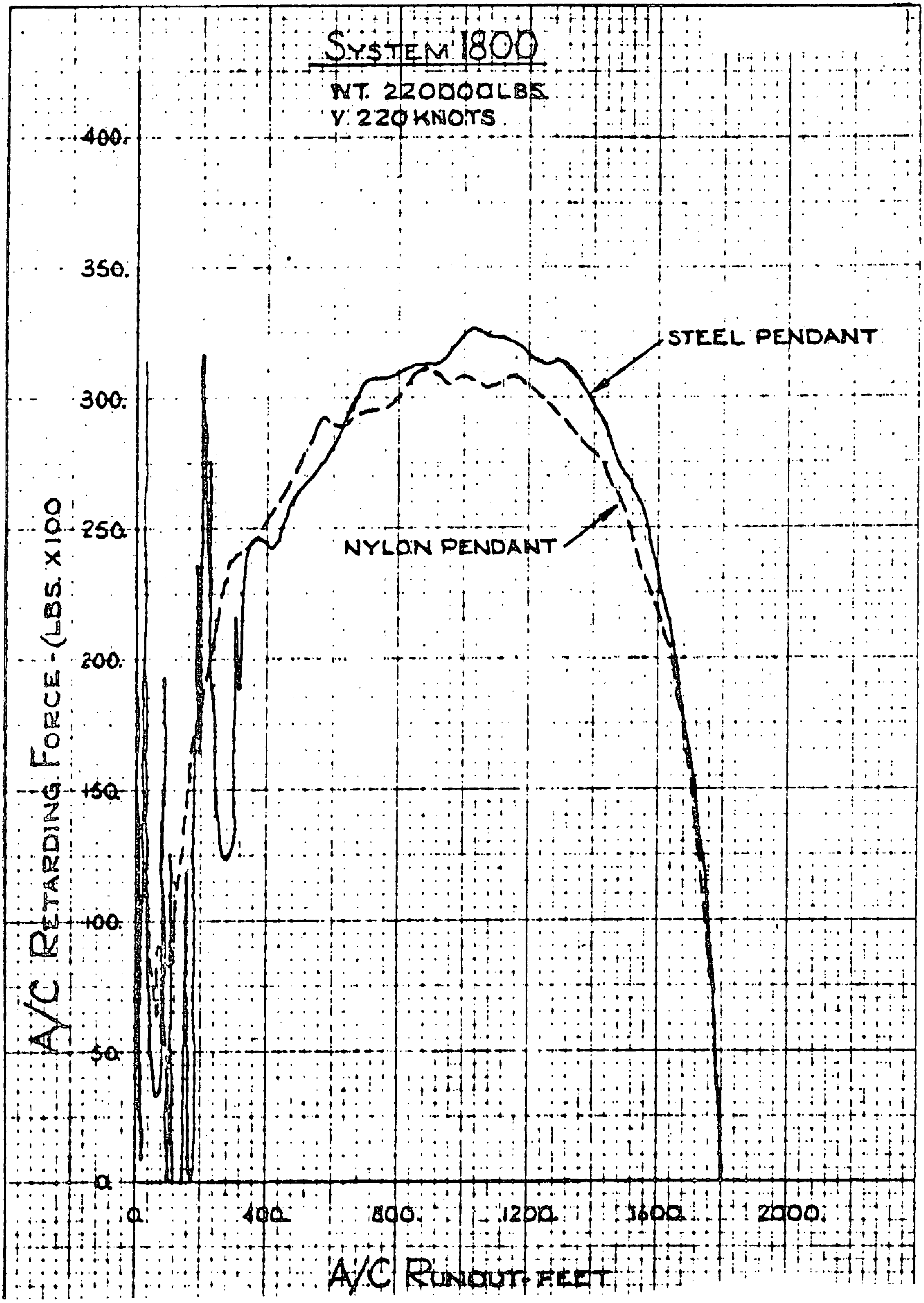

Figure 7. System 1800 (WT. 220,000 lbs. V 220 knots)
AC Retarding Force/AC Runout-Feet

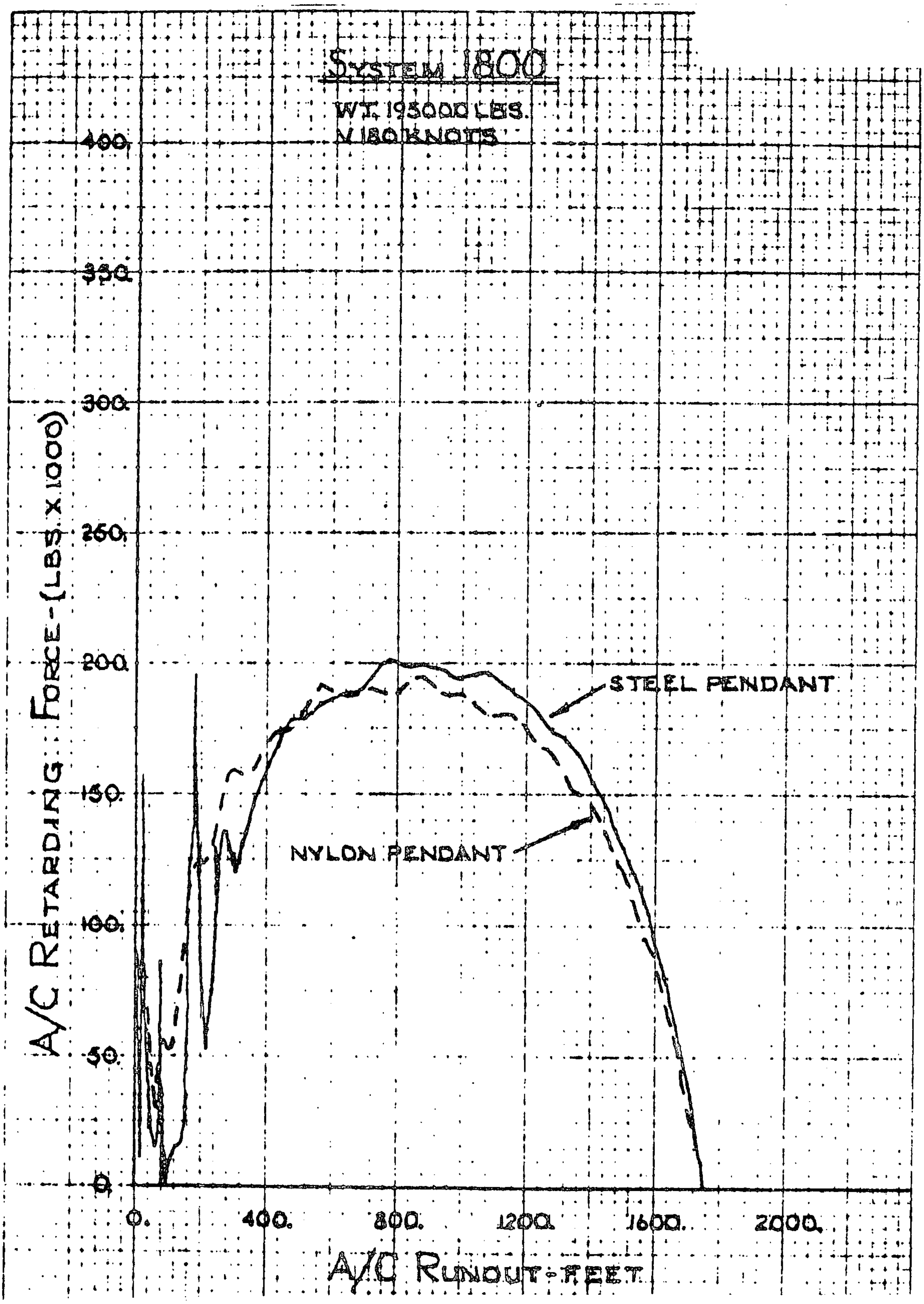

Figure 8. System 1800 (WT. 195,000 lbs. V 180 knots)
AC Retarding Force/AC Runout-Feet

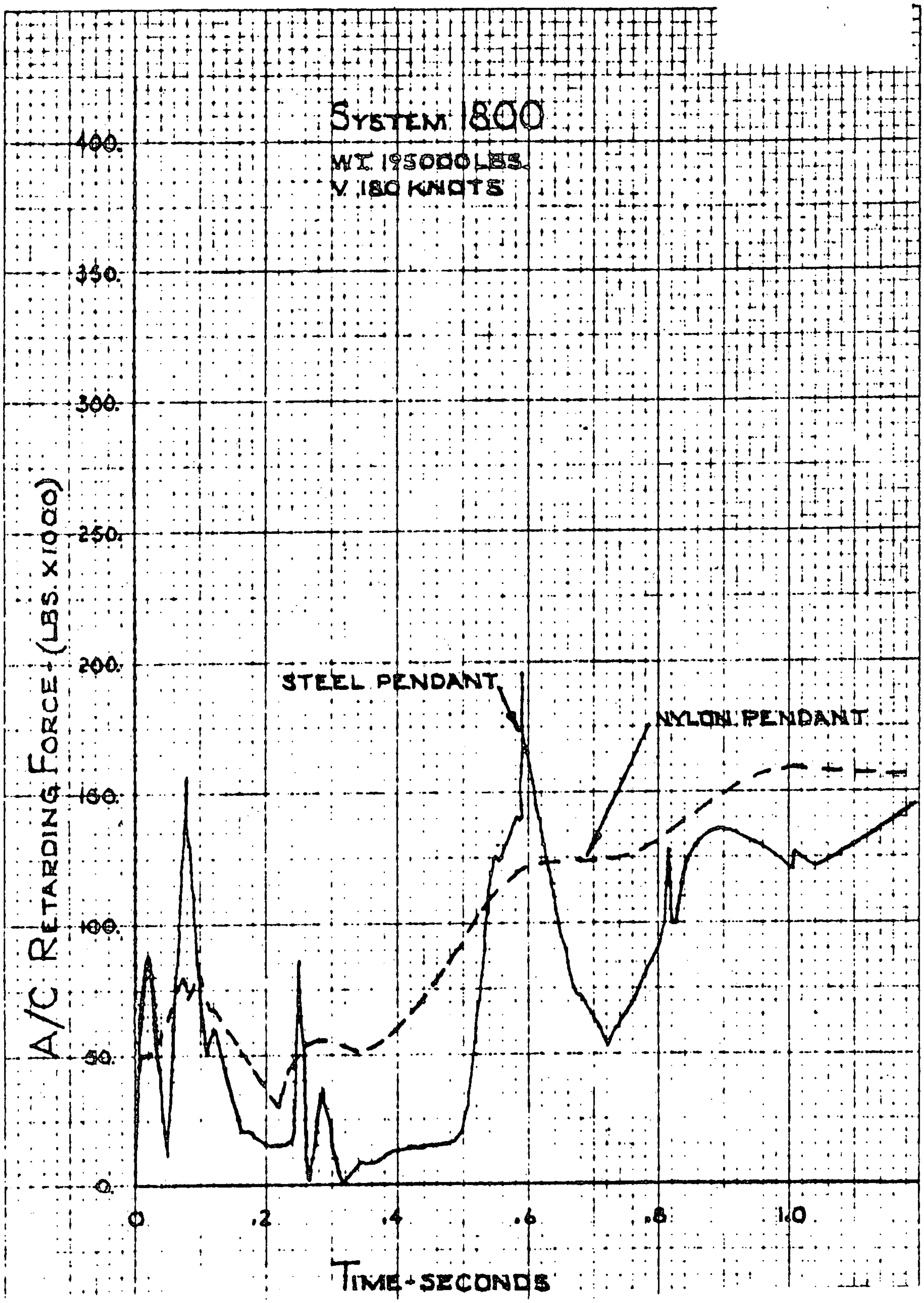

Figure 9. System 1800 (WT. 195,000 lbs. V 180 knots)
AC Retarding Force/Time-Seconds

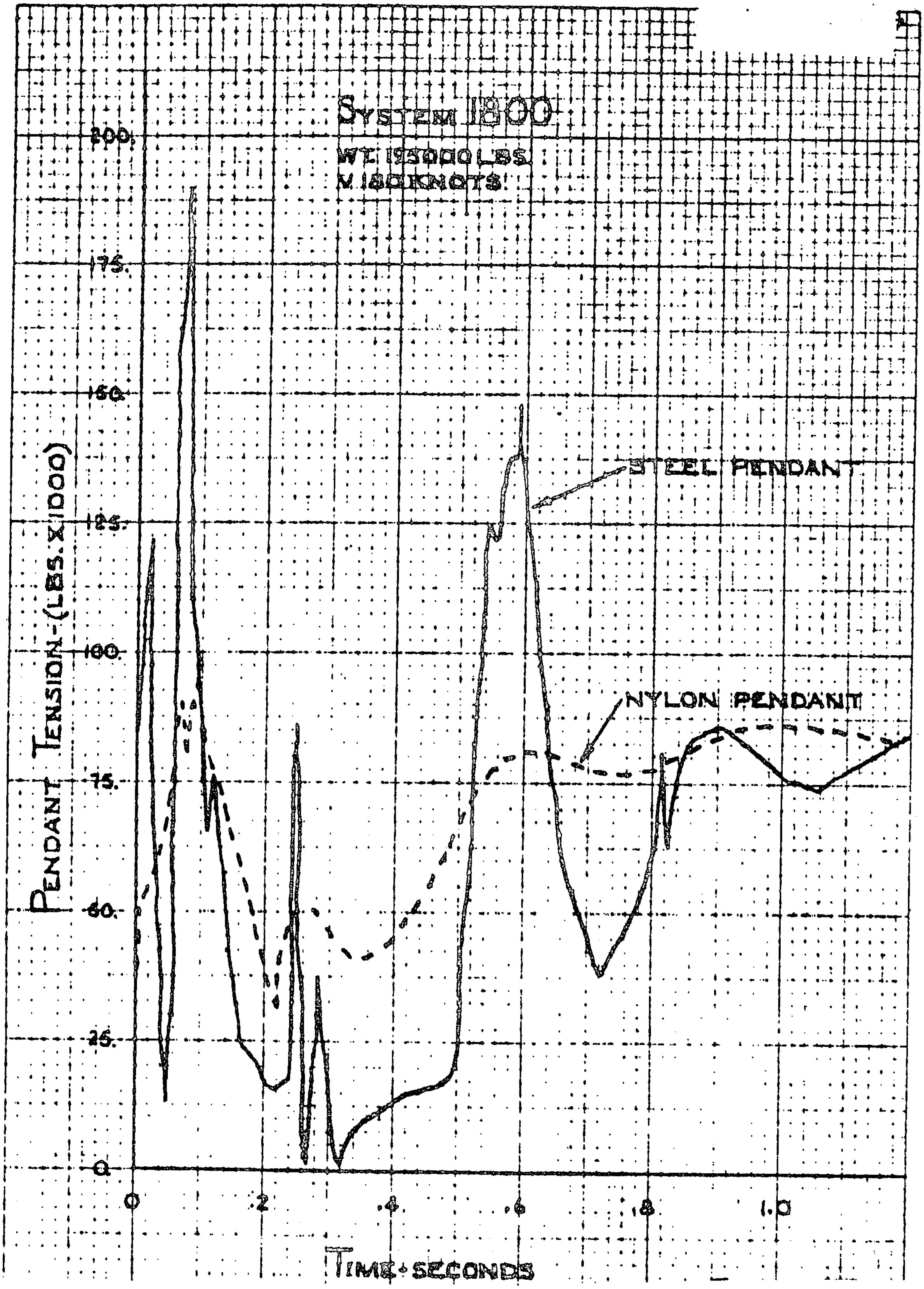

Figure 10. System 1800 (WT. 195,000 lbs. V 180 knots)
Pendant Tension/Time-Seconds

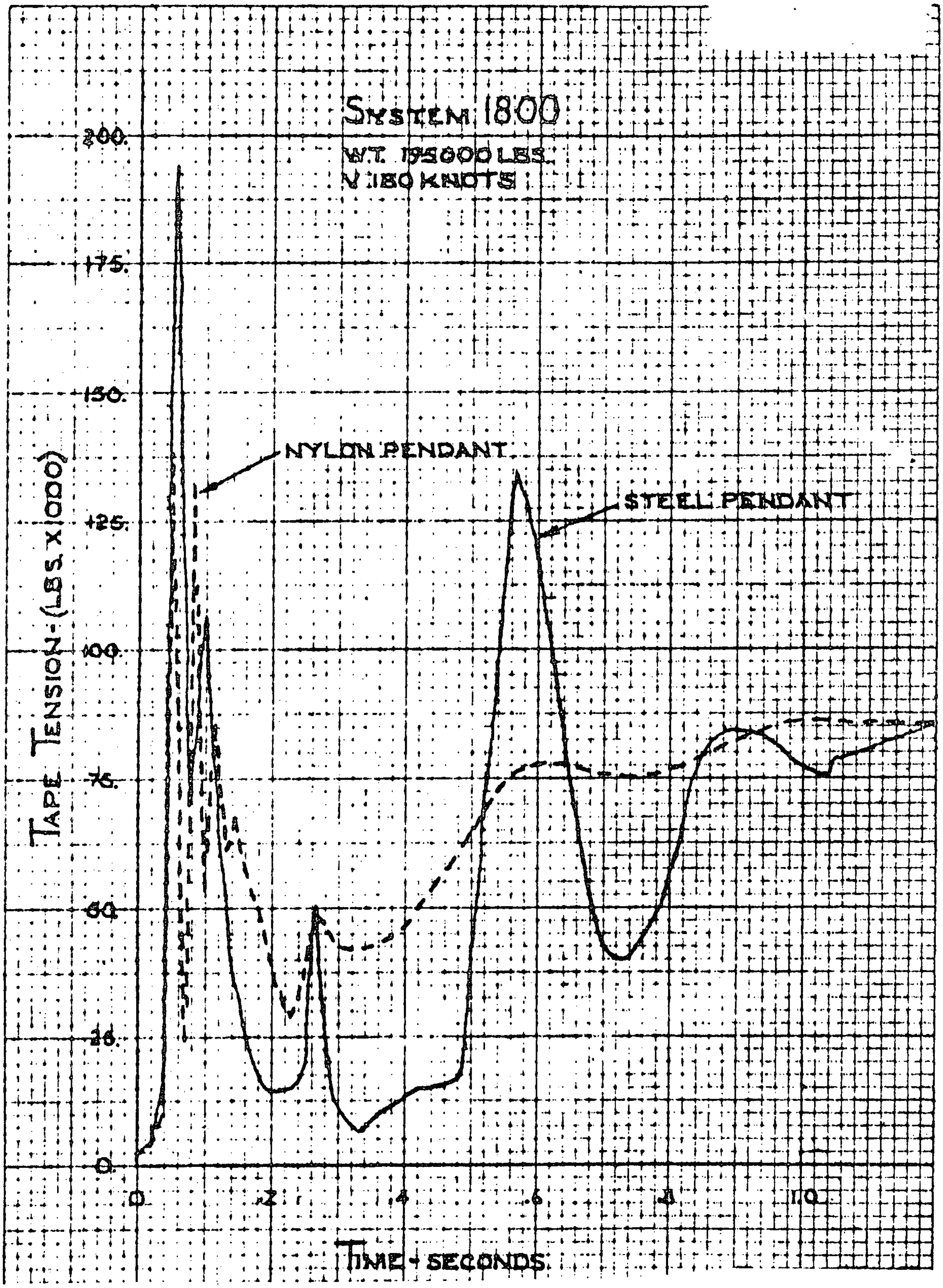

Figure 11. System 1800 (WT. 195,000 lbs. V 180 knots)
Tape Tension/Time-Seconds

Table 1. System 1800, Nylon Pendant

System N1800
Design Runout 1800 ft.

Design

1. Energy Absorber
   - a. Rotor Diameter - 64 inches
   - b. Torque Capacity - 1.05 ft.-lbs./(rpm)^2
   - c. Energy Capacity - 300 x 10^6 ft.-lbs.
2. Tape Reel
   - a. Hub Inner Radius - 10.5 in.
   - b. Flanges - Stationary-Diameter - 8.5 ft.
3. Pendant
   - a. Type - Nylon - 2 in 1 Braided Construction - Polyurethane Coated
   - b. Length - 290 ft.
4. Tape
   - a. Type - Nylon - Uncoated
   - b. Length - 1700 ft.
5. Deck Span - 200 to 400 ft.

Performance	Orbitor Mode Max Landing	Ferry Mode Max Abort Takeoff	Ferry Mode Max Future Growth
1. Aircraft Weight - lbs.	195,000	220,000	275,000
2. Aircraft Engaging Speed - knots	180	220	220
3. Aircraft Kinetic Energy - ft.-lbs.	280 x 10^6	472 x 10^6	590 x 10^6
4. Max Deceleration - g's	1.0	1.42	1.38
5. Max Retarding Force - lbs.	195,000	312,000	379,000
6. Max Runout - ft.	1,750	1,800	1,860
7. Pendant			
a. Size Diameter - inches	3-7/8	3-7/8	3-7/8
b. Breaking Strength - lbs.	400,000	400,000	400,000
c. Factor of Safety			
(1) Dynamic	4.2	3.2	3.2
(2) Steady State	4.0	2.5	2.1
8. Tape			
a. Size - inches	18 x .4	18 x .4	18 x .4
b. Breaking Strength - lbs.	400,000	400,000	400,000
c. Factor of Safety			
(1) Dynamic	2.9	2.2	2.2
(2) Steady State	4.0	2.5	2.1

Table 2. System 1800, Steel Pendant

System S1800
Design Runout 1800 ft.

Design

1. Energy Absorber
   - a. Rotor Diameter - 64 inches
   - b. Torque Capacity - 1.05 ft.-lbs./(rpm)^2
   - c. Energy Capacity - 300 x 10^6 ft.-lbs.
2. Tape Reel
   - a. Hub Inner Radius - 10.5 in.
   - b. Flanges - Stationary-Diameter - 8.5 ft.
3. Pendant
   - a. Type - Steel Wire Rope - (12 x 6)/(6 x 30) Construction
   - b. Length - 290 ft.
4. Tape
   - a. Type - Nylon - Uncoated
   - b. Length - 1700 ft.
5. Deck Span - 400 ft. minimum

Performance	Orbiter Mode Max Landing	Ferry Mode Max Abort Takeoff	Ferry Mode Max Future Growth
1. Aircraft Weight - lbs.	195,000	220,000	275,000
2. Aircraft Engaging Speed - knots	180	220	220
3. Aircraft Kinetic Energy - ft.-lbs.	280 x 10^6	472 x 10^6	590 x 10^6
4. Max Deceleration - g's	1.04	1.48	1.45
5. Max Retarding Force - lbs.	202,000	326,000	398,000
6. Max Runout - ft.	1,750	1,800	1,860
7. Pendant			
a. Size Diameter - inches	1-5/8	2.0	2.0
b. Breaking Strength - lbs.	254,000	384,000	384,000
c. Factor of Safety			
(1) Dynamic	1.7	1.6	1.6
(2) Steady State	2.4	2.3	1.9
8. Tape			
a. Size - inches	18 x .4	18 x .4	18 x .4
b. Breaking Strength - lbs.	400,000	400,000	400,000
c. Factor of Safety			
(1) Dynamic	3.0	2.1	2.1
(2) Steady State	3.8	2.4	2.0

Table 3. System 2400, Nylon Pendant

System N2400
Design Runout 2400 ft.

Design

1. Energy Absorber
   - a. Rotor Diameter - 64 inches
   - b. Torque Capacity - 1.05 ft.-lbs./(rpm)^2
   - c. Energy Capacity - 300 x 10^6 ft.-lbs.
2. Tape Reel
   - a. Hub Inner Radius - 10.5 in.
   - b. Flanges - Stationary-Diameter - 10 ft.
3. Pendant
   - a. Type - Nylon - 2 in 1 Braided Construction - Polyurethane Coated
   - b. Length - 290 ft.
4. Tape
   - a. Type - Nylon - Uncoated
   - b. Length - 2300 ft.
5. Deck Span - 200 to 400 ft.

Performance	Orbiter Mode Max Landing	Ferry Mode Max Abort Takeoff	Ferry Mode Max Future Growth
1. Aircraft Weight - lbs.	195,000	220,000	275,000
2. Aircraft Engaging Speed - knots	180	220	220
3. Aircraft Kinetic Energy - ft.-lbs.	280 x 10^6	472 x 10^6	590 x 10^6
4. Max Deceleration - g's	0.68	1.00	1.01
5. Max Retarding Force - lbs.	133,000	220,000	278,000
6. Max Runout - ft.	2,320	2,390	2,470
7. Pendant			
a. Size Diameter - inches	3-7/8	3-7/8	3-7/8
b. Breaking Strength - lbs.	400,000	400,000	400,000
c. Factor of Safety			
(1) Dynamic	3.9	3.0	3.0
(2) Steady State	5.9	3.5	2.8
8. Tape			
a. Size - inches	18 x .4	18 x .4	18 x .4
b. Breaking Strength - lbs.	400,000	400,000	400,000
c. Factor of Safety			
(1) Dynamic	2.8	2.0	2.0
(2) Steady State	5.9	3.5	2.8

Table 4. System 2400, Steel Pendant

System S2400
Design Runout 2400 ft.

Design

1. Energy Absorber
    a. Rotor Diameter - 64 inches
    b. Torque Capacity - 1.05 ft.-lbs./(rpm)^2
    c. Energy Capacity - 300 x 10^6 ft.-lbs.
2. Tape Reel
    a. Hub Inner Radius - 10.5 in.
    b. Flanges - Stationary-Diameter - 10 ft.
3. Pendant
    a. Type - Steel Wire Rope - (12 x 6)/(6 x 30) Construction
    b. Length - 290 ft.
4. Tape
    a. Type - Nylon-Uncoated
    b. Length - 2300 ft.
5. Deck Span - 400 ft. minimum

Performance	Orbiter Mode Max Landing	Ferry Mode Max Abort Takeoff	Ferry Mode Max Future Growth
1. Aircraft Weight - lbs.	195,000	220,000	275,000
2. Aircraft Engaging Speed - knots	180	220	220
3. Aircraft Kinetic Energy - ft.-lbs.	280 x 10^6	472 x 10^6	590 x 10^6
4. Max Deceleration - g's	0.71	1.03	1.05
5. Max Retarding Force - lbs.	138,000	226,000	288,000
6. Max Runout - ft.	2,330	2,410	2,480
7. Pendant			
a. Size Diameter - inches	1-3/8	1-5/8	1-7/8
b. Breaking Strength - lbs.	182,000	254,000	338,000
c. Factor of Safety			
(1) Dynamic	1.9	1.7	1.7
(2) Steady State	2.6	2.2	2.3
8. Tape			
a. Size - inches	11 x .4	11 x .4	14 x .4
b. Breaking Strength - lbs.	246,000	246,000	314,000
c. Factor of Safety			
(1) Dynamic	3.0	1.9	1.9
(2) Steady State	3.5	2.1	2.1

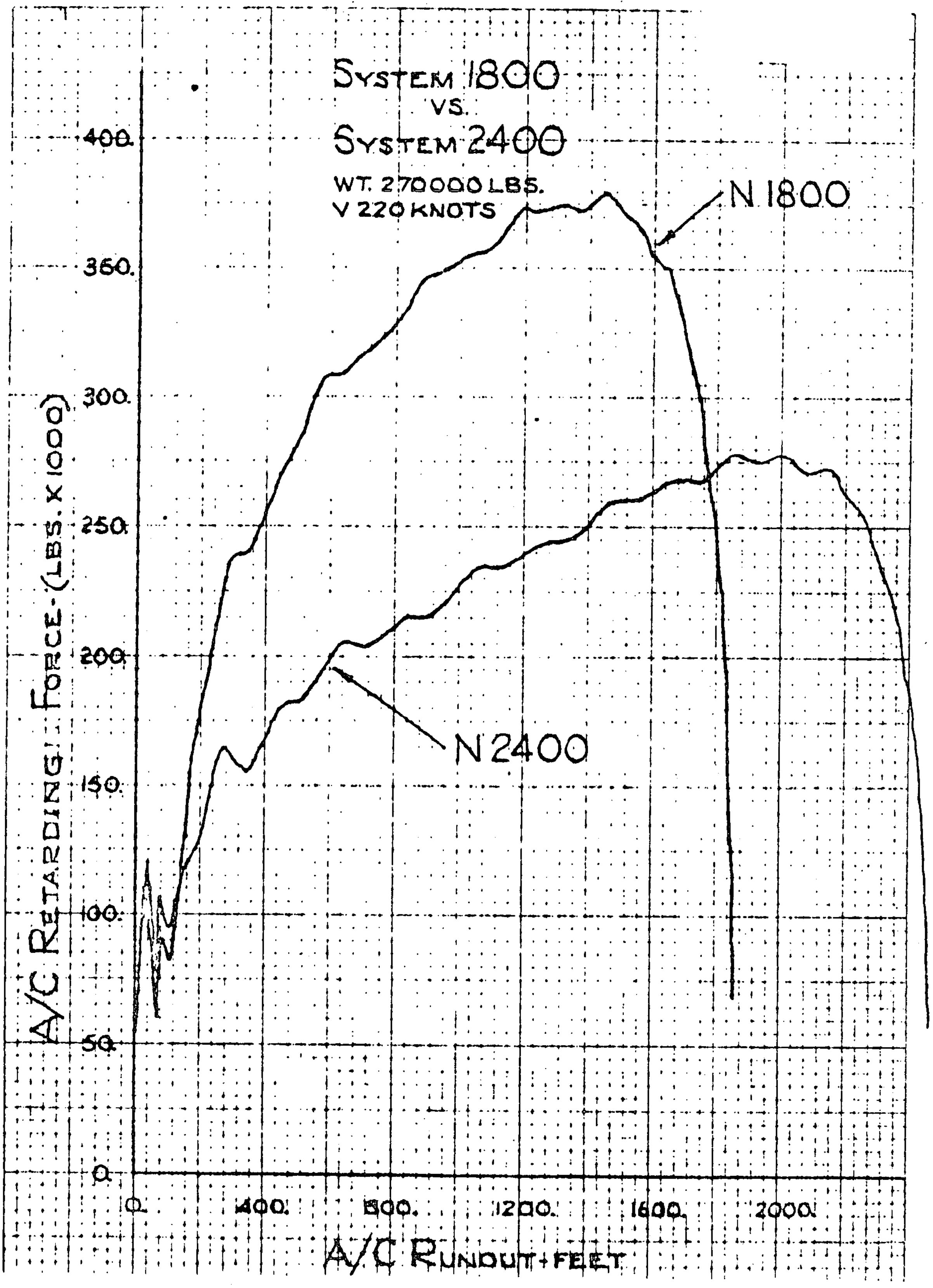

Figure 12. System 1800 vs. System 2400 (WT. 270,000 lbs. V 220 knots)
AC Retarding Force/AC Runout-Feet

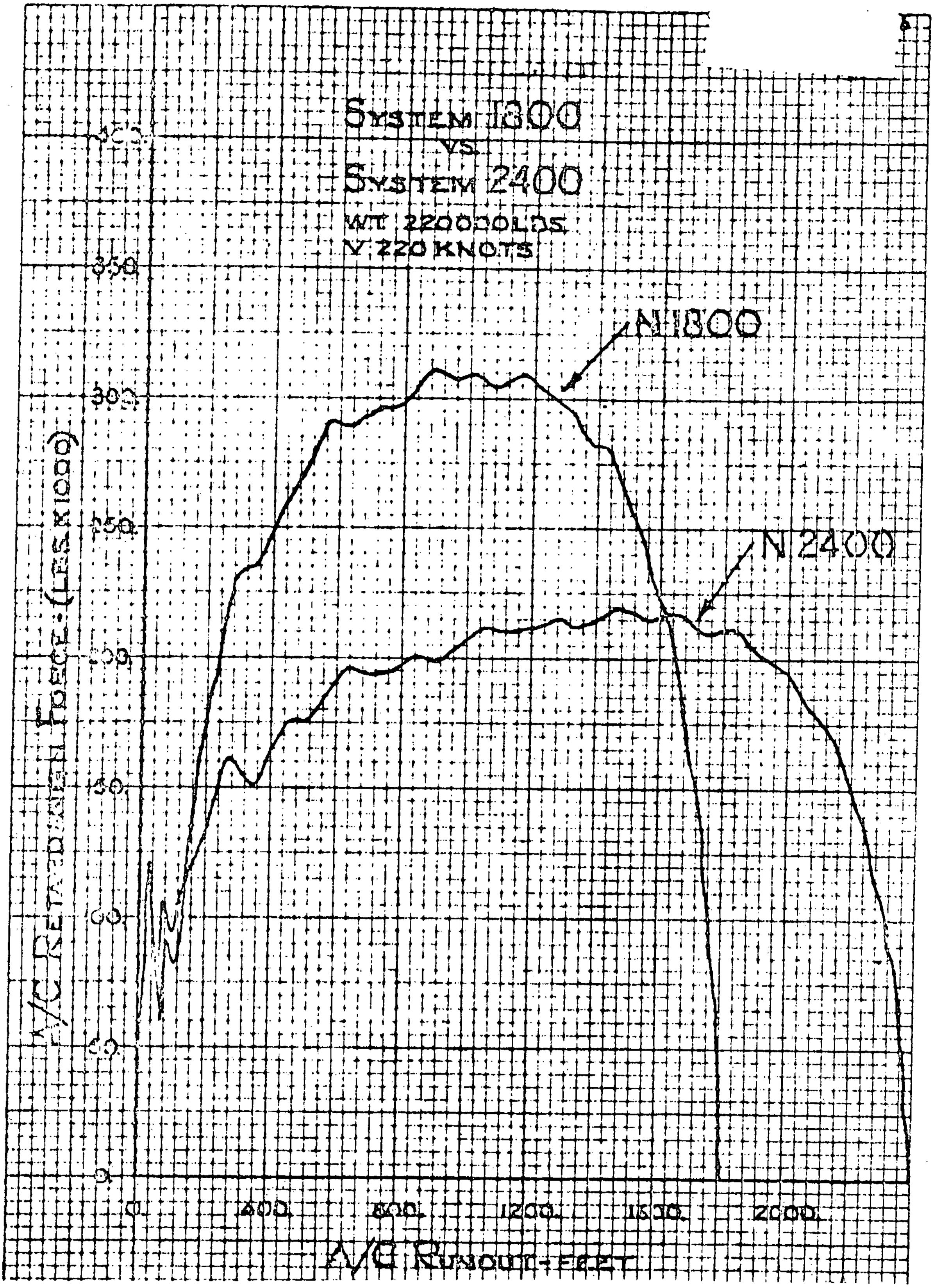

Figure 13. System 1800 vs. System 2400 (WT. 220,000 lbs. V 220 knots)
AC Retarding Force/AC Runout-Feet

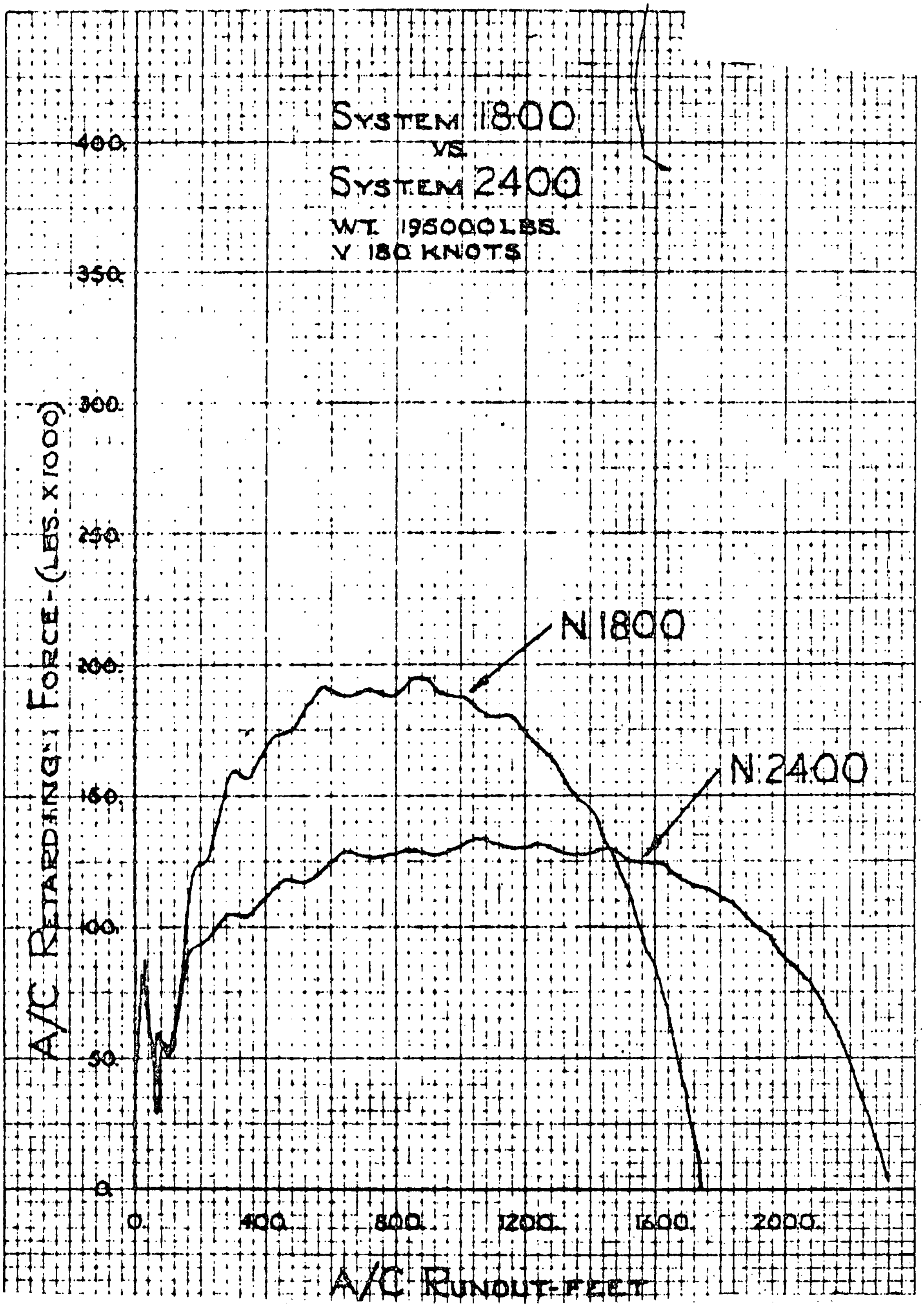

Figure 14. System 1800 vs. System 2400 (WT. 195,000 lbs. V 180 knots)
AC Retarding Force/AC Runout-Feet

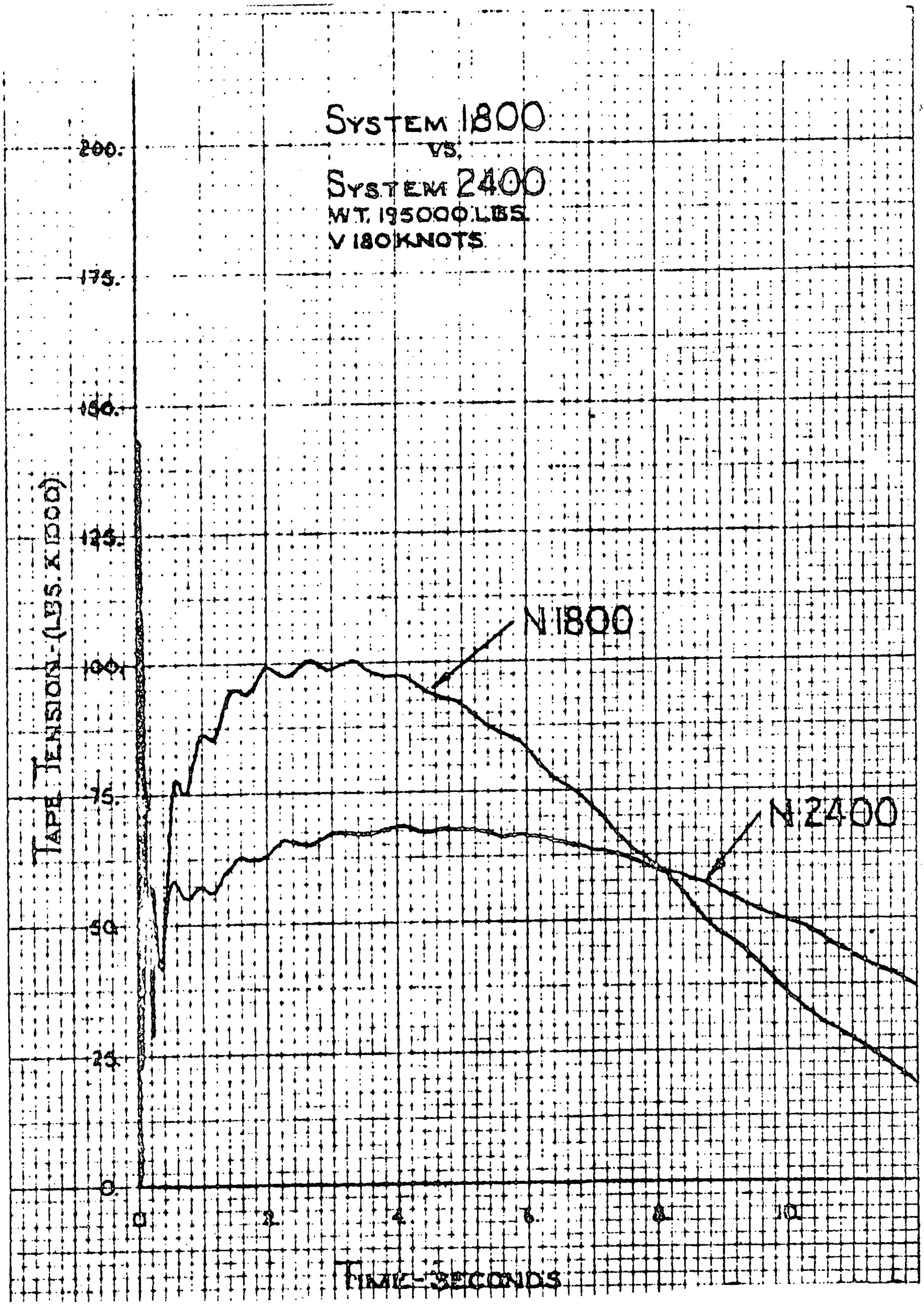

Figure 15. System 1800 vs. System 2400 (WT. 195,000 lbs. V 180 knots) Tape Tension/Time-Seconds

D

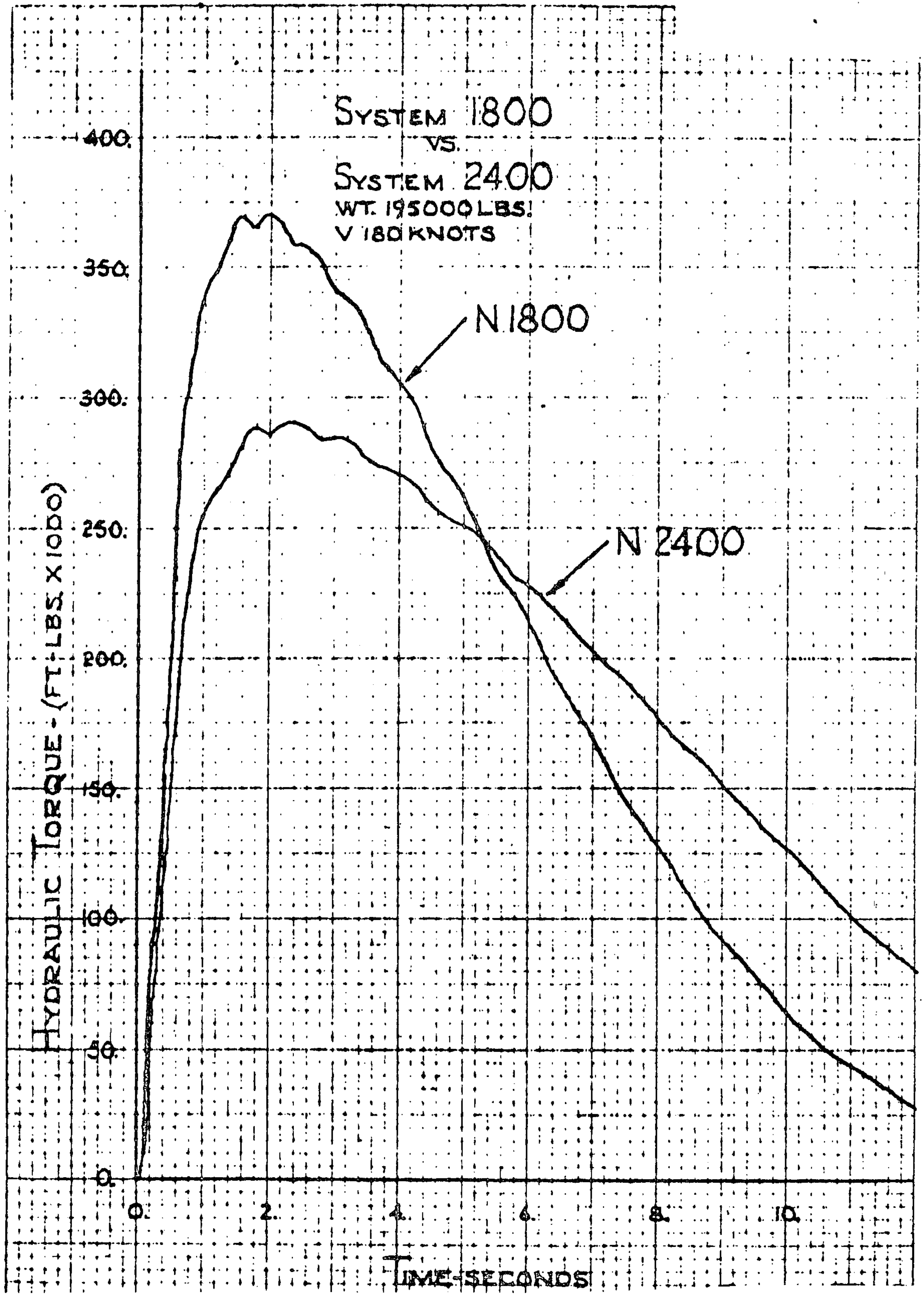

Figure 16. System 1800 vs. System 2400 (WT. 195,000 lbs. V 180 knots)
Hydraulic Torque/Time-Seconds

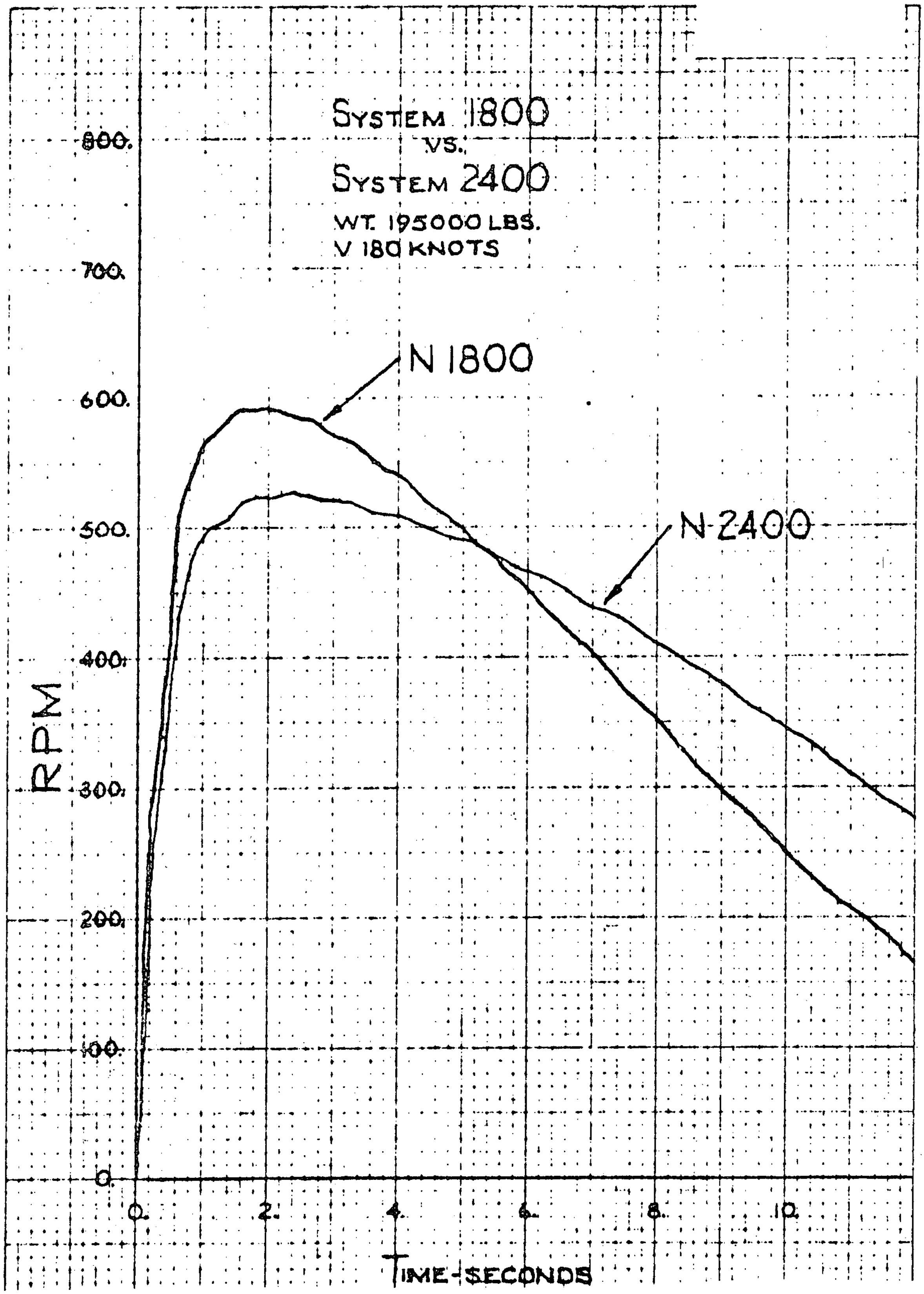

Figure 17. System 1800 vs. System 2400 (WT. 195,000 lbs. V 180 knots) RPM/Time-Seconds

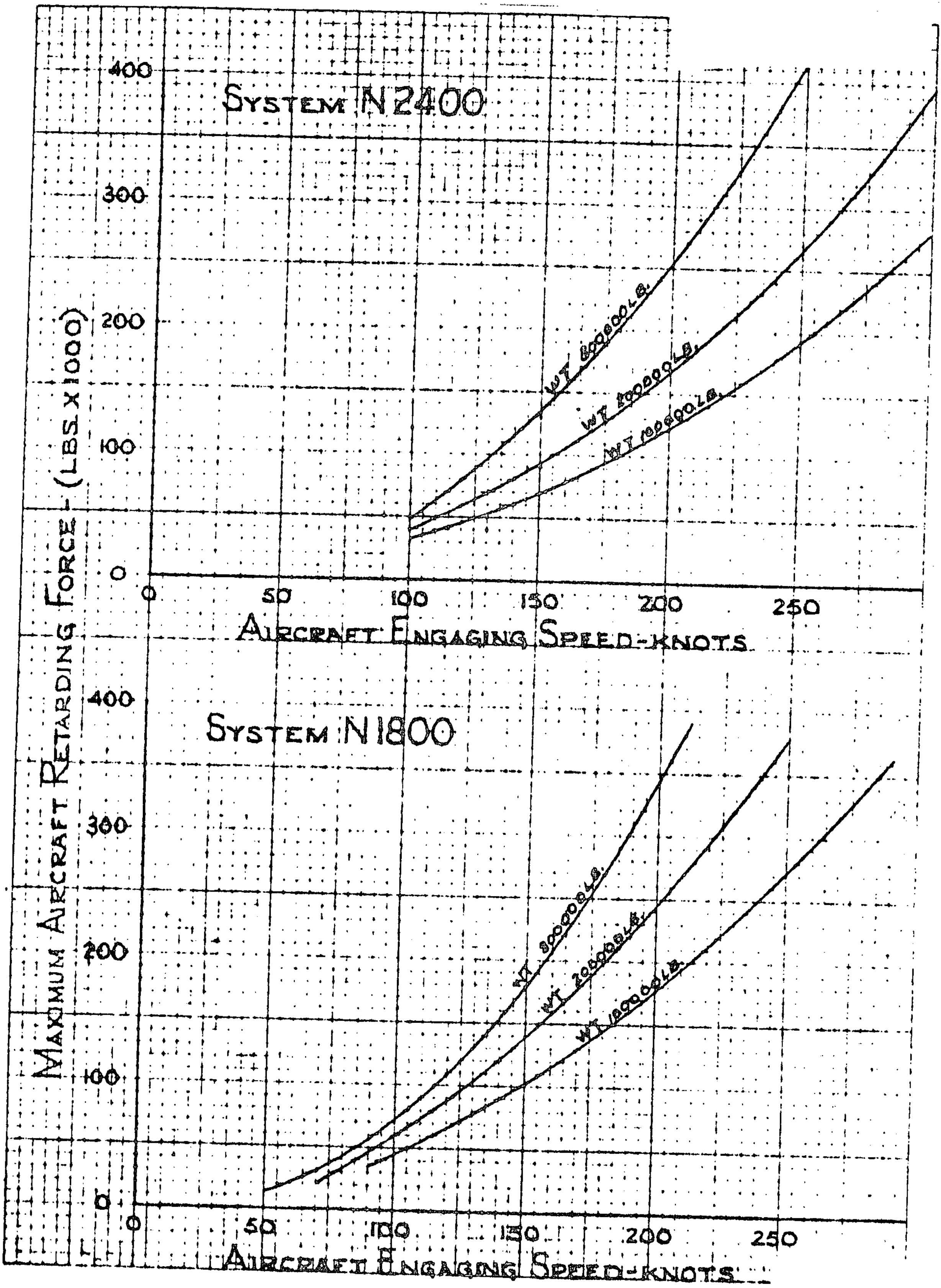

Figure 18. System N2400 and System N1800 Maximum AC Retarding Force/AC Engaging Speed-Knots

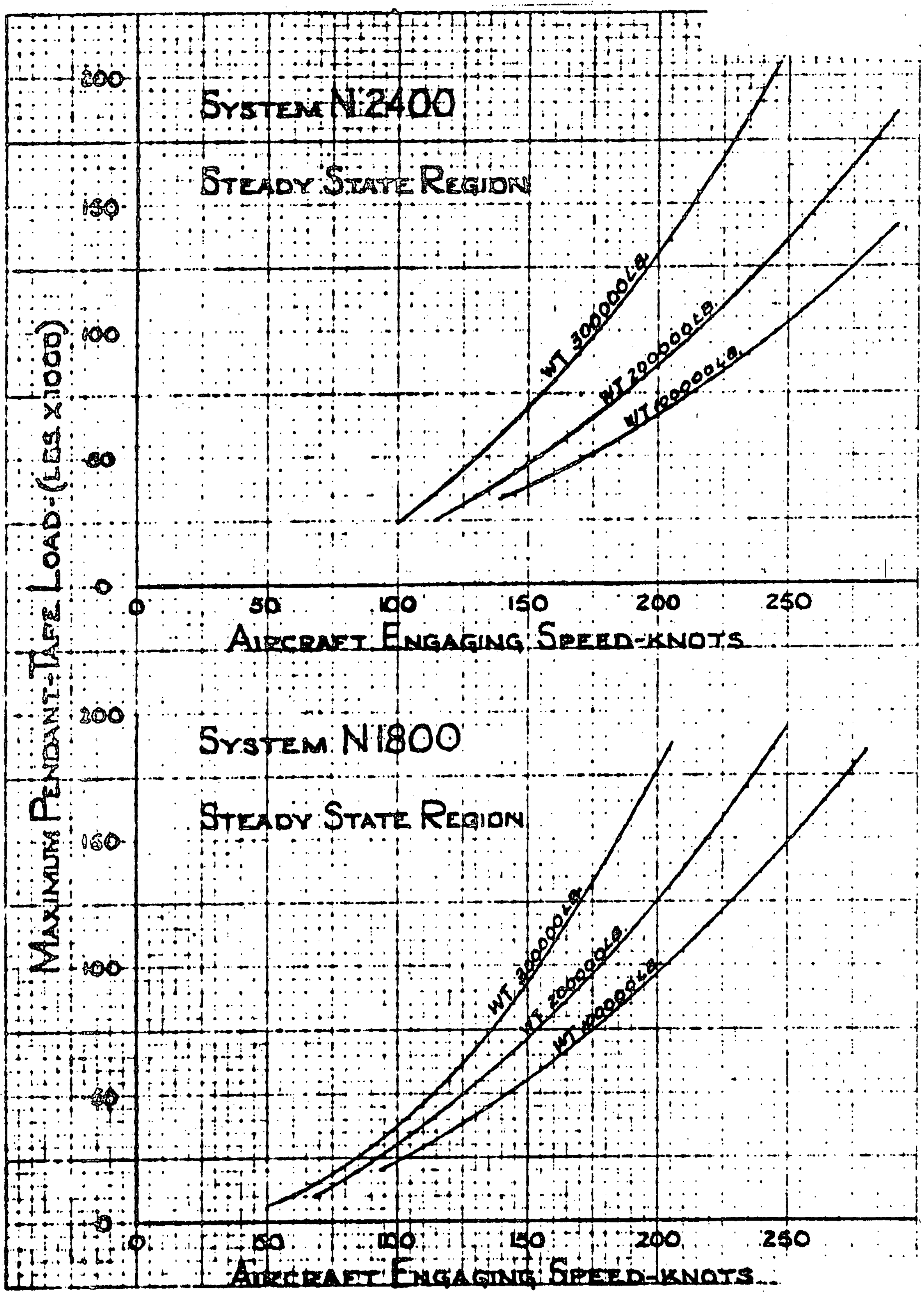

Figure 19. System N2400 and System N1800, Steady State Region Maximum Pendant Tape Load/AC Engaging Speed-Knots

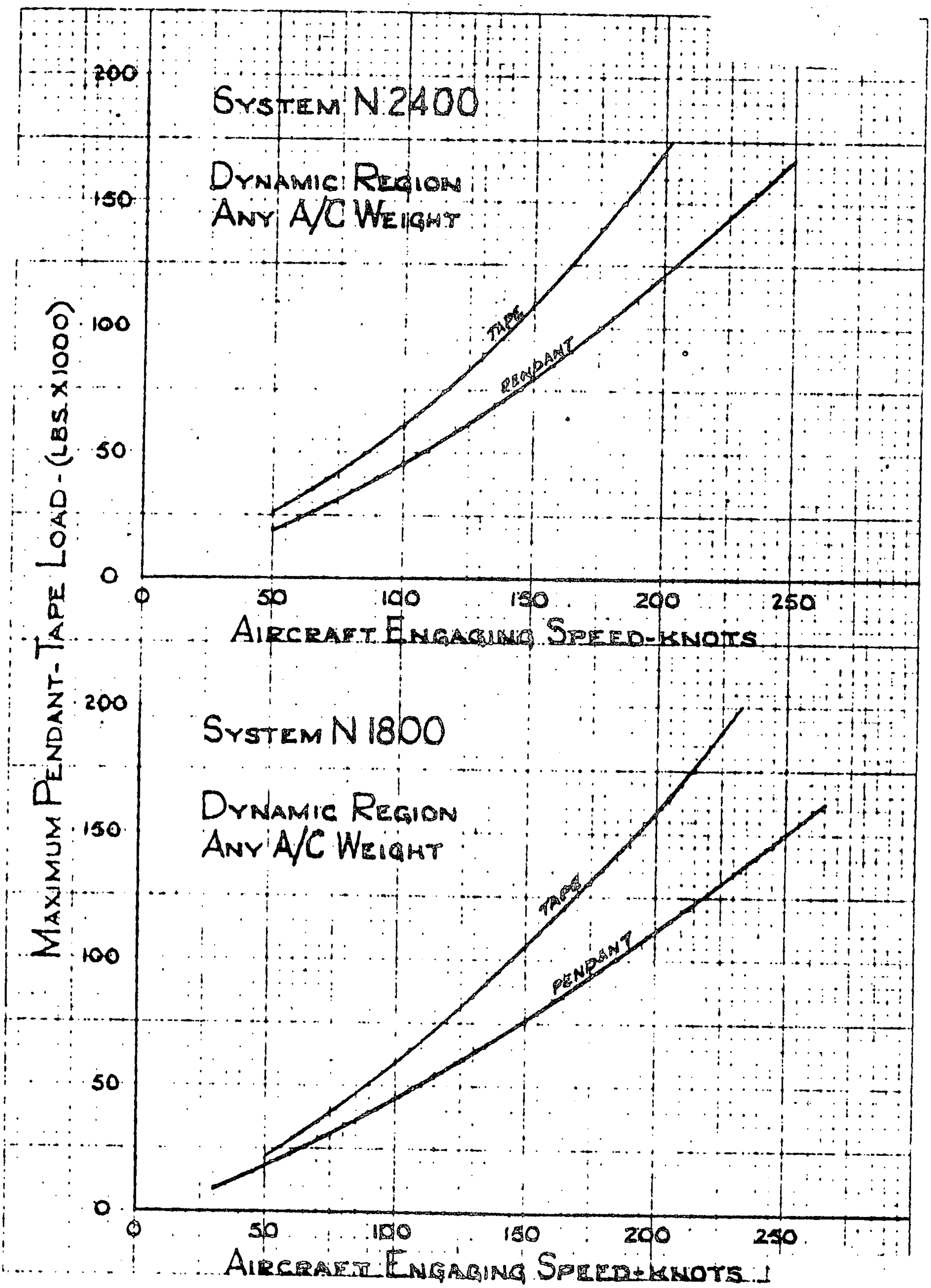

Figure 20. System N2400 and System N1800, Dynamic Region, Any AC Weight Maximum Pendant Tape Load/AC Engaging Speed-Knots

1.4.5 COMPONENTS DESIGN. Selection of size.

a. Arresting Engine.

Systems 1800 and 2400 require the same engine.

Torque Capacity = 1.05 ft.-lbs/(rpm)^2.

Energy Capacity = 300 x 10^6ft.-lbs. per unit (600 x 10^6 total system.)

This torque capacity will require a unit with a rotor diameter of 64 inches. Engines of this size and torque capacity have been manufactured. These units performed adequately during a small test program with limited engaging energy conditions. Maximum tested energy absorbed was 180 x 10^6ft.-lbs., less than 1/3 the required maximum energy capacity of the intended design. However, no major design or development problems are expected in attaining this increased energy absorbing capacity.

b. Tape Reel.

(1) Systems 1800 and 2400 require the same hub inner radius.

Hub Radius = 10.5 inches.

Minimum hub radius allowable is dependent upon the rotor and shaft size and the purchase tape size. The rotor and shaft sizes are determined by material strength and the torque capacity required. Tape size required determines the smallest radius to which this tape can safely be wrapped. A hub radius of 10.5 inches is compatible with the torque capacity and tape sizes required with either system.

(2) Flange Diameter = 8.5 ft. System 1800

Flange Diameter = 10 ft. System 2400

Experience with stationary flanges is limited. Experience with flanges as large as these is non-existant, but no major design or development problems are expected.

c. Tape.

System	Tape Width (in.)	Thickness (in.)	Length (ft.)
N or S1800	18	0.4	1700
N2400	18	0.4	2300
S2400	14	0.4	2300
S2400	11	0.4	2300

Nylon tapes of 18 x 0.4 cross-sectional size have been successfully manufactured, and are available in continuous lengths in excess of 2300 ft. The smaller width tapes required for System S2400 should also be readily available.

d. Pendant

(1) Nylon Rope.

Diameter - 3-7/8 inches. Systems N1800 or N2400

Length 290 ft. for 300 ft. deck span.

Construction 2 in 1 braided.

Coating - polyurethane.

This is a standard "off the shelf" item, readily available in continuous lengths in excess of 290 feet. Previous experience with smaller nylon pendants has indicated the performance advantages of this type. Nylon pendants have not gained acceptance in military systems due to their short service lives and an inability to establish good replacement criteria. These two requirements are not factors for design of the Space Shuttle Recovery System; the pendant can be replaced after each arrestment. The hook can be designed to accommodate any size pendant. A pendant as large as this may introduce a "rollover" problem when the landing gear passes over it, but this problem should be minor. The nylon pendant is judged acceptable for this system.

(2) Steel Wire Rope.

Diameters - 1-5/8" and 2"	System S1800
Diameter - 1-3/8", 1-5/8" and 1-7/8"	System S2400

Length - 290 feet for 400 ft. deck span.

Construction - (12 x 6)/(6 x 30)

Steel wire rope pendants of this construction have been manufactured in only one size - 1-1/4 inch diameter. However, experience in the manufacture of other types of wire rope indicates that these sizes can readily be built with this construction. Steel wire rope pendants are standard with military systems and would be acceptable with the Space Shuttle System.

1.5 RECOMMENDATIONS

The system should be designed with a nylon pendant.

The shorter runout system, N1800, is preferred. Although the loads and accelerations are higher than System N2400, they are acceptable. Also, the shorter runout system is less likely to incur an aircraft tracking problem. Since Systems N2400 and N1800 differ only in the minimum flange size required and length of tape wrapped on the reel, design for System N2400 . Then by varying the length of tape, any aircraft runout less than 2400 ft. can be obtained. The optimum runout will be determined by development tests.

Incorporate all components sized by this study into the final design regardless of the engagement mode chosen. Replace only the pendant by the barricade net or landing gear entanglement member.

1.6 REFERENCES

Naval Air Engineering Center, Engineering Department (SI) Report, NAEC-ENG-6169 "Cable Dynamics" of 27 Dec 1956 by Friebrich O. Ringleb.

APPENDIX B

ENGAGEMENT MODE: TRADE-OFF STUDY

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX B

ENGAGEMENT MODE: TRADE-OFF STUDY

1.0 INTRODUCTION

The objective of this study is to determine the proper mode of engaging the aircraft and recovery system. All feasible modes of engagement are evaluated, and the optimum one chosen.

1.1 ENGAGEMENT MODES EVALUATED

a. Hook Pendant Engagement. A hook attached to the aircraft is dragged along the runway to pick up a pendant stretched across the deck.

b. Barricade Engagement. The entire aircraft passes into and is enveloped by a nylon net suspended across the runway.

c. Landing Gear Entanglement. The main landing gear of the aircraft engage a pendant/net which must be raised off the deck after the forward landing gear has passed over the pendant/net.

d. It should be noted that the Naval Air Engineering Center has had extensive experience in the design, development, test and actual field or aircraft carrier usage of each of the three engagement modes studied. This experience was applied in most of the areas involved in this evaluation.

1.2 PROCEDURE

a. A performance/cost trade-off study was conducted to determine the proper mode of engagement. Each engaging system was evaluated on a performance or cost basis for several factors pertinent to the aircraft recovery system operation. The evaluation of several engaging systems, by a comparison study which includes many different factors, results in a complex decision making problem.

b. An analytical technique, known as the "Emphasis Curve", was used to help simplify the problem. The technique gives emphasis to the more important parameters to be considered in selecting the proper system, while deemphasizing the less important ones. The procedure does not substitute for the judgment of the evaluator; it merely helps him to systematize the decision making process by keeping account of all parameters and by determining the importance of each in relation to all others. In this way, each parameter can be weighted in proportion to its importance. These weighting factors, called RIF (Relative Importance Factors), are assigned to each parameter through the analysis.

c. After determining the importance of each parameter to be used in the evaluation, each engaging system is assigned a numerical score, by the evaluator, for each parameter. This score is proportional to the degree in which the particular engaging system satisfies the requirements of the parameter.

d. By multiplying each score by the weighting factor assigned for that parameter, we generate a table of effective scores for each engaging system and each parameter. The effective scores for each engaging system are totaled, and the system with the greatest total is the optimum one.

1.3 TRADE-OFF STUDY

1.3.1 PARAMETERS. Parameters used in trade-off study are as follows:

a. Weight penalty - addition to basic aircraft weight caused by modifications required to use the engaging system.

b. Cost of required aircraft modifications - cost to design, develop and install any modifications to the aircraft required to use the engaging system.

c. Technical risk of required aircraft modifications - risk of successfully designing and developing a reliable system required to use the engaging system. This includes reliability of activating these devices and their operational reliability throughout the arrestment.

d. Engagement reliability - reliability of engaging the recovery system.

e. Safe arrestment reliability - assuming a successful engagement, this is the probability of retaining the engaging member throughout the arrestment without abnormal damage to the vehicle or injury to the crew.

f. Normal operational damage - assuming a successful arrestment, this is normal aircraft damage expected as a result of the engaging device.

g. Technical risk of engaging device - the risk of designing and developing a reliable engaging system. Includes consideration of interaction between the aircraft and the engaging member and compatibility of aircraft with engaging member as judged from past experience.

h. Cost and time of system design.

i. Cost and time of development test program - relative time and cost advantages and disadvantages for each engaging system regardless of the type of test program conducted.

j. Cost of system installation.

k. Cost of system operation and maintenance.

l. Cost of prototype system procurement.

m. Cost of production systems procurement.

n. Compatibility with other aircraft - the potential of using the engaging system and energy absorber with other aircraft.

NOTES: (1) All three engaging systems will impose approximately the same retarding load on the aircraft and will require approximately the same aircraft runout to dissipate the energy.

(2) Exclusive of the engaging system, all components of the recovery system, such as energy absorber, tape size, etc., are identical regardless of which engagement mode is selected.

1.3.2 EMPHASIS CURVE

a. Technique. Table 1 is a work sheet which illustrates the operation of the "Emphasis Curve" technique.

(1) The parameters to be used in the comparison study are listed in any order.

(2) Each parameter is then compared with every other parameter on a one for one basis. The evaluator must determine which of two parameters is the more important factor to be considered, when selecting an engagement mode. For example, if Engagement Reliability (E) is more important than Installation Cost (J), circle E on the work sheet where this comparison is indicated.

(3) When every one of these individual comparisons is made, a summation is made of the number of times each parameter is circled. The parameter with the highest score is the most important, the lowest score indicates the least important. These values indicate the relative importance of each parameter - and are called Relative Importance Factors (RIF).

Table 1. Emphasis Curve Work Sheet

	PARAMETER	ANALYSIS																
A	WEIGHT PENALTY	Ⓐ B	Ⓐ C	Ⓐ D	Ⓐ E	Ⓐ F	Ⓐ G	Ⓐ H	Ⓐ I	Ⓐ J	Ⓐ K	Ⓐ L	Ⓐ M	Ⓐ N	A O	A P	⑬	A
B	COST - A/C MODIFICATIONS		B Ⓒ	B Ⓓ	B Ⓔ	B Ⓕ	Ⓑ G	Ⓑ H	B Ⓘ	Ⓑ J	Ⓑ K	Ⓑ L	Ⓑ M	Ⓑ N	B O	B P	⑦	B
C	TECHNICAL RISK - A/C MODIFICATIONS			C Ⓓ	Ⓒ E	Ⓒ F	Ⓒ G	Ⓒ H	Ⓒ I	Ⓒ J	Ⓒ K	Ⓒ L	Ⓒ M	Ⓒ N	C O	C P	⑪	C
D	SAFE ARRESTMENT RELIABILITY				Ⓓ E	Ⓓ F	Ⓓ G	Ⓓ H	Ⓓ I	Ⓓ J	Ⓓ K	Ⓓ L	Ⓓ M	Ⓓ N	D O	D P	⑫	D
E	ENGAGEMENT RELIABILITY					Ⓔ F	Ⓔ G	Ⓔ H	Ⓔ I	Ⓔ J	Ⓔ K	Ⓔ L	Ⓔ M	Ⓔ N	E O	E P	⑩	E
F	NORMAL OPERATIONAL DAMAGE						Ⓕ G	Ⓕ H	Ⓕ I	Ⓕ J	Ⓕ K	Ⓕ L	Ⓕ M	Ⓕ N	F O	F P	⑨	F
G	TECHNICAL RISK - ENGAGING SYSTEM							Ⓖ H	G Ⓘ	Ⓖ J	Ⓖ K	Ⓖ L	Ⓖ M	Ⓖ N	G O	G P	⑥	G
H	COST AND TIME-DESIGN-ENGAGING SYSTEM								H Ⓘ	Ⓗ J	Ⓗ K	Ⓗ L	H Ⓜ	Ⓗ N	H O	H P	④	H
I	COST AND TIME - DEVELOPMENT TEST									Ⓘ J	Ⓘ K	Ⓘ L	Ⓘ M	Ⓘ N	I O	I P	⑧	I
J	COST - INSTALLATION										J Ⓚ	J Ⓛ	J Ⓜ	Ⓙ N	J O	J P	①	J
K	COST - OPERATIONS AND MAINTENANCE											Ⓚ L	K Ⓜ	Ⓚ N	K O	K P	③	K
L	PROCUREMENT COST - PROTOTYPE												L Ⓜ	Ⓛ N	L O	L P	②	L
M	PROCUREMENT COST - PRODUCTION													Ⓜ N	M O	M P	⑤	M
N	COMPATIBILITY WITH OTHER AIRCRAFT														N O	N P	⓪	N
O																O P	○	O

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b. Results of Emphasis Curve Analysis.

Parameter	RIF
Weight Penalty	13
Safe Arrestment reliability	12
Technical risk - aircraft modification required	11
Engagement reliability	10
Normal operational damage	9
Cost and time - development test program	8
Cost - aircraft modifications required	7
Technical risk - engaging system	6
Procurement cost - production	5
Cost and time - design of engaging system	4
Cost - operation and maintenance	3
Procurement cost - prototype	2
Cost - installation	1
Compatibility with other aircraft	0

c. Discussion. The analysis yields an excellent qualitative ranking of the importance of each parameter, and a rough quantitative ranking. Additional discussion on the importance of these parameters will be found in Paragraph 1.3. We assumed for the following Trade Off Study that the RIF's developed in the "Emphasis Curve" analysis permit a quantitative ranking of parameters.

3. Scoring of Engaging Systems. Each engaging system is now assigned a score for each parameter. A high score indicates a system which satisfies the requirement of the parameter; a low score means the system does not satisfy the requirement. See Table 2.

10	Maximum
9	Good
8	
7	
6	Average
5	
4	Poor
3	
2	
1	Minimum

1.3.4 ASSIGNING SCORES

a. Weight Penalty.

(1) The barricade was assigned the maximum score of 10 for this parameter since no aircraft modifications or additions would be necessary to be able to use this engaging device. Also, modifications which could be made to conventional aircraft to improve barricade compatibility, such as protrusions on the wing to retain and evenly distribute the loading straps, would seriously complicate the Space Shuttle design, to say the least. Hence, no additions to or modifications of the aircraft are needed or would be permitted for the barricade.

(2) The landing gear entanglement system was assigned a very good 9 since normal landing gear designs should provide sufficient strength to withstand the proposed arrestment loading, but small additions to the landing gear to help retain the barrier may be necessary.

(3) The hook-pendant system was scored a poor value of 3. A significant weight penalty will be incurred with this system due to the following additions to the Space Shuttle:

(a) Hook.

(b) Attachment structure, hook to aircraft.

(c) Activating mechanism.

(d) Heat shield for hook system.

b. Safe Arrestment Reliability

(1) A very good score of 9 was assigned to the hook system. The excellent safety record of this system has been adequately demonstrated with millions of trouble free arrestments of Navy, Marine and Air Force aircraft. Inexperience with engaging energies of the Space Shuttle magnitudes caused this score to be reduced from 10 to 9.

(2) The barricade was assigned a very poor value of 2. The many hazards associated with this type of engagement, such as retaining the net throughout the arrestment and poor off-center performance, have also been demonstrated by actual fleet experience. However, identification of these hazards has not yet led to the proper design techniques to eliminate or even reduce many of these problem areas. Barricade engagement of a high energy, swept and smooth surfaced wing vehicle would be extremely dangerous.

(3) The landing gear entanglement system was assigned an average score of 6. Assuming a successful engagement, the system should be quite safe, but actual field experience with the design and the distant possibility of poor off-center performance with this system reduce reliability.

c. Technical Risk - Aircraft Modifications Required.

Cost - Aircraft Modifications Required.

(1) Since no modifications or additions to the aircraft are required or permitted with the barricade system, we must assign the maximum score of 10 for these parameters.

(2) Little or no modification of the aircraft is expected for the landing gear entanglement system; hence, the very good score of 9 was assigned.

(3) The additions to and modifications of the Space Shuttle, required for the hook-pendant system, are nearly identical to those required to equip conventional aircraft for this type of engagement. Sufficient experience has been gained to rate the reliability of operation of these components quite high. One area of unknown is the need to shield the hook from reentry heating and then remove this shield prior to activating the hook. Hence, an overall score of 7 (fairly good) was assigned for technical risk and a poor score of 3 for cost.

d. Engagement Reliability.

(1) No problems are envisioned in designing a barricade net which would engage the aircraft with 100% reliability. Even a system which would be raised and positioned in a few seconds on a signal from the pilot should have very high reliability. Hence, a score of 10 was assigned for the barricade.

(2) The landing gear entanglement system historically has a very low engagement reliability. This problem has led to the discontinued use of this system by the military. A sensing and activating system is required to allow the forward landing gear to pass over the barrier and then engage both main landing gear. At the proposed engaging speeds and distance between landing gear, activation times of approximately 1/8 of a second are required. Equipment which would stretch "state of the art" technology in several disciplines would be required for such a system. This would result in low system reliability. Multiple systems would improve reliability by reducing the chance of a missed engagement caused by system malfunction, but they would not substitute for inadequate system performance. Hence, the landing gear entanglement system was assigned the minimum value of 1 for engagement reliability.

(3) Hook-pendant system engagement reliability of military aircraft with landbased recovery systems is quite high. Unlike the landing gear entanglement system, the pendant is an inactive member; it is merely held up off the deck a small amount to be engaged by the hook. There is no complex system operation to contribute to a reliability problem; hence, multiple pendants will significantly improve engagement reliability. The aircraft hook, however, must be activated. This operation is normally quite simple, but the Space Shuttle design may require a removable heat shield for the hook. Additional systems to insure hook activation should eliminate this problem. Hence, this system is assigned a very good score of 9.

e. Normal Operational Damage.

(1) The hook-pendant system is the operational mode of engagement for Naval aircraft on board aircraft carriers. A normal engagement and recovery with this system results in no damage to the aircraft. Hence, this systems rates a maximum score of 10 for this category.

(2) The barricade system is the emergency mode of engagement on board carriers. It is employed very infrequently and only when hook-pendant engagement is not possible, and if a shorebased landing cannot be made. A successful barricade arrestment is defined as one with little or no injury to the crew. Normal operational damage to the aircraft is accepted and is sometimes quite severe. Hence, this system is assigned a very poor score of 2.

(3) Normal operational damage to the aircraft should be quite low with the landing gear entanglement system. However, off center engagement may cause some damage since the barrier would tend to slip relative to the landing gear struts. Also, experience with this system requires that we assign an average score of 5.

f. Cost and Time - Development Test Program.

(1) A test program of the barricade engagement system requires using an actual aircraft as the test vehicle. A simulated aircraft may be used which duplicates the aircraft's wings, tail, nose and landing gear, and has the same weight and center of gravity location. This vehicle is very costly. Normal operational damage and possible extensive damage caused by barricade systems, especially during these development tests, will require extensive repair of this vehicle after each test arrestment. This procedure will be very costly and time consuming. Hence, the barricade system rates a very poor 2.

(2) The landing gear entanglement system also requires use of a simulation vehicle, however, vehicle requirements are less stringent than those of the barricade test vehicle. Also, normal operational damage with this system should be much lower than that of the barricade system, with a subsequent reduction in cost and time. Hence, this system rates an average score of 5.

(3) The test vehicle required for the hook-pendant system is a simple box shaped wheeled frame made of structural steel and weighted to the proper amount. The cost of this vehicle is also included in the barricade and landing gear entanglement test program time and cost estimates, since tests with this vehicle are necessary to develop proper recovery system operation prior to test with the actual engaging member and the simulated aircraft. Also, the hook-pendant engaging system permits testing of the recovery systems with the actual space shuttle vehicle at the installed operational sites. This could result in a cost and time saving for the test program and a final operational checkout of the installed systems. This type of final testing would not be permitted with the other modes of engagement due to the high probability of damage to the aircraft with these systems. Hence, the hook-pendant system is assigned an excellent score of 10.

g. Technical Risk - Engaging System.

(1) Experience indicates that the technical risk involved in designing a barricade system for any aircraft is quite high. The complications arising from smooth swept wings and very high kinetic energies significantly increase risk factors. Hence, this system was assigned a very poor rating of 2.

(2) The previously mentioned "state of the art" technology required to design a sensing and activating system for the landing gear entanglement system imposes very high technical risks. Also, experience with this system requires the assignment of the minimum score of 1.

(3) Technical risk involved in designing the hook-pendant system is quite low. Years of experience and the basic simplicity of the system minimize risk factors. Inexperience with kinetic energies of the magnitude proposed for the Space Shuttle will impose a slight risk, reducing the score for this system to 9.

h. Procurement Cost - Production.

Procurement Cost - Prototype.

(1) Procurement costs for the prototype or production models of the hook-pendant system are minimal. The proposed pendants are standard sizes, readily available. Hence, this system rates maximum scores of 10.

(2) Procurement costs for the landing gear entanglement system are considerable. The sophisticated sensing and activating devices required would be very costly. Hence, a minimum rating of 1 was assigned for prototype procurement costs and a slightly better value of 2 for production costs.

(3) Procurement costs for a specially designed barricade net, stanchion assembly, and sensing-activating device, if needed, would be large. However, these components should be simple compared to those contemplated for the landing gear entanglement system and the costs would be as significant for procurement of production systems as the prototype. Also, the nylon components deteriorate with time and would require periodic replacement with the operational system. The barricade system was, therefore, assigned a poor score of 3 for production procurement costs and a slightly better value of 4 for the prototype.

i. Cost and Time - Design of Engaging System.

(1) Design of a proper barricade net, stanchion and activating device will require a significant design effort. The net design may be critically dependent on the size, shape and strength of certain aircraft components. Delays in final design of

these components, or subsequent changes in them, may require significant redesign of the net. An average value of 5 has been assigned to barricade system design time and cost.

(2) The sensing and activating system for the landing gear entanglement system will require a longer and more costly design program than that of the barricade. Delay or revision of the landing gear design may cause significant delay or revision of this engaging system. Limited experience will be a key design problem causing significant increases in time and cost. The landing gear entanglement system must be assigned a minimum score of 1 for Design Program Time and Cost.

(3) No design problems are expected for the hook-pendant system. Like the barricade or landing gear entanglement systems, the pendant design is dependent on aircraft engaging speed and weight; but unlike these two systems, the pendant design is not dependent on aircraft shape, configuration, etc. Hence, delays or revisions of the aircraft design which cause little or no change in engaging kinetic energy will not complicate the design program of the hook-pendant system. This system is, therefore, assigned the maximum score of 10 for Design Program Time and Cost.

j. Cost - Operation and Maintenance.

Cost - Installation.

(1) The simplicity of the hook-pendant system, and the relatively low cost for replacing components, minimize installation, operation and maintenance costs. These parameters are assigned the maximum score of 10 for the hook-pendant system.

(2) Installation costs are maximum with the barricade system and landing gear entanglement system. The components needing replacement after operations are costly, and the systems required for sensing and activation require constant attention. Both systems are rated the poor value of 3 for these costs.

k. Compatibility with Other Aircraft. No scores need be assigned for this parameter since it was given a RIF of zero.

1.4 RESULTS

a. Table 2 summarizes the trade-off study. It shows:

(1) A list of parameters used in the trade-off study and the relative importance factors of each.

(2) The scores assigned to each engaging system for each parameter.

Table 2. Engagement Mode Trade-Off Study

PARAMETER	RIF	BARRICADE		HOOK-PENDANT		LANDING GEAR ENTANGLEMENT	
		SCORE	RIF x SCORE	SCORE	RIF x SCORE	SCORE	RIF x SCORE
Weight Penalty	13	10	130	3	39	9	117
Safe Arrestment Reliability	12	2	24	9	108	6	72
Technical Risk - Aircraft Modifications	11	10	110	7	77	9	99
Engagement Reliability	10	10	100	9	90	1	10
Normal Operational Damage	9	2	18	10	90	5	45
Cost/Time - Development Test	8	2	16	10	80	5	40
Cost - Aircraft Modifications	7	10	70	3	21	9	63
Technical Risk - Engaging Device	6	2	12	9	54	1	6
Procurement Cost - Production	5	3	15	10	50	2	10
Cost/Time - Design - Engaging System	4	5	20	10	40	2	8
Cost - Operation and Maintenance	3	3	9	10	30	3	9
Procurement Cost - Prototype	2	4	8	10	20	1	2
Cost - Installation	1	3	3	10	10	3	3
Total	910		535		709		484
r = Total/Max Possible			.59		.78		.53

(3) The effective scores of each system for each parameter, obtained by multiplying the proper score and RIF.

(4) Total effective score of each system; and ratio of this total to the maximum possible score.

b. This study shows that the optimum mode of engagement is the hook-pendant system.

c. Several qualified evaluators used this technique and arrived at the same conclusion; i.e., that the hook-pendant system was optimum. Only minor differences in scores assigned or RIF's determined were experienced when the various analyses were compared. The values presented in this report are in agreement with all the evaluations.

d. Importance of Parameters.

(1) Safe Arrestment Reliability. A Relative Importance Factor of 12 was assigned to this parameter by the "Emphasis Curve" analysis. If Weight Penalty was not such an expensive item, or the recovery system was the primary system to arrest the aircraft, this parameter would be the only one considered in evaluating engagement mode. This would result in selection of the hook-pendant engagement mode.

(2) Weight Penalty. The previous analysis assumes that a Weight Penalty will be accepted if the Trade-Off Study indicates that it would be advantageous to do so. If no weight penalty can be permitted, then this parameter becomes the only one to consider in evaluating engagement mode. This would result in selection of the barricade engagement mode.

APPENDIX C

RECOVERY SYSTEM DESIGN AND DESCRIPTION

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

APPENDIX C

RECOVERY SYSTEM DESIGN AND DESCRIPTION

1.0 INTRODUCTION

a. This study presents drawings and descriptions of the proposed recovery system's major components. These conceptual designs were used to prepare time and cost estimates for design and manufacture of both the prototype and production systems. A preliminary cost effectiveness trade off study for equipping alternate operating sites with recovery systems is also included.

b. The recovery system is composed of the main components designed in Appendix A, one of the engaging systems discussed in Appendix B and other necessary support equipment. In the following descriptions, all recovery system components except the engaging member are included in the arresting gear discussion.

1.1 ARRESTING GEAR DESCRIPTION (Figure 1.)

a. The arresting gear utilized in the space shuttle recovery system is the same, regardless of the mode of vehicle engagement. This arresting gear consists of two arresting engines installed on a concrete pad, one on each side of the runway. Each engine is equipped with a nylon purchase tape which is stored on a reel, reeved through a deflector sheave and coupled to the vehicle engaging device.

b. The major components of the arresting engine are the energy absorber, the retrieve system, the tape support flanges, a tape pressure roller system and a deflector sheave. All are mounted on a single steel base plate.

c. The tape hub and energy absorber rotor are splined to the main shaft. The tape hub and rotor function as a unit. Pullout of the tape drives the hub and rotor, whose motion is resisted by the fluid in the housing.

d. The electrically powered retrieve system is used to wind the tapes onto the reels and pretension the engaging device in preparation for arrestment. The system is automatically disengaged from the tape hub at the time of vehicle engagement by a pretension release mechanism. Thus, the tape hub and rotor are allowed to run free of the retrieve system during arrestment.

e. The tape pressure roller system ensures an even, tight wrapping of tape on the hub during retrieve. It consists of a roller mounted on an arm which is pivoted in a bracket secured to the arresting engine base. The arm is tensioned by a spring and winch assembly.

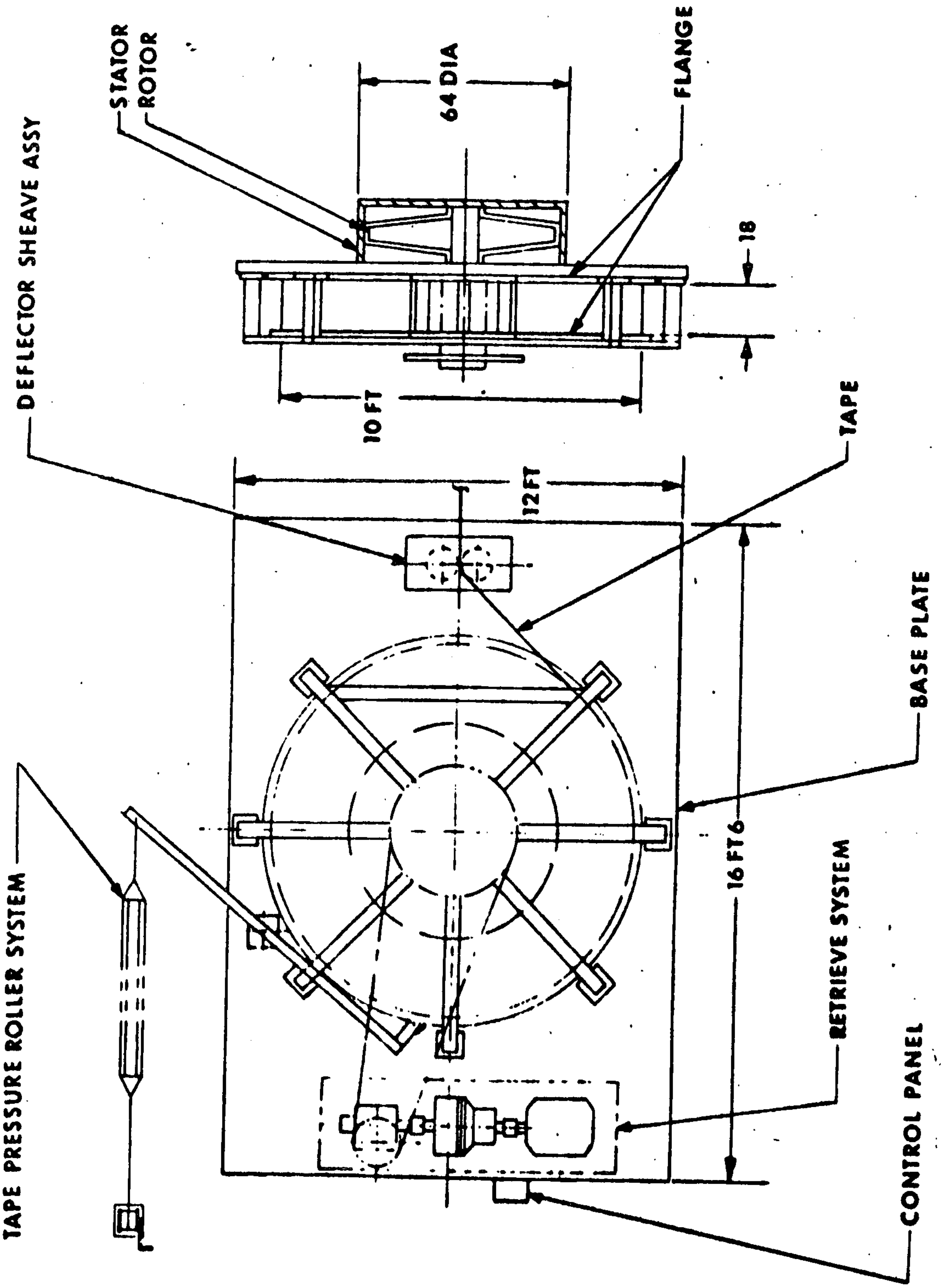


Figure 1. Space Shuttle, Arresting Engine

1.2 ENGAGEMENT MODES

a. The pendant system consists of a pendant or rope stretched across the runway and elevated at set intervals by pendant supports (Figure 2). The pendant is attached to the purchase tape by a tape connector. During arrestment, it is engaged by a hook mounted on the vehicle.

b. The second method of engagement is by the use of a barricade, a large nylon net (Figure 3). The barricade is stretched across the runway and when engaged, deploys itself over the wings of the vehicle (Figure 4). It is attached to the purchase tape by means of nylon straps.

(1) The barricade is raised and supported by stanchions. The means employed in raising the stanchions is dependent upon the desired erection time. A quick erect system (2 to 3 seconds) would be required in an abort situation which could be encountered during flight tests. A slow erect system (20 to 30 seconds) would be suitable for any operational situation where the barricade can be pre-rigged as a precautionary measure prior to landing.

(2) The quick erect system (Figure 5) uses rack and pinion type rotary actuators to raise the stanchions. The actuators are powered by a hydraulic power pack which utilizes accumulators, a series of distribution and flow control valves and an automatic recharge system. The entire system is activated by an electrical control signal.

(3) The slow erect system (Figure 6) uses an electrically powered winch to raise the stanchions. Control is exercised at the barricade site.

c. The landing gear entanglement system (Figure 7) uses a nylon net connected to the purchase tapes, to ensnare the main landing gear of the vehicle. A detection device is used to continuously compute the distance between the oncoming vehicle and the arresting gear. At the proper instant the device sends a signal to the net pop-up system, which throws the net up into the path of the main landing gear. Timing of the net actuation is critical because the net must remain in a retracted or recessed position until the nose gear has passed over it. Ensnaring the nose gear would result in failure of the strut and/or severe aircraft swerve during the arrestment due to concentration and location of the retarding load forward of the aircraft center of gravity. A similar problem exists if only one main gear is engaged by the net. With the desired engaging speeds and current estimates of vehicle landing gear configuration, the time available for complete and accurate net deployment is approximately 1/8 second.

1.3 TIME AND COST ESTIMATES

Design and manufacture of the prototype system and manufacture of production systems' time and cost estimates are presented in Appendix E.

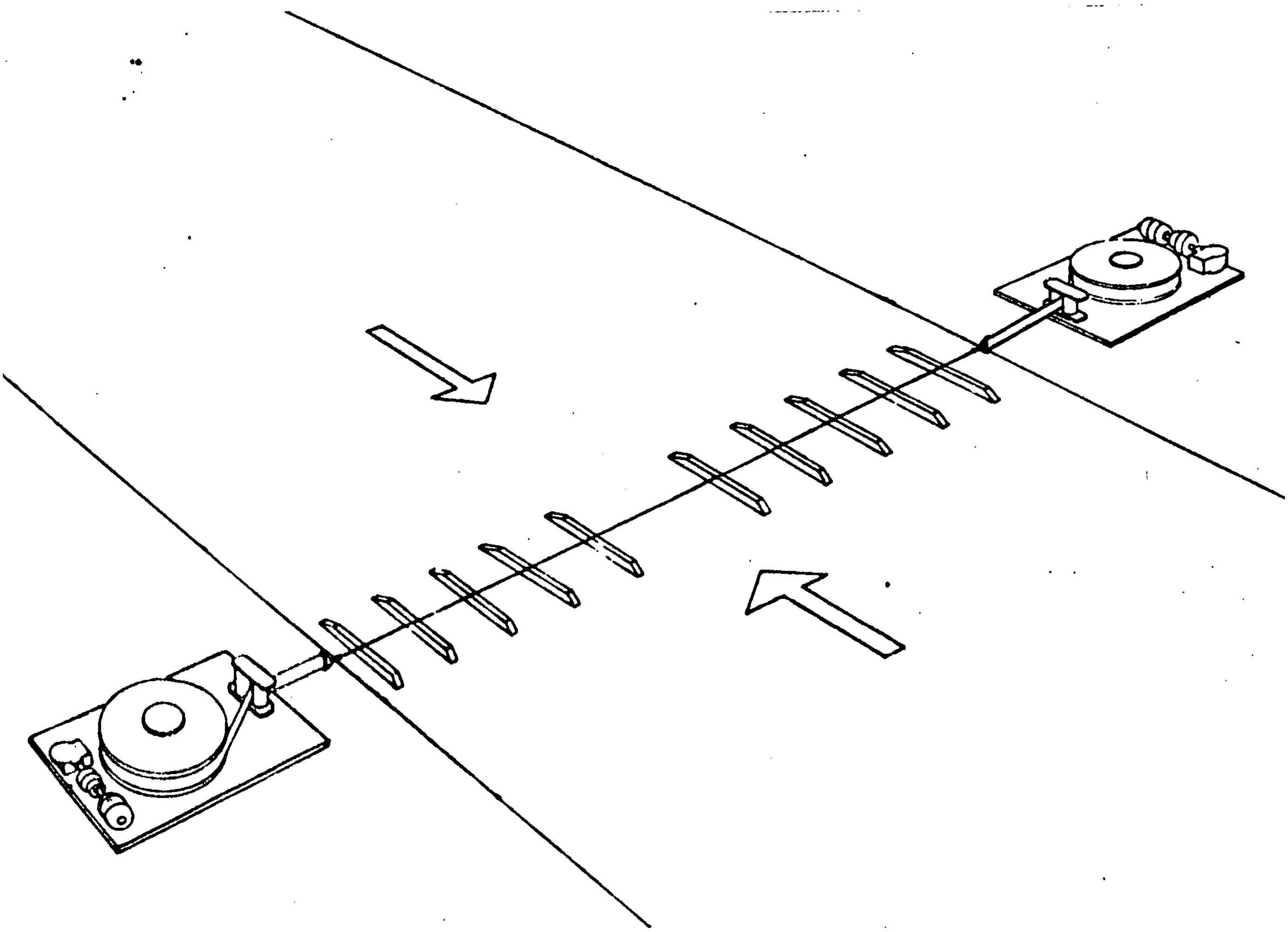


Figure 2. Recovery System, Hook Engagement

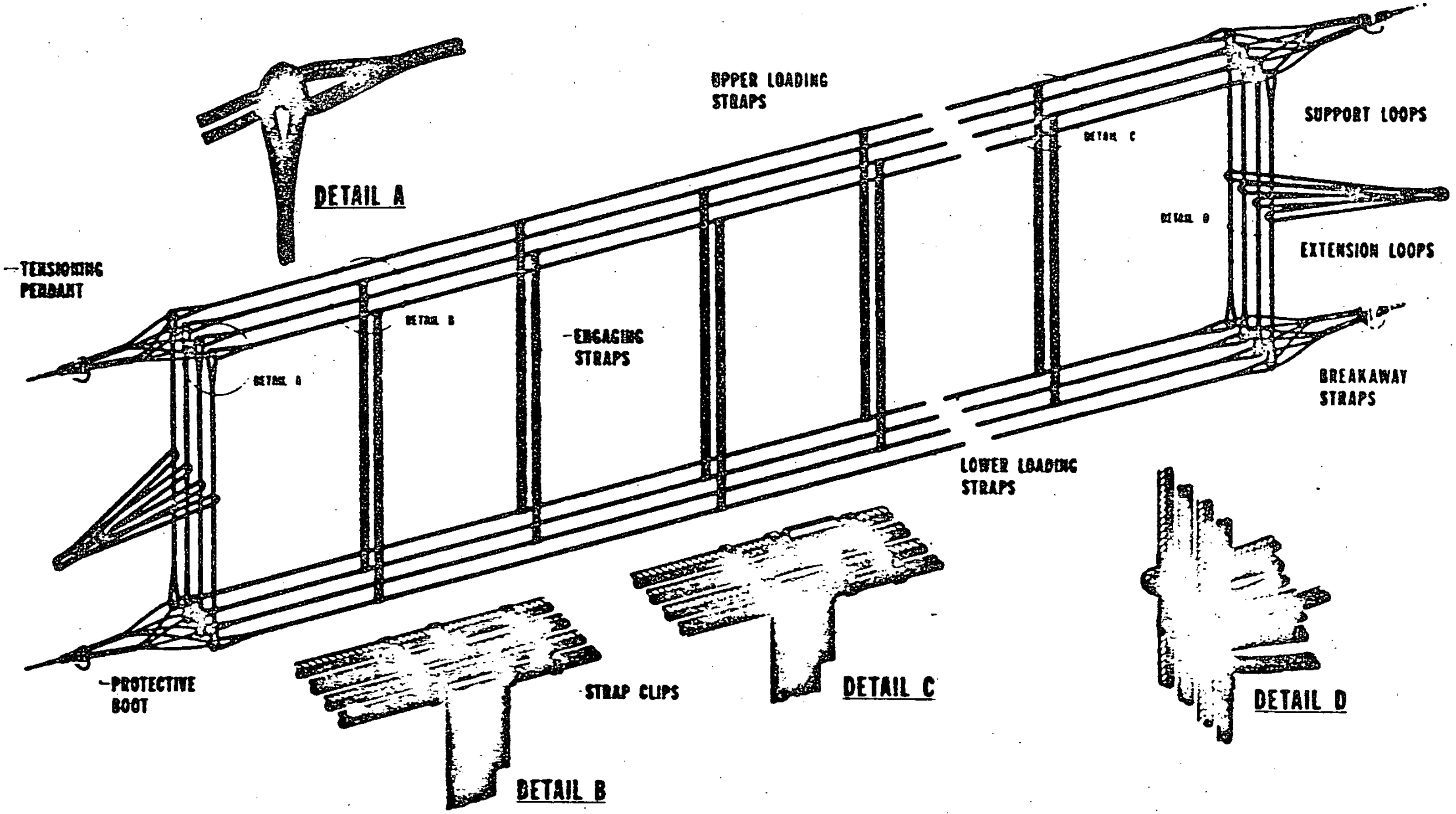


Figure 3. Proposed Barricade, Space Shuttle Orbiter

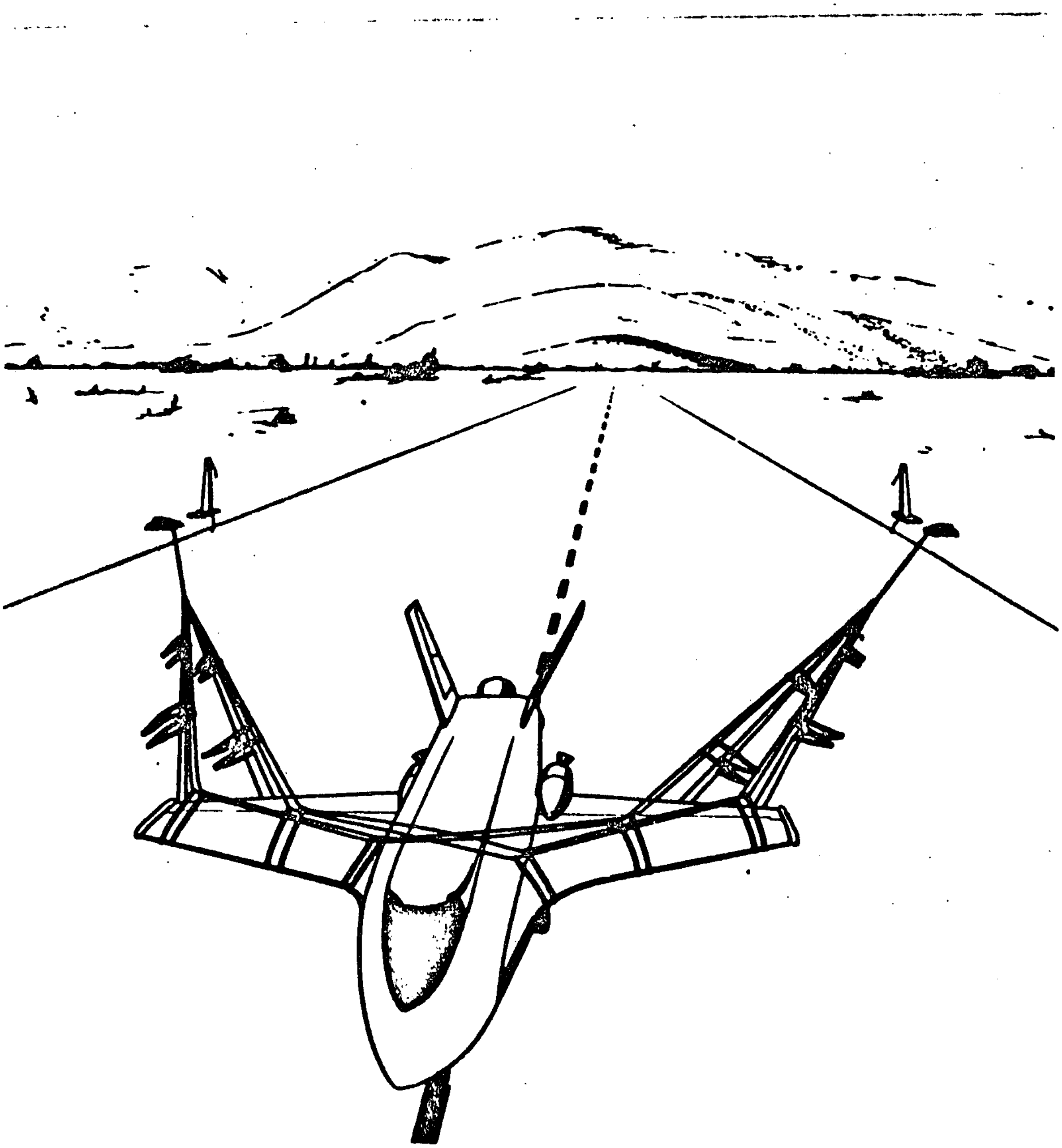


Figure 4. Orbiter Engagement

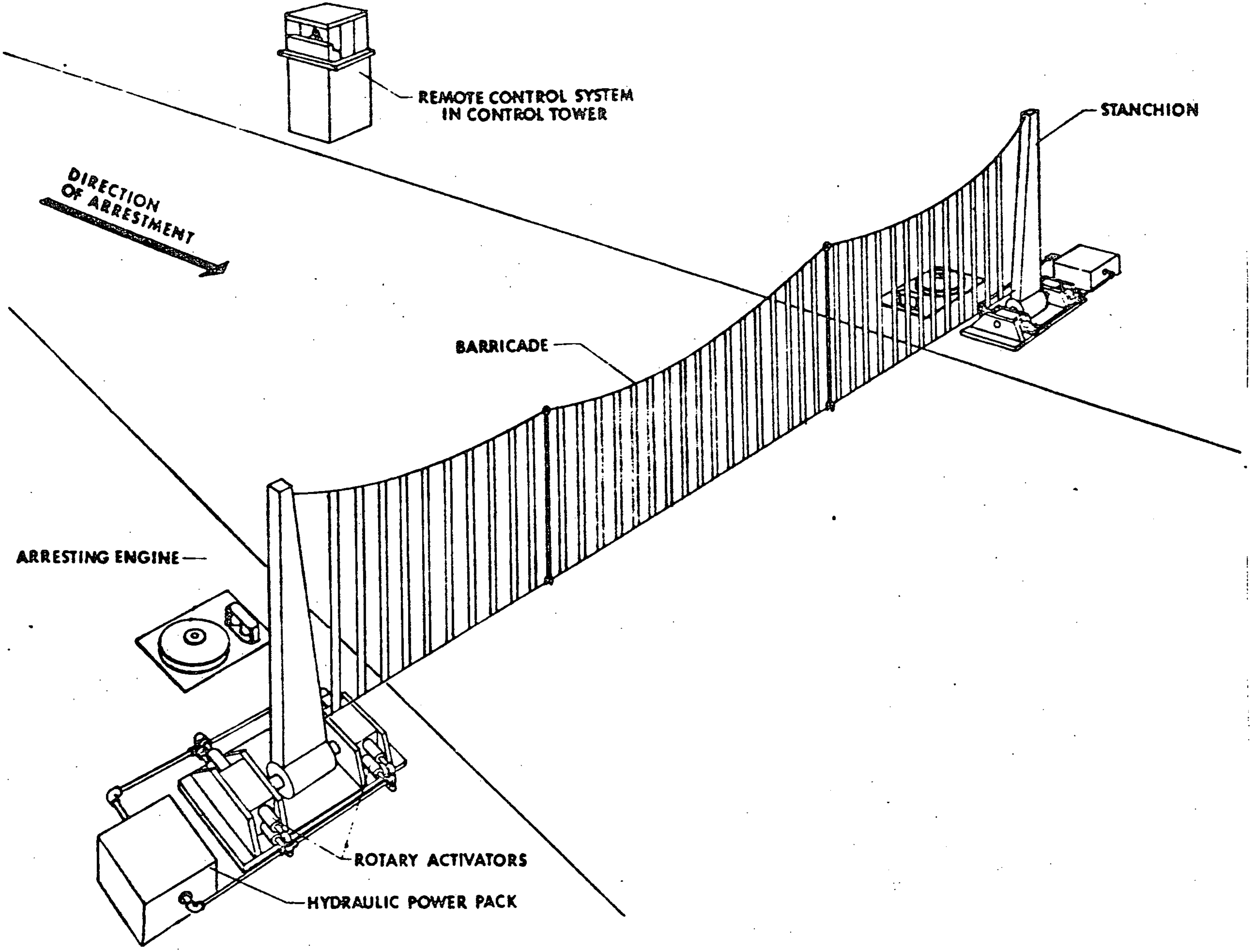


Figure 5. Barricade, Quick Erect

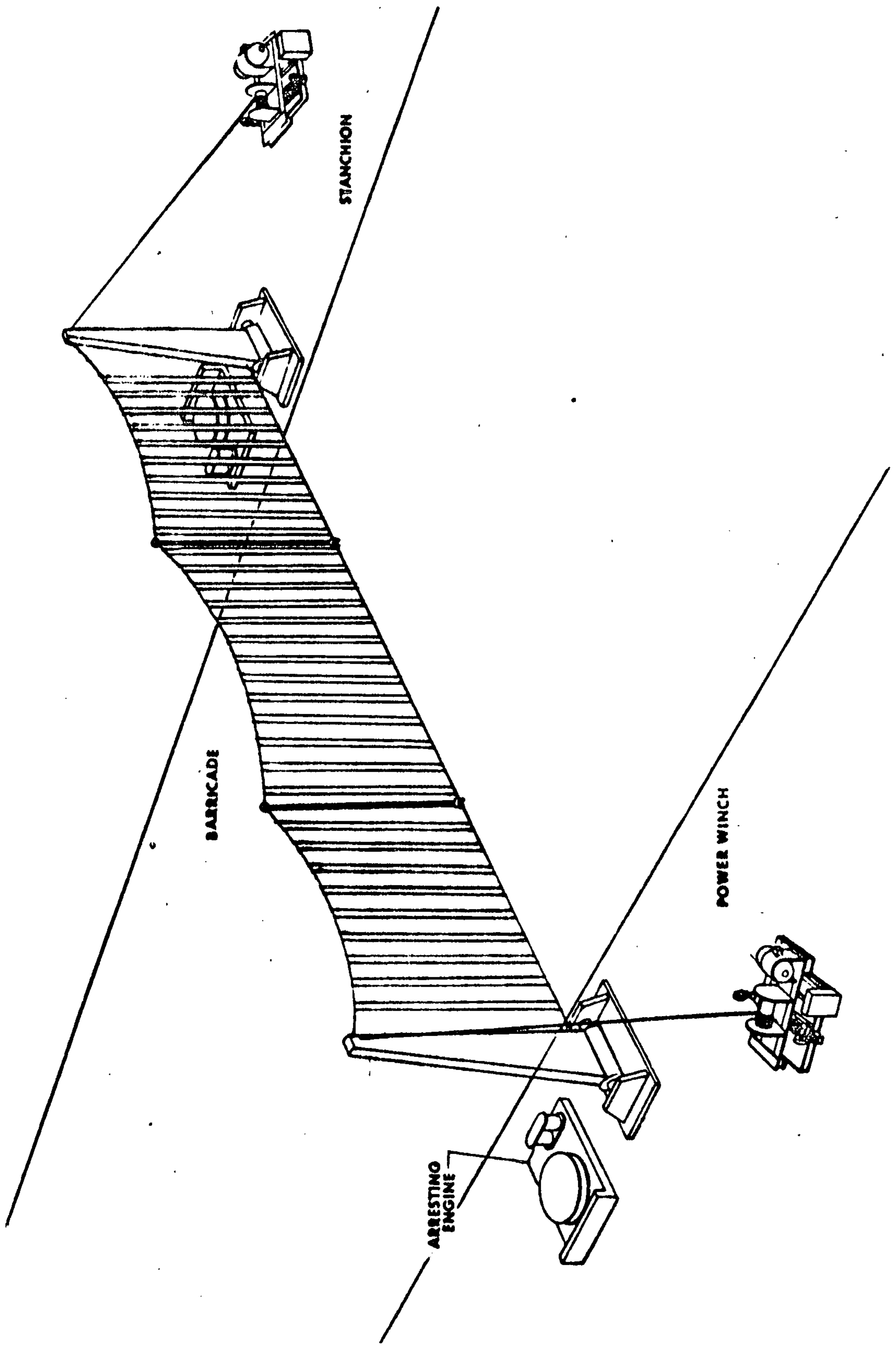


Figure 6. Barricade, Slow Erect

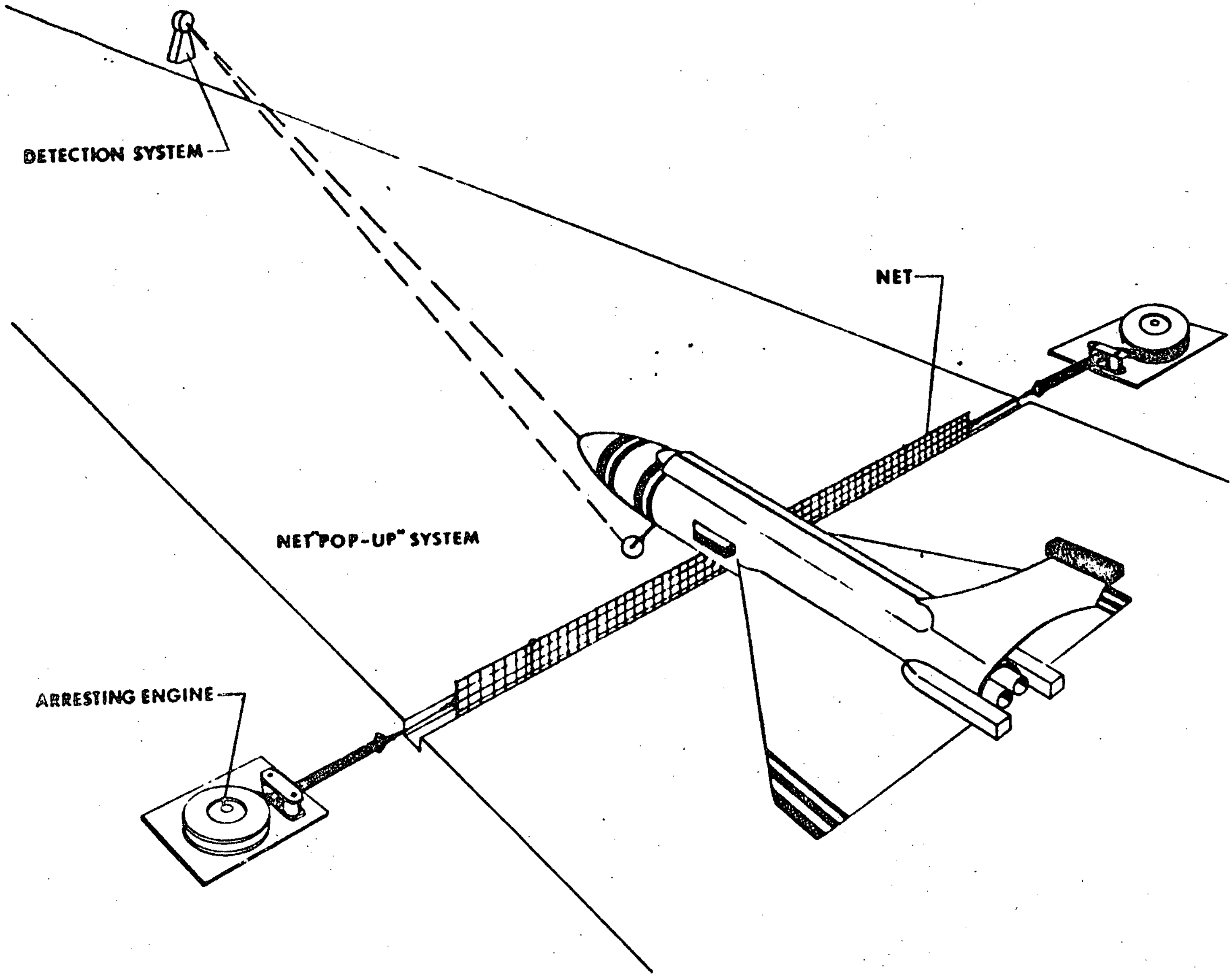


Figure 7. Landing Gear Entanglement Recovery System

1.4 ALTERNATE LANDING SITES

a. Permanent installations of recovery systems are planned for primary landing sites; however, in the event that a primary site becomes unavailable for operation, suitable alternate recovery sites are planned. For these sites, recovery system installations can be one of three types: mobile, semi-mobile or permanent.

b. Mobile or expeditionary installations (Figure 8), similar to the Marine Corps M-21 system, are currently used with a high degree of success. However, because of the size and loading requirements of the proposed system, it is estimated that installation would require a minimum of three days after delivery of the equipment to the site. For barricade or landing gear entanglement systems, this time would be significantly greater. This delay in availability of the system is considered to be unacceptable.

c. The semi-mobile system is mobile in that it can be transported to and mounted at any alternate site. However, each alternate site would have permanent foundations and facilities already installed.

The advantages are as follows:

(1) One recovery system can be used for several sites, thus reducing procurement costs.

(2) The system can be made available for arrestment within 24 hours after delivery of equipment to the site.

The disadvantages are as follows:

(3) Foundation and facility costs are as high as with permanent type installation.

(4) Handling equipment is required for each system.

(5) Repeated transportation and installation costs are encountered.

(6) Manpower requirements are increased.

d. A permanent recovery system, of course, has no mobility; however, it has one major advantage which weighs heavily in its favor. The system is always available for immediate use. There is no lead time required for transportation and installation. The major disadvantage is that a complete system must be procured for each location.

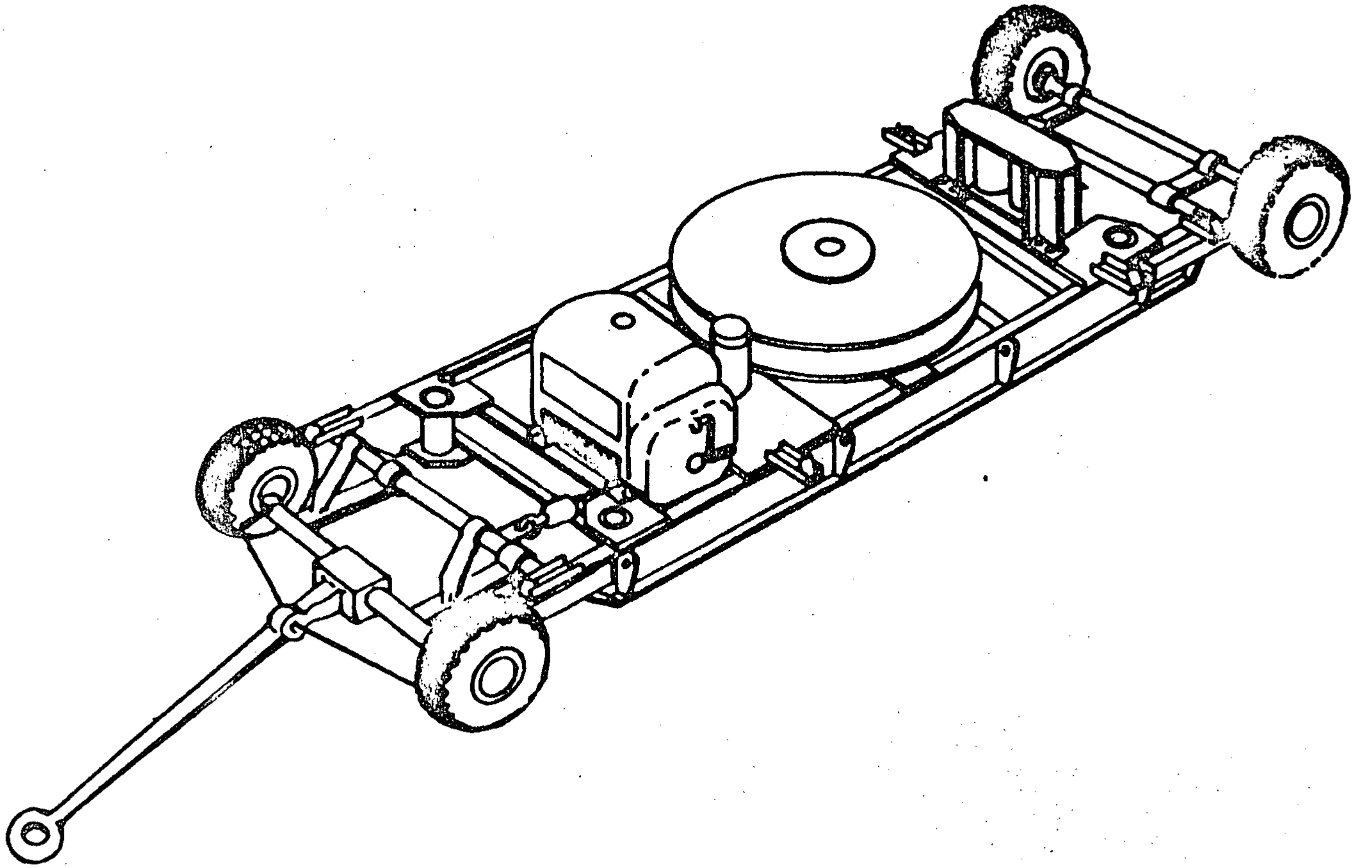


Figure 8. Mobile Arresting System

e. A cost effectiveness study of the permanent and semi-mobile installations was undertaken by considering costs such as procurement (number of systems), installation, transportation and special handling equipment. It soon became apparent that the cost advantage varies with the type of system selected (pendant, barricade or landing gear entanglement) and the number of alternate sites to be considered. Therefore, quantitative results of this study are not pertinent until these variables are fixed. The study can be resumed at any point in time during the development program.

f. Based on preliminary estimates and considering operational and cost advantages, the following are recommended:

(1) Pendant system for three or less alternate runways, two systems per runway - permanent installations.

(2) Pendant system for more than three alternate runways, two systems per runway - semi-mobile installations.

(3) Barricade or landing gear entanglement systems for two or more alternate runways, two systems per runway - semi-mobile installations.

g. It should be noted that since both of the recommended types of installation require the same site preparation and foundation, a delay in the selection of the desired type will not affect design or development of the arresting gear system.

h. If by future assessment of operational requirements, the delay in availability involved with the mobile system is considered acceptable, additional time and cost will be incurred for design and manufacture of the installation hardware.

APPENDIX D

TEST PROGRAMS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

APPENDIX D
TEST PROGRAMS

1.0 INTRODUCTION

Time and cost estimates are presented to test the recovery system. Test program cost factors are dependent on the engagement mode chosen and the maximum kinetic energy to be tested. Hence, several estimates are provided. Descriptions of test procedures and test site facilities required are also presented.

1.1 TEST FACILITIES

a. Tests of the recovery system are conducted by instrumenting and recording the response of the system to the engagement of an unmanned test vehicle. The weight and engaging speed of the test vehicle are adjusted to simulate actual operating conditions. Modifications of the recovery systems are conducted, if necessary, to produce proper system operation.

b. The kinetic energy of the test vehicle is developed by pushing it down a long track with a jet car. The jet car is a vehicle on which jet engines are mounted for propulsion. Both the jet car and test vehicles are guided down the track by steel I beam rails imbedded in the concrete track. At a fixed point on the track, the jet car is stopped and the test vehicle continues on to be engaged by the recovery system. The length of track over which the test vehicle is accelerated by the jet car is constant. The jet engine thrust is varied to produce various engaging kinetic energies.

c. As the test vehicle separates from the jet car and engages the recovery system, it is freed from the guide rails.

d. In addition to duplicating the kinetic energy of the actual aircraft, the test vehicle must simulate various aircraft components depending on the mode of engagement chosen for the recovery system.

(1) For hook-pendant mode of engagement, the test vehicle can be a simple box-shaped, wheeled vehicle ("deadload" vehicle) made of structural steel with a hood attached. The hook need not be the same length as the one designed for the aircraft, but the hook point should be the same (e.g. not critical).

(2) For barricade mode of engagement, the test vehicle must closely resemble the actual aircraft. The vehicle must duplicate the aircraft's wings, tail, nose, undercarriage, landing gear and center of gravity location.

(3) For landing gear entanglement mode of engagement, the test vehicle must duplicate the aircraft's undercarriage, landing gear and center of gravity location.

e. Steps d(2) and d(3) require the test vehicle to duplicate the landing gear and undercarriage of the aircraft. During the power stroke with the jet car, these vehicles must use the rails for guidance. To accomplish these two requirements, a shuttle frame vehicle is employed. The shuttle frame vehicle is pushed ahead of the jet car and is guided by the rails. The test vehicle is mounted on top of the shuttle frame. When the jet car is brought to a stop at the end of the power stroke, the shuttle frame also stops, and only the test vehicle continues on to be arrested.

f. The initial stage of the test program is used to check out and adjust the operation of the arresting engines. This phase is conducted with hood-pendant mode of engagement and the simple "deadload" test vehicle regardless of the engaging mode chosen for the actual system.

g. Subsequent stages of the test program are used to determine compatibility of the aircraft and the selected engaging member, and total system performance.

h. Summary of Main Test Facilities Required.

(1) Test Vehicle - Deadload

(a) Required to test hook/pendant engagement mode

(b) Required to test arresting engines for any engagement mode

(2) Test Vehicle - Simulated aircraft required to test barricade or landing gear engagement modes

(3) Jet Car - Propels test vehicle

(4) Shuttle Frame Vehicle - Guides simulated aircraft test vehicle.

(5) Jet Car Track - Jet car power stroke track

(6) Support Services - Instrumentation equipment and trained personnel

1.2 TEST PROGRAMS

1.2.1 STANDARD

a. Recovery systems designed for U.S. Navy aircraft are always tested under expected operational conditions. The test program attempts to duplicate the total environment under which these systems will operate. This obviously includes testing all possible combinations of aircraft weights and speeds which may be encountered. This procedure is the only way to develop a safe, reliable system.

b. Therefore, it is strongly recommended that a standard test program, which would include all possible aircraft weight and speed combinations expected for the NASA Space Shuttle, be conducted.

c. In order to conduct the standard test program a major upgrading of the current test facilities is required. This would include new test vehicles, new jet car and shuttle frame (if required), extension of the jet car track and recovery area and additional support services. The cost of these facilities is \$8.5 to \$9.4 million, depending on the engagement mode selected. This would provide a kinetic energy capacity of 590 x 10^6 ft-lb or 275,000 lb at a speed of 220 knots. Preliminary design layouts of the deadload, simulated aircraft, and jet car are shown in Figures 1 thru 3, respectively.

1.2.2 NON-STANDARD

a. Preliminary cost estimates to provide test facilities for the standard test program, presented at the Mid-Program Review of this study, were of necessity quite large. At the request of attending NASA representatives, several other test programs were investigated. These programs attempt to minimize facilities improvement costs by eliminating the design and manufacture of the new high-energy jet car (estimated cost \$5.5 million). Two of the programs are based on using existing jet car track facilities at the Naval Air Test Facility, Lakehurst, N.J.

b. Existing Facilities Test Program.

(1) The maximum engaging energy conditions capable of being tested with existing jet car and track are considerably less than the maximum energy condition used as design criteria for this recovery system. Extrapolation of hook-pendant performance data from these low test energies to desired operating energies involves a very high technical risk which could result in inadequate performance when the system is most needed. Extrapolation of test data for barricade or landing gear entanglement engagements is, from past experience, virtually impossible. Hence, the reliability and safety of the recovery system at the higher engaging energies would be almost impossible to predict.

(2) This program requires new test vehicles and extension of the runout area for a facilities cost of \$1.7 to \$2.6 million, depending on engagement mode selected. The maximum kinetic energy capacity is 145 x 10^6 ft-lb.

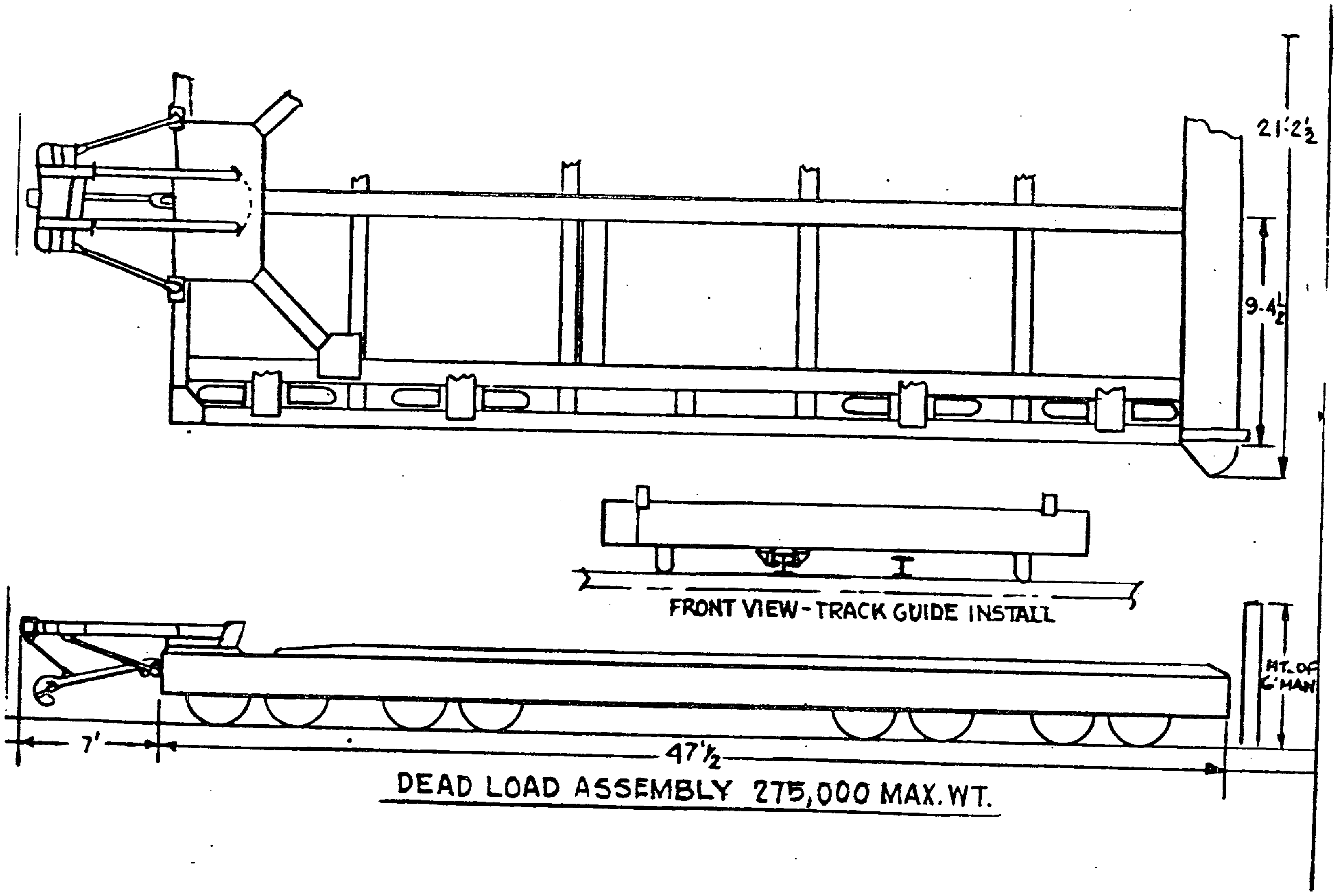


Figure 1. Dead Load Assembly, 275,000 Lbs. Max. Wt.

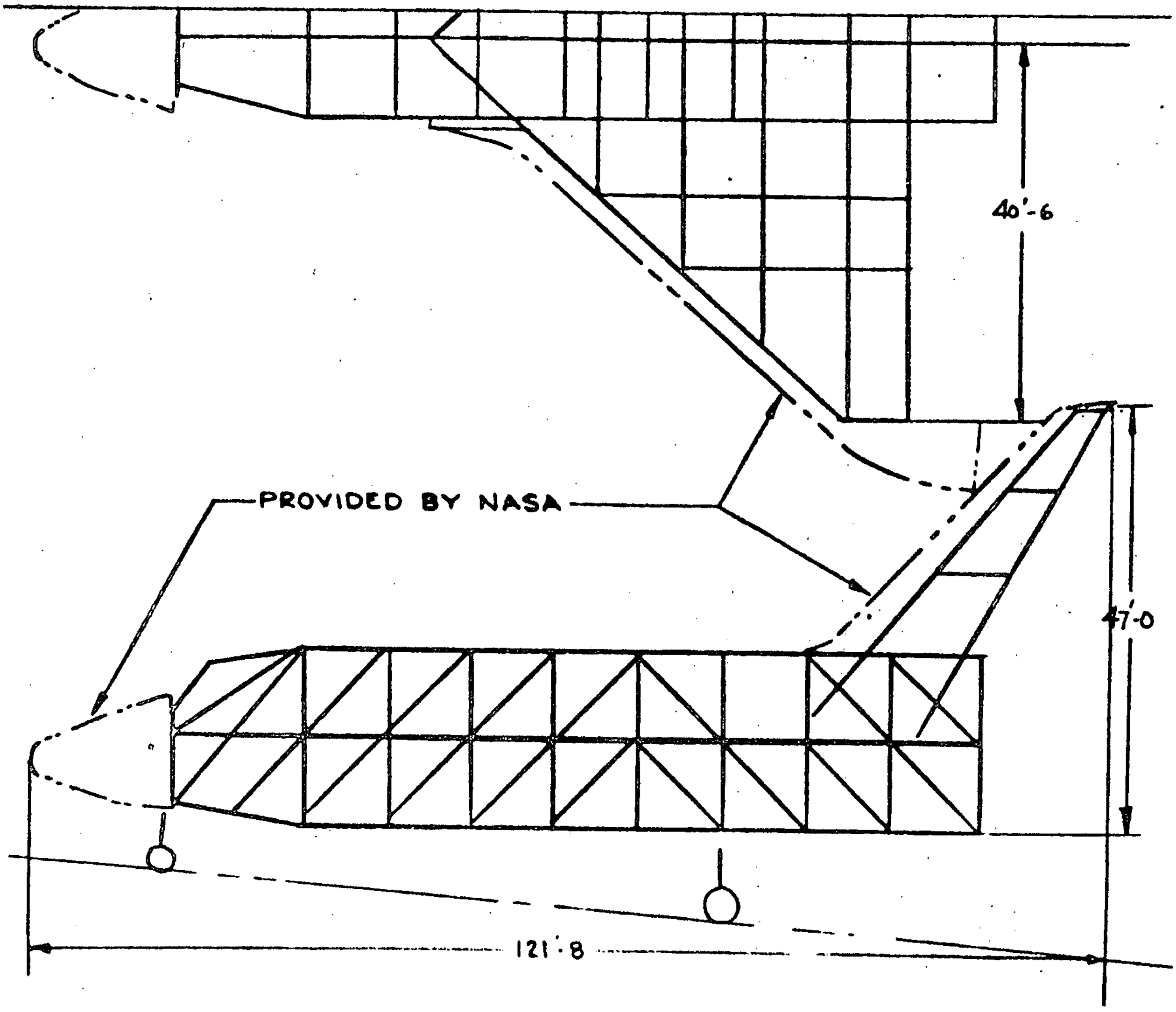


Figure 2. Proposed Space Shuttle Deadload

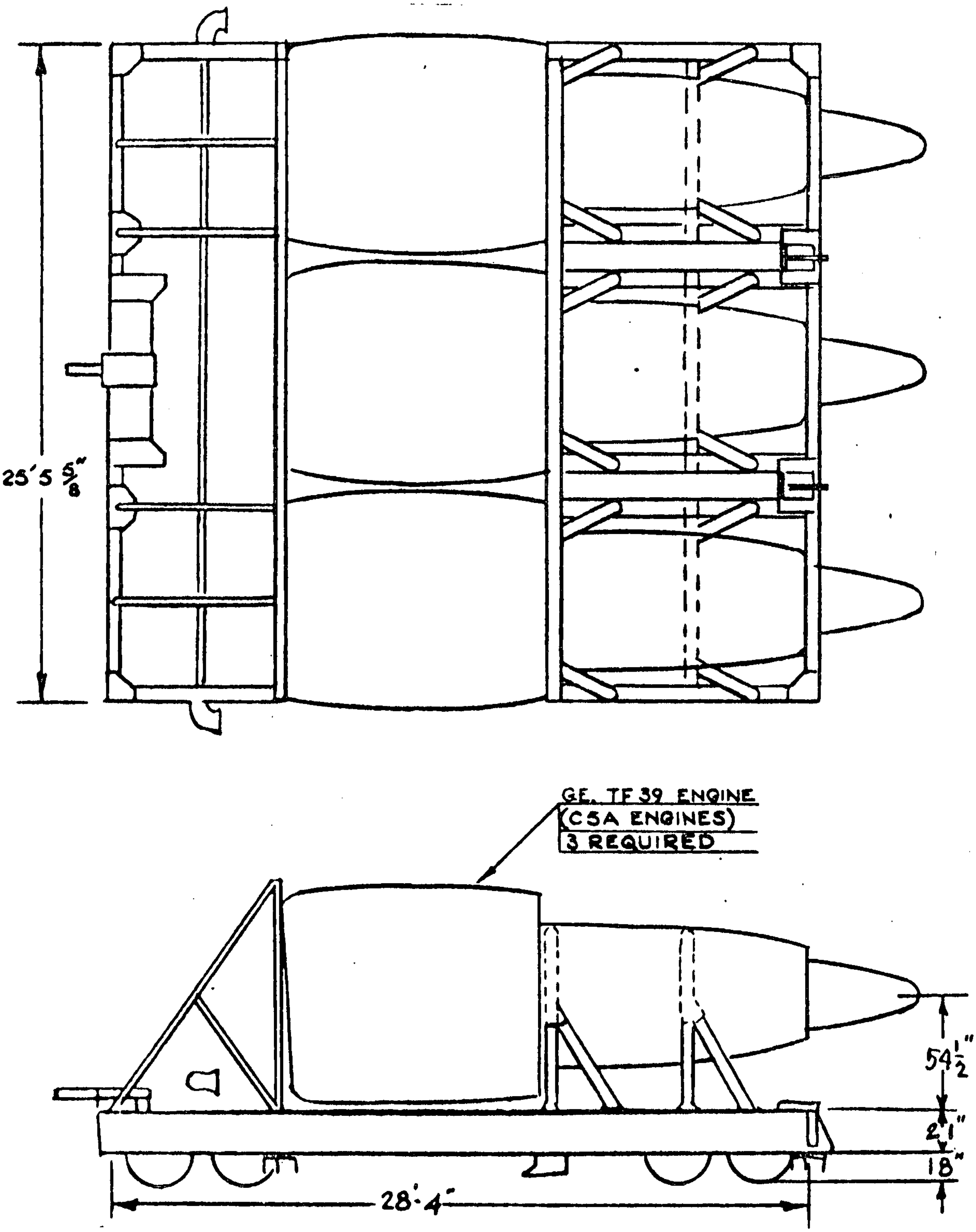


Figure 3. Proposed Jet Pusher Car, Space Shuttle Deadload

C

c. Existing Facilities with Rocket Assist Program.

In order to more closely approach the desired test energies without the cost of the new jet car, use of rockets to augment the existing jet car thrust was investigated. By use of 30,000 lb thrust rockets with a 60-second burn time, engaging energies up to 277 x 10^6 ft-lb can be obtained. This reduces significantly the amount of data extrapolation required and reduces the technical risk involved. The cost of this program is only slightly higher than the previous one, excluding cost of the rockets. It is anticipated that these rockets will be provided by NASA, however, their availability has not been determined to date.

d. Existing Jet Car With Extended Track Program.

Another method of providing increased energy capacity, approximately the same as the rocket assist program, is by extending the jet car track to provide a longer power stroke for the existing jet car. While offering the same advantages as the rocket assist program, the facilities improvement costs for this program are higher (again, excluding rocket cost). This cost would be $3.0 to $4.0 million, depending on engagement mode selected.

1.3 SUMMARY OF TEST PROGRAMS AND FACILITIES COST

Table 1 contains a summary of the various test programs for the three engaging modes, the related facilities improvement costs and the maximum engaging energies and conditions attainable. The costs of conducting the test programs are included in Appendix E.

Table 1. Test Programs Summary

	STANDARD TEST PROGRAM			EXISTING FACILITIES PROGRAM		
	Hook-Pendant System	Barricade System	Landing Gear System	Hook-Pendant System	Barricade System	Landing Gear System
NUMBER OF ENGAGEMENTS	135	80 Deadload 20 Airframe	80 Deadload 20 Airframe	100	60 Deadload 14 Airframe	60 Deadload 14 Airframe
MAXIMUM WEIGHT	275,000 Lbs.	275,000 Lbs.	275,000 Lbs.	230,000 Lbs.	230,000 Lbs.	230,000 Lbs.
MAXIMUM SPEED FOR MAXIMUM WEIGHT	220 Knots	220 Knots	220 Knots	119 Knots	119 Knots	119 Knots
MAXIMUM KINETIC ENERGY	590×10^6 Ft-Lb	590×10^6 Ft-Lb	590×10^6 Ft-Lb	145×10^6 Ft-Lb	145×10^6 Ft-Lb	145×10^6 Ft-Lb
FACILITIES IMPROVEMENT COST	$8,540 K	$9,416 K	$9,160 K	$1,680 K	$2,556 K	$2,300 K

	ROCKET ASSIST PROGRAM			EXTENDED TRACK PROGRAM		
	Hook-Pendant System	Barricade System	Landing Gear System	Hook-Pendant System	Barricade System	Landing Gear System
NUMBER OF ENGAGEMENTS	104	64 Deadload 18 Airframe	64 Deadload 18 Airframe	104	64 Deadload 18 Airframe	64 Deadload 18 Airframe
MAXIMUM WEIGHT	230,000 Lbs.	230,000 Lbs.	230,000 Lbs.	230,000 Lbs.	230,000 Lbs.	230,000 Lbs.
MAXIMUM SPEED FOR MAXIMUM WEIGHT	162 Knots	162 Knots	162 Knots	162 Knots	162 Knots	162 Knots
MAXIMUM KINETIC ENERGY	277×10^6 Ft-Lb	277×10^6 Ft-Lb	277×10^6 Ft-Lb	277×10^6 Ft-Lb	277×10^6 Ft-Lb	277×10^6 Ft-Lb
FACILITIES IMPROVEMENT COST	$1,710 K Plus Rockets	$2,586 K Plus Rockets	$2,330 K Plus Rockets	$3,040 K	$3,916 K	$3,660 K

APPENDIX E

COST SCHEDULES

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX E

COST SCHEDULES

1.0 DEVELOPMENT PROGRAM COSTS

Summaries of overall program time and cost estimates, exclusive of production systems to be installed on NASA sites, are presented in Tables 1 thru 9. The costs include design and manufacture of the prototype arresting system, test facilities improvement costs and test program costs. Due to the results of the aforementioned Mid-Program Review, detailed cost estimates for the standard Navy type test program (full rated energy) have not been included. Estimates are provided for the three engagement modes and three test methods for each. The number of test engagements recommended for each program has been carefully selected to produce the greatest amount of useful information for the least possible cost, within the energy capability of the test method. Consideration was also given to the relatively short time available until the tentative required delivery date of the initial recovery system. Time estimates given are in years from initiation of the program.

1.1 PRODUCTION SYSTEM COSTS

Cost estimates for production models of the pendant, slow erect barricade, fast erect barricade and landing gear entanglement systems are presented in Tables 10 thru 13 respectively. Again, time estimates are given in years from initiation of the program. Note that costs include the complete recovery system, site preparation and system installation and spare components.

1.2 TOTAL PROGRAM COST (Determination)

Determination of total program cost first involves selection of an engagement mode and a test method to establish development program costs. Subsequently, the number of production systems to be procured must be established to determine landing site provisioning costs. This involves the number of landing sites and the number of systems to be installed per runway. When considering the number of systems to install per runway, the reliability of the engaging system is of prime importance.

a. Hook-pendant system engagement reliability is good and can be improved by use of multiple pendants. Therefore, two systems per runway, one at each end, each system having two pendants attached (dual pendant system), are recommended.

b. Engagement into the barricade webbing has a high degree of reliability. Two systems per runway, one at each end, are recommended.

c. Landing gear entanglement system engagement reliability is very low, but can be improved somewhat by use of multiple engaging devices. However, spacing required between the primary engaging member and the backup engaging member precludes attaching both to the same energy absorber. Therefore, the only means of increasing engagement reliability appears to be by use of four systems per runway, two at each end.

Table 1. Pendant System Test, Site Capability

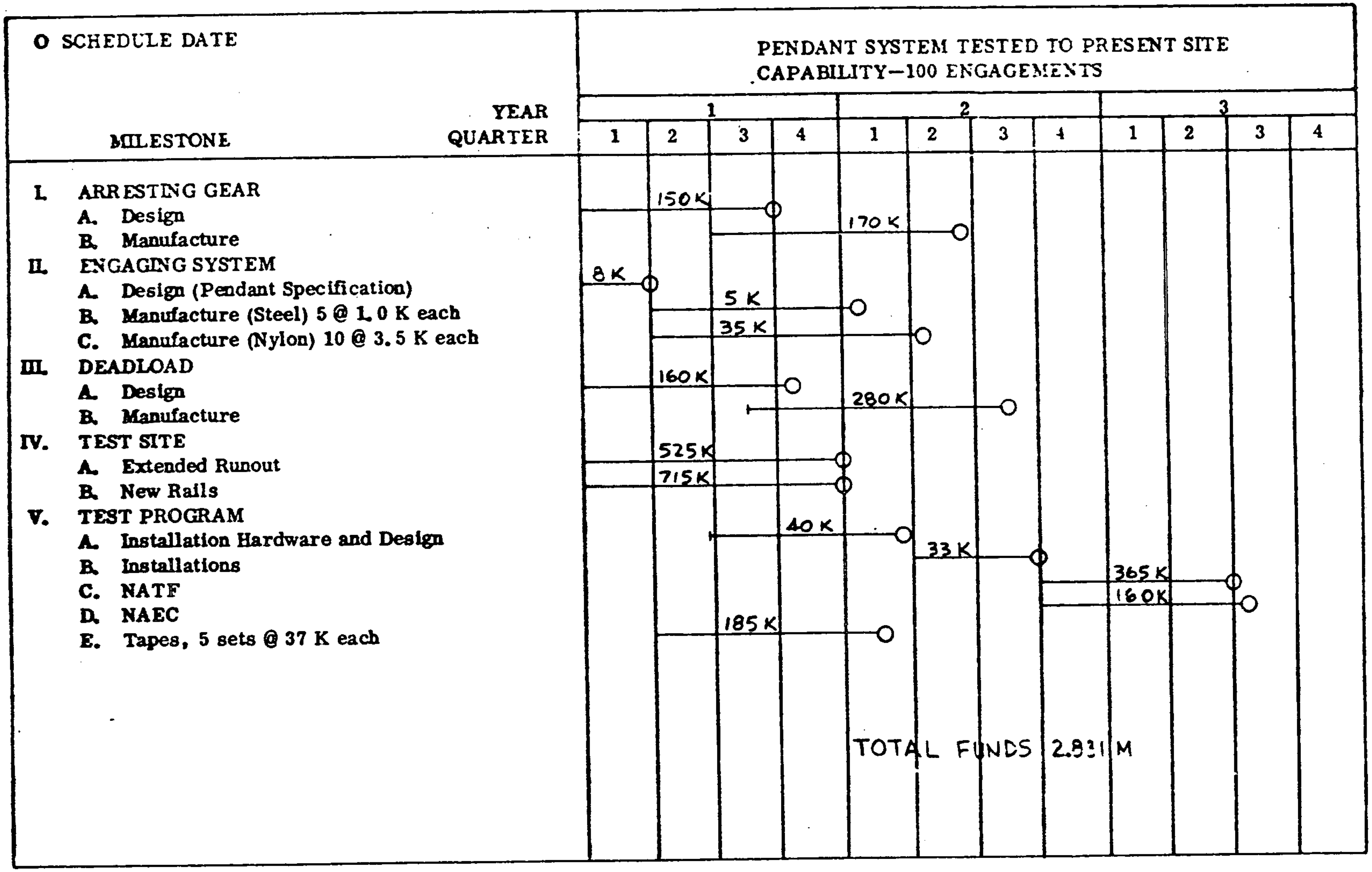


Table 2. Pendant System Test, Jet Car/Rocket Assist

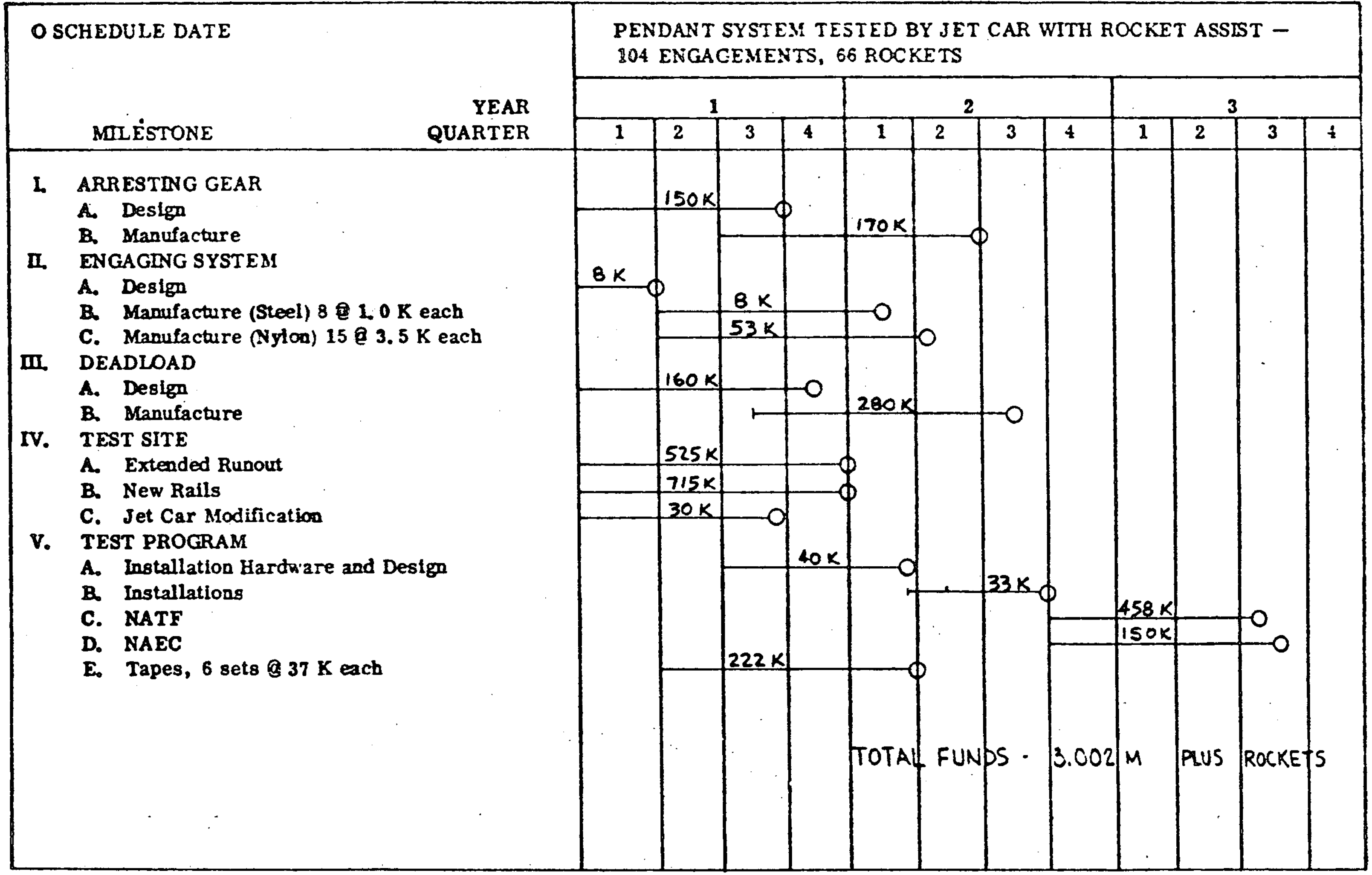


Table 3. Pendant System Test, Jet Car/Extended Track

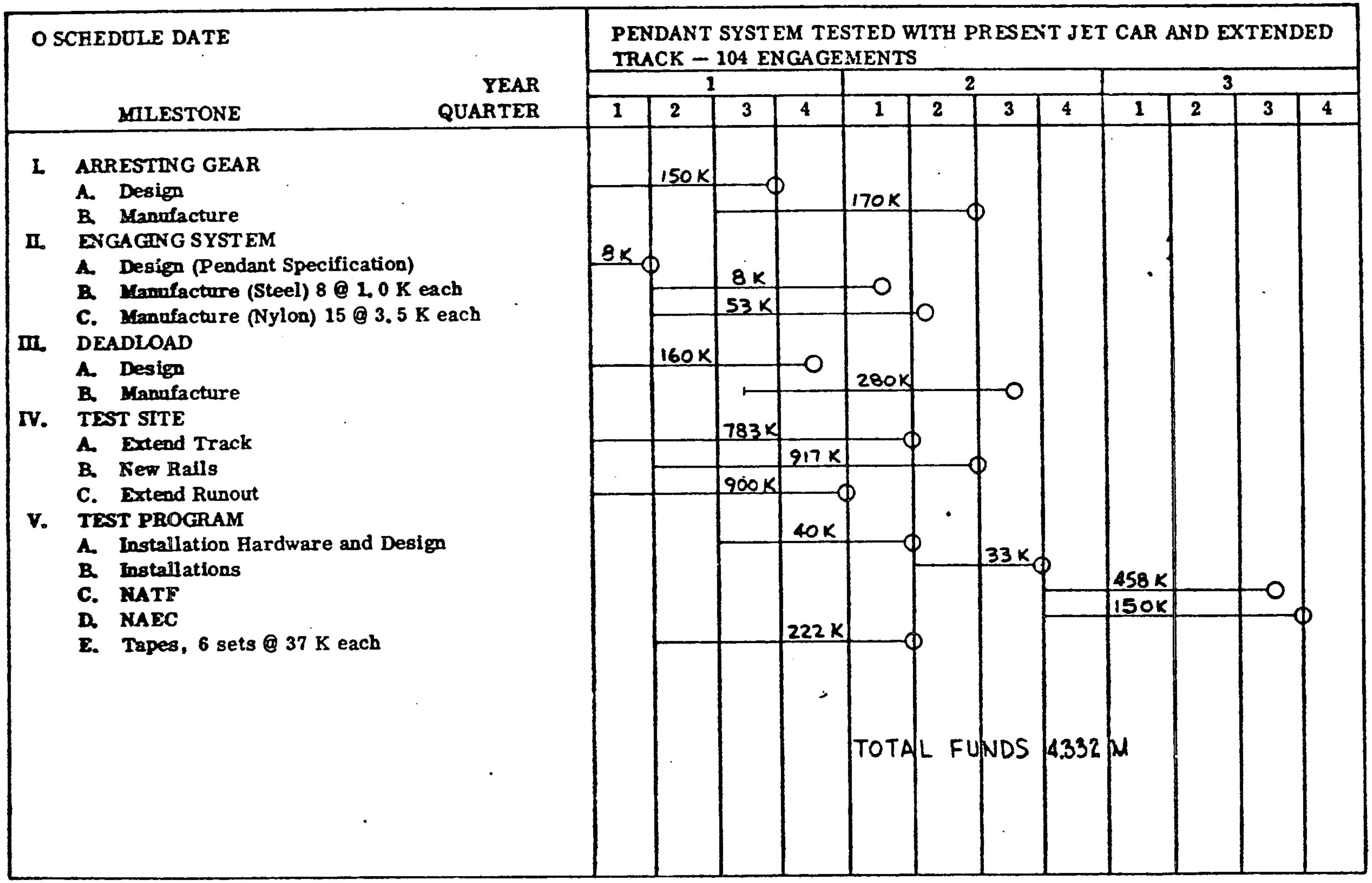


Table 4. Barricade System Test, Site Capability

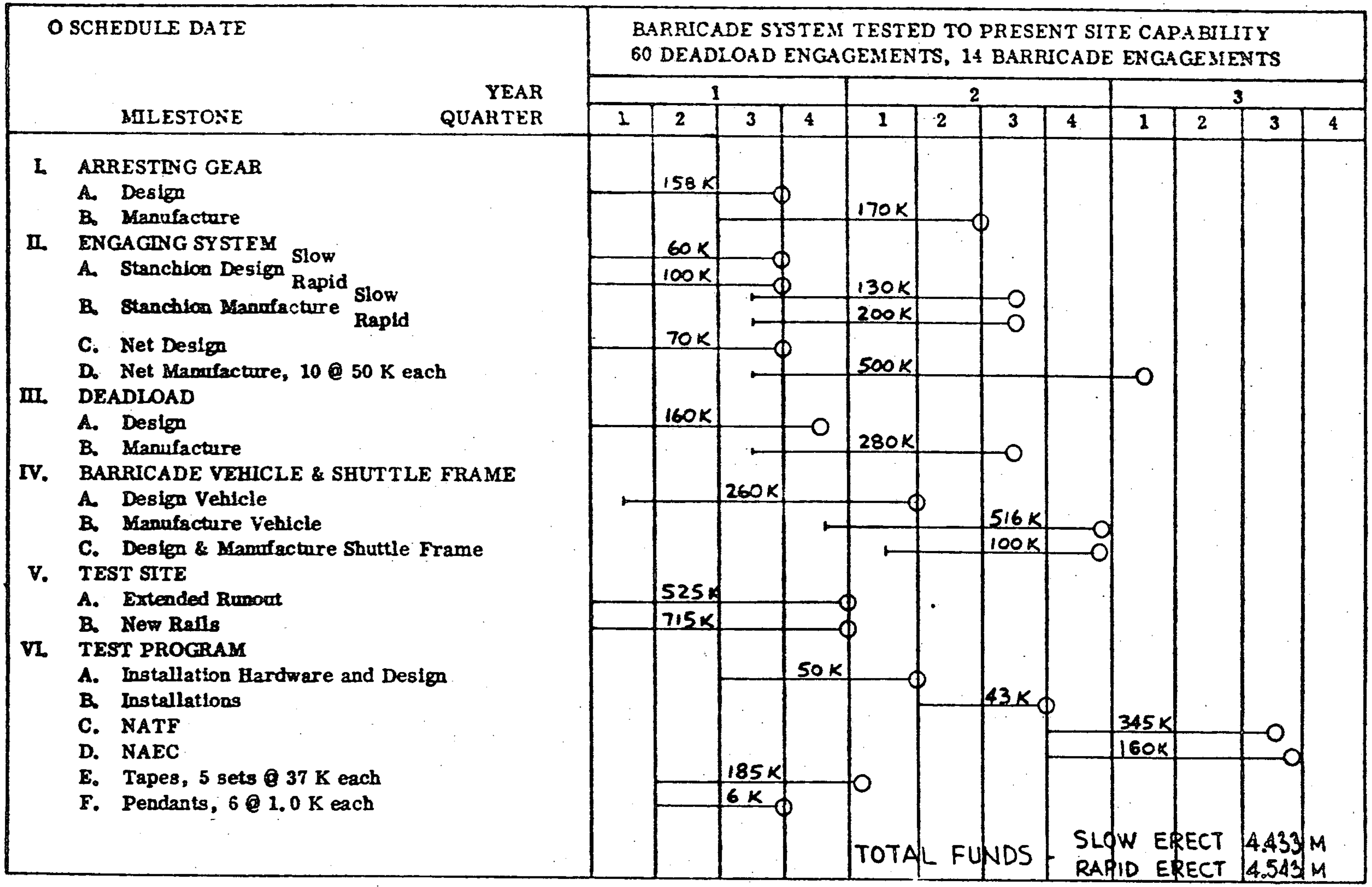
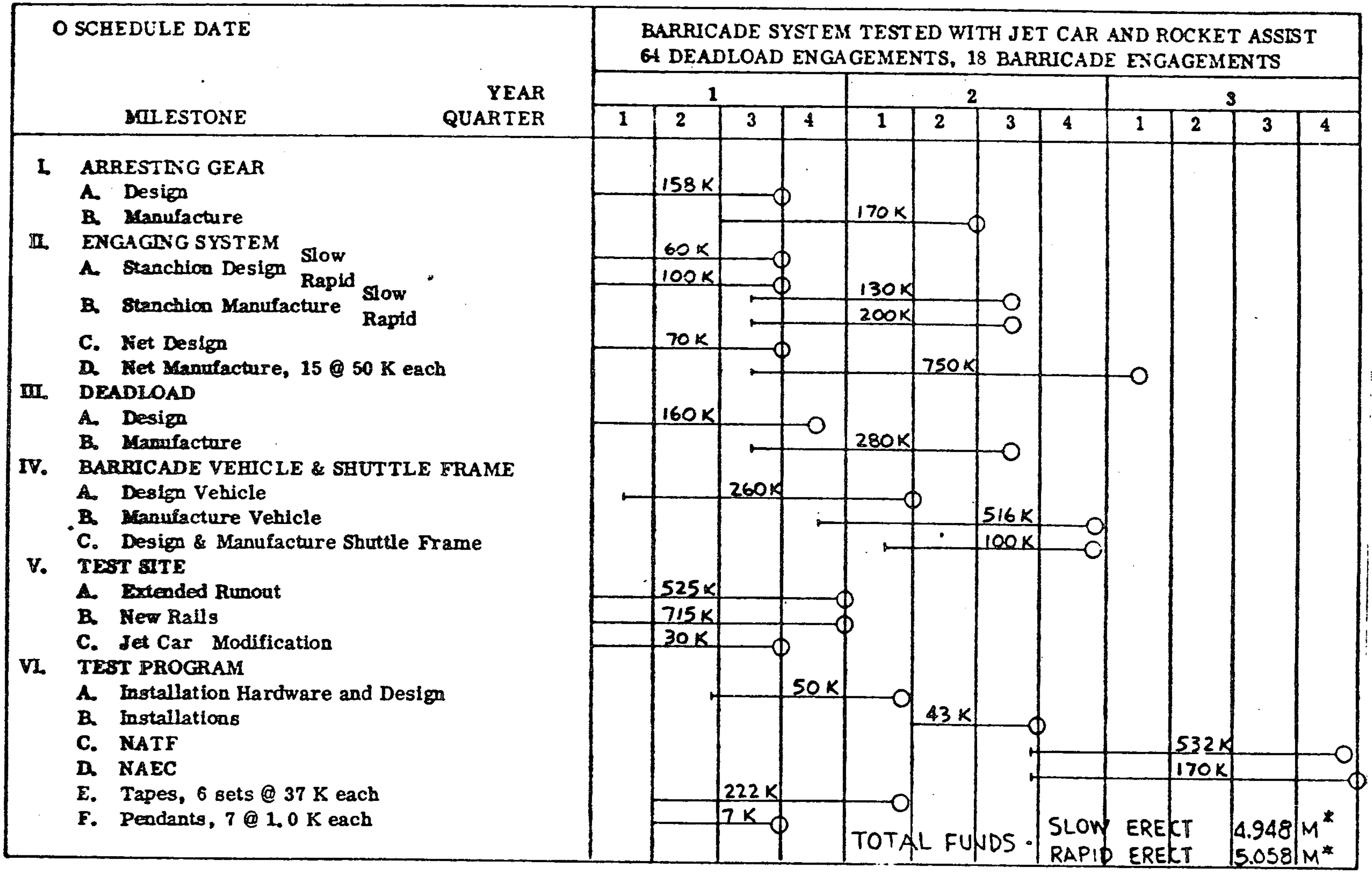


Table 5. Barricade System Test, Jet Car/Rocket Assist



* PLUS ROCKETS

Table 6. Barricade System Test, Jet Car/Extended Track

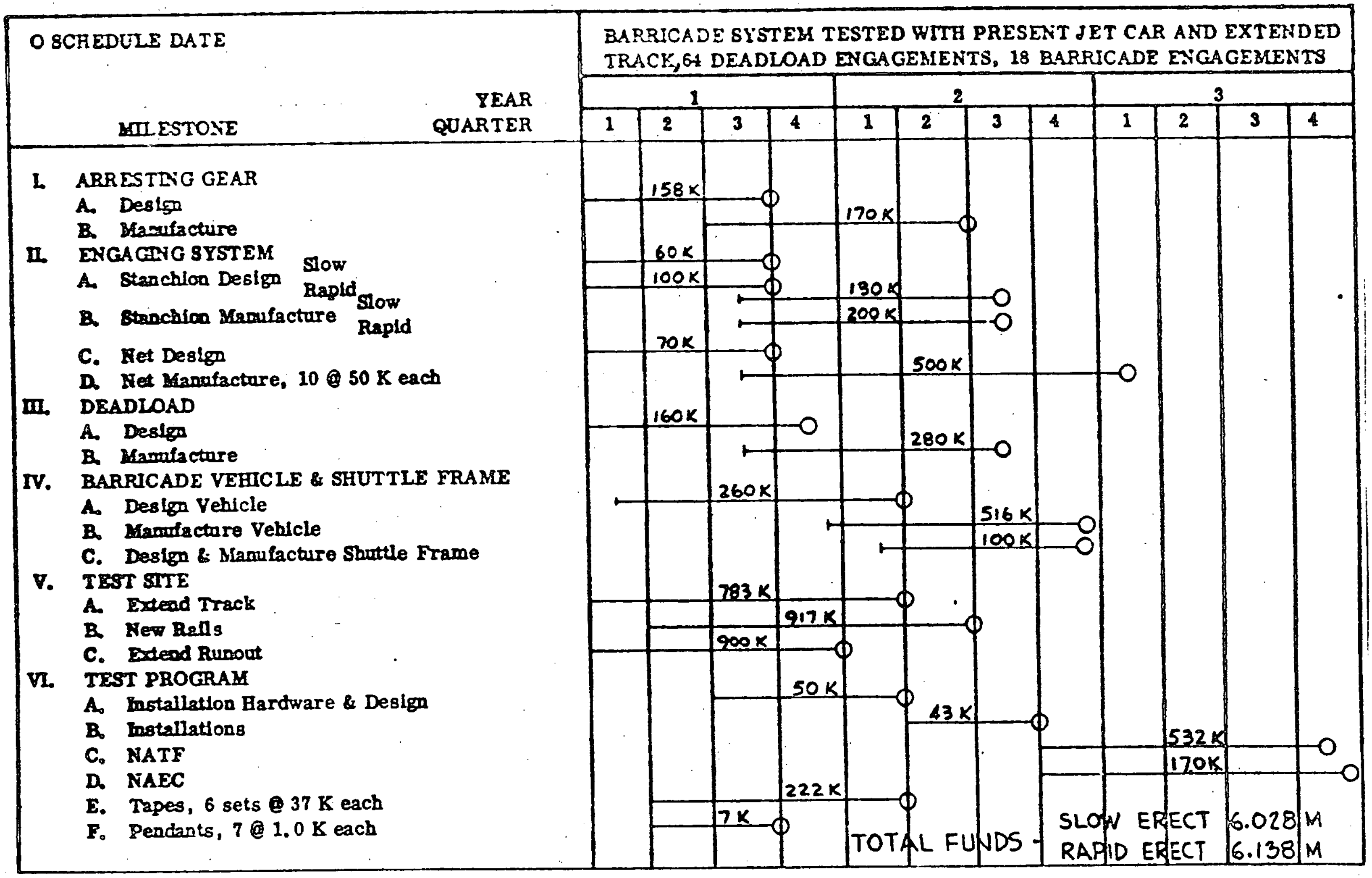


Table 7. Gear Entanglement System Test, Site Capability

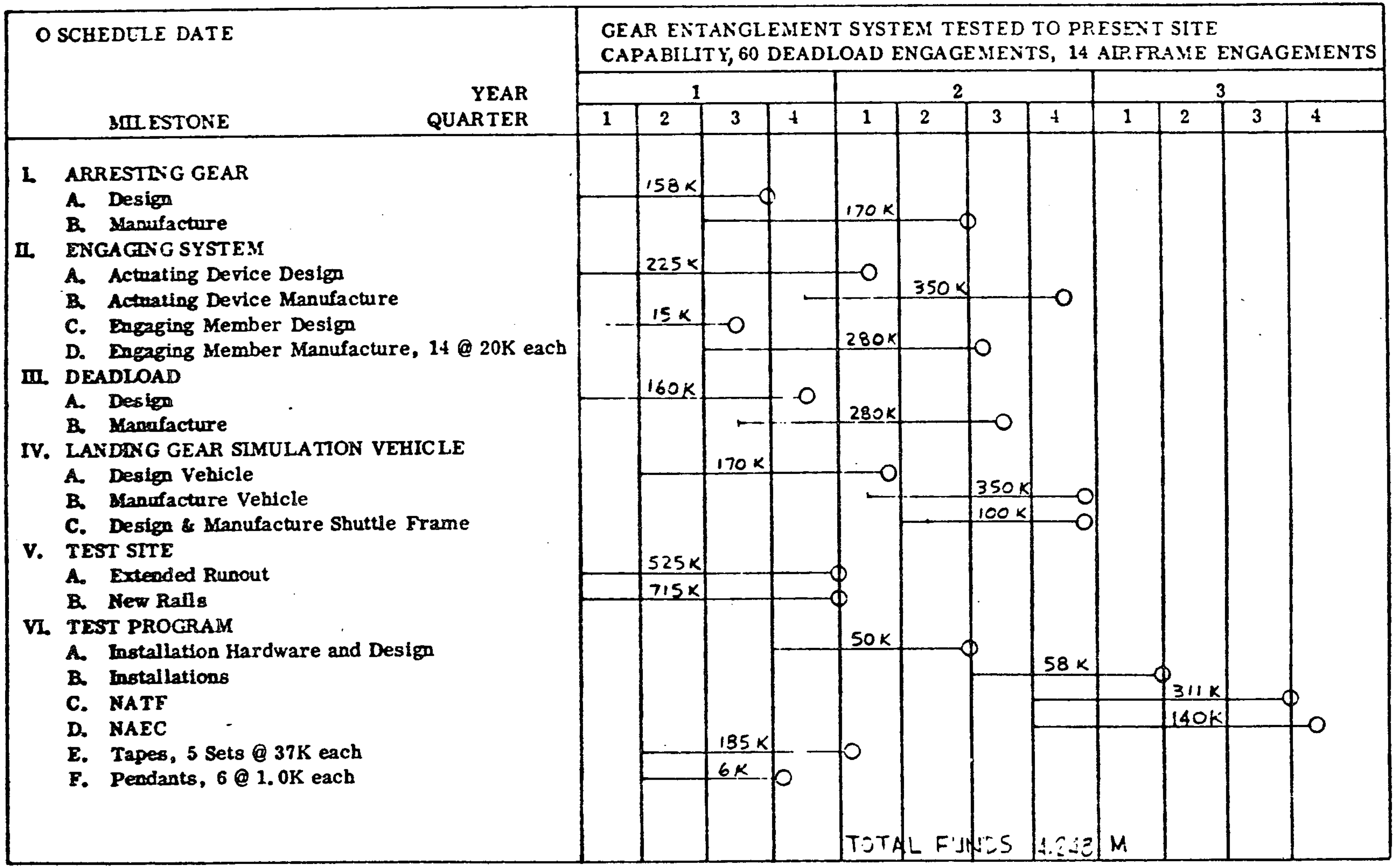


Table 8. Gear Entanglement System Test, Jet Car/Rocket Assist

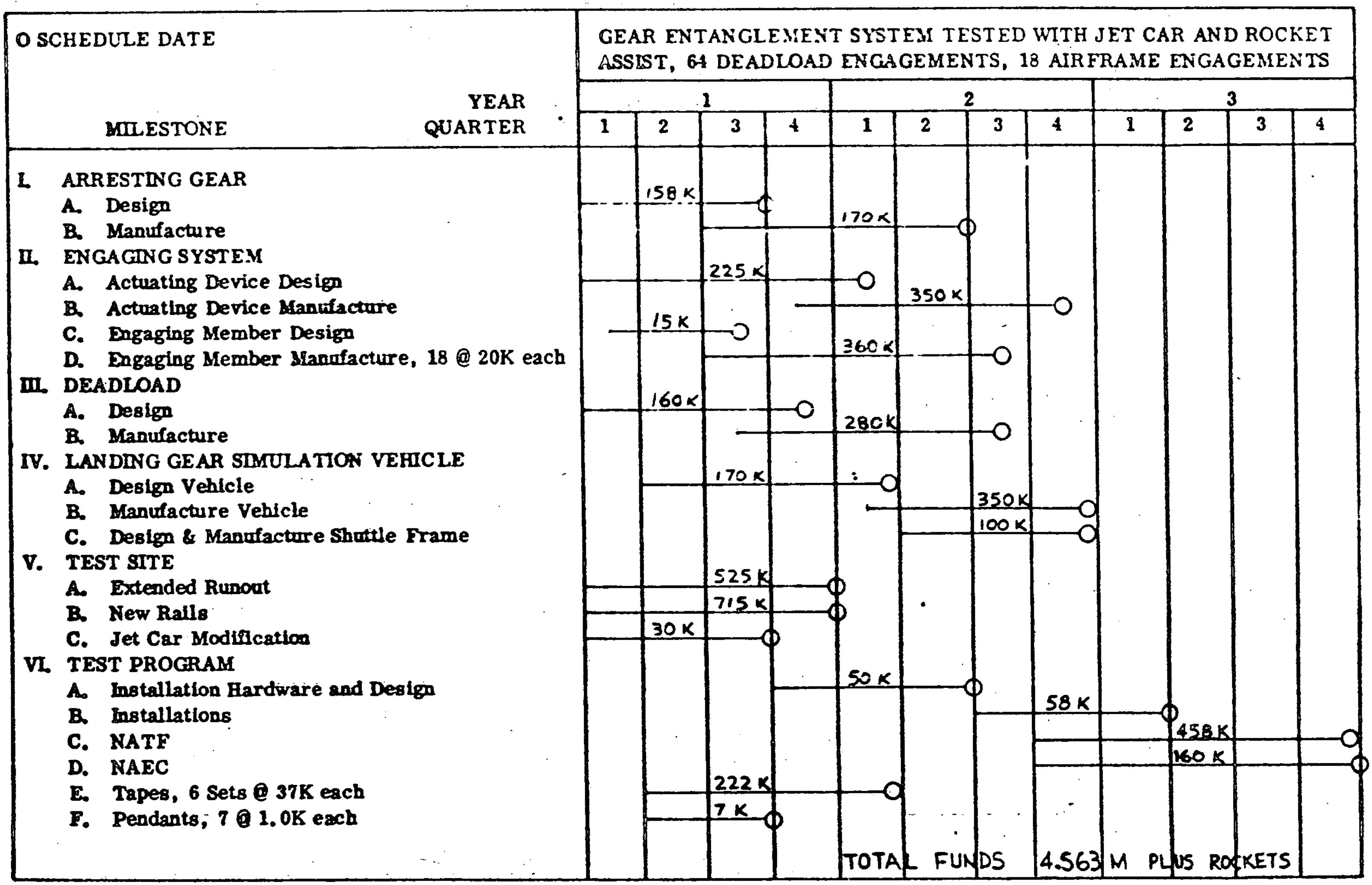


Table 9. Gear Entanglement System Test, Jet Car/Extended Track

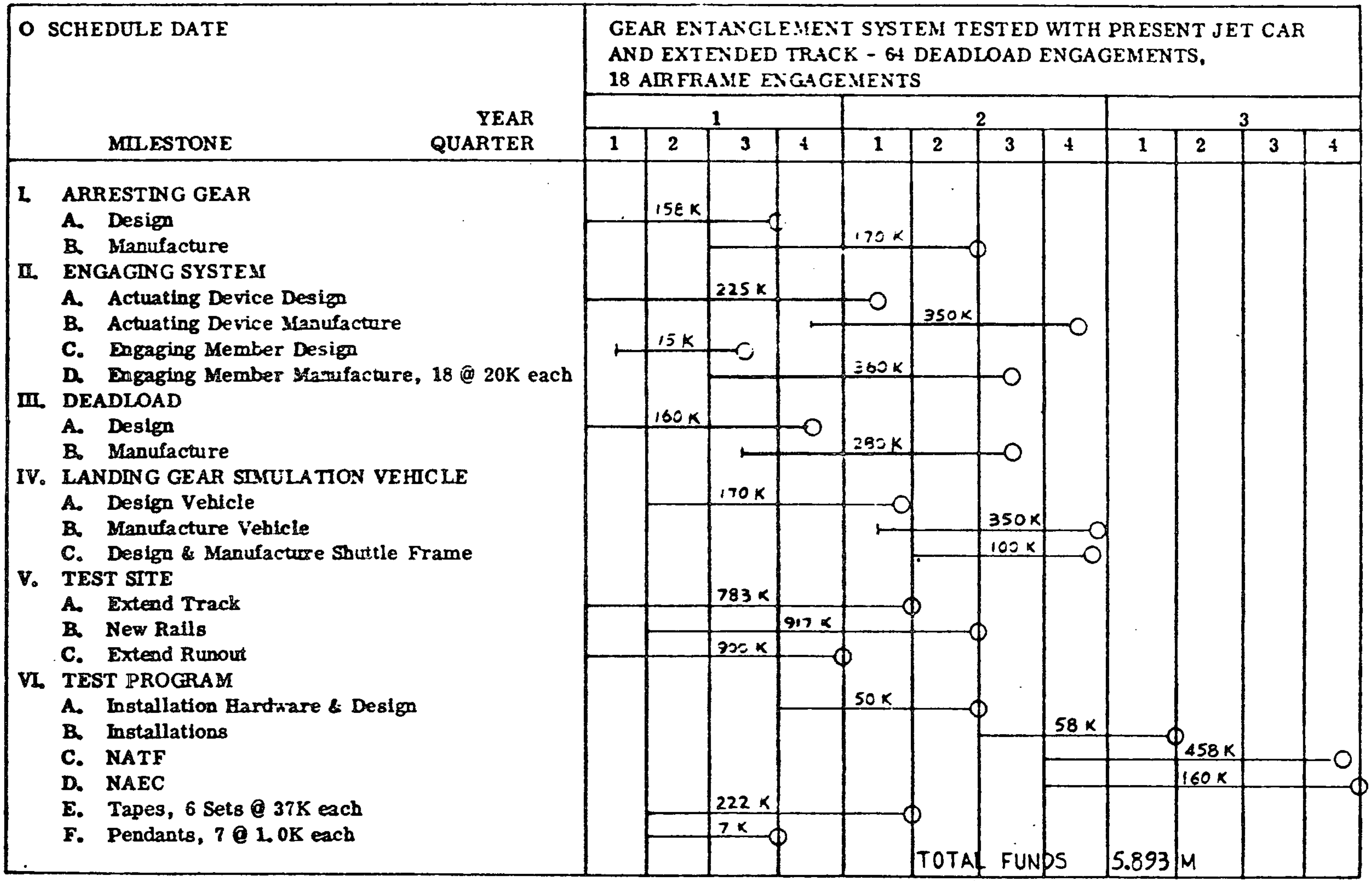


Table 10. Hook-Pendant System

O SCHEDULE DATE	NASA PRODUCTION SYSTEM COSTS - HOOK/PENDANT SYSTEM											
YEAR	2				3				4			
MILESTONE QUARTER	1	2	3	4	1	2	3	4	1	2	3	4
1. INSTALLATION DRAWINGS*					15 K	○						
2. OPERATION AND MAINTENANCE MANUALS*						25 K	— ○					
3. ARRESTING GEAR PRODUCTION						—	150 K	— ○				
4. PURCHASE TAPES						—	36.8 K	— ○				
5. PENDANT						—	3.5 K	— ○				
6. SPARES**						—	45 K	— ○				
7. SITE PREPARATION AND INSTALLATION							125 K	—	○			
FIRST SYSTEM COST							400.3 K					
EACH ADDITIONAL SYSTEM							360.3 K					

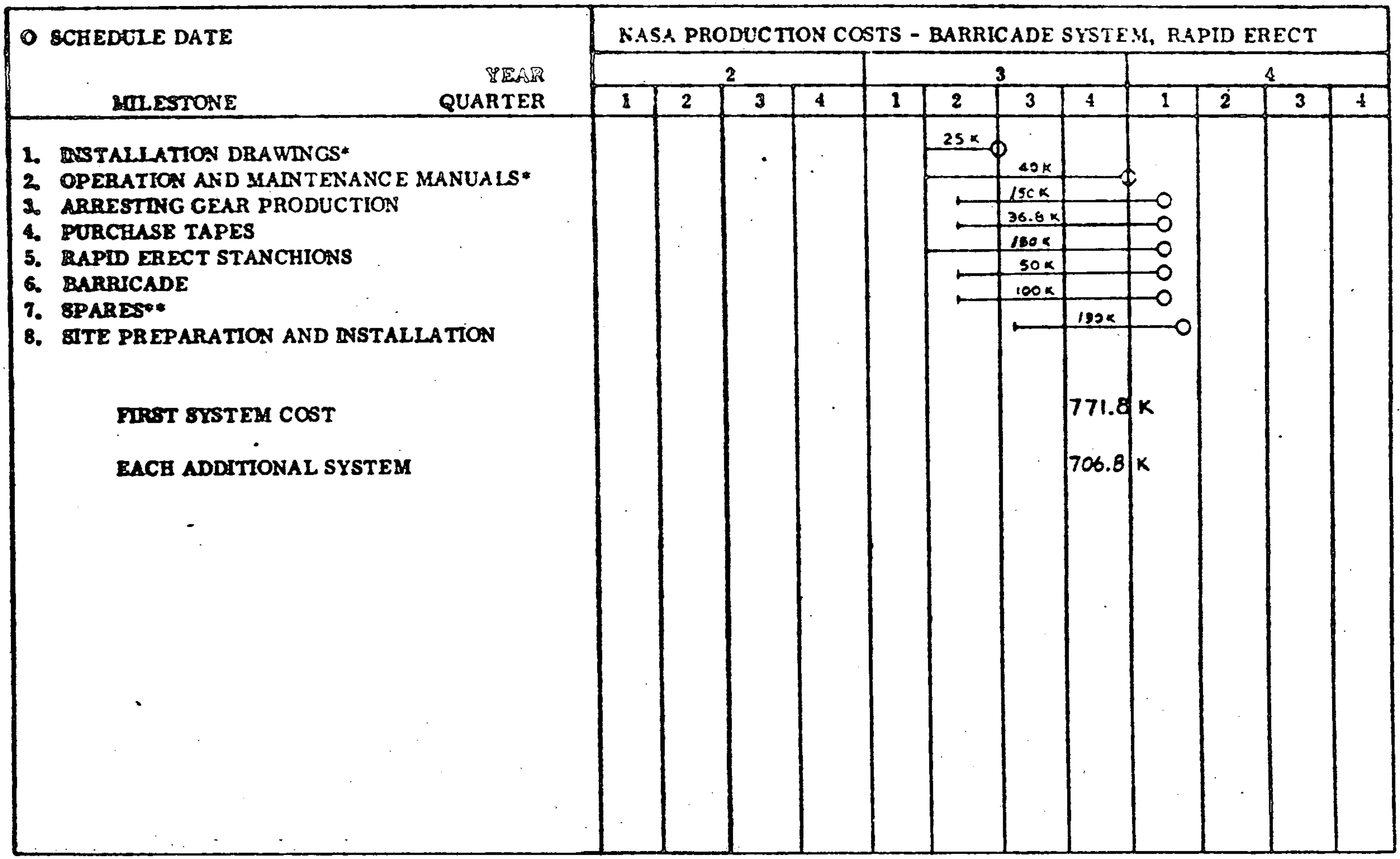
* Not Recurring Costs
** Includes Two Tapes and One Pendant

Table 11. Barricade System, Slow Erect

○ SCHEDULE DATE	NASA PRODUCTION SYSTEM COSTS - BARRICADE SYSTEM, SLOW ERECT											
YEAR	2				3				4			
MILESTONE QUARTER	1	2	3	4	1	2	3	4	1	2	3	4
1. INSTALLATION DRAWINGS*						25 K ○						
2. OPERATION AND MAINTENANCE MANUALS*							40 K		○			
3. ARRESTING GEAR PRODUCTION							150 K		○			
4. PURCHASE TAPES							36.8 K		○			
5. SLOW ERECT STANCHIONS							115 K		○			
6. BARRICADE								50 K	○			
7. SPARES**								100 K	○			
8. SITE PREPARATION AND INSTALLATION								150 K	○			
FIRST SYSTEM COST								666.8	K			
EACH ADDITIONAL SYSTEM								601.8	K			

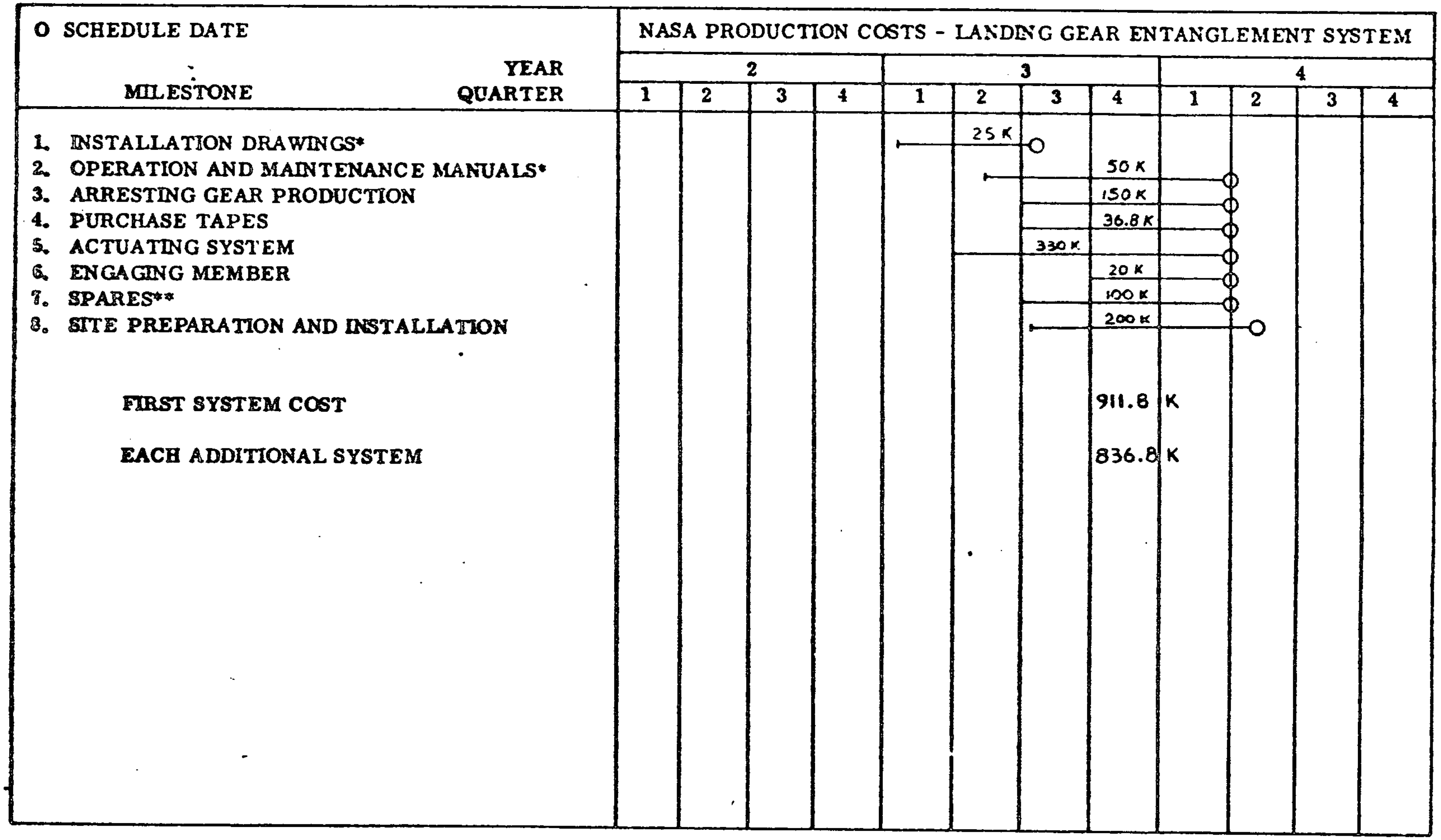
* Not Recurring Costs
** Includes Two Tapes and One Barricade

Table 12. Barricade System, Rapid Erect



* Not Recurring Costs
** Includes Two Tapes and One Barricade

Table 13. Gear Entanglement System



O SCHEDULE DATE	NASA PRODUCTION COSTS - LANDING GEAR ENTANGLEMENT SYSTEM											
YEAR	2				3				4			
MILESTONE QUARTER	1	2	3	4	1	2	3	4	1	2	3	4
1. INSTALLATION DRAWINGS*						25 K						
2. OPERATION AND MAINTENANCE MANUALS*								50 K				
3. ARRESTING GEAR PRODUCTION								150 K				
4. PURCHASE TAPES								36.8 K				
5. ACTUATING SYSTEM							330 K					
6. ENGAGING MEMBER								20 K				
7. SPARES**								100 K				
8. SITE PREPARATION AND INSTALLATION								200 K				
FIRST SYSTEM COST								911.8 K				
EACH ADDITIONAL SYSTEM								836.8 K				

* Not Recurring Costs
** Includes Two Tapes and One Engaging Member