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DEVELOPMENT OF CARGO SLINGS WITH NONDESTRUCTIVE CHECKOUT SYSTEMS

Horace T. Hone, et al

United Aircraft Corporation

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EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by Sikorsky Aircraft Division of United Aircraft Corporation under the terms of Contract DAAJ02-72-C-0008. It documents an advanced development program for a family of slings with payload capabilities up to 110,000 pounds. The slings are compatibile with the payload capabilities of all current and planned Army helicopters.

The objectives of this contractural effort were to develop a minimum number of slings with maximum utility for payloads up to 60,000 pounds and a nondestructive checkout system to ensure that the slings could safely transport their rated payloads.

This effort has provided the information necessary to proceed with the engineering development of a family of slings. The objectives of the program were met, and eventual use of these slings will result in more efficient helicopter external cargo transport with a significant reduction of payload losses.

The conclusions contained herein are concurred in by this directorate.

The technical monitor for this contract was J. Everette Forehand, Military Operations Technology Division.

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13. ABSTRACT

This report describes the design, fabrication and testing of the following equipment which was developed to extend the facilities for carrying external loads on U.S. Army helicopters.

1. Four-legged wire rope slings of 6,000, 25,000 and 60,000 pounds nominal capacity.

2. Four-legged nylon rope slings of 6,000 and 25,000 pounds nominal capacity.

3. Nylon rope pendants of 6,000 and 20,000 pounds nominal capacity for use in conjunction with the 6,000- and 25,000-pound slings.

4. Nondestructive test apparatus for the wire rope slings.

168

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Final Report

By

Horace T. Hone
Walter E. Huebner
Donald J. Baxter

Prepared by

Sikorsky Aircraft
Division of United Aircraft
Stratford, Connecticut

for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

ii

SUMMARY

A set of slings has been designed, fabricated and successfully tested for the U. S. Army to carry external helicopter loads up to 60,000 pounds, with growth potential to 110,000 pounds. They are intended to replace existing slings (FSN 1670-902-3082) that are deficient in strength and life expectancy.

Sling size optimums were established from studies of the range of loads to be carried and of the lift capabilities of the helicopters designated to carry them. Various designs and materials for slings and associated pendants were also studied.

Based on these studies, two designs were established. They consist of a braided nylon rope pendant plus either a braided nylon-rope or a stainless-steel wire-rope sling having four legs of adjustable length. The slings can be used in single-point or multi-point configuration. Nylon rope has commendable strength/weight ratio, handling quality, and elasticity. However, stainless-steel wire rope has a much more predictable life expectancy.

Concurrent investigations into nondestructive test techniques have shown that such procedures can be successfully applied only to metallic sling materials. An electromagnetic device is recommended for detection of defects in the wire rope slings.

A full range of prototype hardware was fabricated. Components were subjected to structural and environmental testing. This was followed by simulated operational usage on a representative selection of loads ranging from a 560-pound cargo trailer to a 31,000-pound crane. A movie film was made of these trials.

The performance of the prototype slings proved the designs to be satisfactory. Minor improvements recommended for production slings are a different type of standard chain connector for easier disassembly and reduction in weight of the sling apex fittings. Minor improvements recommended for production pendants are a stronger release handle assembly and reduction in weight of the pendant hooks.

A draft manual describing general operating procedures for slinging equipment and rigging techniques for specific loads has been prepared.

FOREWORD

This program was executed under Contract DAAJ02-72-C-0008 for Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

Any trade names used in this report are for identification purposes only and do not signify an endorsement of the product.

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TABLE OF CONTENTS

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Page

LIST OF ILLUSTRATIONS

LIST OF TABLES

Table		Page

LIST OF SYMBOLS

P = factored local load

P_{au} = allowable ultimate load

P_{tru} = allowable ultimate transverse load

σ = sustained tensile stress

F_{au} = maximum allowable sustained tensile stress

F_{ty} = yield tensile stress

F_{tu} = ultimate tensile stress

F_{su} = ultimate shear stress

F_{bru} = ultimate bearing stress

INTRODUCTION

PROGRAM OBJECTIVE

The primary purpose of this task was to design, fabricate and test a series of slings of various sizes up to 60,000 pounds, to supplement and ultimately replace the existing slings used for transporting loads on certain current and future U. S. Army helicopters. Secondary outputs from the program were the preliminary design for a sling of 110,000 pounds capacity; the design, fabrication and testing of the pendants associated with the slings; and the development of a nondestructive test technique for sling legs.

BACKGROUND

The carriage of externally suspended cargo loads on Army helicopters has been developed in recent years to the extent that such loads are carried on 80% of all heavy and medium helicopter missions and on an increasing number of light helicopter missions. However, the only sling set specifically intended to support these missions was developed in 1958. It is supplemented by various airdrop slings and adaptations of commercial slings.

Deficiencies in this equipment cause serious operational difficulties. For instance, the maximum safe rating of available slings is 15,000 pounds, which is well below the payloads of the CH-47 and CH-54. Improvisations to enhance slinging capabilities result in complex, time-consuming rigging procedures. In flight they contribute to unacceptable levels of vibration, unstabilizing load oscillations, and vertical bounce, leading to unsafe conditions and occasional load jettison or sling failure. Conventional synthetic webbings can be restructured to improve their tensile strength, but this adversely affects the stiffness characteristics in relation to vertical bounce resonances. Hitherto, the criteria used for establishing a safe working load for sling structures have been developed empirically and based on static considerations only. They do not compensate for the viscoelastic nature of the material, dynamic, or operational factors. In the absence of a valid, established method for determining residual tensile capacity of current sling assemblies, only a visual inspection is made prior to use. Oftentimes this method is deceptive in that the detrimental effects of wear, environment, storage and prolonged use cannot be assessed. This contribution to in-flight failures substantially reduces confidence in the reliability of current slings and has imposed arbitrary limitations on sling life. Hence an urgent need exists for higher capacity and more reliable slings of a type that can be subjected to a nondestructive test procedure which will indicate that at least 90% of the original strength remains.

TERMINOLOGY

Throughout this report, the terms "sling" and "pendant" are used in the manner defined by Figure 1, which depicts a complete sling system designed in accordance with the recommendations of this report. (Major components and their functions are defined in the next section.) On aircraft which do not require the use of a pendant (for reasons explained in the next section) the slings may be operated as shown in Figure 2, in either single-point or multi-point configuration.

Nominal capacities of slings, pendants, and their component parts are designated in this report by suffix "K" representing "pounds X 1000".

The expressions "nondestructive tester" or "nondestructive testing" are sometimes abbreviated to "NDT".

COMPONENT FUNCTIONS

The sling is a quadruple suspension member tactically deployed with the load. It is attached in accordance with instructions specific to the load, normally, but not necessarily, using all four legs.

The pendant is a singular suspension member tactically deployed with the aircraft. The helicopter arrives over the load with the pendant suspended from the cargo hook, to which it may have been attached before or during flight.

To acquire the load, the helicopter descends to a convenient height above it, and a hookup man, stationed beside or on top of the load, couples the sling to the pendant. Uncoupling is performed from the helicopter, or from the ground, after the load has touched down and the aircraft has maneuvered to one side so that the sling does not damage the load when released. The pendant remains with the aircraft, but emergency in-flight release from the cargo hook is possible (with or without a sling load).

The sling has four functional characteristics:

1. It provides essentially the tension members between the load and the pendant hook or aircraft cargo hook.
2. It provides a unified top attachment point for the tension members.
3. It provides means for adjusting the lengths of the tension members to match a variety of load forms.
4. It provides means for attaching the tension members

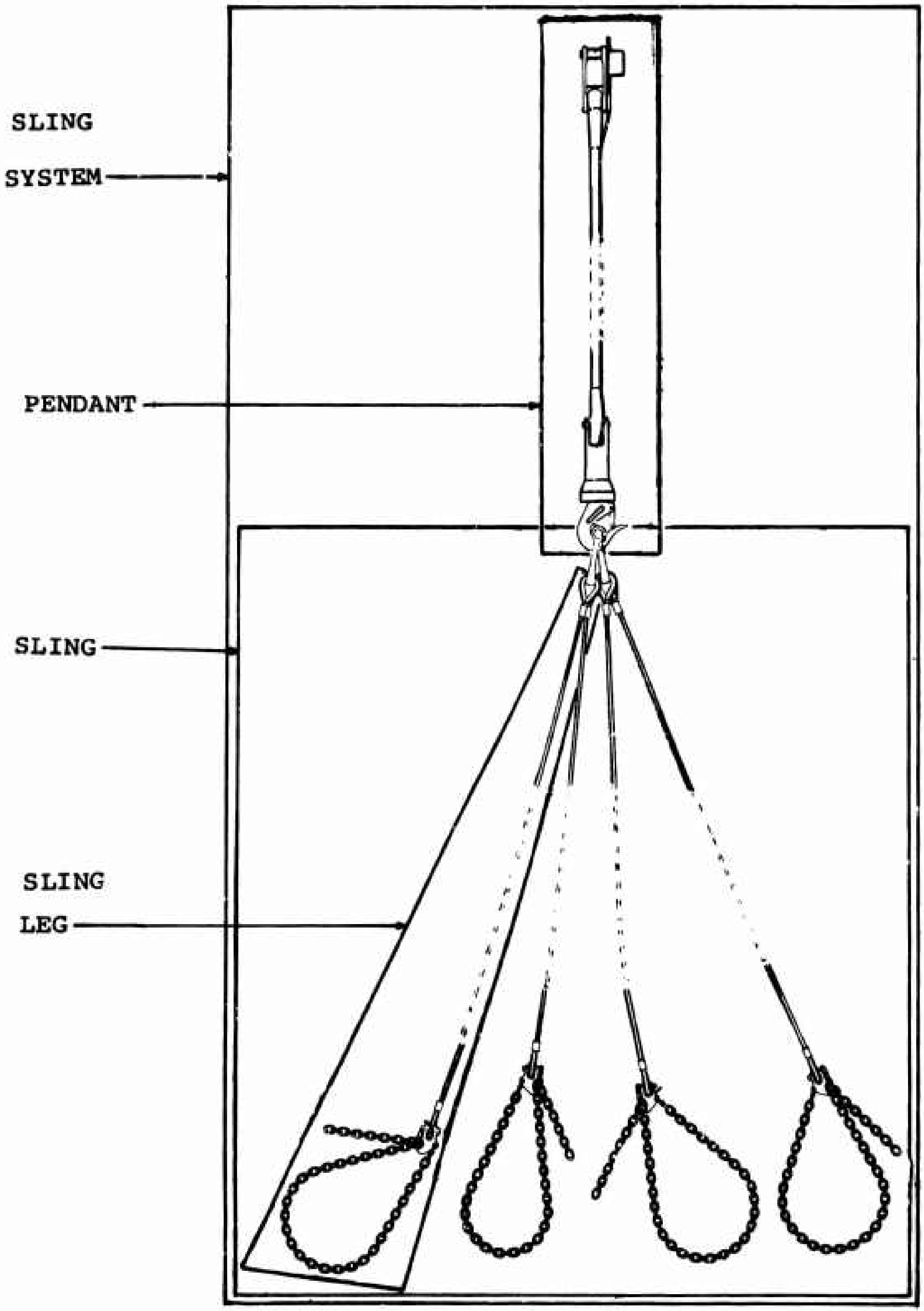

Figure 1. Definition of Terms.

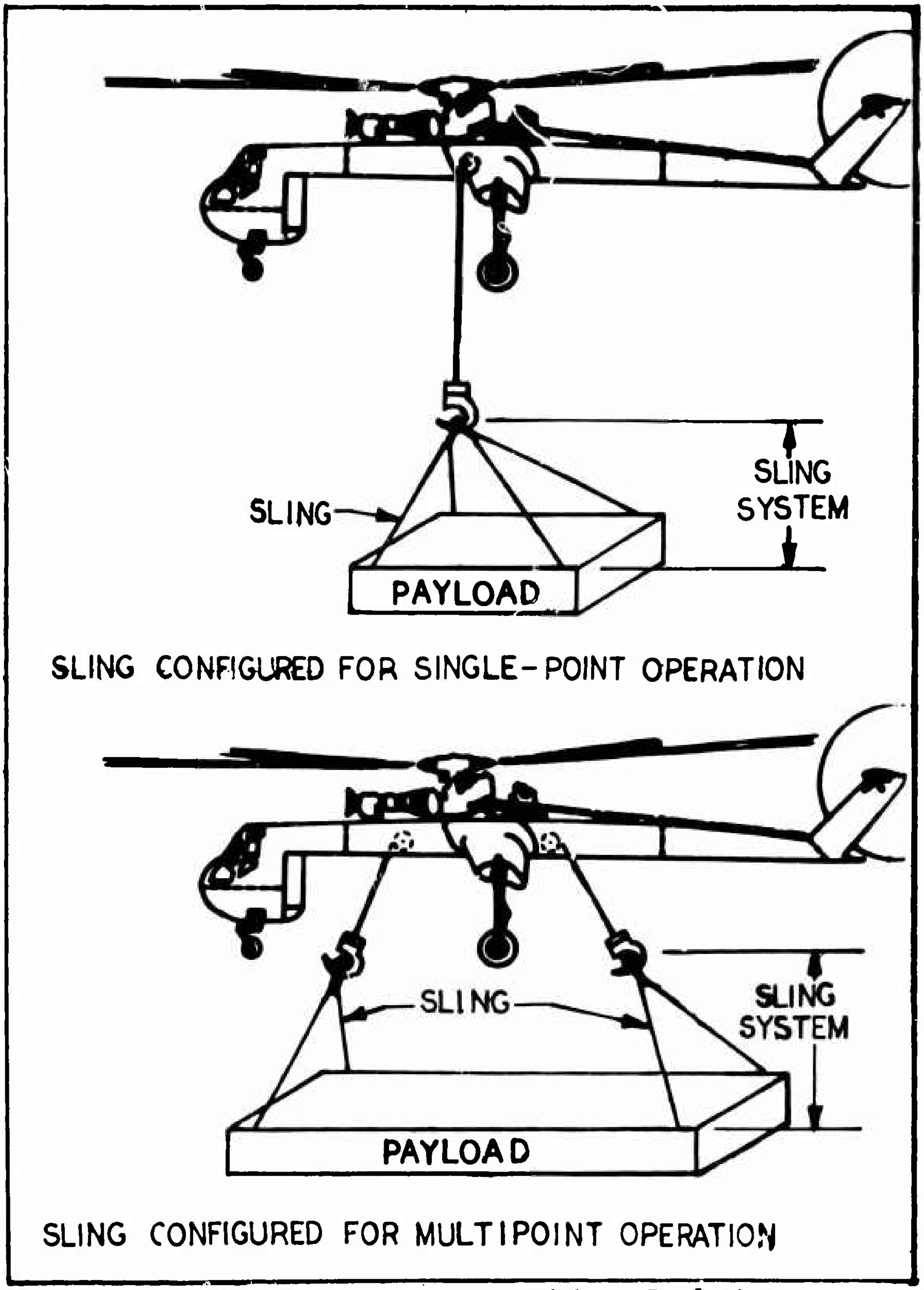

Figure 2. Sling System Without Pendant.

to the load.

(The sling is not required for loads which have single lifting points located over the center of gravity. Such loads, e.g., certain skid-mounted generator sets, can be coupled directly to a pendant hook, provided it is physically compatible.

Basic components of a sling are:

1. Four tension members.

2. An apex fitting, by which the sling legs are all attached to the pendant hook or aircraft cargo hook.

3. Four length adjustment devices by which the sling legs are configured to optimize the attitude of the lifted load.

4. Four load attachment devices by which the sling legs are attached to the load.

The pendant has four functional characteristics:

1. It provides sufficient in-flight clearance between the load and the aircraft to prevent portions of the load striking the aircraft due to aerodynamic forces, maneuvers or load oscillations.

2. It provides clearance between the bottom of the aircraft and the hookup man.

3. It provides degrees of freedom to facilitate the sling coupling operation.

4. It provides, by virtue of its elasticity, load isolation to prevent objectionable vertical bounce.

(The pendant is not required for aircraft equipped with cargo hoists having integral load isolators. Such aircraft, e.g., the CH-54 and CH-62, can raise or lower the cargo hook to any desired position to provide clearance, while the load isolators damp out vertical bounce.)

Basic components of a pendant are:

1. A tension member.

2. An apex fitting, by which the tension member is attached to the aircraft cargo hook.

3. A swivel hook, by which the sling is attached to the pendant without any possibility of the load winding up

the pendant due to rotor swirl.

4. A release system, by which the hook can be opened from a point at the top of the pendant, or directly from the hook itself.

RATIONALE FOR SIZE SELECTION

At an early stage in the design study, the optimum number of sling and pendant sizes and their optimum utility had to be determined. These parameters were influenced by the range of loads to be carried and the payload capabilities of the helicopters which were designated to carry them; namely, UH-1, UTTAS, CH-47, CH-54, CH-62. Problems of this sort are frequently resolved on a basis of large, medium and small sizes with suitable cutoff points assessed for each size. It was deduced that the vehicles could be grouped into three load ranges with maximums around 6,000 pounds, 25,000 pounds and 60,000 pounds, respectively.

A 6K sling can handle small trucks and trailers; also it is compatible with the UH-1 and UTTAS payloads. A 25K sling can handle large semitrailers, vans, 2-1/2-ton trucks of several varieties, most engineer equipment and most Army aircraft; also, it is 100% compatible with the CH-54B payload and 80% compatible with the CH-47 and CH-54A payloads. A 60K sling can handle heavy trucks (loaded), heavy engineer equipment, and most tactical vehicles; also, it is compatible with projected CH-62 type payloads. These three values were therefore adopted for the basic sling sizes. However, there remain a few loads, such as heavy tactical vehicles, tanks, tank recovery vehicles, prime movers, heavy self-propelled guns, and heavy construction equipment, that exceed 60,000 pounds. These need an extra-large sling with a capacity up to 110,000 pounds. Alternatively, since the number of such vehicles is limited, each could have its own specifically designed sling. (Preliminary designs were in fact made for a generic 110K sling, but the requirement for this size was not extended to the fabrication stage.)

Pendants associated with slings can be restricted to the small and medium sizes, since the large slings are applicable only to aircraft having integral hoists with decouplers. For the UH-1 and UTTAS aircraft, a 6K pendant is appropriate, and it will carry loads via a 6K sling. For the CH-47 aircraft, a 20K pendant is appropriate, and it will carry loads via a 25K sling.

Note that the 5,000-pound differential between the last-mentioned pendant and sling capacities arises from the fact that the pendant size is dictated by the payload of the CH-47, whereas the sling size is selected to accommodate an optimum range of loads. Hence, the sling is designed to take loads up to 25,000 pounds on the CH-54B and CH-62, which have integral hoists.

COMPATIBILITY REQUIREMENTS

The preceding section specified the basic requirements of the chosen sling and pendant sizes; i.e., the 6K sling is to be used on UH-1 and UTTAS by means of the 6K pendant, the 25K sling is to be used on CH-47 by means of the 20K pendant and on CH-54 directly, and the 60K sling is to be used on CH-62 directly. Three other compatibility factors should be mentioned. The CH-47 will often be required to carry a 6,000-pound load, and therefore the 6K pendant must fit the cargo hook of this aircraft. Also, it must be possible to fit a 6K sling to a 20K pendant in order to enhance the utilization of both on the CH-47. (There is, however, no case for fitting a 25K sling to a 6K pendant.) Finally, it must be possible to fit a pendant to a pendant of the same size in order to provide extra clearance for certain loads.

Note that the 6K sling system is associated with UTTAS, which in fact can carry 7,000 pounds from its cargo hook. The system can, however, carry 7,000-pound loads provided that they are not Type III (see Reference 1). Any currently existing UTTAS loads are Type I or II and can therefore be carried on the 6K sling system up to the full capacity of the helicopter. This spotlights the fact that the capacities quoted for the slings and pendants refer only to their lifting capabilities with "worst case" loads, i.e., Type III. With Type I or II loads, their nominal capacities may be exceeded, within limits indicated by Reference 1.

Table I summarizes the compatibility criteria.

TABLE I. SLING/PENDANT/HELICOPTER COMPATIBILITY

Item	Required To Fit
6K Sling	UH-1 via 6K Pendant UTTAS via 6K Pendant CH-47 via 6K or 20K Pendant
25K Sling	CH-47 via 20K Pendant CH-54 directly on Cargo Hook CH-62 directly on Cargo Hook
60K Sling	CH-62 directly on Cargo Hook
6K Pendant	UH-1 Cargo Hook UTTAS Cargo Hook CH-47 Cargo Hook 6K Pendant Hook
20K Pendant	CH-47 Cargo Hook 20K Pendant Hook

DESIGN STUDY

SLINGS

Discussion

The purpose of the design study was to establish the best materials and general formats for the sling components. Basically, each size of sling had to comprise four sling legs, adjustable in length from 18 feet to 22 feet, approximately, and suspended from an apex fitting capable of single-point or multi-point configuration. These requirements are derived from Reference 1, which recommends (on pages 2 and 4) that loads should be provided with four lift points and the length of legs (plus apex fitting and load attachment fittings) should be 20 $\pm$ 2 feet.

Detailed design was not included, and structural analysis was taken only far enough to determine approximate sizes, from which initial weight and cost estimates were derived. Design loads were based on the capacity and compatibility requirements outlined in the preceding sections using flight factors specified in Reference 1.

Existing designs were used as a starting point in the preliminary design of the four major sling components.

Sling legs for helicopter external loads are currently made of webbings, in either nylon (to Specification MIL-W-4088) or Dacron (to Specification MIL-W-25361). They are built up into several layers or plies to achieve the required strength. The same materials are made into rope form by several manufacturers, and they are widely used for slings in marine applications. They are woven or braided in various ways to achieve the required characteristics. The most prevalent sling materials for industrial use are undoubtedly steel wire ropes, and they are also commonly used on aircraft ground support equipment. They are made to several specifications and in a wide range of constructions. The aforementioned materials and variants therefore received most attention during the preliminary investigations, and many others were examined, particularly some of the newer synthetic fibers; but the most promising ones were too embryonic to be seriously considered within the time scale of this project.

Apex fittings are usually closed loops, whether metallic or textile. Steel apex fittings of the commercial type are often simple rings, circular in cross section, but are sometimes oval or pear shaped. Webbing apex fittings are made by winding the required number of layers into a toroid and stitching them together. The closed-loop concept is inexpensive and fits easily onto a hook, but sling legs cannot be attached without intermediate shackles. A clumsy and unnecessarily heavy assembly results. Hence, considerable design effort was directed toward loop forms which could be split and inserted directly into the eyes of the sling legs.

The other two functional components of the sling, namely, the length adjustment device and the load attachment device, were the subject of concurrent deliberation, since in existing slings there is one device which successfully combines both functions. That is the familiar chain and grab link arrangement, in which the chain loops through the lift point of the load and is then secured into the grab link at an appropriate point along its length. Many variations on this theme were developed, but several quite different methods of length adjustment were also considered (most of them requiring an additional device, such as a hook, to make the load attachment).

Sling material, apex fitting format, and length adjustment method were chosen on the basis of results derived from numerical trade-off charts. By this method, significant parameters, or characteristics, applicable to the item under study, are selected, e.g., "cost". Rating factors are then assigned to each parameter according to its relative importance; thus, "cost" generally has the highest rating. Each candidate for the item under study is then assessed against each parameter, and a numerical value is assigned to indicate its anticipated performance against that parameter; thus, the most economical candidate would be assigned a high performance value for the "cost" parameter. These values are then multiplied by the parameter rating factors to yield "weighted products" for each candidate against each parameter. The "weighted products" for all parameters against each candidate are then added. From these "weighted product totals" an order of merit for all the candidates can be derived.

The assignment of rating factors to parameters is a matter of subjective deliberation, as is the assignment of most of the performance values, since most parameters are of a purely qualitative nature. However, for some parameters, e.g., "cost", reliable quantitative data is generally available, thus providing a basis for realistic performance values.

Figures 3 through 8 are typical of many sling arrangements drawn up during the design study. They do not represent the preliminary recommended design, but they are included here to illustrate some of the features mentioned below.

Sling Materials

Twenty-two different materials for sling legs were traded off after eliminating obviously unsuitable types. They are listed below (Figure 9 summarizes their differences).

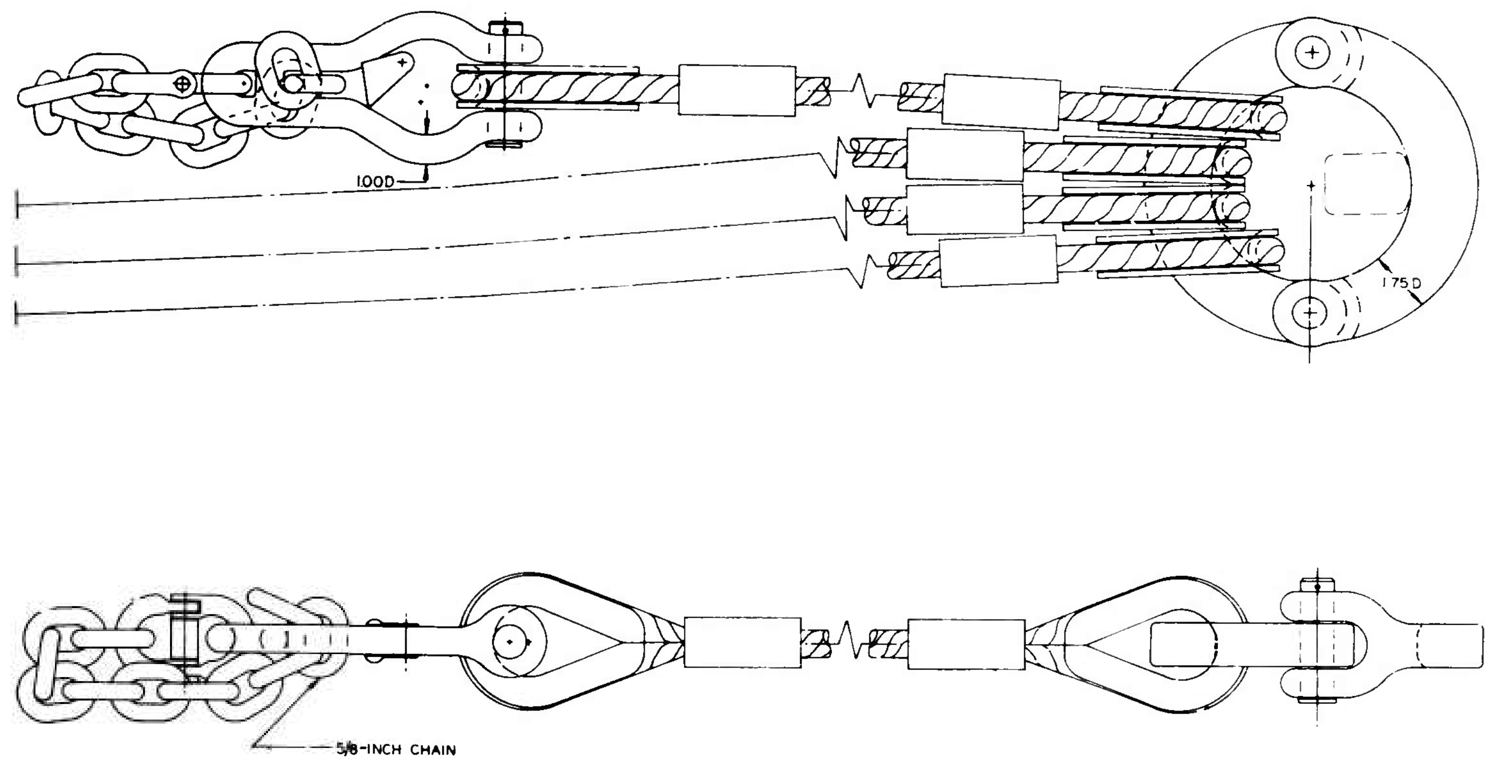

Figure 3. Typical Sling Design, Wire Rope, 60K.

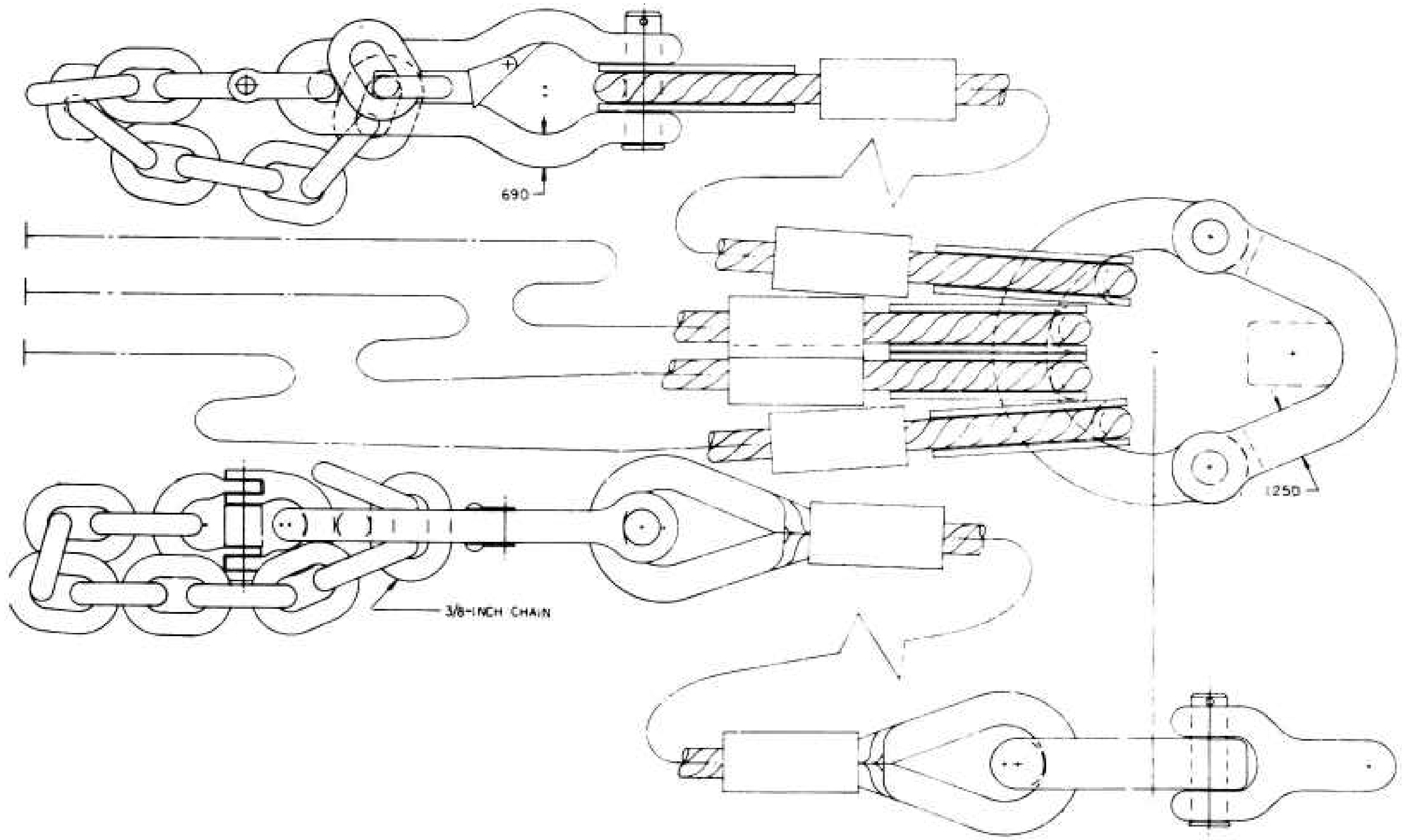

Figure 4. Typical Sling Design, Wire Rope, 25K.

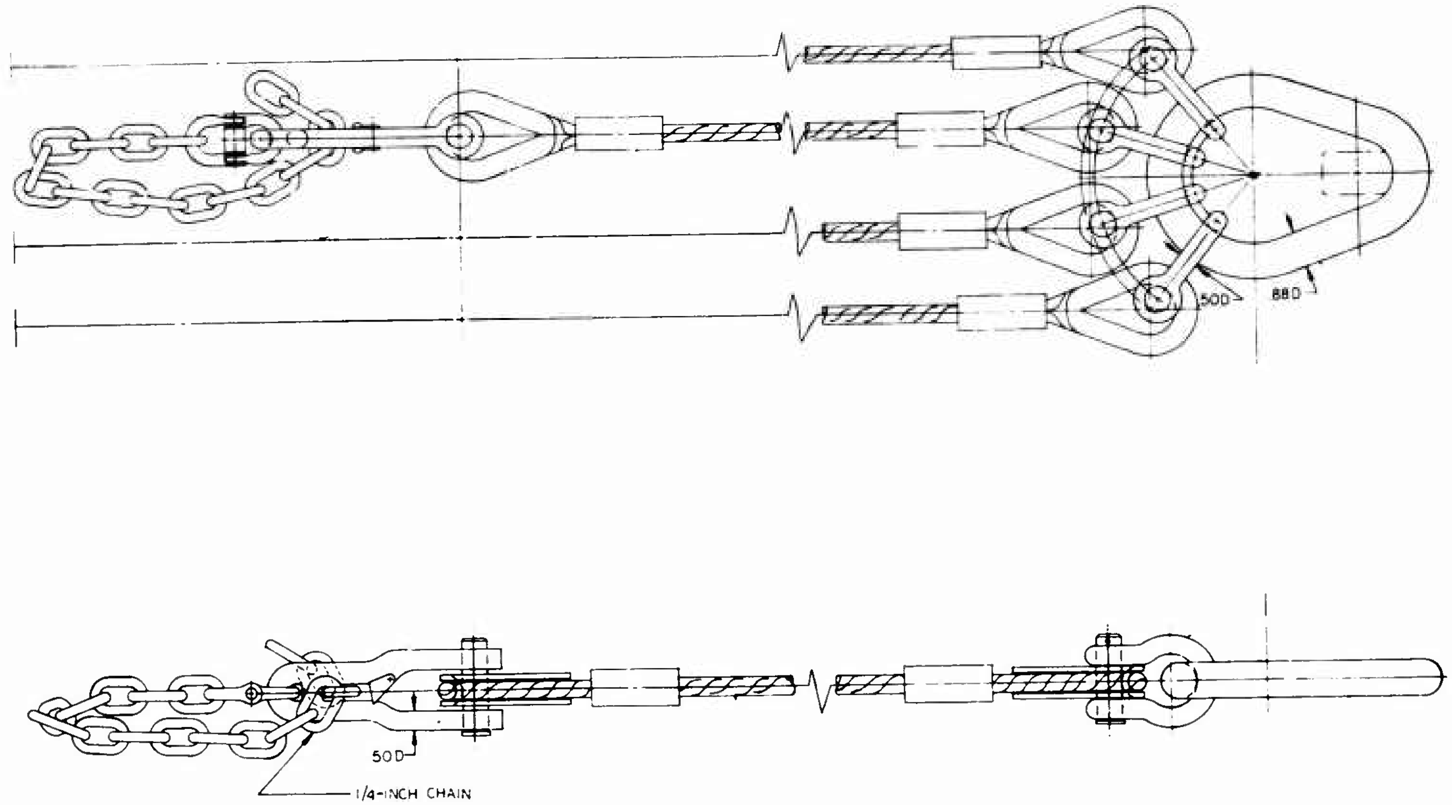

Figure 5. Typical Sling Design, Wire Rope, 6K.

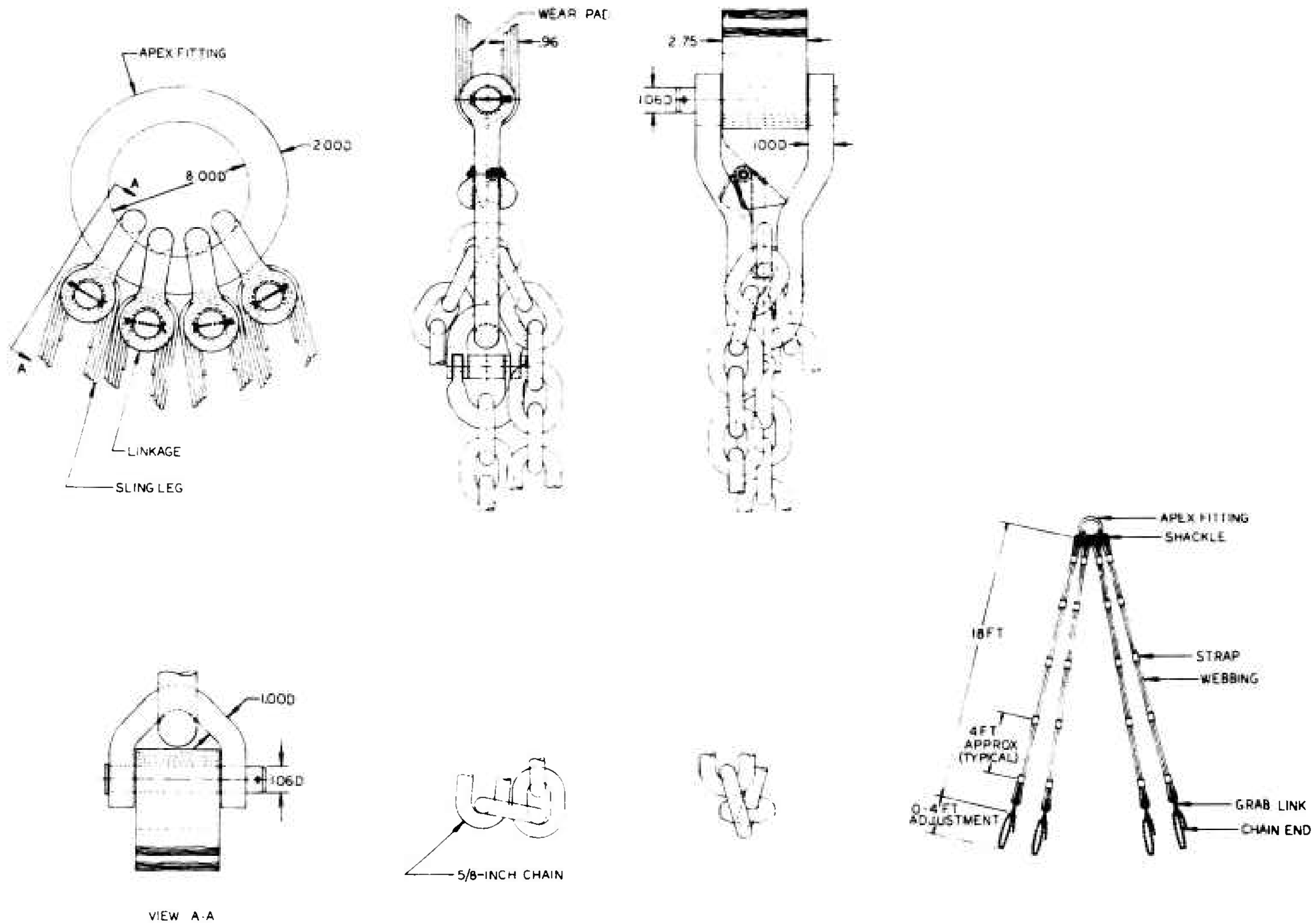

Figure 5. Typical Sling Design, Nylon Webbing, 60K.

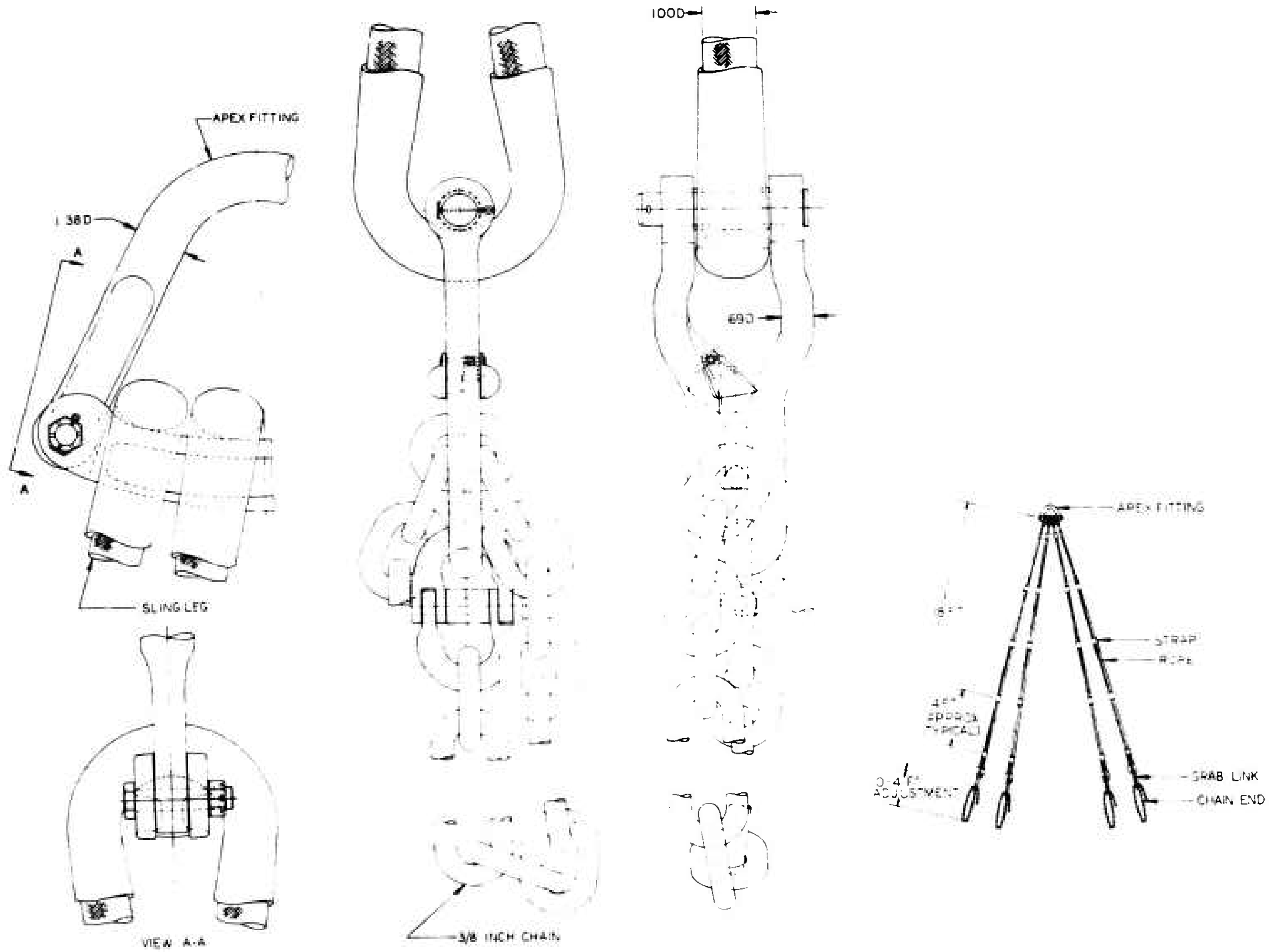

Figure 7. Typical Sling Design, Double-Braided Nylon Rope, 25K.

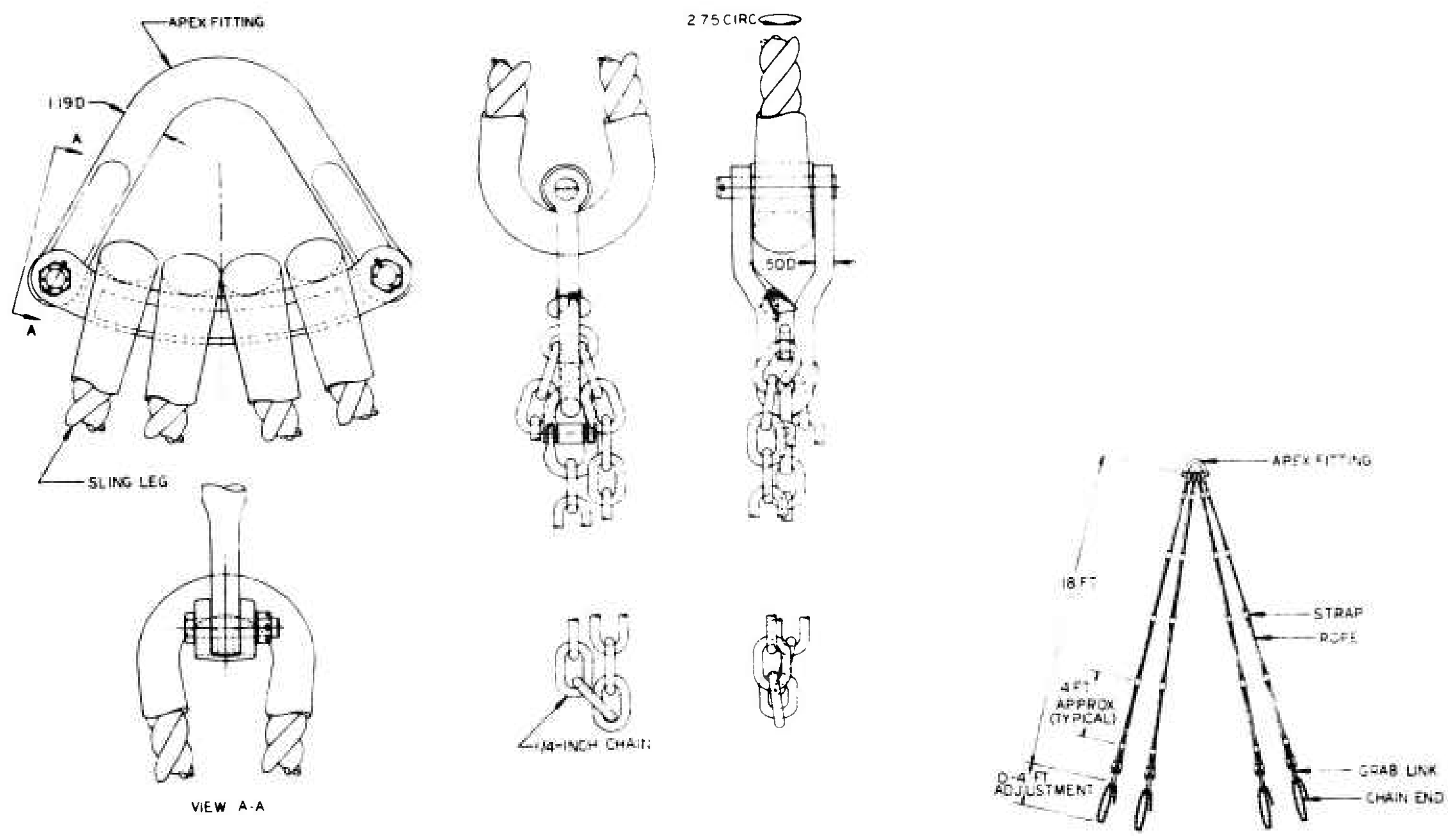

Figure 8. Typical Sling Design, Three-Strand Nylon Rope, 6K.

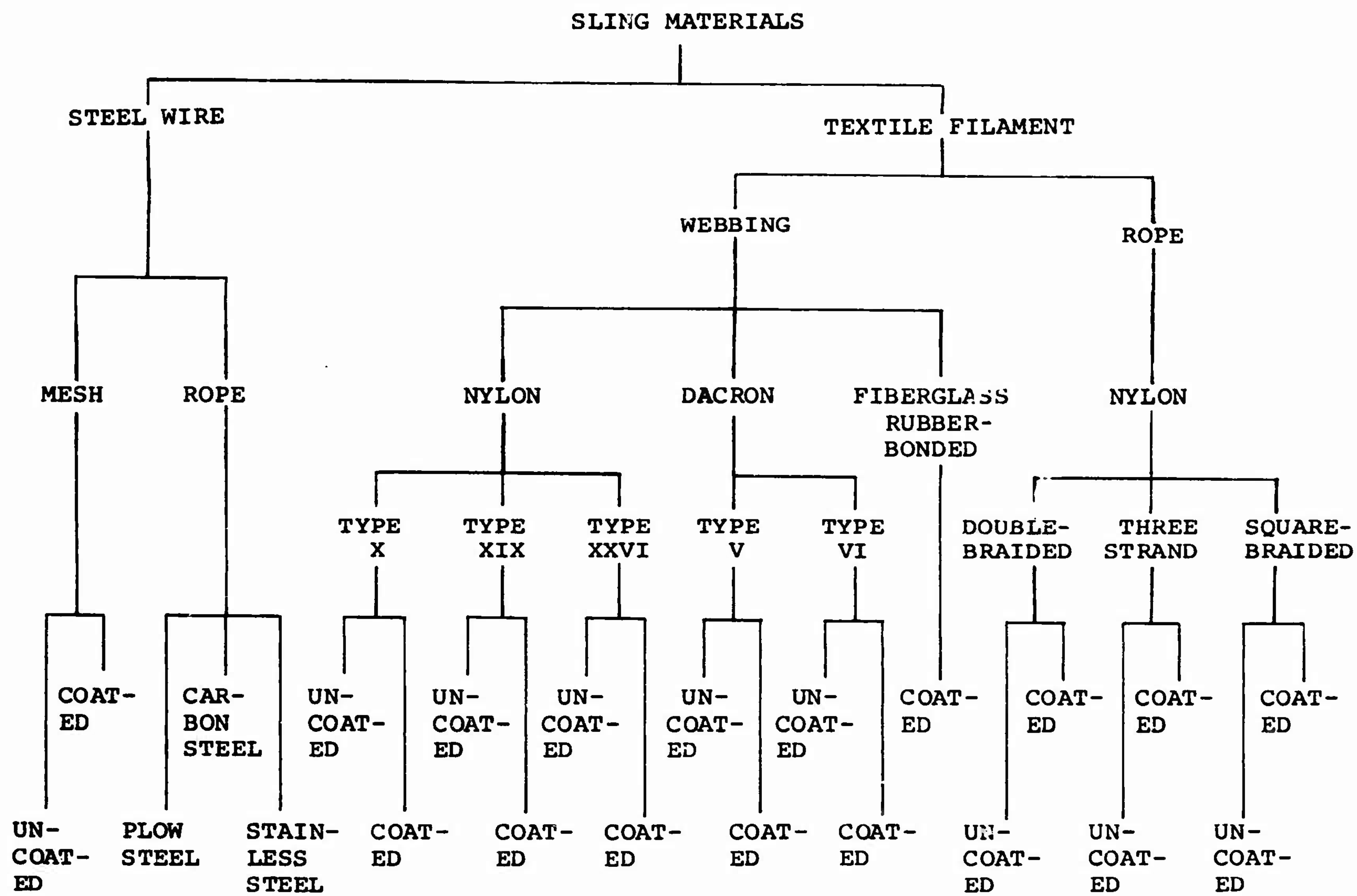

Figure 9. Sling Leg Material Types.

1. Wire mesh, uncoated (high carbon steel made in 10, 12 and 14 gage forms).

2. Wire mesh, coated (as above, covered with black neoprene or clear polyvinyl chloride).

3. Wire rope, plow steel.

4. Wire rope, carbon steel.

5. Wire rope, stainless steel (see Figures 3, 4, and 5).

6. Webbing, nylon, Type X, uncoated (see Figure 6).

7. Webbing, nylon, Type X, coated (as above, covered with a synthetic polymer).

8. Webbing, nylon, Type XIX, uncoated.

9. Webbing, nylon, Type XIX, coated (as above, covered with a synthetic polymer).

10. Webbing, nylon, Type XXXVI, uncoated.

11. Webbing, nylon, Type XXVI, coated (as above, covered with a synthetic polymer).

12. Webbing, dacron Type V, uncoated.

13. Webbing, Dacron, Type V, coated (as above, covered with a synthetic polymer).

14. Webbing, Dacron, Type VI, uncoated.

15. Webbing, Dacron, Type VI, coated (as above, covered with a synthetic polymer).

16. Webbing, fiberglass, rubber molded (experimental material consisting of a continuous rubber-bonded fiberglass filament formed into a closed loop by multiple winding, and bonded into a rubber sleeve).

17. Rope, nylon, double braided, uncoated (see Figure 7).

18. Rope, nylon, double braided, coated (as above, covered with a synthetic polymer).

19. Rope, nylon, three strand, uncoated (see Figure 8).

20. Rope, nylon, three strand, coated (as above, covered with a synthetic polymer).

21. Rope, nylon, square braided, uncoated.

22. Rope, nylon, square braided, coated (as above, covered with a synthetic polymer).

The following parameters were considered in the trade-off. A numerical rating factor was assigned to each, up to a maximum of eight.

1. "Cost per unit time" (the ratio of overall cost to anticipated life). In order to facilitate a comparison of costs and life expectancy, a separate assessment of these factors was made for each material. Table II shows a subsidiary trade-off covering the life factors, and Table III gives an analysis of material initial costs in terms of dollars per 20-foot length of material per 1,000 pounds of ultimate strength.

2. "Strength/weight ratio" (compares the densities of the materials required for a given ultimate strength). In order to facilitate the assessment of this parameter, it was quantified for each material as shown in Table IV, where the ratio is expressed in terms of 1,000 pounds of ultimate strength per pound weight of material per 20-foot length of material.

3. "Handling weight" (reflects any manhandling problems that might be encountered due to the weight of the material).

4. "Flexibility" (expresses the manageability of materials on the ground).

5. "Texture" (depicts the nature of the material surface).

6. "Climatic" (indicative of any adverse effects on the handling qualities arising from arctic or tropical conditions).

7. "Cargo interference" (covers the extent to which a sling material is liable to cause damage to, or be damaged by, the cargo, due to impact).

8. "Aerodynamics" (concerns the behavior of the sling material in the horizontal and vertical wake).

9. "Adaptability" (deals with the practicability of attaching end fittings to a sling material).

10. "Storage facility" (identifies materials that can be close coiled to occupy minimum space).

Sling Material / Parameter and Rating Factor		Wire Mesh, Uncoated	Wire Mesh, Coated	Wire Rope, Plow Steel	Wire Rope, Carbon Steel, Galvan-ized	Wire Rope, Stain-less Steel	Webbing, Nylon, Type X, Uncoated	Webbing, Nylon, Type X, Coated	Webbin Nylon, Type XIX, Uncoat
Ultraviolet	8	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(1) 8	(3) 24	(1)
Temperature	7	(8) 56	(8) 56	(8) 56	(8) 56	(8) 56	(8) 56	(8) 56	(8)
Moisture	8	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(6) 48	(8) 64	(6)
Corrosion	6	(6) 36	(6) 36	(6) 36	(7) 42	(8) 48	(5) 30	(6) 36	(6)
Decomposition	5	(8) 40	(8) 40	(8) 40	(8) 40	(8) 40	(7) 35	(8) 40	(7)
Abrasion	8	(6) 48	(7) 56	(7) 56	(7) 56	(7) 56	(1) 8	(6) 48	(1)
Mishandling	7	(4) 28	(4) 28	(4) 28	(4) 28	(4) 28	(8) 56	(7) 49	(8)
Shock Loading	7	(5) 35	(5) 35	(5) 35	(5) 35	(5) 35	(8) 56	(8) 56	(8)
Factored Product Totals		371	379	379	385	391	297	373	3
Merit Order		7	4	4	2	1	12	5	

Note:

TABLE II. SLING MATERIALS LIFE FACTORS

.ng, ı, :d	Webbing, Nylon, Type XIX, Uncoated		Webbing, Nylon, Type XIX, Coated		Webbing, Nylon, Type XXVI, Uncoated		Webbing, Nylon, Type XXVI, Coated		Webbing, Dacron, Type V, Uncoated		Webbing, Dacron, Type V, Coated		Webbing, Dacron, Type VI, Uncoated		Webbing, Dacron, Type VI, Coated		Strap, Fiber-glass, Rubber Bonded		Rope, Nylon, Double Braided, Uncoated		F N D E C
24	(1)	8	(3)	24	(0)	0	(2)	16	(1)	8	(3)	24	(2)	16	(4)	32	(6)	48	(1)	8	(
56	(8)	56	(8)	56	(7)	49	(7)	49	(8)	56	(8)	56	(7)	49	(7)	49	(6)	42	(7)	49	(
64	(6)	48	(8)	64	(6)	48	(8)	64	(6)	48	(8)	64	(6)	48	(8)	64	(8)	64	(6)	48	(
36	(6)	36	(7)	42	(6)	36	(7)	42	(7)	42	(7)	42	(7)	42	(7)	42	(6)	36	(6)	36	(
40	(7)	35	(8)	40	(7)	35	(8)	40	(7)	35	(8)	40	(7)	35	(8)	40	(6)	30	(7)	35	(
48	(1)	8	(6)	48	(1)	8	(6)	48	(1)	8	(6)	48	(1)	8	(6)	48	(6)	48	(1)	8	(
49	(8)	56	(7)	49	(8)	56	(7)	49	(8)	56	(7)	49	(8)	56	(7)	49	(7)	49	(8)	56	(
56	(8)	56	(8)	56	(8)	56	(8)	56	(7)	49	(7)	49	(7)	49	(7)	49	(5)	35	(8)	56	(
373		303		379		288		364		302		372		363		373		352		296	
5		10		4		14		8		11		6		10		5		9		13	

Note: Numbers in parentheses are performance values.

Webbing, Dacron, Type V, Coated	Webbing, Dacron, Type VI, Uncoated	Webbing, Dacron, Type VI, Coated	Strap, Fiber-glass, Rubber Bonded	Rope, Nylon, Double Braided, Uncoated	Rope, Nylon, Double Braided, Coated	Rope, Nylon, Three Strand, Uncoated	Rope, Nylon, Three Strand, Coated	Rope, Nylon, Square Braided, Uncoated	Rope, Nylon, Square Braided, Coated
(3) 24	(2) 16	(4) 32	(6) 48	(1) 8	(3) 24	(1) 8	(3) 24	(1) 8	(3) 24
(8) 56	(7) 49	(7) 49	(6) 42	(7) 49	(7) 49	(7) 49	(7) 49	(7) 49	(7) 49
(8) 64	(6) 48	(8) 64	(8) 64	(6) 48	(8) 64	(6) 48	(8) 64	(6) 48	(8) 64
(7) 42	(7) 42	(7) 42	(6) 36	(6) 36	(7) 42	(6) 36	(7) 42	(6) 36	(7) 42
(8) 40	(7) 35	(8) 40	(6) 30	(7) 35	(8) 40	(7) 35	(8) 40	(7) 35	(8) 40
(6) 48	(1) 8	(6) 48	(6) 48	(1) 8	(7) 56	(1) 8	(6) 48	(1) 8	(6) 48
(7) 49	(8) 56	(7) 49	(7) 49	(8) 56	(7) 49	(8) 56	(7) 49	(8) 56	(7) 49
(7) 49	(7) 49	(7) 49	(5) 35	(8) 56	(8) 56	(8) 56	(8) 56	(8) 56	(8) 56
372	303	373	352	296	380	296	372	296	372
6	10	5	9	13	3	13	6	13	6

ues.

Sling Material	Wire Mesh, Uncoated	Wire Mesh, Coated	Wire Rope, Plow Steel	Wire Rope, Carbon Steel, Galvan- ized	Wire Rope, Stain- less Steel	Webbing, Nylon, Type X, Uncoated	Webbing, Nylon, Type X, Coated	Webb Nylo Type XIX Unco
Cost/Strength	2.00-4.00	4.00-6.00	.20-.30	.20-.30	.75-1.00	1.85-2.46	1.91-2.54	1.85
See Note	A	A	B	B	B	C	C	(
Rating Factor	2	0	8	8	6	4	4	

The above table gives approxi
the trade-off study. The rat
1,000 pounds ultimate strengt
length sling leg of 18 feet).
pounds capacity.

Notes :

A. Based on Lift-
safe working
decreases cons

B. Based on Unive
brochures. Ra

C. Based on Lift-
70-11 Test Da
uncoated mate
increment fac
number factor
increases wit

D. Based on test
presumably, w

E. Based on Sams
temperature,
increase in c

F. Based on Amer
ultraviolet,
strength. Ca
remains subst

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TABLE III. SLING MATERIALS COST/STRENGTH RATIOS

bing, on, e X, oated	Webbing, Nylon, Type XIX, Coated	Webbing, Nylon, Type XXVI, Uncoated	Webbing, Nylon, Type XXVI, Coated	Webbing, Dacron, Type V, Uncoated	Webbing, Dacron, Type V, Coated	Webbing, Dacron, Type VI, Uncoated	Webbing, Dacron, Type VI, Coated	Strap, Fiber-glass, Rubber Bonded	Rope, Nylon, Double Braided, Uncoated	Rope, Nylon, Double Braided, Coated
5-2.46	1.91-2.54	1.85-2.46	1.91-2.54	2.21-2.94	2.28-3.04	2.21-2.94	2.28-3.04	.10-.20	.69-.72	.71-.74
C	C	C	C	C	C	C	C	D	E	E
4	4	4	4	3	3	3	3	8	6	6

‹imate cost/strength ratios for the sling materials under consideration in
ıtios are expressed in terms of dollars per 20-foot length of material per
jth (20 feet is the approximate material length required for a standard-
). The ratios cover the range of sling sizes from 6,000 to 110,000

t-All Company General Catalog (Reference 5). Ultimate strength is 5 times
load. Capacities over 25,000 pounds are not currently available. Ratio
ısiderably with increase in capacity.

versal Wire Products Catalog (Reference 6) and various manufacturers'
Ratio increases irregularly with increase in capacity.

t-All Company General Catalog (Reference 5) and U.S. AVLABS House Task
ıta (Reference 4), with allowances for ultraviolet factor of 0.65 (for
erial) or 0.85 (for coated material), temperature factor of 0.94, cost
ctor of 1.35 (for coated material), stitching factor of 0.7, and ply
r of 1.00 (for 1 ply) to 0.78 (for 8 or more plies). Ratio
th increase in capacity due to necessity for extra plies.

ts of 4 samples and very approximate cost estimate. Ratio decreases,
with increase in capacity.

son Cordage Works Catalog (Reference 7), with allowances for ultraviolet,
and cost increment factors as in Note C. Ratio increases slightly with
capacity.

rican Manufacturing Company brochure (Reference 8), with allowances for
temperature, and cost increment factors as in Note C, and -10% in
apacities under 60,000 pounds are not currently available. Ratio
tantially constant within the subject range of capacities.

IOS

ebbing, acron, ype V, oated	Webbing, Dacron, Type VI, Uncoated	Webbing, Dacron, Type VI, Coated	Strap, Fiber-glass, Rubber Bonded	Rope, Nylon, Double Braided, Uncoated	Rope, Nylon, Double Braided, Coated	Rope, Nylon, Three Strand, Uncoated	Rope, Nylon, Three Strand, Coated	Rope, Nylon, Square Braided, Uncoated	Rope, Nylon, Square Braided, Coated
.28-3.04	2.21-2.94	2.28-3.04	.10-.20	.69-.72	.71-.74	.42-.43	.43-.44	.42-.43	.43-.44
C	C	C	D	E	E	F	F	F	F
3	3	3	8	6	6	7	7	7	7

als under consideration in
oot length of material per
required for a standard-
rom 6,000 to 110,000

timate strength is 5 times
rrently available. Ratio

arious manufacturers'
acity.

U.S. AVLABS House Task
et factor of 0.65 (for
e factor of 0.94, cost
ctor of 0.7, and ply
es). Ratio
ra plies.

te. Ratio decreases,

lowances for ultraviolet,
increases slightly with

8), with allowances for
lote C, and -10% in
available. Ratio
apacities.

TA

Sling Material	Wire Mesh, Uncoated	Wire Mesh, Coated	Wire Rope, Plow Steel	Wire Rope, Carbon Steel, Galvan-ized	Wire Rope, Stain-less Steel	Webbing, Nylon, Type X, Uncoated	Webbing, Nylon, Type X, Coated	Webbi Nylon Type XIX, Uncoa
Strength/Weight	.28-.40	.15-.25	2.15-2.80	2.15-2.80	2.15-2.80	2.13-2.85	2.12-2.83	2.20-
See Note	A	A	B	B	B	C	C	C
Rating Factor	1	0	5	5	5	5	5	5

The above table gives approxi
in the trade-off study. The
per 20-foot length of materia
length sling leg of 18 feet).
capacity.

Notes:

A. Based on Lift-
safe working l
over 25,000 po
increase in ca

B. Based on Table
Hardpoints (Re
steadily with

C. Based on U. S.
ultraviolet fa
temperature fa
stitching fact
8 or more plie
extra plies.

D. Based on tests
potential, ass
of rubber carr

E. Based on Samsc
temperature ar
decreases slic

F. Based on Amer:
ultraviolet, 1
weight, -10% :
available. R
capacities.

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TABLE IV. SLING MATERIALS STRENGTH/WEIGHT RATIOS

Webbing, Nylon, Type X, Coated	Webbing, Nylon, Type XIX, Uncoated	Webbing, Nylon, Type XIX, Coated	Webbing, Nylon, Type XXVI, Uncoated	Webbing, Nylon, Type XXVI, Coated	Webbing, Dacron, Type V, Uncoated	Webbing, Dacron, Type V, Coated	Webbing, Dacron, Type VI, Uncoated	Webbing, Dacron, Type VI, Coated	Strap, Fiber-glass, Rubber Bonded	Rope, Nylor Doubl Braic Uncoa
2.12-2.83	2.20-2.95	2.19-2.93	2.57-3.43	2.55-3.40	2.35-3.15	2.34-3.13	1.99-2.67	1.98-2.65	2.50-3.00	3.17-
C	C	C	C	C	C	C	C	C	D	E
5	5	5	6	6	5	5	5	5	5	7

.e gives approximate strength/weight ratios for the sling materials under consideration ›ff study. The ratios are expressed in terms of 1,000 pounds ultimate strength per pound ıngth of material (20 feet is the approximate material length required for a standard- .eg of 18 feet). The ratios cover the range of sling sizes from 6,000 to 110,000 pounds

Based on Lift-All Company Bulletin WM-1C (Refernce 5). Ultimate strength is 5 times safe working load. Weight for coated wire mesh obtained from 2 samples. Capacities over 25,000 pounds are not currently available. Ratio increases considerably with increase in capacity.

Based on Table III of Design Guide for Load Suspension Points, Slings and Aircraft Hardpoints (Reference 1), and various manufacturers' brochures. Ratio decreases steadily with increase in capacity.

Based on U. S. AVLABS House Task 70-11 Test Data (Reference 4), with allowances for ultraviolet factor of 0.65 (for uncoated material) or 0.85 (for coated material), temperature factor of 0.94, weight increment factor of 1.31 (for coated material), stitching factor of 0.7, and ply number factor of 1.00 (for 1 ply) to 0.78 (for 8 or more plies). Ratio decreases with increase in capacity due to necessity for extra plies.

Based on tests of 4 samples. Upper limit is an estimate based on development potential, assuming that most improvement can be achieved by reducing the weight of rubber carried. Ratio increases, apparently, with increase in capacity.

Based on Samson Cordage Works Catalog (Reference 7), with allowances for ultraviolet, temperature and weight increment factors as in Note C and ±5% in weight. Ratio decreases slightly with capacity.

Based on American Manufacturing Company Brochure (Reference 8), with allowances for ultraviolet, temperature, and weight increment factors as in Note C, and +5% in weight, -10% in strength. Capacitites under 60,000 pounds are not currently available. Ratio remains substantially constant within the subject range of capacities.

g, ,	Webbing, Dacron, Type VI, Uncoated	Webbing, Dacron, Type VI, Coated	Strap, Fiber- glass, Rubber Bonded	Rope, Nylon, Double Braided, Uncoated	Rope, Nylon, Double Braided, Coated	Rope, Nylon, Three Strand, Uncoated	Rope, Nylon, Three Strand, Coated	Rope, Nylon, Square Braided, Uncoated	Rope, Nylon, Square Braided, Coated
.13	1.99-2.67	1.98-2.65	2.50-3.00	3.17-3.85	3.15-3.82	3.27-3.78	3.25-3.75	3.50-4.10	3.48-4.07
	C	C	D	E	E	F	F	F	F
	5	5	5	7	7	7	7	8	8

under consideration
ıte strength per pound
'ed for a standard-
ı00 to 110,000 pounds

ıtrength is 5 times
ımples. Capacities
:onsiderably with

.ngs and Aircraft
ıatio decreases

.th allowances for
ıated material),
:oated material),
to 0.78 (for
:o necessity for

development
:ing the weight
capacity.

:es for ultraviolet,
reight. Ratio

.th allowances for
C, and +5% in
: currently
:t range of

11. "Elasticity" (measures the material's ability to reduce the effects of vertical bounce oscillations).

12. "NDT feasibility" (refers to the possibility of applying a nondestructive test to the material).

13. "NDT facility" (takes account of the degree of difficulty involved in nondestructive testing).

14. "NDT reliability" (a supplement to the last two parameters, to convey a degree of confidence in the nondestructive testing technique).

The following are among the more significant alternative sling materials which were examined: steel chain, mylar rope, DuPont B2, DuPont PRD 49, manila and other traditional vegetable fibers.

The following are among the more significant characteristics which were examined but not analyzed in the trade-off: untwisting under load, bulk, conductivity, and sparking from abrasion.

Table V summarizes the results of the trade-off study and shows that ropes are superior to webbings and wire rope surpass textile ropes. However, metals are not exclusively superior to textiles, for the wire meshes come below the textile webbings. There is no overlap in the merit order of the various groups of materials (see Table VI). The rubber-bonded fiberglass strap falls between the textile ropes and webbings.

The three wire ropes are comparable in all aspects except cost per unit time, in which a slight lead is shown by stainless steel. Its first cost is much higher (by a factor of about three), but the costs of fittings and assembly are similar for all three materials; so when these are taken into account (and they are an important part of the total cost), the price gap is relatively reduced. Moreover, the stainless steel wire rope will require less frequent inspection for corrosion and abrasion. The labor and equipment required for these operations are more significant than the price of the sling. Hence, cost per unit time for the other two wire ropes eventually exceeds that of stainless. The galvanized carbon steel and plow steel showed equal scores in the trade-off chart, but a more refined analysis would indicate a marginal preference for the former, since it has partial corrosion protection at little extra cost. Hot dipped galvanizing provides higher resistance but with a 10% strength penalty and a similar cost penalty, which would neutralize the advantages of galvanized wire rope.

Wire ropes gain most over textiles in the NDT parameters and in cost per unit time. Their greatest disadvantages lie in the handling parameters. The textile ropes show distinct merit in terms of strength/weight ratio and flexibility. Rubber-bonded fiberglass could probably exceed in performance the textile ropes, given sufficient development, but would probably not be competitive with wire ropes. Ideally, the rubber-coated fiberglass filament should be directly wound and molded to form a finished sling with integrally molded eye-ends, instead of going through an intermediate webbing or rope stage. The textile webbings have no prominently good or bad points, except that, like all the textile materials, they are unamenable to nondestructive testing, and the uncoated versions are susceptible to abrasion. The metal meshes might appear, at first sight, to combine the virtues of wire ropes, chains and webbings, but infortunately they seem to possess most of the vices instead.

The effects of ultraviolet on the life of a textile rope can be offset either by increasing its cross-section above the nominal requirement, or by applying coating. For a specified strength and life, the weight of an oversized rope and a coated rope would be approximately equal. Therefore, if coating is considered purely as ultraviolet protection, it is hardly beneficial, especially as it is detrimental to handling qualities. However, coating has other important functions such as providing protection against external abrasion, corrosion, heat, and preventing ingress of water and sand. Moisture alone is not detrimental to textiles, but a saturated sling may impose handling difficulties. Sand, however, can cause internal abrasion with disastrous rapidity, resulting in high "cost per unit time" for the uncoated textiles. Therefore, a decision regarding coating depends on these factors rather than the ultraviolet criterion, and it must be considered against such disadvantages as reduced flexibility and adverse surface texture. It is conjectured that a heavy protective layer will make the larger slings unacceptably rigid (and, therefore, subject to deterioration through kinking), whereas the absence of any protection will result in very short life, due to abrasion rather than untraviolet. Textile sleeves can provide good ultraviolet shielding without much detriment to handling qualities; unfortunately, they permit the ingress of sand, grit and water. On balance, it is considered that a light to medium impregnation with a polymer such as urethane constitutes the best compromise. The larger sizes of sling should not have much more than the so-called standard coating to keep out sand, but the smaller ones can take a somewhat heavier protection without becoming unmanageable. Extra cover, such as polyvinyl chloride or textile sleeving, should always be provided at vulnerable areas, particularly at sling eyes and splices. The coating must extend well under the sleeves; otherwise, under load, the sleeves retract from the rope and expose noncoated surfaces. This presents a slight problem with the eye splices on ropes (the sleeve obviously has to be fitted before splicing, but the coating is applied after splicing).

Sling Material / Parameter and Rating Factor		Wire Mesh, Uncoated	Wire Mesh, Coated	Wire Rope, Plow Steel	Wire Rope, Carbon Steel, Galvan-ized	Wire Rope, Stain-less Steel	Webbing, Nylon, Type X, Uncoated	Webbing, Nylon, Type X, Coated	Web Nyl Typ XI Unc
Cost per Unit Time	8	(1) 8	(3) 24	(7) 56	(7) 56	(8) 64	(1) 8	(4) 32	(1)
Strength/Weight Ratio	4	(1) 4	(0) 0	(5) 20	(5) 20	(5) 20	(5) 20	(5) 20	(5)
Handling Weight	6	(1) 6	(0) 0	(5) 30	(5) 30	(5) 30	(5) 30	(5) 30	(5)
Flexibility	5	(3) 15	(0) 0	(2) 10	(2) 10	(2) 10	(6) 30	(4) 20	(6)
Texture	3	(5) 15	(6) 18	(4) 12	(4) 12	(4) 12	(6) 18	(4) 12	(6)
Climatic	3	(3) 9	(5) 15	(3) 9	(3) 9	(3) 9	(6) 18	(5) 15	(6)
Cargo Interference	2	(2) 4	(4) 8	(3) 6	(3) 6	(3) 6	(4) 8	(5) 10	(4)
Aerodyanmics	2	(4) 8	(3) 6	(6) 12	(6) 12	(6) 12	(3) 6	(3) 6	(3)
Adaptability	1	(6) 6	(5) 5	(7) 7	(7) 7	(7) 7	(5) 5	(4) 4	(5)
Storage Facility	2	(4) 8	(1) 2	(3) 6	(3) 6	(3) 6	(6) 12	(4) 8	(6)
Elasticity	2	(1) 2	(1) 2	(1) 2	(1) 2	(1) 2	(5) 10	(5) 10	(5)
NDT Feasibility	6	(6) 36	(6) 36	(7) 42	(7) 42	(7) 42	(2) 12	(2) 12	(2)
NDT Facility	4	(5) 20	(5) 20	(6) 24	(6) 24	(6) 24	(3) 12	(3) 12	(3)
NDT Reliability	3	(7) 21	(7) 21	(7) 21	(7) 21	(7) 21	(1) 3	(1) 3	(1)
Factored Product Total		162	157	257	257	265	192	194	
Merit Order		16	17	2	2	1	14	13	

Note :

TABLE V. SLING MATERIALS TRADE-OFF

bing, on, e ted	Webbing, Nylon, Type XIX, Uncoated		Webbing, Nylon, Type XIX, Coated		Webbing, Nylon, Type XXVI, Uncoated		Webbing, Nylon, Type XXVI, Coated		Webbing, Dacron, Type V, Uncoated		Webbing, Dacron, Type V, Coated		Webbing, Dacron, Type VI, Uncoated		Webbing, Dacron, Type VI, Coated		Strap, Fiber-glass, Rubber Bonded		Rope, Nylon, Double Braided, Uncoated	
32	(1)	8	(5)	40	(1)	8	(4)	32	(1)	8	(4)	32	(1)	8	(4)	32	(6)	48	(2)	16
20	(5)	20	(5)	20	(6)	24	(6)	24	(5)	20	(5)	20	(5)	20	(5)	20	(5)	20	(7)	28
30	(5)	30	(5)	30	(6)	36	(6)	36	(5)	30	(5)	30	(5)	30	(5)	30	(5)	30	(7)	42
20	(6)	30	(4)	20	(6)	30	(4)	20	(6)	30	(4)	20	(6)	30	(4)	20	(4)	20	(7)	35
12	(6)	18	(4)	12	(6)	18	(4)	12	(6)	18	(4)	12	(6)	18	(4)	12	(6)	18	(6)	18
15	(6)	18	(5)	15	(6)	18	(5)	15	(6)	18	(5)	15	(6)	18	(5)	15	(6)	18	(5)	15
10	(4)	8	(5)	10	(4)	8	(5)	10	(4)	8	(5)	10	(4)	8	(5)	10	(5)	10	(5)	10
6	(3)	6	(3)	6	(3)	6	(3)	6	(3)	6	(3)	6	(3)	6	(3)	6	(3)	6	(5)	10
4	(5)	5	(4)	4	(5)	5	(4)	4	(5)	5	(4)	4	(5)	5	(4)	4	(7)	7	(5)	5
8	(6)	12	(4)	8	(6)	12	(4)	8	(6)	12	(4)	8	(6)	12	(4)	8	(6)	12	(7)	14
10	(5)	10	(5)	10	(6)	12	(6)	12	(4)	8	(4)	8	(4)	8	(4)	8	(1)	2	(6)	12
12	(2)	12	(2)	12	(2)	12	(2)	12	(2)	12	(2)	12	(2)	12	(2)	12	(2)	12	(2)	12
12	(3)	12	(3)	12	(3)	12	(3)	12	(3)	12	(3)	12	(3)	12	(3)	12	(3)	12	(3)	12
3	(1)	3	(1)	3	(1)	3	(1)	3	(1)	3	(1)	3	(1)	3	(1)	3	(1)	3	(1)	3
194		192		202		204		206		190		192		190		192		218		232
13		14		12		11		10		15		14		15		14		9		6

Note: Numbers in parentheses are performance values.

ebbing, acron, ype ', oated	Webbing, Dacron, Type VI, Uncoated	Webbing, Dacron, Type VI, Coated	Strap, Fiber-glass, Rubber Bonded	Rope, Nylon, Double Braided, Uncoated	Rope, Nylon, Double Braided, Coated	Rope, Nylon, Three Strand, Uncoated	Rope, Nylon, Three Strand, Coated	Rope, Nylon, Square Braided, Uncoated	Rope, Nylon, Square Braided, Coated
) 32	(1) 8	(4) 32	(6) 48	(2) 16	(6) 48	(2) 16	(6) 48	(2) 16	(6) 48
) 20	(5) 20	(5) 20	(5) 20	(7) 28	(7) 28	(7) 28	(7) 28	(8) 32	(8) 32
) 30	(5) 30	(5) 30	(5) 30	(7) 42	(7) 42	(7) 42	(7) 42	(8) 48	(8) 48
) 20	(6) 30	(4) 20	(4) 20	(7) 35	(4) 20	(6) 30	(3) 15	(7) 35	(4) 20
) 12	(6) 18	(4) 12	(6) 18	(6) 18	(4) 12	(6) 18	(4) 12	(7) 21	(5) 15
) 15	(6) 18	(5) 15	(6) 18	(5) 15	(4) 12	(6) 18	(5) 15	(7) 21	(5) 15
) 10	(4) 8	(5) 10	(5) 10	(5) 10	(6) 12	(3) 6	(4) 8	(3) 6	(4) 8
) 6	(3) 6)	(3) 6	(3) 6	(5) 10	(5) 10	(4) 8	(4) 8	(4) 8	(4) 8
) 4	(5) 5	(4) 4	(7) 7	(5) 5	(4) 4	(4) 4	(3) 3	(4) 4	(3) 3
) 8	(6) 12	(4) 8	(6) 12	(7) 14	(5) 10	(6) 12	(4) 8	(7) 14	(5) 10
) 8	(4) 8	(4) 8	(1) 2	(6) 12	(6) 12	(5) 10	(5) 10	(7) 14	(7) 14
) 12	(2) 12	(2) 12	(2) 12	(2) 12	(2) 12	(2) 12	(2) 12	(2) 12	(2) 12
) 12	(3) 12	(3) 12	(3) 12	(3) 12	(3) 12	(3) 12	(3) 12	(3) 12	(3) 12
) 3	(1) 3	(1) 3	(1) 3	(1) 3	(1) 3	(1) 3	(1) 3	(1) 3	(1) 3
192	190	192	218	232	237	219	224	246	248
14	15	14	9	6	5	8	7	4	3

Sling Material	Wire Rope, Stain-less Steel	Wire Rope, Carbon Steel, Galvan-ized	Wire Rope, Plow Steel	Rope, Nylon, Square Braided, Coated	Rope, Nylon, Square Braided, Uncoated	Rope, Nylon, Double Braided, Coated	Rope, Nylon, Double Braided, Uncoated	Rop Nyl Thr Str Coa
Group	Wire Rope			Textile Rope				
Factored Product Total	265	257	257	248	246	237	232	
Merit Order	1	2	2	3	4	5	6	

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TABLE VI. SLING MATERIALS MERIT ORDER

Rope, Nylon, Double Braided, Uncoated	Rope, Nylon, Three Strand, Coated	Rope, Nylon, Three Strand, Uncoated	Strap, Fiber-glass Rubber Bonded	Webbing, Nylon, Type XXVI, Coated	Webbing, Nylon, Type XXVI, Uncoated	Webbing, Nylon, Type XIX, Coated	Webbing, Nylon, Type X, Coated	Webbing, Nylon, Type XIX, Uncoated	Webbing, Nylon, Type X, Uncoated	Webbi Dacro Type V, Coate
ope			FG	Textile Webbings						
232	224	219	218	206	204	202	194	192	192	
6	7	8	9	10	11	12	13	14	14	

ebbing, lon, pe IX, oated	Webbing, Nylon, Type X, Coated	Webbing, Nylon, Type XIX, Uncoated	Webbing, Nylon, Type X, Uncoated	Webbing, Dacron, Type V, Coated	Webbing, Dacron, Type VI, Coated	Webbing, Dacron, Type V, Uncoated	Webbing, Dacron, Type VI, Uncoated	Wire Mesh, Uncoated	Wire Mesh, Uncoated
Textile Webbings								Wire Mesh	
202	194	192	192	192	192	190	190	162	157
12	13	14	14	14	14	15	15	16	17

It was concluded from the trade-off study that stainless steel wire rope should be used for the sling material. Ropes show strength advantages over webbings, and the outstanding reason for preferring wire rope to textile rope is that no satisfactory nondestructive test technique is available for the latter. Stainless steel wire rope has an economic advantage over other wire ropes when all cost elements are considered.

In the longer term, there might be a case for PRD-49-III or rubber-bonded fiberglass, but not within the time scale of this program.

Subsequent to the trade-off study, a more detailed analysis was made of eight different sling leg materials, namely:

1. Stainless steel wire rope, eye-to-eye assembly.
2. Nylon webbing, coated, endless assembly.
3. Double-braided nylon rope, coated, eye-to-eye assembly.
4. Double-braided nylon rope, coated, endless assembly.
5. Three-strand nylon rope, coated, eye-to-eye assembly.
6. Three-strand nylon rope, coated, endless assembly.
7. Square-braided nylon rope, coated, eye-to-eye assembly.
8. Square-braided nylon rope, coated, endless assembly.

(An eye-to-eye assembly has standard eye splices at the end of a single length of material. An endless assembly consists of a continuous loop of material having its ends joined by a straight splice. Wire ropes are seldom used in endless configuration, but webbings are usually endless, since multi-ply webbings can very easily be made in this manner.)

These eight types were size estimated, weight estimated, and cost estimated as 18-foot long assemblies at four different capacity ratings; namely, 6K, 15K, 25K, 60K. The results of the analysis are shown graphically on Figures 10, 11, and 12. The 25,000-pound and 60,000-pound sling designs were based on load factors of 2.87, since they are for Types I and II loads at 2.6G (see Design Criteria). The 6,000-pound sling has a load factor of 5.80, for Type III loads at 3.0G. Therefore, on Figures 10, 11 and 12, the size, weight and cost values for this sling are not plotted against 6,000 pounds but against this figure multiplied by 5.80/2.87, i.e., 12,120 pounds. Thus, a meaningful graphical relationship between this and the two larger slings is effected. The 15,000-pound sling values were

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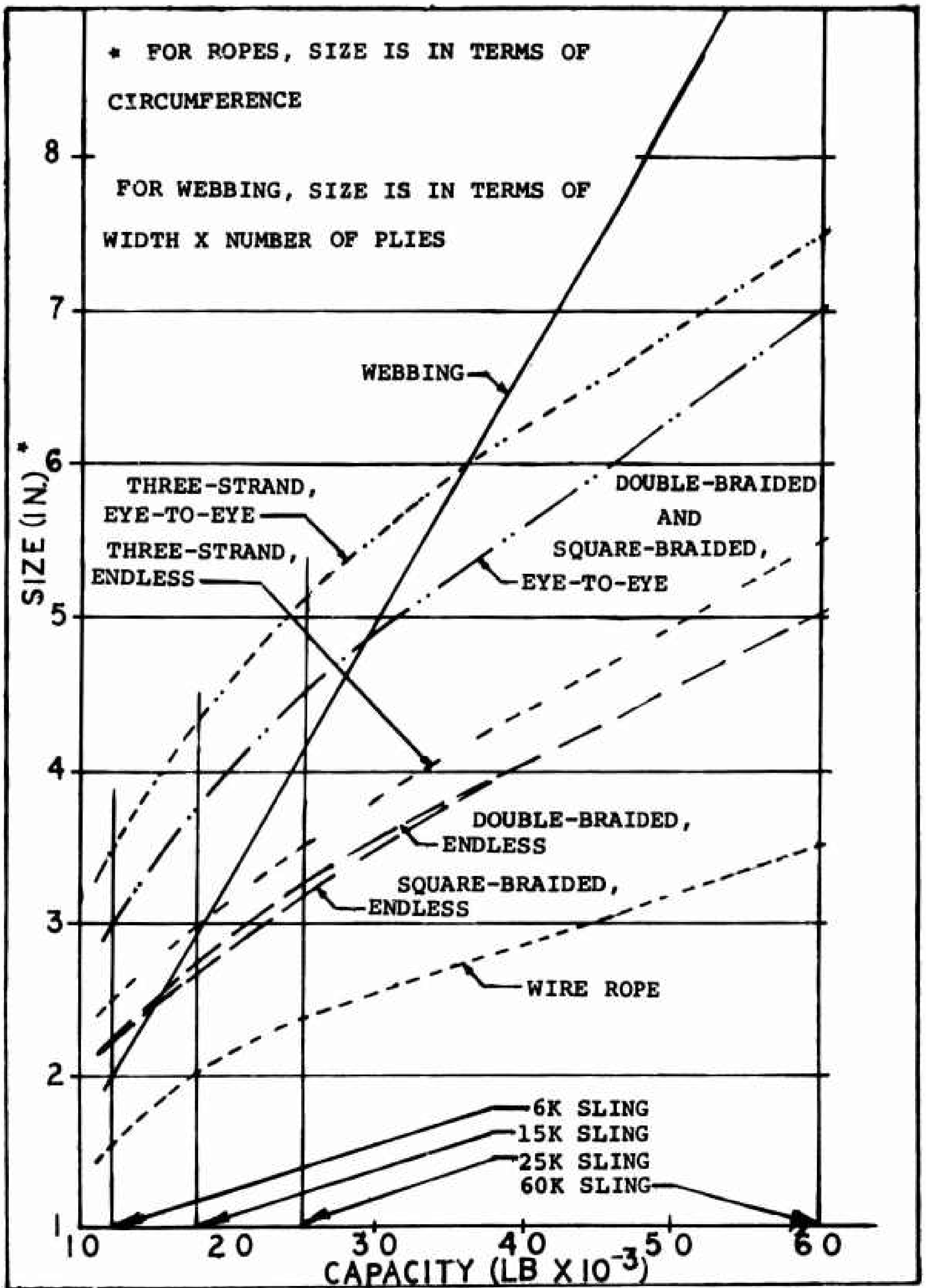

Figure 10. Sling Leg Material - Size Versus Capacity.

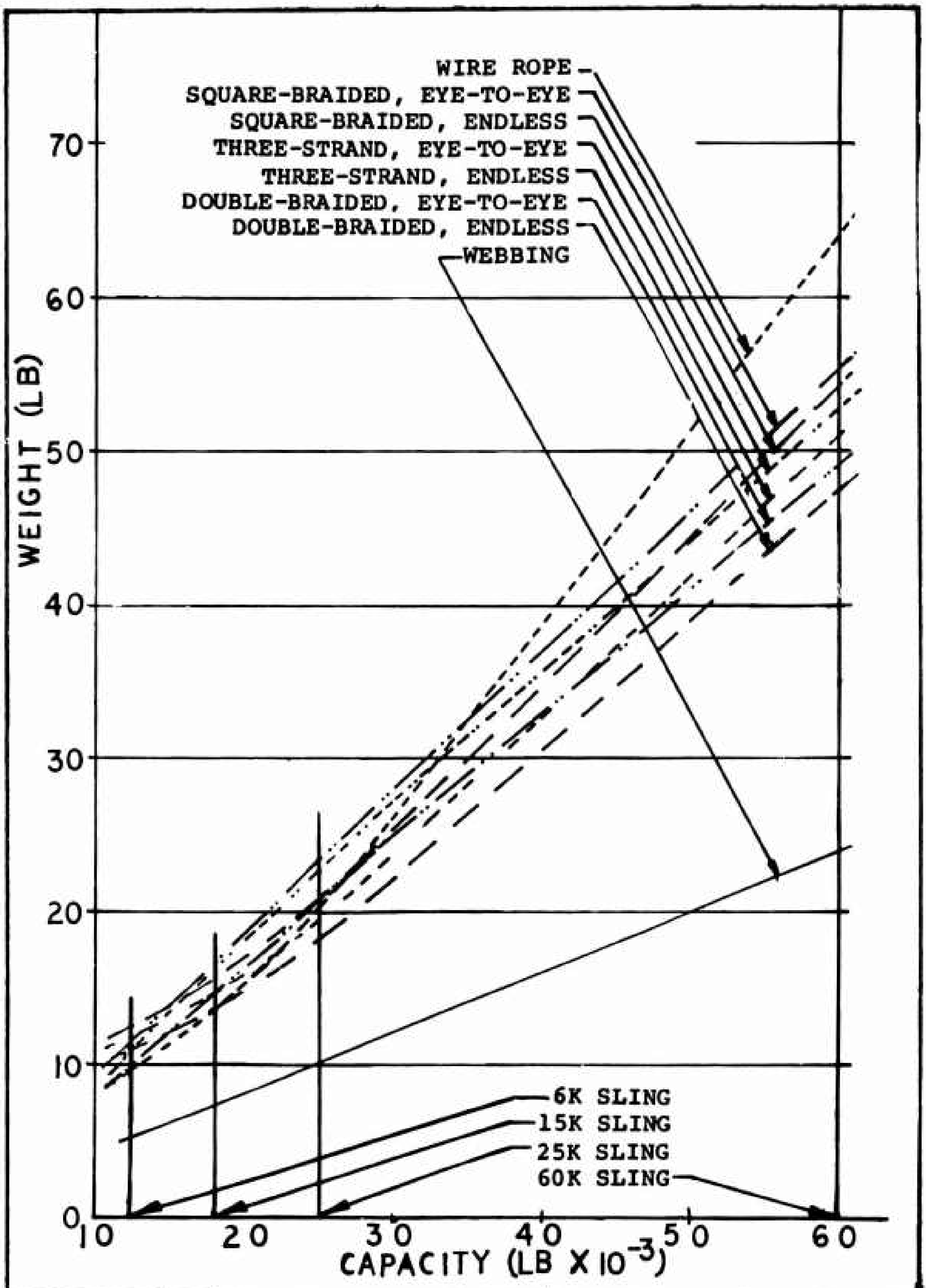

Figure 11. Sling Leg Material - Weight Versus Capacity.

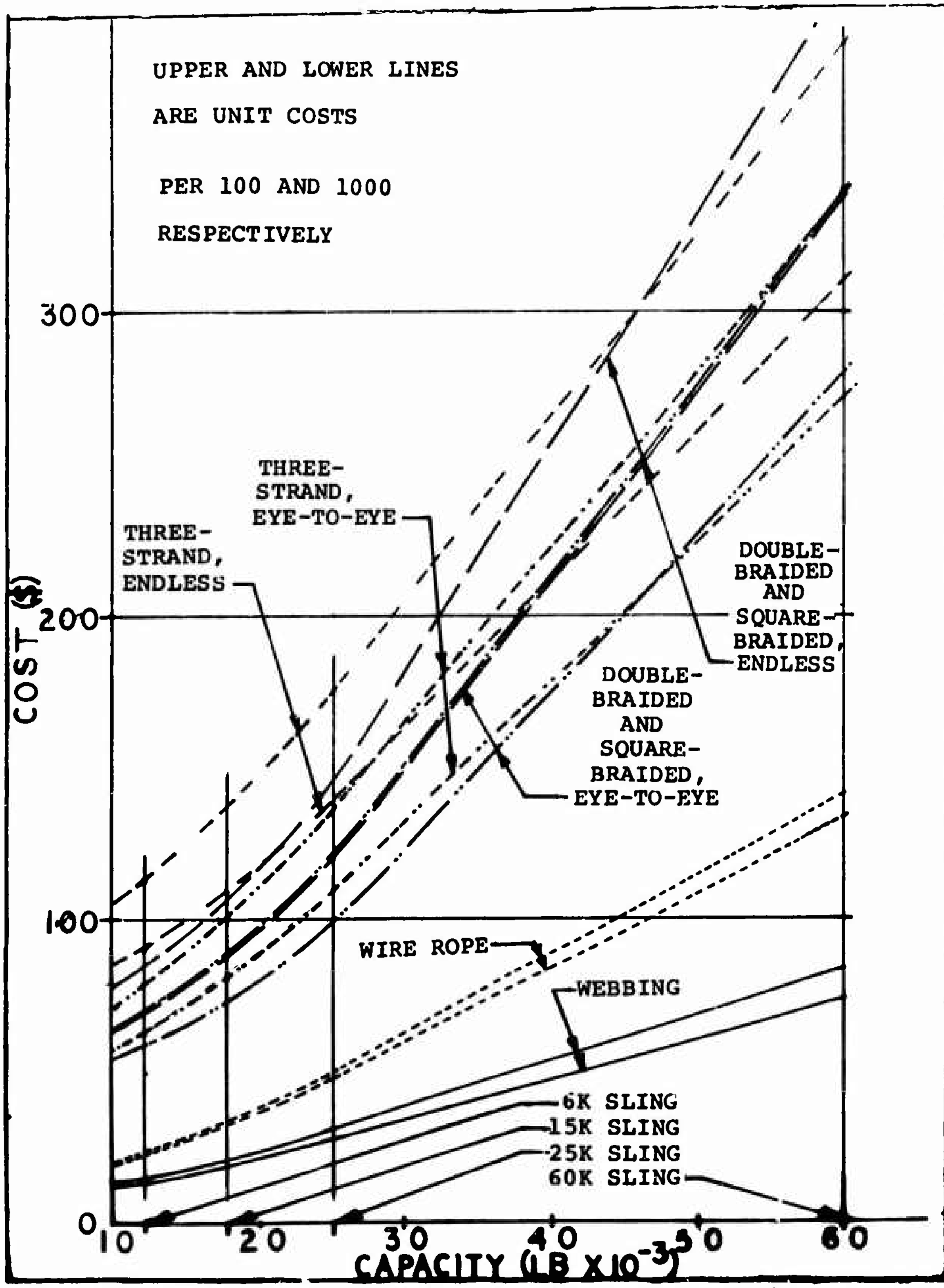

Figure 12. Sling Leg Material - Cost Versus Capacity.

interpolated by making a similar conversion. This sling has a load factor of 3.41, for Types I and II loads at 3.0G. Therefore, the size, weight and cost values must be read at 15,000 pounds multiplied by 3.41/2.87, i.e., 17,800 pounds. (The rationale governing the selection of load Types and G values is explained in Design Criteria.)

It was concluded from the supplementary trade-off study that weight and cost differentials between nylon ropes and webbing had reduced, to the latter's advantage, but stainless steel wire rope still had an ultimate cost advantage and an assembled weight advantage. Between the 25K and 60K level, wire rope loses its weight advantage (due to less efficient load sharing by its multiple strands, which are not so elastic as their textile counterparts). However, NDT considerations remain as overriding factors.

Eye-to-eye ropes were deemed preferable to endless ropes since they provide more material at the critical load application point. To achieve comparable strength, an endless rope would have greater total cross section and will therefore have a lower strength/weight ratio. Alternatives to these two traditional methods of load application were considered. As far as textile ropes are concerned, the choice is limited. It is possible to obtain end fittings which attach to such ropes by a clamping action, but they lack the strength of splices. It is also possible to splice wire ropes to textile ropes and hence produce a less bulky eye end, but again the strength is deficient. Wire ropes can have swaged or spelter socket end fittings as an alternative to eye splices, and both types can develop 100% of the tensile strength of the rope. However, they are rather vulnerable in bending, and show no significant advantages. The spelter socket (in which the rope is bonded to the fitting by pouring in molten zinc) is particularly heavy and bulky.

Apex Fittings

Ten different formats for sling apex fittings were traded off after eliminating obviously unsuitable types. They are listed below (Figure 13 summarizes their differences).

1. Solid forged steel rings (circular-section hoops). (See Figure 6.)

2. Solid forged steel pear shapes (circular-section variants of the last). (See Figure 5.)

3. Solid forged steel split rings (circular-section hoops comprising two semicircular components joined by bolts). (See Figure 3.)

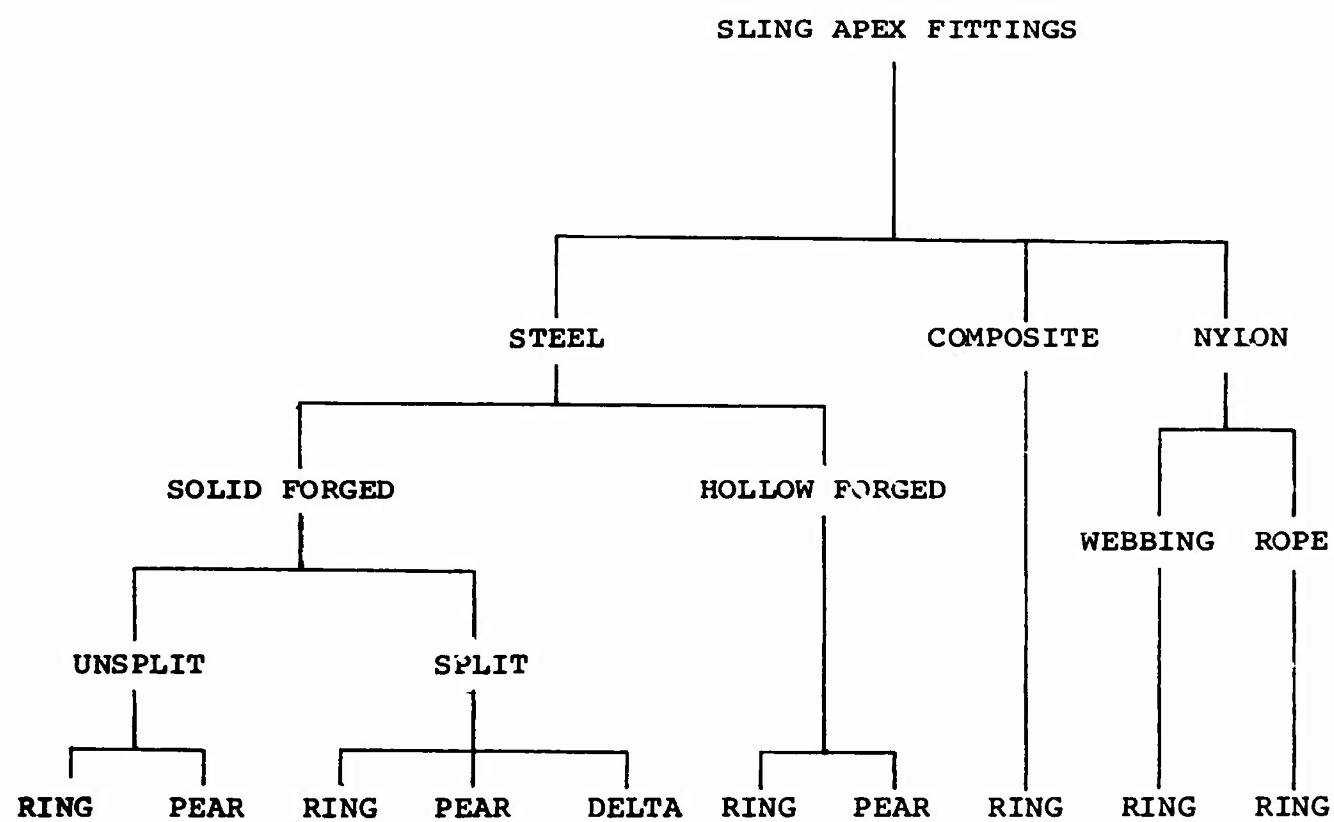

Figure 13. Sling Apex Fitting Formats.

4. Solid forged steel split pear shapes (circular-section variants of the last, comprising two generally semi-circular components joined by bolts). (See Figure 4.)

5. Solid forged steel split deltas (variants of the last, comprising two components joined by bolts, the upper part being a circular cross section inverted V, and the lower part being an I-section shallow curved beam). (See Figures 7 and 8.)

6. Hollow forged steel rings (U-section hoops).

7. Hollow forged steel pear shapes (U-section variants of the last).

8. Composite rings (circular section hoops or hoop variants made of fiber or filament material embedded in an epoxy matrix).

9. Webbing rings (hoops of woven textile material stitched together in multiple-ply configuration).

10. Rope rings (hoops of twisted or braided textile material spliced end to end).

The following parameters were considered in the trade-off. A numerical weighting was assigned to each up to a maximum of eight.

1. "Cost per unit time" (ratio of overall cost to anticipated life).

2. "Design" (indicative of the relative design problems likely to be encountered).

3. "Fabrication" (permits a comparison of manufacturing costs alone).

4. "Weight" (refers to handling qualities rather than airborne mass penalty).

5. "Handling" (reflects any problems likely to be enountered in attaching the fitting to the pendant hook, apart from those due to weight).

6. "Adaptability to load" (compares the load attachment facility).

7. "Vulnerability" (takes account of susceptibility to damage between flights).

8. "Texture" (depicts the nature of the material surface, which has some bearing on the handling qualities).

9. "Climatic" (records adverse effects on the handling qualities arising from arctic or tropical conditions).

10. "Cargo interference" (indicates the extent to which an apex fitting is liable to damage the cargo due to impact after release).

Table VII summarizes the results of the trade-off study and shows that steel apex fittings are preferable to textile or composite ones, and this is due to lower cost per unit time and the combined effect of some minor advantages. The three pear shapes are marginally superior to the corresponding rings only because they are fractionally lighter. The U-sections are well ahead of the circular sections, due to weight and one or two other factors. Better still are the split circular sections; consequently, the split pear shape with circular section (Figure 4) is the winning contender, immediately followed by the split delta (Figures 7 and 8) which it closely resembles. These results suggest that a split pear shape with a U-section (or some other noncircular section) would surpass the circular section type, but owing to the complexity of the component forgings, there are overriding design and production problems.

It was concluded from the trade-off study that a solid-forged-steel split pear shape with circular section should be used for the apex fitting. Steel has greater longevity at lower cost than other materials; the split configuration is more adaptable and convenient than a permanently closed loop; and the pear shape is marginally lighter than a ring of equivalent strength. This conclusion would be modified in favor of a variant having an I-section lower portion if the sling legs were to be made of textile material instead of wire rope.

Subsequent to the trade-off, an improved design was investigated, consisting of two solid forged steel shackles suspended from a common pin, two sling legs being fitted to each shackle. This showed considerable advantage over the split pear shape since it is easier to manufacture and eliminates some stress problems, as each shackle is free to align with its sling legs. Moreover, reconfiguration from single-point to two-point suspension requires only an additional pin rather than a whole extra apex assembly. This arrangement was therefore substituted in the final design. The sling-bearing loops of the shackles were designed with a semielliptic cross section to provide a bearing surface suitable for nylon rope eyes as well as wire rope eyes.

TABLE VII. SLING APEX FITTINGS TRADE-OFF

Type of Apex Fitting / Parameter and Rating Factor		Solid Forged-Steel Ring	Solid Forged-Steel Pear Shape	Solid Forged-Steel Split Ring	Solid Forged-Steel Split Pear Shape	Solid Forged-Steel Split Delta	Hollow Forged-Steel Ring	Hollow Forged-Steel Pear Shape	Composite Ring	Webbing Ring	Rope Ring
Cost per Unit Time	7	(8) 56	(8) 56	(8) 56	(8) 56	(8) 56	(7) 49	(7) 49	(1) 7	(2) 14	(2) 14
Design	2	(8) 16	(8) 16	(7) 14	(7) 14	(6) 12	(6) 12	(6) 12	(3) 6	(8) 16	(8) 16
Fabrication	4	(8) 32	(8) 32	(7) 28	(7) 28	(6) 24	(7) 28	(7) 28	(2) 8	(8) 32	(8) 32
Weight	8	(3) 24	(4) 32	(4) 32	(5) 40	(6) 48	(6) 48	(7) 56	(8) 64	(7) 56	(6) 48
Handling	8	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(6) 48	(6) 48
Adaptability	7	(2) 14	(2) 14	(7) 49	(7) 49	(7) 49	(3) 21	(3) 21	(4) 28	(2) 14	(3) 21
Vulnerability	6	(8) 48	(8) 48	(7) 42	(7) 42	(7) 42	(7) 42	(7) 42	(6) 36	(5) 30	(5) 30
Texture	4	(5) 20	(5) 20	(4) 16	(4) 16	(3) 12	(4) 16	(4) 16	(6) 24	(5) 20	(6) 24
Climatic	4	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(5) 20	(5) 20	(7) 28	(7) 28	(7) 28
Cargo Interference	4	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(6) 24	(8) 32	(8) 32
Factored Product Totals		306	314	333	341	339	316	324	289	290	293
Merit Order		7	6	3	1	2	5	4	10	9	8

Note: Numbers in parentheses are performance values.

TABLE VII. SLING APEX FITTINGS TRADE-OFF

Type of Apex Fitting / Parameter and Rating Factor		Solid Forged-Steel Ring	Solid Forged-Steel Pear Shape	Solid Forged-Steel Split Ring	Solid Forged-Steel Split Pear Shape	Solid Forged-Steel Split Delta	Hollow Forged-Steel Ring	Hollow Forged-Steel Pear Shape	Com R
Cost per Unit Time	7	(8) 56	(8) 56	(8) 56	(8) 56	(8) 56	(7) 49	(7) 49	(1)
Design	2	(8) 16	(8) 16	(7) 14	(7) 14	(6) 12	(6) 12	(6) 12	(3)
Fabrication	4	(8) 32	(8) 32	(7) 28	(7) 28	(6) 24	(7) 28	(7) 28	(2)
Weight	8	(3) 24	(4) 32	(4) 32	(5) 40	(6) 48	(6) 48	(7) 56	(8)
Handling	8	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8)
Adaptability	7	(2) 14	(2) 14	(7) 49	(7) 49	(7) 49	(3) 21	(3) 21	(4
Vulnerability	6	(8) 48	(8) 48	(7) 42	(7) 42	(7) 42	(7) 42	(7) 42	(6
Texture	4	(5) 20	(5) 20	(4) 16	(4) 16	(3) 12	(4) 16	(4) 16	(6
Climatic	4	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(5) 20	(5) 20	(7
Cargo Interference	4	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(6
Factored Product Totals		306	314	333	341	339	316	324	
Merit Order		7	6	3	1	2	5	4	

Note: Numbers in parentheses are performance values.

TABLE VII. SLING APEX FITTINGS TRADE-OFF

Solid Forged-Steel Pear Shape	Solid Forged-Steel Split Ring	Solid Forged-Steel Split Pear Shape	Solid Forged-Steel Split Delta	Hollow Forged-Steel Ring	Hollow Forged-Steel Pear Shape	Composite Ring	Webbing Ring	Rope Ring
(8) 56	(8) 56	(8) 56	(8) 56	(7) 49	(7) 49	(1) 7	(2) 14	(2) 14
(8) 16	(7) 14	(7) 14	(6) 12	(6) 12	(6) 12	(3) 6	(8) 16	(8) 16
(8) 32	(7) 28	(7) 28	(6) 24	(7) 28	(7) 28	(2) 8	(8) 32	(8) 32
(4) 32	(4) 32	(5) 40	(6) 48	(6) 48	(7) 56	(8) 64	(7) 56	(6) 48
(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(8) 64	(6) 48	(6) 48
(2) 14	(7) 49	(7) 49	(7) 49	(3) 21	(3) 21	(4) 28	(2) 14	(3) 21
(8) 48	(7) 42	(7) 42	(7) 42	(7) 42	(7) 42	(6) 36	(5) 30	(5) 30
(5) 20	(4) 16	(4) 16	(3) 12	(4) 16	(4) 16	(6) 24	(5) 20	(6) 24
(4) 16	(4) 16	(4) 16	(4) 16	(5) 20	(5) 20	(7) 28	(7) 28	(7) 28
(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(4) 16	(6) 24	(8) 32	(8) 32
314	333	341	339	316	324	289	290	293
6	3	1	2	5	4	10	9	8

Note: Numbers in parentheses are performance values.

Sling Length Adjusters

Twelve different methods of adjusting sling length by 4 feet, in intervals of about 3 inches, were traded-off after eliminating obviously unsuitable types. They are listed below (Figure 14 summarizes their differences).

1. Chain and grab link method (see Figure 15a and Figures 3 through 8).

2. Chain and grab hook, with spring-loaded keeper (see Figure 15b).

3. Chain and grab hook, with load-dependent keeper (see Figure 15c).

4. Chain and bifurcated grab hook, with load-dependent keeper (see Figure 15d).

5. Chain and cranked eye grab hook, with load-dependent keeper (see Figure 15e).

6. Chain and cranked eye grab hook, with load-dependent keeper integral with shackle (see Figure 15f).

7. Chain and duplicated cranked eye grab hooks, with integral load-dependent keeper (see Figure 15g).

8. Adjustable strut (see Figure 15h).

9. Adjustable rod assembly, with load-dependent keeper (see Figure 15i).

10. Adjustable rod and strip assembly, with spring-loaded keeper (see Figure 15j).

11. Wire rope with spacing collars (see Figure 15k).

12. Webbing with gripper fitting (see Figure 15 l).

The following parameters were considered in the trade-off. A numerical weighting was assigned to each up to a maximum of eight.

1. "Cost per unit time" (the ratio of overall cost to anticipated life).

2. "Design" (indicative of the relative design problems likely to be enountered).

3. "Fabrication" (permits a comparison of manufacturing costs alone).

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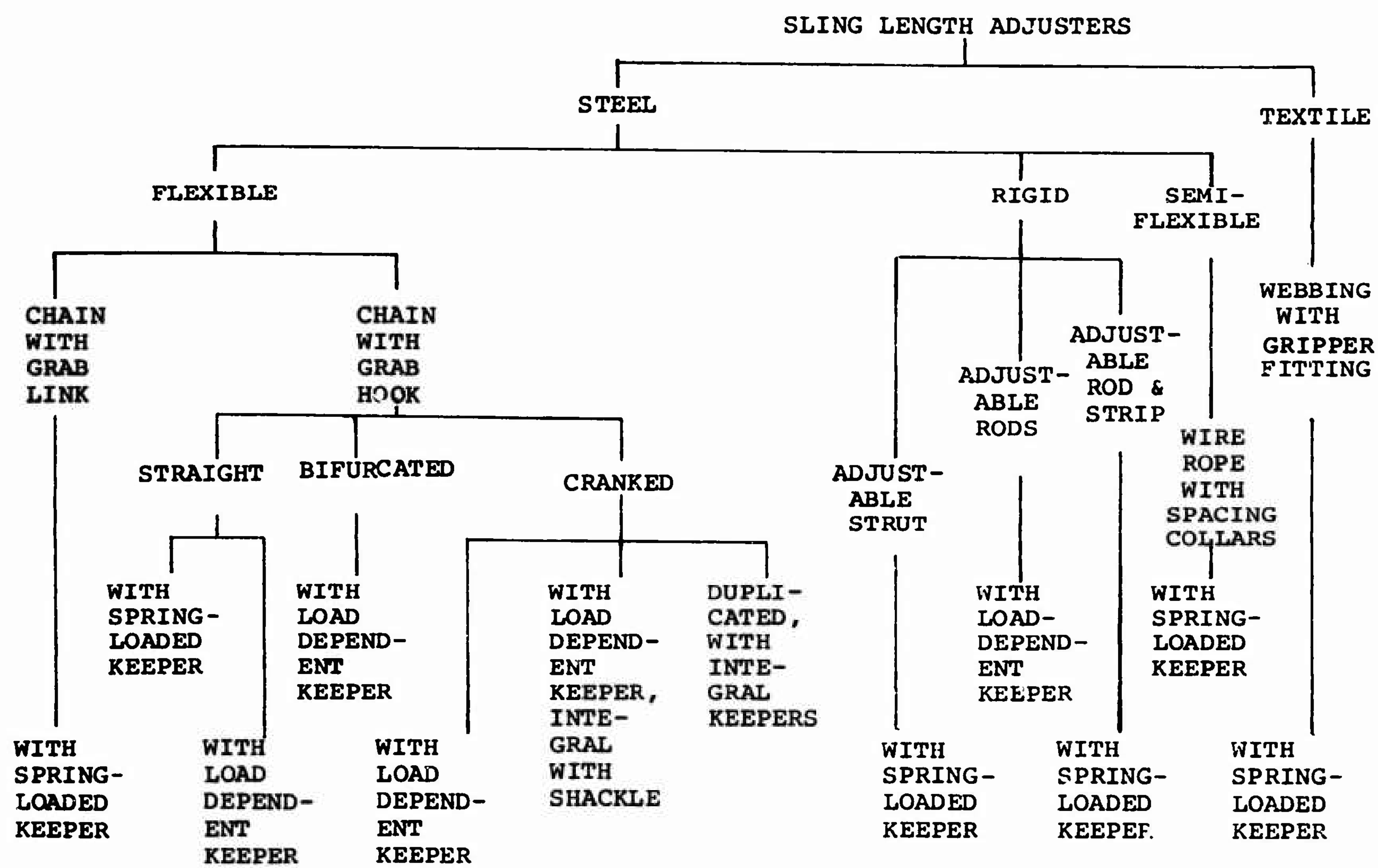


Figure 14. Sling Length Adjustment Methods.

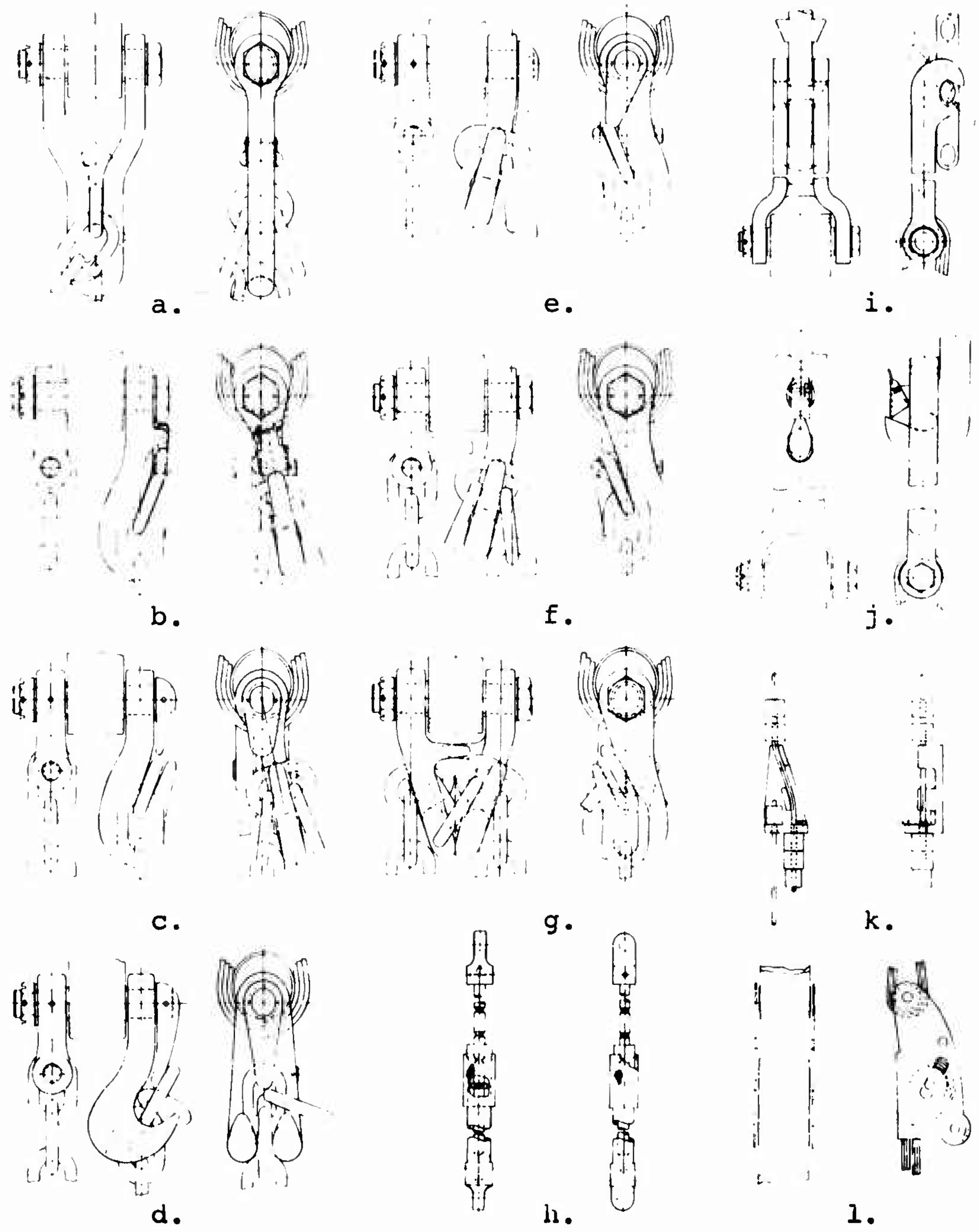


Figure 15. Sling Length Adjusters.

4. "Weight" (considered only as a manhandling factor).

5. "Handling" (reflects any problems likely to be encountered in lifting, holding, adjusting, locking, and other manual operations).

6. "Length increments" (demonstrates whether the length variation is fine enough to permit accurate load leveling).

7. "Length indication" (shows whether length can be readily measured or indicated in some manner when the length is being adjusted).

8. "Length retention" (measures the positiveness with which the length is maintained).

9. "Keeper reliability" (assesses the likelihood of keeper failure, coupled with a consideration of the possible consequences of keeper failure).

10. "Attitude" (applies only to those devices using chains, and measures the possibility of the retained chain link assuming an attitude which subjects it to an unusual bending stress or an amplified tensile stress).

11. "Adaptability to load" (compares the load attachment facility).

12. "Vulnerability" (takes account of susceptibility to damage between flights).

Table VIII summarizes the results of the trade-off study and shows that all the devices incorporating chains achieve high scores, despite the inherent inefficiency of chains in terms of strength/weight ratio. There are several reasons for this. The chain, in conjunction with a link grabbing device, not only provides a convenient and positive means of adjusting length in small increments but also forms a superior method of attachment to the load. It thus serves a dual function; and the chain retention device is also the load retention device Chain production is a highly developed process which insures reasonable cost and reliability. Vulnerability, handling and length indication are also parameters in which the chain devices score heavily. Of the remaining designs (all of which need two keepers), the adjustable rod and strip assembly shows the best trade-off, but is vulnerable and inconvenient. The adjustable strut is undoubtedly the easiest device of all to adjust, but it has several weak features: weight, keeper reliability, adaptability, vulnerability. The wire rope with spacers appeared to be a promising new approach, and several variations of the scheme illustrated were examined. None, however, could

TABLE VIII. SLING LEN

Sling Length Adjuster Configuration / Parameter and Rating Factor		Chain and Grab Link, Spring-Loaded Keeper (Figure 15a)		Chain and Grab Hook, Spring-Loaded Keeper (Figure 15b)		Chain and Grab Hook, Load-Dependent Keeper (Figure 15c)		Chain and Bifurcated Grab Hook, Load-Dependent Keeper (Figure 15d)		Chain and Cranked Eye Grab Hook, Load-Dependent Keeper (Figure 15e)	
Cost per Unit Time	8	(6)	48	(7)	56	(7)	56	(6)	48	(7)	56
Design	2	(5)	10	(7)	14	(7)	14	(6)	12	(7)	14
Fabrication	4	(6)	24	(7)	28	(7)	28	(6)	24	(7)	28
Weight	5	(5)	25	(6)	30	(6)	30	(5)	25	(6)	30
Handling	8	(5)	40	(6)	48	(7)	56	(7)	56	(7)	56
Length Increments	6	(6)	36	(6)	36	(6)	36	(6)	36	(6)	36
Length Indication	5	(5)	25	(7)	35	(7)	35	(8)	40	(7)	35
Length Retention	8	(8)	64	(8)	64	(8)	64	(8)	64	(8)	64
Keeper Reliablity	6	(5)	30	(5)	30	(2)	12	(3)	18	(2)	12
Attitude	5	(5)	25	(7)	35	(7)	35	(8)	40	(5)	25
Adaptability to Load	7	(7)	49	(7)	49	(7)	49	(7)	49	(7)	49
Vulnerability	6	(7)	42	(7)	42	(7)	42	(7)	42	(7)	42
Factored Product Totals			418		467		457		454		447
Merit Order			8		1		3		4		5

Note: Numbers in paren

TABLE VIII. SLING LENGTH ADJUSTERS TRADE-OFF

Chain and Bifurcated Grab Hook, Load-Dependent Keeper (Figure 15d)	Chain and Cranked Eye Grab Hook, Load-Dependent Keeper (Figure 15e)	Chain and Cranked Eye Grab Hook, Load-Dependent Keeper Integral With Shackle (Figure 15f)	Chain and Duplicated Cranked Eye Grab Hooks, Integral Load-Dependent Keepers (Figure 15g)	Adjustable Strut, Spring-Loaded Keeper (Figure 15h)	Adjustable Rods Assembly, Load-Dependent Keeper (Figure 15i)	Adjustable Rod/Strip Assembly, Spring-Loaded Keeper (Figure 15j)	Wire Rope With Spacing Collars, Spring-Loaded Keeper (Figure
(6) 48	(7) 56	(7) 56	(7) 56	(6) 48	(6) 48	(7) 56	(6) 48
(6) 12	(7) 14	(7) 14	(6) 12	(6) 12	(6) 12	(7) 14	(7) 14
(6) 24	(7) 28	(8) 32	(7) 28	(7) 28	(7) 28	(8) 32	(7) 28
(5) 25	(6) 30	(6) 30	(5) 25	(3) 15	(5) 25	(5) 25	(4) 20
(7) 56	(7) 56	(8) 64	(5) 40	(8) 64	(6) 48	(7) 56	(5) 40
(6) 36	(6) 36	(6) 36	(6) 36	(6) 36	(5) 30	(5) 30	(6) 36
(8) 40	(7) 35	(7) 35	(7) 35	(7) 35	(6) 30	(6) 30	(7) 35
(8) 64	(8) 64	(8) 64	(8) 64	(7) 56	(8) 64	(8) 64	(8) 64
(3) 18	(2) 12	(2) 12	(4) 24	(3) 18	(3) 18	(4) 24	(4) 24
(8) 40	(5) 25	(5) 25	(5) 25	(8) 40	(8) 40	(8) 40	(8) 40
(7) 49	(7) 49	(7) 49	(7) 49	(3) 21	(3) 21	(3) 21	(5) 35
(7) 42	(7) 42	(7) 42	(7) 42	(3) 18	(3) 18	(3) 18	(6) 36
454	447	459	436	391	382	410	420
4	5	2	6	11	12	9	7

Note: Numbers in parentheses are performance values.

NGTH ADJUSTERS TRADE-OFF

Chain and Cranked Eye Grab Hook, Load-Dependent Keeper Integral With Shackle (Figure 15f)	Chain and Duplicated Cranked Eye Grab Hooks, Integral Load-Dependent Keepers (Figure 15g)	Adjustable Strut, Spring-Loaded Keeper (Figure 15h)	Adjustable Rods Assembly, Load-Dependent Keeper (Figure 15i)	Adjustable Rod/Strip Assembly, Spring-Loaded Keeper (Figure 15j)	Wire Rope With Spacing Collars, Spring-Loaded Keeper (Figure 15k)	Webbing With Gripper Fitting, Spring-Loaded Keeper (Figure 15l)
(7) 56	(7) 56	(6) 48	(6) 48	(7) 56	(6) 48	(5) 40
(7) 14	(6) 12	(6) 12	(6) 12	(7) 14	(7) 14	(7) 14
(8) 32	(7) 28	(7) 28	(7) 28	(8) 32	(7) 28	(8) 32
(6) 30	(5) 25	(3) 15	(5) 25	(5) 25	(4) 20	(8) 40
(8) 64	(5) 40	(8) 64	(6) 48	(7) 56	(5) 40	(6) 48
(6) 36	(6) 36	(6) 36	(5) 30	(5) 30	(6) 36	(8) 48
(7) 35	(7) 35	(7) 35	(6) 30	(6) 30	(7) 35	(8) 40
(8) 64	(8) 64	(7) 56	(8) 64	(8) 64	(8) 64	(2) 16
(2) 12	(4) 24	(3) 18	(3) 18	(4) 24	(4) 24	(2) 12
(5) 25	(5) 25	(8) 40	(8) 40	(8) 40	(8) 40	(8) 40
(7) 49	(7) 49	(3) 21	(3) 21	(3) 21	(5) 35	(5) 35
(7) 42	(7) 42	(3) 18	(3) 18	(3) 18	(6) 36	(6) 36
459	436	391	382	410	420	401
2	6	11	12	9	7	10

theses are performance values.

be made competitive with the chain devices. The webbing gripper has many good points, but they are counteracted by its non-positive retention and relatively short life.

There can be no doubt that a chain device is the solution to the adjustment problem, and it only remains to determine the best link grabbing method. The load-dependent keepers are attractive in many respects, but there will always remain a nagging doubt as to their reliability; and the design which is least likely to become inadvertently uncoupled (the duplicated hooks) is also the most difficult to mate. Two of the seven chain devices have spring-loaded keepers, and it is interesting to note that the grab hook version scores highest out of the seven, and the grab link lowest. The parameters which account for this are cost, weight, handling, length indication, attitude, design and fabrication. These two devices were reassessed against each other, to confirm that the grab hook had distinct advantages over the grab link.

It was concluded from the trade-off study that a chain and grab hook with spring-loaded keeper should be used for length adjustment, subject to the completion of satisfactory trials. The superiority of chains is well-established, There is insuffucent confidence in load-dependent keepers to justify their introduction in airborne operations. The only other candidate with a spring-loaded keeper finished lowest among the chain devices.

Subsequent to the trade-off, it was decided to integrate into a common forging the grab hook and the shackle which anchors the fixed end of the chain loop, in order to achieve a more stable assembly. This partially negates the self-aligning, stress-relieving feature, but not critically. The chain anchorage was then simplified by substituting for the shackle pin a standard chain connecting link, passing through a hole in the forging. The keeper was lengthened by repositioning the pivot, to facilitate operation.

Conclusions

The trade-off studies for the preliminary design of the slings resulted in the following recommendations:

The sling leg material should be stainless steel wire rope, which should be eye-spliced and thimbled at each end. (A supplementary trade-off study confirmed this choice.)

The sling apex fitting should be a solid forged-steel split pear shape with circular section. (This subsequently evolved into a solid forged-steel twin shackle assembly.)

The sling length adjustment should employ the chain and grab hook method, using a spring-loaded keeper on the latter. (The configuration was later improved by combining the grab hook with its associated shackle to stabilize the assembly.)

Figure 16 depicts the preliminary recommended sling design.

PENDANTS

Discussion

The purpose of the design study was principally to determine the most suitable material for the pendant rope. The requirements for the other components, i.e., the apex fitting, the swivel hook, and the release system, were secondary considerations (though many problems were encountered in the design of the latter).

Of paramount importance in the selection of a pendant rope material is the spring rate, which must be low enough to provide the required load-isolating feature. This precludes the use of wire rope and many textiles. In fact, there are so few materials that can satisfy the strength requirements and also possess a low spring rate over a reasonably short length, that a formalized trade-off chart was not necessary. Alternative methods of providing load isolation without relying on the elasticity of a long pendant rope were also investigated but were rejected as impracticable. (See Figure 17.)

Consideration also has to be given to "dangerous hook release" conditions. In the event of an inflight loss of payload from the pendant (due to inadvertent opening of the pendant hook, or to failure of either the hook or the sling apex fitting), the stored energy in the fully stretched pendant will impart considerable upward momentum to the hook end of the rope. Ground tests have shown that the pendant hook will usually rise about half the length of the pendant, but in some cases it may strike the fuselage. It is most unlikely that the hook end of the rope would approach the rotor disc, but to preclude this possibility, an appropriate limitation on the length should be imposed.

The apex fitting was seen to be a straightforward design exercise and was not investigated in great depth at this stage.

The pendant swivel hook is the largest and most complex part of a sling system, but this also could be designed along conventional lines.

The hook release system called for manual operation from the upper end of the pendant and therefore required a release cable which expanded and contracted in synchronism with the pendant rope. This caused more problems than were envisaged in the

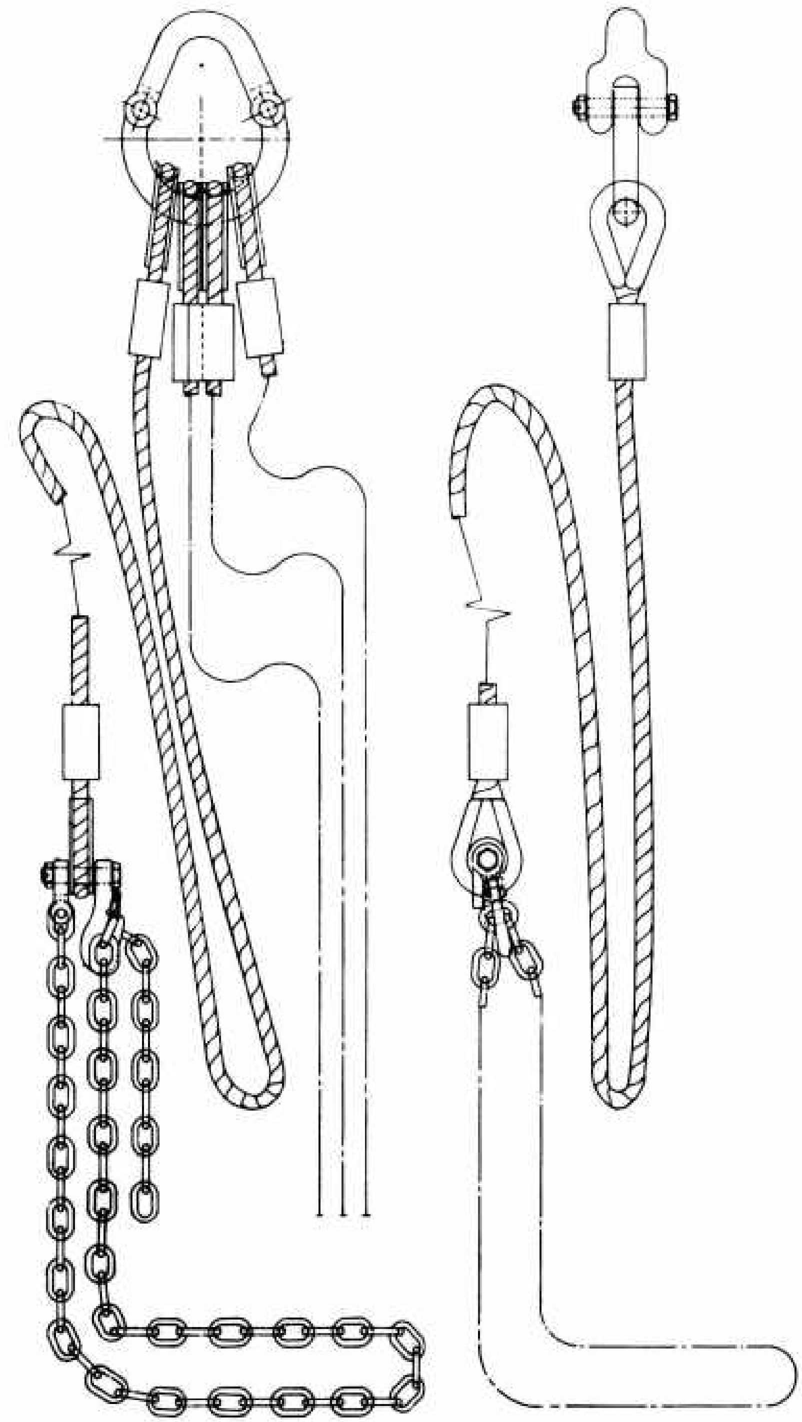


Figure 16. Preliminary Sling Design - Wire Rope (Recommended).

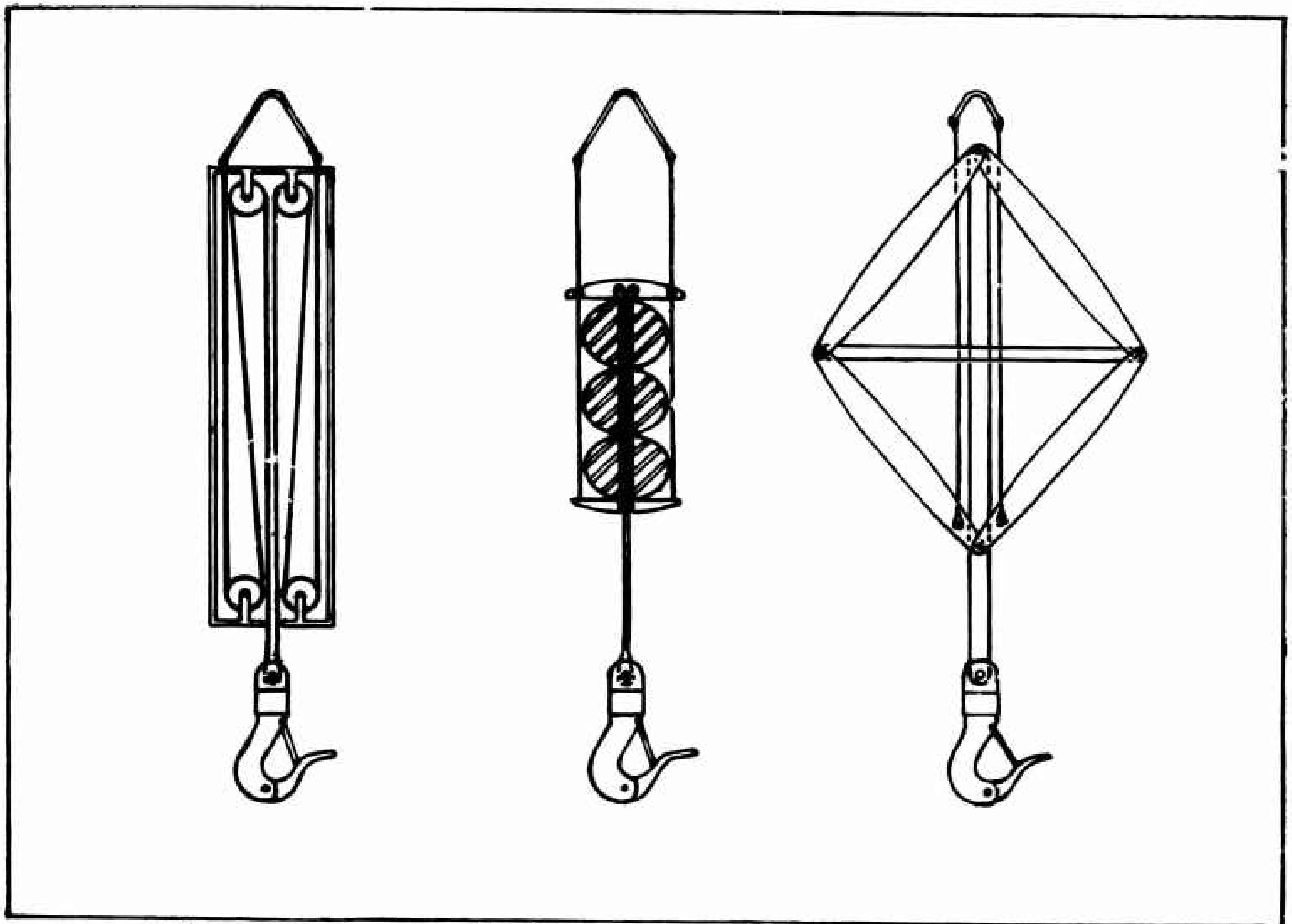


Figure 17. Hypothetical Methods of Reducing Pendant Length.

preliminary design.

Pendant components were not subjected to numerical trade-off charts since the choice of suitable condidates was limited.

Pendant Materials

Four different materials for pendant ropes were investigated, no other materials being sufficiently elastic to warrant consideration. They are listed below.

1. Webbing, nylon, Type 19, uncoated. (See Figure 18.)

2. Webbing, nylon, Type 19, coated.

3. Rope, nylon, square braided, uncoated. (See Figure 19.)

4. Rope, nylon, square braided, uncoated.

The following parameters were considered in the trade-off:

1. "Spring rate" (not to exceed 2000 lb/in. for the 6K pendant or 4000 lb/in. for the 20K pendant).

2. All the characteristics listed for sling materials except "Cargo interference" and "Elasticity" (which is covered by 1, above). The "Adaptability" parameter was extended to include consideration of the hook release facility.

The trade-off study showed that a coated material had to be used (to provide protection against internal and external abrasion, moisture, corrosion, heat and ultraviolet), leaving only two materials to be considered, namely, the coated versions of Type 19 nylon webbing and square braided nylon rope. Their spring rates are almost equal, but in almost all other respects nylon rope came out ahead of nylon webbing in the trade-off for sling materials.

It was concluded from the trade-off study that coated square-braided nylon rope should be used for the pendant material, being slightly superior to the only other candidate.

Subsequent to the trade-off study, a new type of double-braided nylon rope was developed, with a different weave to increase its elasticity. Its spring rate was found to be within the required limits, and it had some advantages over square-braided nylon rope. For instance, it does not have a unidirectional twist, and the surface is not undulated; hence, a more uniform, less vulnerable coating can be applied. This material was therefore substituted in the final design.

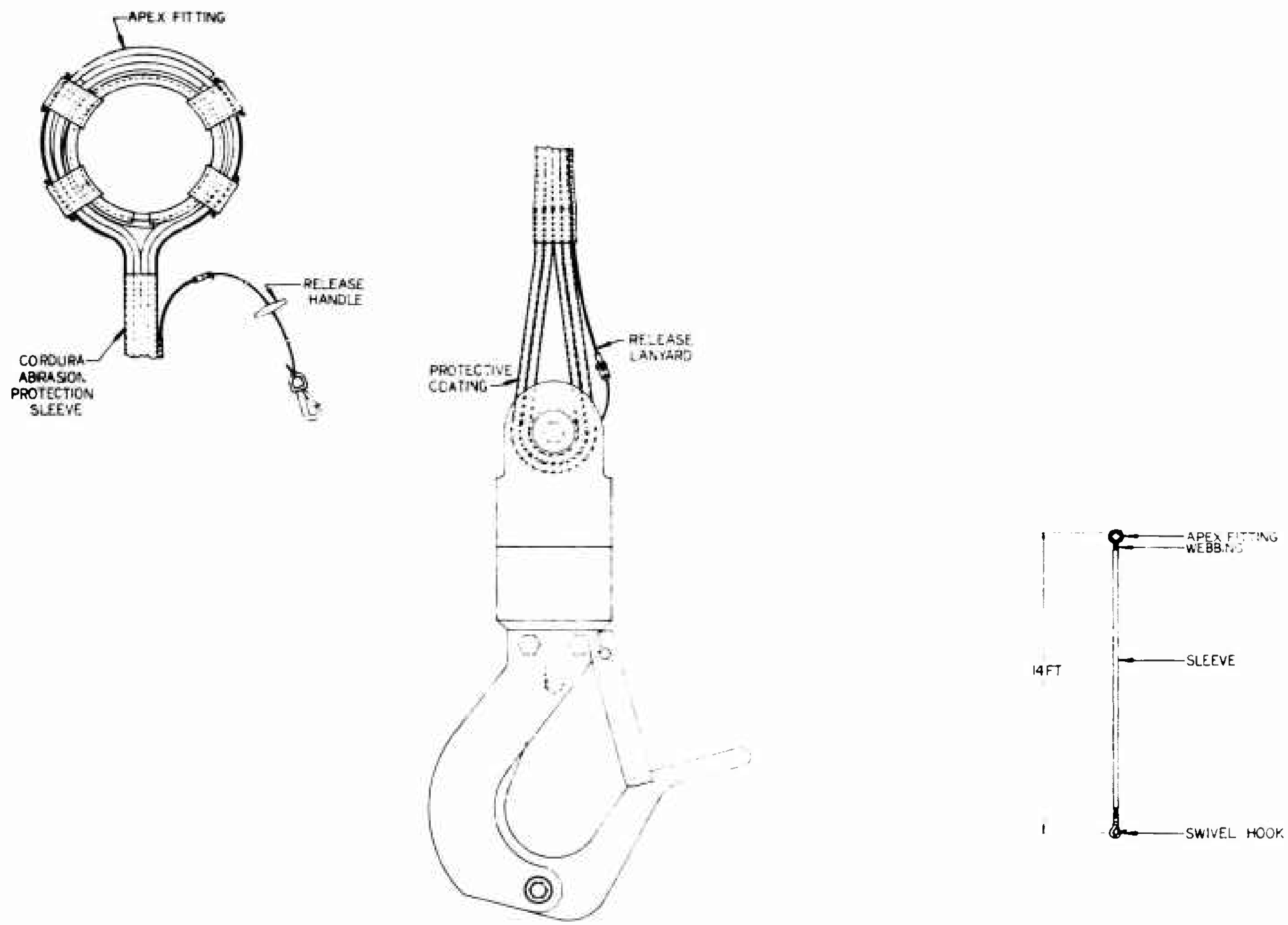


Figure 18. Preliminary Pendant Design - Nylon Webbing.

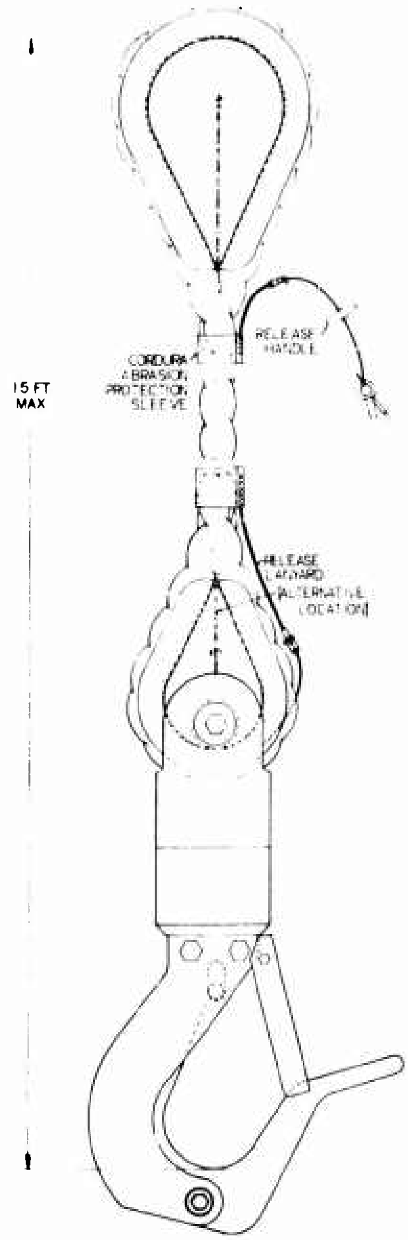


Figure 19. Preliminary Pendant Design - Nylon Rope (Recommended).

Apex Fittings

An integral apex fitting was envisaged for the pendant rope, meaning that the rope would be eye-spliced and fitted with a metal thimble. However, an improved rope material was introduced for the final design, as explained above, and it was found difficult to design an integral apex fitting that could be accommodated on all the applicable aircraft cargo hooks with adequate clearance. A simple, fabricated, metal apex fitting was therefore substituted in the final design.

Swivel Hook

There were no existing swivel hooks of the required capacity that could be traded off, but there were two or three designs that were usable as a basis for the 6K and 20K swivel hooks by appropriate scaling. Layout sketches were made for size, weight and cost estimating purposes.

Release System

There was one existing design of release system which allowed the pendant rope to stretch without inducing an inadvertent release, and it was considered suitable for adoption. It allowed the release cable to be retracted by a spring around the inside of the swivel hook housing. Subsequent analysis, however, showed that it could not be adapted to the relatively large changes in length that are demanded by the pendants. A spring-loaded spool type take-up mechanism mounted on the apex fitting was introduced in the final design.

Conclusions

The trade-off studies for the preliminary design of the pendants resulted in the following recommendations:

> The pendant rope material should be coated, square-braided nylon rope. (A newly developed type of double-braided nylon rope was substituted later.)
>
> The pendant apex fitting should be an integral eye splice on the pendant rope, lined with a metal thimble. (A separate metal fabricated apex fitting was subtituted later to provide adequate cargo hook clearance.)
>
> The pendant swivel hook should be based on an existing design.
>
> The release system should be based on an existing design, but with a revised release cable take-up device.

Figure 19 depicts the preliminary recommended pendant design.

NONDESTRUCTIVE TESTER

Discussion

The design study for the nondestructive tester took the form of a comprehensive search for information on methods of testing and for existing test equipment. Literature research was performed at the Engineering Societies Library, United Engineering Center, New York City, to catalog existing methods and to determine which materials are amenable to testing. Techniques employed by various major corporations were also examined. Any potentially useful schemes resulting from the above research were then tested.

Review of Methods

Among the methods of nondestructive testing studied were: fluoroscopy, radiography, ultrasonic waves, electromagnetic microwaves, interferometry, Schlieren methods, brittle coating test, centimetric radio waves, liquid penetrants, infrared, thermal image, natural frequency measurement, and eddy current testing.

With the exceptions of the natural frequency measurement and the eddy current method, all of the aforementioned tests have inherent limitations for testing the characteristics of wire rope and nylon, the primary materials considered for the slings. These limitations are basically of two types:

1. Only homogeneous materials may be investigated. There are nondestructive tests in use today for the examination of man-made fibers. The three basic types are birefringence, dichroism, and X-ray. These methods are satisfactory, but only for individual fibers. A fiber is homogeneous by itself but loses it homogeneous identity when woven, as in the case of webbing or rope. The same reasoning applies to wire rope. The individual wires may be examined, but when wires are twisted to form a rope, the tests fail to produce coherent results.

2. Investigation is limited to small areas. A typical sling contains nearly 100 feet of material which must be inspected. With most tests, only an inch or two of surface may be examined at a time, so that investigation of an entire sling is impractical.

Research has shown that there is a definitive relation between corrosion, broken wires, abrasion, internal wear, and the remaining strength in a wire rope (see Reference 2). A procedure established 40 years ago produces a very valid estimate of residual life. It is rather time-consuming and involves the use of Roebling charts. These consist of pairs of nomograms which enable the strength of a wire rope to be determined after the number of broken wires have been counted and the length of abrasion in the worst lay of the rope has been measured.

A cataloging of currently produced synthetics was also attempted during the library search. This proved to be unfeasible as the number of man-made products is staggering, and to investigate every material thoroughly is impracticable. The investigation did show that, in general, synthetics must be either woven or encapsulated in some way in order to produce the strength required. Once this is done, the identical problem of heterogeneous substances arises, and a nondestructive test becomes difficult to determine.

Information was sought from corporations that are either directly or indirectly associated with materials for slings or nondestructive tests. These are producers, suppliers, or users of materials from which cargo slings are made. It was reasoned that in order to sell or use their product, some assurance of its performance must be needed. The contacts were divided into two groups: one for nylon and the other for wire rope. For the textile group, a further subdivision was made. This was necessary because textile materials, including nylon, are susceptible to damage by ultraviolet radiation. Therefore, corporations which have had experience with detecting ultraviolet exposure were also contacted. If the amount of exposure could be detected, a correlation might be made between this and the remaining strength. The following were contacted in regard to this matter: Polaroid Corporation, Eastman Kodak, National Cash Register, Technical Operations, Inc., DuPont, American Cyanamid, G.A.F., Dow Chemical, John L. Armitage & Corp., and Chemical Products Corp.

The next group contacted were the producers, suppliers, and users of nylon webbing and rope. They were: DuPont, Buffalo Weaving & Belting, Ocean Products Research, Naval Air Engr. Lab., International Webbing, and Pioneer Parachutes.

It was found that the tests performed by the producers of nylon materials are of two types: proof loading and ultimate loading. These producers had no nondestructive test other than a purely visual inspection. Many are producing webbing with two added features over their original designs. One is the weaving of several rows of orange- or red-colored nylon within the webbing. When these rows are made visible to the user by wearing of the webbing, the webbing should be discarded. The other feature is coating the webbing with urethane to reduce degradation of the nylon fibers by ultraviolet radiation. It also increases resistance to internal and external abrasion. In general, the users of nylon webbing assure performance by overdesign and programmed obsolescence.

The final group of corporations contacted were the producers and users of wire rope products. Among the companies contacted were: Universal Wire Products, Roebling Div. of C.F.& I. Steel Corp., and Hall Lifts.

The tests performed by these companies are the same as those of the nylon manufacturers: destructuve and visual. The users have programmed obsolescence in much the same way as the nylon users.

The general consensus among the companies contacted is that:

1. Nylon and wire rope are the primary materials of which slinging material is to be made.

2. With the exception of the use of eddy currents for testing of wire rope, no nondestructive tester is yet available for the detection of faults in either wire rope or nylon rope.

3. "Add-on" devices such as wires woven within webbing, exposure tabs placed on sling legs, etc., are not practical ways of determining the remaining strength in a material. Correlations between such "add-on" devices and the physical characteristics of materials would be inexact and would be a source of error in the determination of factor of safety remaining.

Testing of Methods

The two major sections of the NDT study - library search and outside contacts - were to provide information which would generate ideas for testing either new or established methods of nondestructive tests which could be applied to slinging materials. Two concrete tests were established from the research: the Roebling charts and McPhar Manufacturing's electromagnetic wire rope tester. Both these methods have considerable substantiating data on their performance (see, for instance, References 2 and 3), and it was considered unnecessary to substantiate these findings further. The only doubtful area was the use of natural frequency as a medium for a practicable nondestructive test. This nondestructive test would be applicable to both nylon and wire rope. Conversations with several leading wire rope manufacturers were indecisive as to the effectiveness of this method, so a comprehensive test program was set up to obtain further data. No useful results were obtained. It was found that changes in natural frequency due to damage did not become significant until such damage exceeded levels which were visually obvious. Opportunity presented itself during these tests to evaluate the performance of an electronic product developed by Vemco Industries, Inc., called Vibra Tension. This device measures the fundamental frequency of vibration in a wire rope. It electronically computes and displays the resulting tension on a meter. Although this product performed admirably, the use of natural frequency as a means of detecting flaws in wire rope is not acceptable, since it is valid only on ropes which are defective to an already manifest extent.

Outside vendors were also used in an attempt to find a workable nondestructive test. Of those contacted, two American-based manufacturers, Branon Instruments and Magnetic Analysis Corp., were found to have instrumentation similar to that of McPhar Manufacturing , which is a Canadian company. A defective cable was supplied to both these firms, and the results from both indicate the same degree of confidence as the McPhar electromagnetic wire rope tester.

While the test cable was at the Magnetic Analysis company, an additional test was carried out using a magnetometer. This device detects magnetic fields caused by breaks and separation of wires in a rope. It did detect all the breaks in the sample but was not capable of detecting worn wires. This is not practical for use on slings because the primary damage is expected to be wear. Hence, an eddy current device is preferred.

Conclusions

The studies of nondestructive test techniques resulted in the following recommendations:

> If wire ropes are used for slings, an accurate and expeditious evaluation can be achieved by the use of an eddy current comparator, models of which are already in existence, e.g., Magnetic Analysis "Minimac". Alternatively, the residual strength can be fairly accurately assessed by a visual inspection, particularly if Roebling charts are used.
>
> If textile ropes are used for slings, the residual strength can be assessed only by a visual inspection, the validity of which will be dubious.

Subsequent to the study, a supplementary investigation was made to determine a relationship between the time spent on inspection and the degree of confidence that can be expected in the results, and also to assess the economic aspects of an eddy current tester. It was confirmed that a visual inspection of a sling component, taking five or ten minutes, is sufficient to enable a decision to be made in respect of an item in very good condition or very bad condition, whether it is made of wire rope or synthetic textile material. For marginal cases, the degree of confidence in the decision will be appreciably higher for wire rope, since the effects of the degradation factors are more firmly established. The expenditure of more inspection time on a synthetic textile material will provide very little additional information and will not, therefore, enhance the degree of confidence. For wire ropes, however, extra time spent on the Roebling procedure produces a very valid estimate of residual life. For synthetic textile materials, more research and statistical analysis is needed to reduce the areas of uncertainty, but they can never approach the same level as wire rope. The expenditure of approximately $3,500 on an eddy-current device at depot level should reduce the testing time of steel wire rope from a maximum of 60 minutes to less than 5 minutes, including setting-up time. Moreover, highly accurate results are obtainable without relying on experienced personnel or human judgment. No comparable automated device is available for synthetic textile materials.

DESIGN CRITERIA

SLINGS

Discussion

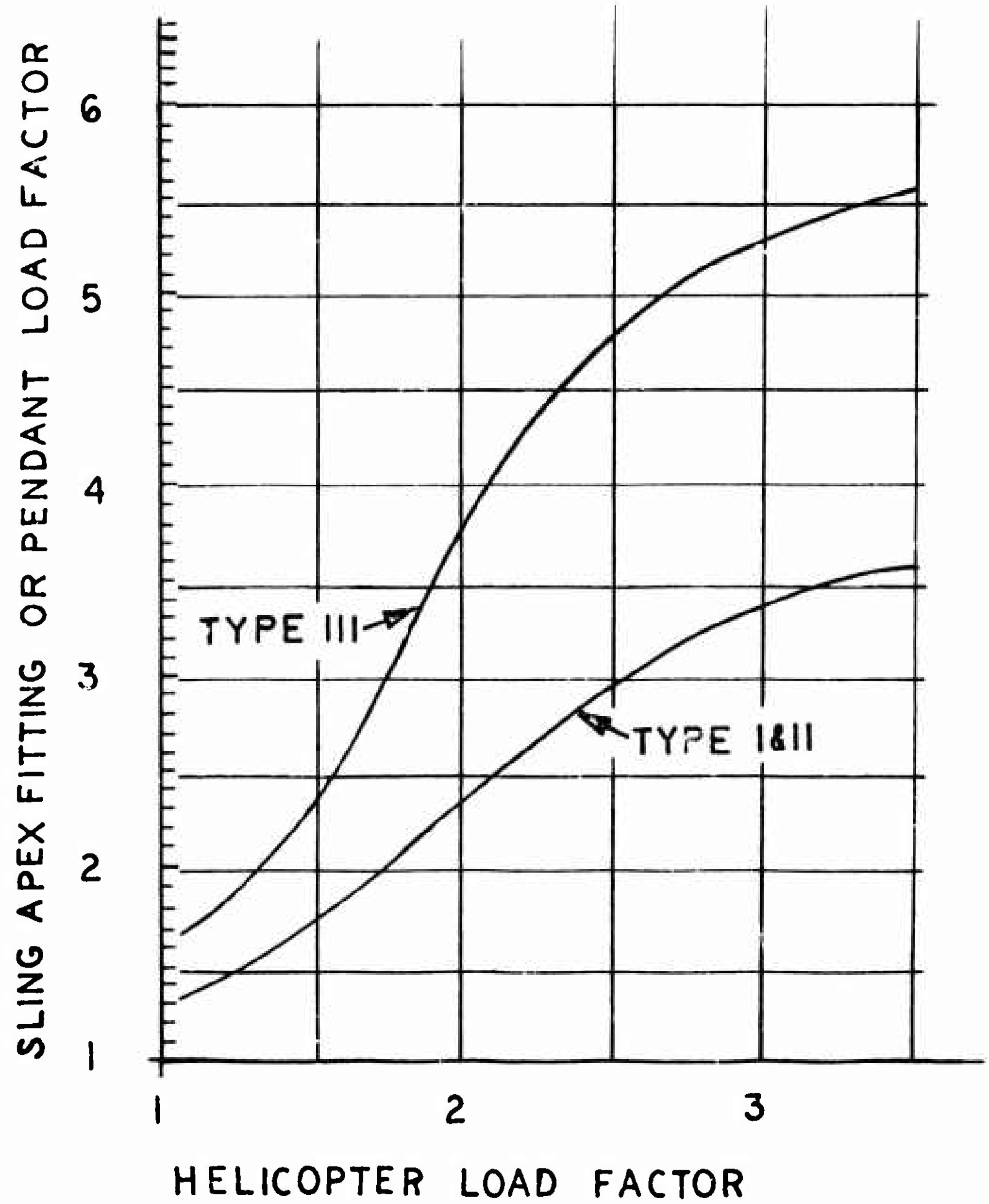
This section quotes the derivations and actual values of the factors used to determine the sling ultimate strength requirements, and reiterates the compatibility requirements which dictate physical dimensions. It covers the 6K wire rope sling, 6K nylon rope sling, 25K wire rope sling, 25K nylon rope sling, 60K wire rope sling, and 110K wire rope sling. (The latter was not developed beyond the preliminary design stage, but the criteria are included here for record purposes.)

To determine the ultimate strength requirement of a sling apex fitting, the nominal capacity is first multiplied by the load factor derived from the relevant graphs in Reference 1 (see Figure 20), then by the minimum ultimate factor of safety (1.5 for this equipment) in accordance with Reference 3 (page 3). To determine the ultimate strength requirement of a sling leg, the nominal capacity (of the whole sling) is first multiplied by the load factor derived from the relevant graphs in Reference 1 (see Figure 21), then by the leg factor (.6 for a four-legged sling) in accordance with Reference 1 (page 39). The latter is an omnibus factor which allows for unequal distribution of the load between the legs (due to leg angle differences and load center-of-gravity eccentricity) and also incorporates the minimum ultimate factor of safety mentioned above.

It should be noted that the load factor graph for sling apex fittings is also the graph for pendants, but a different graph is used for sling legs. Use of these graphs involves a consideration of the worst type of load that the sling will experience and also the highest aircraft load factor of any helicopter on which the sling will be fitted. These two parameters are specified below for each size of sling.

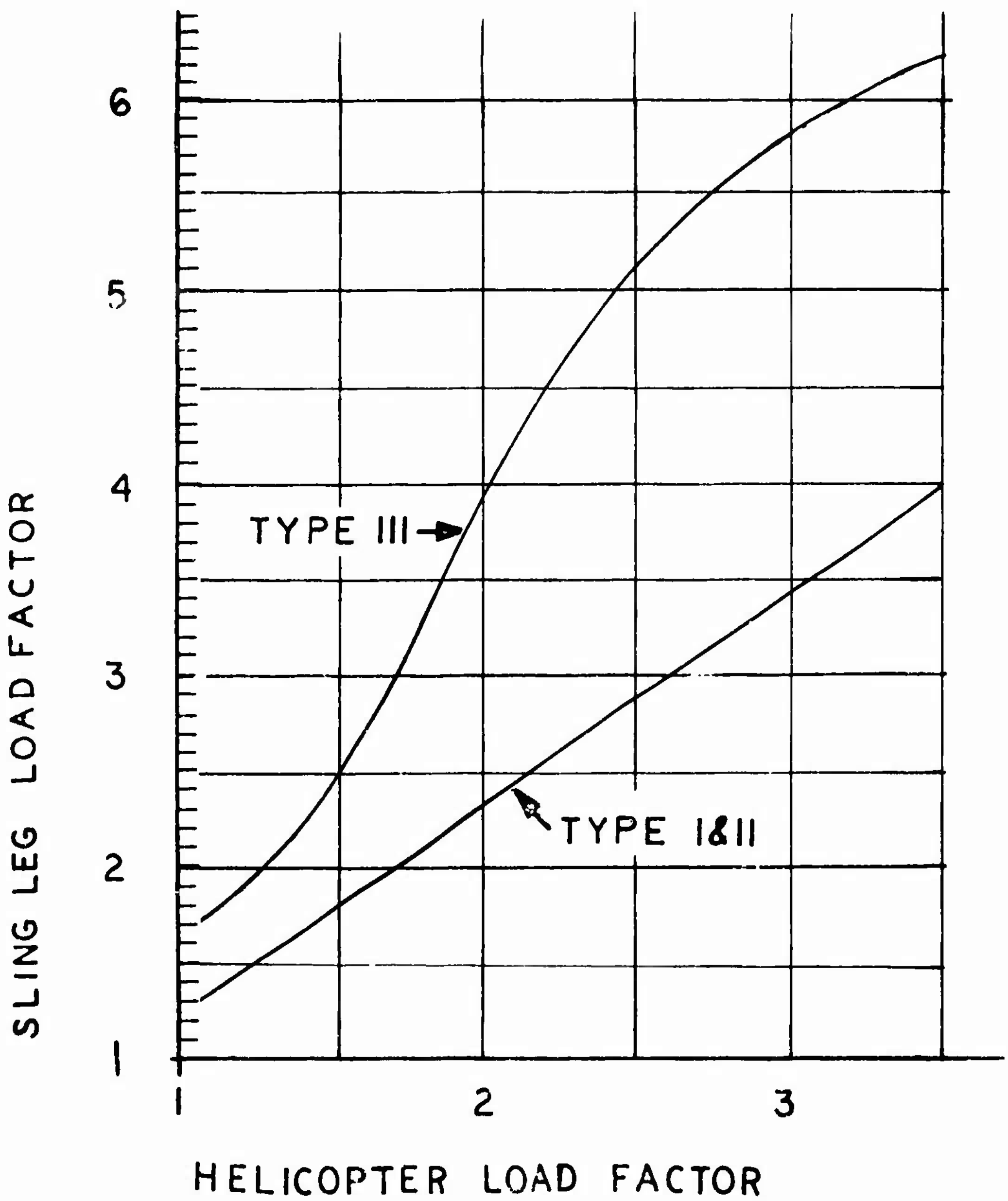
The textile portions of nylon rope sling legs need further factors to compensate for degradation due to environment in accordance with Reference 1 (page 31). Thus, so that the rope will retain a residual strength at the end of its life equal to the calculated required ultimate, the latter value is divided by .85 and .94 to allow for the effects of ultraviolet and temperature, respectively. This gives the revised ultimates for the rope as new. Other environmental factors and pin diameter factors are made unity by appropriate design.

All sling legs, irrespective of size or material, are to be positively adjustable in length from 18 feet to 22 feet in accordance with Reference 1 (page 4), this being achieved by the grab hook and chain loop method.



Reproduced from Figure 22 of Reference 1, page 37.

Figure 20. Sling Apex Fitting or Pendant Load Factor Curves.



Reporduced from Figure 23 of Reference 1, page 38.

Figure 21. Sling Leg Load Factor Curves.

The slings must be readily convertible from single-point to multi-point configuration (i.e., a pair of two-legged slings, each with its own apex fitting), as shown in Figure 2, in order to achieve compatibility with aircraft having two integral hoists.

6K Wire Rope Sling

This size sling can be used for carrying such loads as small trucks and most trailer-mounted equipment, under UH-1, UTTAS and CH-47 helicopters, by means of either the 6K or the 20K pendant. Its apex fitting must therefore be readily attachable to, and releasable from, the hook of both pendants. The worst-case load for this sling (exemplified by an empty container weighing just under 6,000 pounds) would be a Type III, as defined in Appendix V of Reference 1. The worst-case flight condition for this sling is dictated by the capability of the UH-1 which has a maximum aircraft load factor of 3.0g, as shown in Appendix I of Reference 1. Consequently, the sling must be designed with load factors appropriate to Type III loads at 3.0g. Figures 22 and 23 of Reference 1 indicate values of 5.28 and 5.78, respectively, for the apex fitting and the sling leg. The ultimate strength requirements are therefore 6,000 x 5.28 x 1.5 (= 47,250) for the apex fitting and 6,000 x 5.78 x .6 (= 20,800) for each sling leg.

As mentioned earlier (page 7), the 6K sling can carry Type I and Type II loads in excess of 6,000 pounds, the limit being dictated by the rating of the aircraft on which it is used. Extrapolating the sling leg tension factor line for Type I and II loads on Figure 21 yields a value of 4.00 for a 3.5g aircraft such as UTTAS. The limit for the sling in these circumstances becomes 6,000 x 5.78/4.00 = 8,670, which is well above the UTTAS payload requirement of 7,000 pound. The limit for Type III loads remains at 6,000 pounds, which exceeds any existing Type III loads for UTTAS. Hence, the 6K sling, as designed, is fully capable of satisfying the currently envisaged load carrying requirements of UTTAS.

6K Nylon Rope Sling

The design criteria for this sling are the same as for the 6K wire rope sling, except that the aforementioned environmental factors are applied to the textile portion, giving an ultimate strength requirement of 20,800/.85 x .94 (= 26,000) for each sling leg rope, as new.

25K Wire Rope Sling

This size sling can be used for carrying such loads as 2-1/2-ton trucks, large semitrailers, vans, most engineer equipment, and most Army aircraft, under CH-47, CH-54 and CH-62 type helicopters, by means of the 20K pendant in the case of the CH-47 but not necessarily for the CH-54 and CH-62, which have integral decouplers. Its apex fitting must therefore be readily attachable to, and releasable from, the hook of the 20K pendant and the cargo hooks of the CH-54 and CH-62. The worst-case load for this sling would be Type II, as defined in Appendix V of Reference 1 (although Type III loads may be carried, they would all be of such low weight as to be less critical than a Type II at 25,000 pounds). The worst-case flight condition for this sling is dictated by the capability of the CH-62, which has a maximum aircraft load factor of 2.5g. Consequently, the sling must be designed with load factors appropriate to Type II loads at 2.5g. Figures 22 and 23 of Reference 1 indicate values of 2.96 and 2.87, respectively, for the apex fitting and the sling leg. The ultimate strength requirements are therefore 25,000 x 2.96 x 1.5 (= 111,000) for the apex fitting and 25,000 x 2.87 x .6 (= 43,000) for each sling leg.

<u>25K Nylon Rope Sling</u>

The design criteria for this sling are the same as for the 25K wire rope sling, except that the aforementioned environmental factors are applied to the textile portion, giving an ultimate strength requirement of 43,000/.85 x .94 (= 53,800) for each sling leg rope, as new.

<u>60K Wire Rope Sling</u>

This size sling can be used for carrying such loads as heavy trucks (loaded), heavy engineer equipment, and most tactical vehicles, under CH-62 type helicopters, without a pendant since the CH-62 has integral decoupled hoists. Its apex fitting must therefore be readily attachable to, and releasable from, the cargo hook of the CH-62. The worst-case load for this sling would be Type II, as defined in Appendix V of Reference 1, by the same reasoning as for the 25K sling. The worst flight condition for this sling is dictated by the capability of the CH-62, which has a maximum aircraft load factor of 2.5g. Consequently, the sling must be designed with load factors similar to the 25K sling. The ultimate strength requirements are therefore 60,000 x 2.96 x 1.5 (= 266,400) for the apex fitting and 60,000 x 2.87 x .6 (= 103,300) for each sling leg.

<u>110K Wire Rope Sling</u>

This size sling can be used for carrying such loads as tanks, tank recovery vehicles, prime movers, heavy self-propelled guns, and heavy construction equipment, under future-developed HLH type helicopters, without a pendant since they would presumably have integral decoupled hoists. Its apex fitting must therefore be readily attachable to, and releasable from, the cargo hooks of such aircraft. The worst-case load for this sling would be

Type II, as defined in Appendix V of Reference 1, by the same reasoning as for the 25K sling. The worst flight condition for this sling is dictated by the capability of a developed HLH, which has a maximum aircraft load factor assumed to be 2.5g. Consequently, the sling must be designed with load factors similar to the 25K sling. The ultimate strength requirements are therefore 110,000 x 2.96 x 1.5 (= 488,400) for the apex fitting and 110,000 x 2.87 x .6 (= 189,400), or each sling leg.

PENDANTS

Discussion

This section quotes the derivations and actual values of the factors used to determine the pendant spring rate and ultimate strength requirements, and reiterates the compatibility requirements which dictate physical dimensions. It covers the 6K and 20K pendants.

Pendants must be designed with a spring rate low enough to minimize the effect of vertical bounce oscillations, in accordance with the principles outlined in Appendix IV of Reference 1. They must also be short enough to preclude the possibility of the hook hitting the rotor if it should be propelled in that direction following a failure of the hook or sling apex fitting. The decoupling requirements depend on the load range and aircraft type with which the pendant is associated, and they are specified below for each size of pendant.

To determine the ultimate strength requirement of a complete pendant assembly, the nominal capacity is first multiplied by the load factor derived from the relevant graphs in Reference 1 (see Figure 20), then by the minimum ultimate factor of safety (1.5 for this equipment) in accordance with Reference 3 (page 3).

It should be noted that the load factor graph for pendants is also the graph for sling apex fittings, as would be expected. Use of these graphs involves a consideration of the worst type of load that the pendant will experience and also the highest aircraft load factor of any helicopter on which the pendant will be fitted. These two parameters are specified below for each size of pendant.

The textile portions of pendants need further factors to compensate for degradation due to environment in accordance with Reference 1 (page 31). Thus, so that the rope will retain a residual strength at the end of its life equal to the calculated required ultimate, the latter value is divided by .85 and .94 to allow for the effects of ultraviolet and temperature respectively. This gives the revised ultimates for the rope as new. Other environmental factors, and pin diameter factors, are made unity by appropriate design.

The swivel hooks at the lower ends of the pendant have load beams which must automatically lock when the load exceeds specific values. The force required to release the unlocked beam is the same for both sizes of pendants, namely, 10 pounds maximum for the ground manual release handle and 20-50 pounds for the normal release handle. The latter is a common item on both sizes of pendant and must incorporate a safety break to protect the operator if he is holding the handle when an emergency jettison of the load from the aircraft cargo hook occurs. The break is designed to separate at 85-130 pounds. (All the values mentioned were chosen arbitrarily.)

6K Pendant

This size pendant is used in conjunction with the 6K sling on UH-1, UTTAS and CH-47 helicopters. Its apex fitting must therefore be readily attachable to, and releasable from, the cargo hooks of these aircraft, and also its own hook so that two can be used in tandem. It must be designed with load factors corresponding to those of the apex fitting of the sling with which it is associated, i.e., 6K. The ultimate strength requirement is therefore 6,000 x 5.28 x 1.5 (= 47,520). However, as in the case of nylon rope slings, environmental factors are applied to the textile portion, giving an ultimate strength requirement of 47,520/.85 x .94 (= 59,000) for each pendant rope, as new. The pendant must be less than 14-1/2 feet long to clear the rotor of the UH-1 in the event of accidental loss of payload.

The overall length of the pendant is nominally 14 feet unloaded, and the spring rate is governed by the decoupling requirements of loads between 2,500 and 4,000 pounds on the UH-1. As shown in Reference 1 (page 46), the spring rate for this size sling must not exceed 2,000 pounds per inch.

The pendant hook must swivel with a minimum frictional torque of 7 pound-feet, and the load beam must lock in the closed position at loads over 900 pounds ($\pm$300).

20K Pendant

This size pendant is used in conjunction with the 25K sling on CH-47 helicopters. (A 6K sling will also fit the hook.) Its apex fitting must therefore be readily attachable to, and releasable from, the cargo hook of this aircraft, and also its own hook so that two can be used in tandem. It must be designed with load factors corresponding to those of the apex fitting of the sling with which it is associated, i.e. 25K.

The ultimate strength requirement is therefore 20,000 x 2.96 x 1.5 (= 88,800). However, as in the case of nylon rope slings, environmental factors are applied to the textile portion, giving an ultimate strength requirement of 88,800/.85 x .94 (= 111,000) for each pendant rope, as new. The pendant must be less than 18-1/2 feet long to clear the rotor of the CH-47 in the event of accidental loss of payload.

The overall length of the pendant is nominally 17 feet unloaded, and the spring rate is governed by the decoupling requirements of loads between 8,000 and 19,000 pounds on the CH-47. As shown in Reference 1 (page 46), the spring rate for this size sling must not exceed 4,000 pounds per inch.

The pendant hook must swivel with a minimum frictional torque of 10 pound-feet, and the load beam must lock in the closed position at loads over [illegible],000 pounds ($\pm$500).

NONDESTRUCTIVE TESTER

The design criteria for the nondestructive test device or method can be summarized by the following definition:

> "Nondestructive testing is the examination and interpretation of some physical characteristic of a material. The characteristic shall have changed in some physical manner if the conditions to which the material has been subjected cause a deleterious effect. This examination shall result in no deformation of the material's functional performance."

In the case of the nondestructive test requirements for the slings, the above criteria must of course be coupled with considerations of cost, ease and speed of operation, validity, reliability, and practicability at the appropriate level of maintenance.

RECOMMENDED PRELIMINARY DESIGNS

SLINGS

Discussion

The trade-off studies showed that the sling leg material should be stainless steel wire rope, the apex fitting should be a solid forged-steel split pear shape with circular cross section, and the sling length adjuster should consist of a chain and grab hook with spring-loaded keeper.

It was then necessary to consider the assembly of these items (as shown in Figure 16) to insure that they were compatible and suitable for the four sizes of sling under consideration.

No problem was evident in mating the stainless steel wire rope to the sling length adjuster. The eye end of a wire rope is less bulky than that of a textile rope or webbing; consequently, the grab hook and shackle could be closer together than shown on Figure 15b (which depicts a webbing sling). A shorter bolt could therefore be used, and its diameter reduced accordingly. It will be noted on Figures 3 and 4 that the use of a grab link in conjunction with small-diameter ropes necessitates bowing the sides of the grab link to provide the necessary clearance for threading the chain. This is somewhat undesirable, and leads to the conclusion that the winning candidates for sling material and length adjuster were eminently compatible. To make the junction of sling and length adjuster more stable under no-load conditions, a spool was inserted in the sling thimble. This simply filled the gap between the bolt and the thimble to provide a more manageable assembly. With appropriate scaling, Figure 16 can be applied to all four sizes. The only exception is that the 110K sling has no length adjuster. It was reasoned that this size would be needed for very few loads, and it would be preferable to provide each particular load type with a unique sling, having nonadjustable legs of appropriate length. This policy was largely prescribed by the fact that any form of length adjuster commensurate with a fully factored 110K sling would be inordinately heavy.

The stainless steel wire rope sling was also fully compatible with the chosen apex fitting. In the trade-off for the latter, the final form of the fitting depended on the outcome of the sling material trade-off. As a result, the successful candidacy of the stainless steel wire rope dictated the use of the preferred apex fitting rather than its variant.

From the design study (which established the format for the slings) and the design criteria (which specified their performance), the sizes, strength requirements, and weights of the principal components were assessed. Details are given below.

(The total estimated weight figures were applicable at the time of the recommended preliminary design phase, and were refined subsequently in the actual prototype design phase.)

6K Sling

The significant data for the preliminary recommended 6K sling were:

Apex Fitting: 7/8-in. stock steel forging

Required ultimate, 47,520 lb; estimated weight, 3.00 lb

Sling leg: 1/2-in.-dia. stainless steel 6 x 41 cable

Required ultimate, 20,800 lb; estimated weight, 8.75 lb

Chain: 1/4-in.-dia. steel alloy, welded

Required ultimate, 10,400 lb; estimated weight, 5.88 lb

Commercial thimbles and sleeves of appropriate size to be fitted to the cable

Grab hook and associated shackle to be steel forgings compatible with the chain

The total estimated weight for the 6K sling assembly was 74.40 lb.

25K Sling

The significant data for the preliminary recommended 25K sling were:

Apex fitting: 1-1/2-in. stock steel forging

Required ultimate, 111,000 lb; estimated weight, 7.00 lb

Sling leg: 3/4-in.-dia. stainless steel 6 x 41 cable

Required ultimate, 43,000 lb; estimated weight, 20.80 lb

Chain: 3/8-in.-dia. steel alloy, welded

Required ultimate, 21,500 lb; estimated weight, 10.45 lb

Commercial thimbles and sleeves of appropriate size to be fitted to the cable

Grab hook and associated shackle to be steel forgings compatible with the chain

The total estimated weight for the 25K sling assembly was 162.16 lb.

60K Sling

The significant data for the preliminary recommended 60K sling were:

Apex fitting: 1-3/4-in. stock steel forging

Required ultimate, 266,400 lb; estimated weight, 24.50 lb

Sling leg: 1-1/8-in.-dia. stainless steel 6 x 41 cable

Required ultimate, 103,300 lb; estimated weight, 49.10 lb

Chain: 5/8-in.-dia. steel alloy, welded

Required ultimate, 51,650 lb; estimated weight, 30.30 lb

Commercial thimbles and sleeves of appropriate size to be fitted to the thimble

Grab hook and associated shackle to be steel forgings compatible with the chain

The total estimated weight for the 60K sling assembly was 440.70 lb.

110K Sling

The significant data for the preliminary recommended 110K sling were:

Apex fitting: 2-in. stock steel forging

Required ultimate, 488,400 lb; estimated weight, 41.10 lb

Sling leg: 1-1/2-in.-dia. stainless steel 6 x 41 cable

Required ultimate, 189,400 lb; estimated weight, 77.00 lb

Commercial thimbles and sleeves of appropriate size to be fitted to the thimble

Chain, grab hook and associated shackle not required

The total estimated weight for the 110K sling assembly was 602.30 lb.

PENDANTS

Discussion

The trade-off studies showed that the pendant material should be coated, square-braided nylon rope, the apex fitting should be an integral eye splice lined with a metal thimble, and the pendant hook should be of conventional design with a mechanical cable release system operable from the apex fitting.

The compatibility of the pendant with the sling apex fitting depends largely on the pendant hook. The latter would therefore be designed, or be of an existing design, to engage satisfactorily with the chosen sling apex fitting. No problem was evident in this area, as the sling apex fitting was of nonbulky material; and since it was a two-piece item, the interface with the hook could be optimally profiled. The problem of mating the sling apex fitting to the pendant hook was therefore resolved, and it was only necessary to check that the hook could be satisfactorily joined to the chosen pendant material, i.e., square-braided nylon rope. This, again, was a matter of hook design and presented no problems. Figure 18 illustrates the attachment of a webbing pendant to a hook. A rope pendant would be attached by making an eye splice and, if necessary, lining it with a metal thimble or polyvinyl chloride sleeve (as shown in Figure 19). Compared with the corresponding webbing eye, the rope eye requires slightly more depth but less width (see Figures 18 and 19). Hence the eyebolt could be shorter and of less diameter. This fact provides some reinforcement for the judgment in favor of rope for pendant material. The hook had to incorporate a swivelling facility, to prevent twisting of the pendant, and also have a connection with a release cable running down the pendant.

The design of the apex fitting for the pendant was influenced by the type of hook used on the helicopter. The observations made in the trade-off for sling apex fittings are generally applicable to pendants. The first option considered was to make an integral eye splice, lined with a metal thimble or polyvinyl chloride. The resulting cross section at the top of the eye had to be compatible with any relevant helicopter cargo hook, i.e., not to be too thick to pass the hook throat, nor too wide to impede the keeper. A separate forged steel fitting would be designed if necessary.

From the design study (which established the format for the pendants) and the design criteria (which specified their performance), the sizes, strength requirements, and weights of the principal components were assessed. Details are given below. (The total estimated weight figures were applicable at the time of the recommended preliminary design phase, and were refined subsequently in the actual prototype design phase.)

6K Pendant

The significant data for the preliminary recommended 6K pendant were:

Apex fitting: 1-in. thimbled eye splice on pendant rope or separate forged-steel fitting

Required ultimate, 47,520 lb; estimated weight, 1.05 lb

Pendant rope: 3-1/2-in.-circ. square-braided nylon rope, coated

Required ultimate, 59,000 lb; estimated weight, 5.50 lb

Swivel hook: 2-in.-dia. pin capacity steel forging

Required ultimate, 47,520 lb; estimated weight, 20.00 lb

The total estimated weight for the 6K pendant assembly was 27.35 lb.

20K Pendant

The significant data for the preliminary recommended 20K pendant were:

Apex fitting: 2-1/4-in. thimbled eye splice on pendant rope or separate forged-steel fitting

Required ultimate, 88,800 lb; estimated weight, 6.00 lb

Pendant rope: 7-in. circ. square-braided nylon rope, coated

Required ultimate, 111,000 lb; estimated weight, 27.40 lb

Swivel hook: 2-1/2-in.-dia. pin capacity steel forging

Required ultimate, 88,800 lb; estimated weight, 60.00 lb

The total estimated weight for the 20K pendant assembly was 97.90 lb.

NONDESTRUCTIVE TESTER

The design study showed that only wire ropes could be tested nondestructively, and the only methods worth considering used either magnetometers or eddy current devices. The former were rejected, however, since they did not give reliable results for abrasion damage. An alternative procedure involving visual inspection, followed by the use of Roebling charts, was found to be valid but time consuming.

Three companies were found to make eddy current devices; namely, McPhar Manufacturing, Branson Instruments, and Magnetic Analysis Corp.

The Minimac, manufactured by the Magnetic Ana[illegible] Corp., was selected for trials, on the grounds of pri[illegible] [illegible]ailability.

ACTUAL PROTOTYPE DESIGNS

SLINGS

Discussion

The differences between the recommended preliminary designs and the prototype designs are outlined below.

The apex fitting was changed from a solid forged steel split pear shape to a twin-shackle device described in detail later. The shackles carry two sling legs each and are suspended from a common pin which forms the attachment point for the sling to the pendant hook or helicopter cargo hook. This has advantages in respect of manufacture, stress and operation, as explained in Design Study. The concept was applied to all three sling sizes, but the 60K version was seen to involve high forging costs owing to the size of the dies. (The original design would have encountered similar problems.) Consequently, for prototype purposes, it was decided to substitute a conventional connecting link and quadruple shackle arrangement. The link is a commercial oval-shaped ring of circular cross section, and the shackles are also of commercial type, all items being of a size appropriate to the 60K sling.

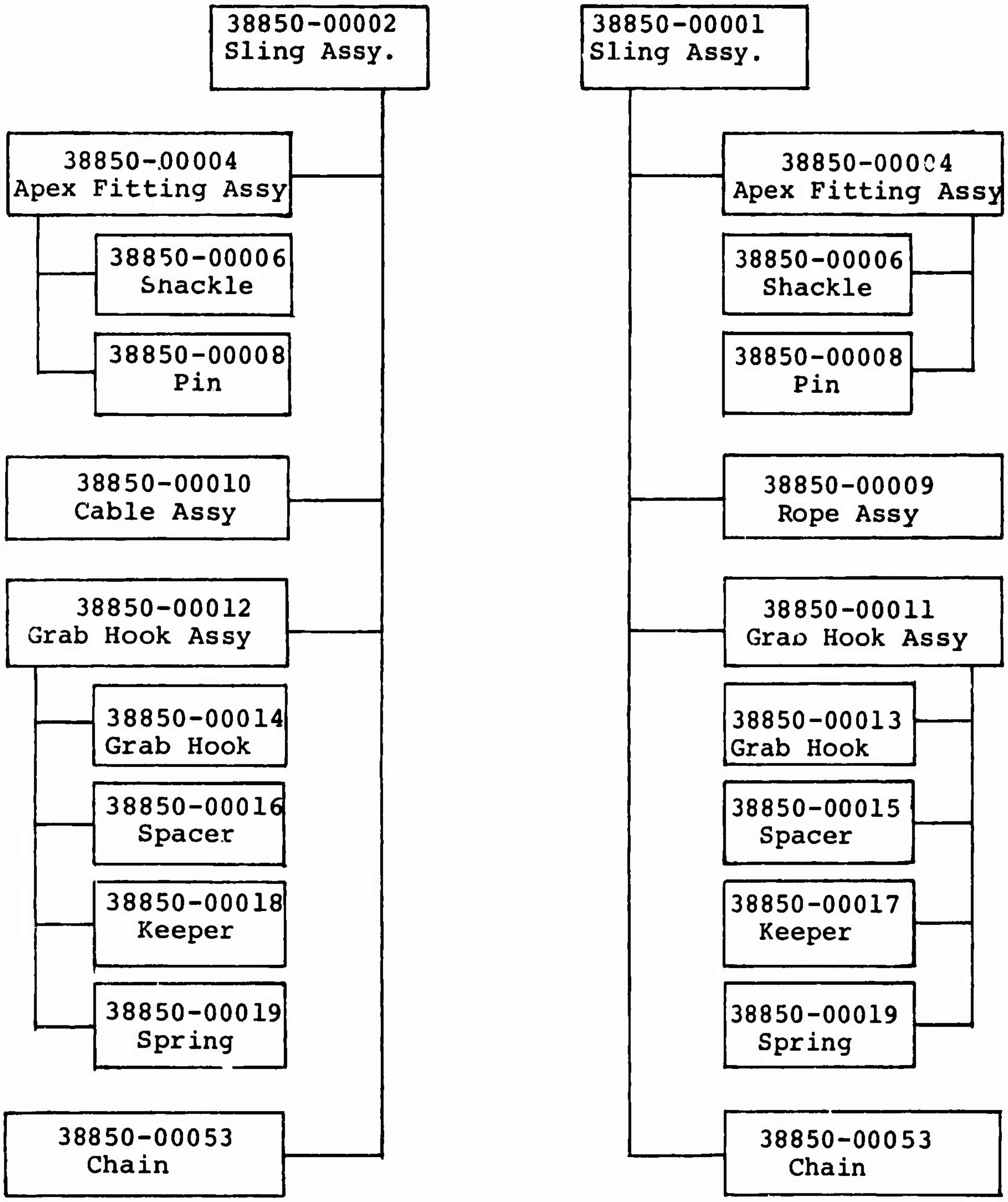
The recommended sling leg material, namely, stainless steel wire rope, was retained. However, an alternative design in nylon rope was authorized in order to obtain a comparison in terms of cost, operation and life. The nylon rope slings are in 6K and 25K sizes only, and have some component features in common with the wire rope slings. Eye-splicing remained the preferred method of attaching end fittings to either type of rope, due to strength or weight considerations, as explained in Design Study.

The grab hook was made into a common forging with its associated shackle as explained in Design Study.

Further generic details of the prototype slings are given below. Figure 22 gives a breakdown of sling drawings. Figure 23 shows a typical prototype wire rope sling assembly, and Figure 24 shows a typical prototype nylon rope sling assembly.

Each sling consists of an apex fitting assembly, four wire rope or nylon rope assemblies, four grab hook assemblies, and four chains.

The apex fitting assemblies for the 6K and 25K sling sizes are each made up from a pair of special steel shackles suspended from a common steel pin, which engages the relevant pendant hook or aircraft hook. The cross section of the shackle stock is generally circular, but broadens to a semielliptic shape at the bottom to provide a good compromise bearing radius for



Wire Rope Sling   Nylon Rope Sling

Figure 22. Wire and Nylon Rope Sling Drawing Breakdown.

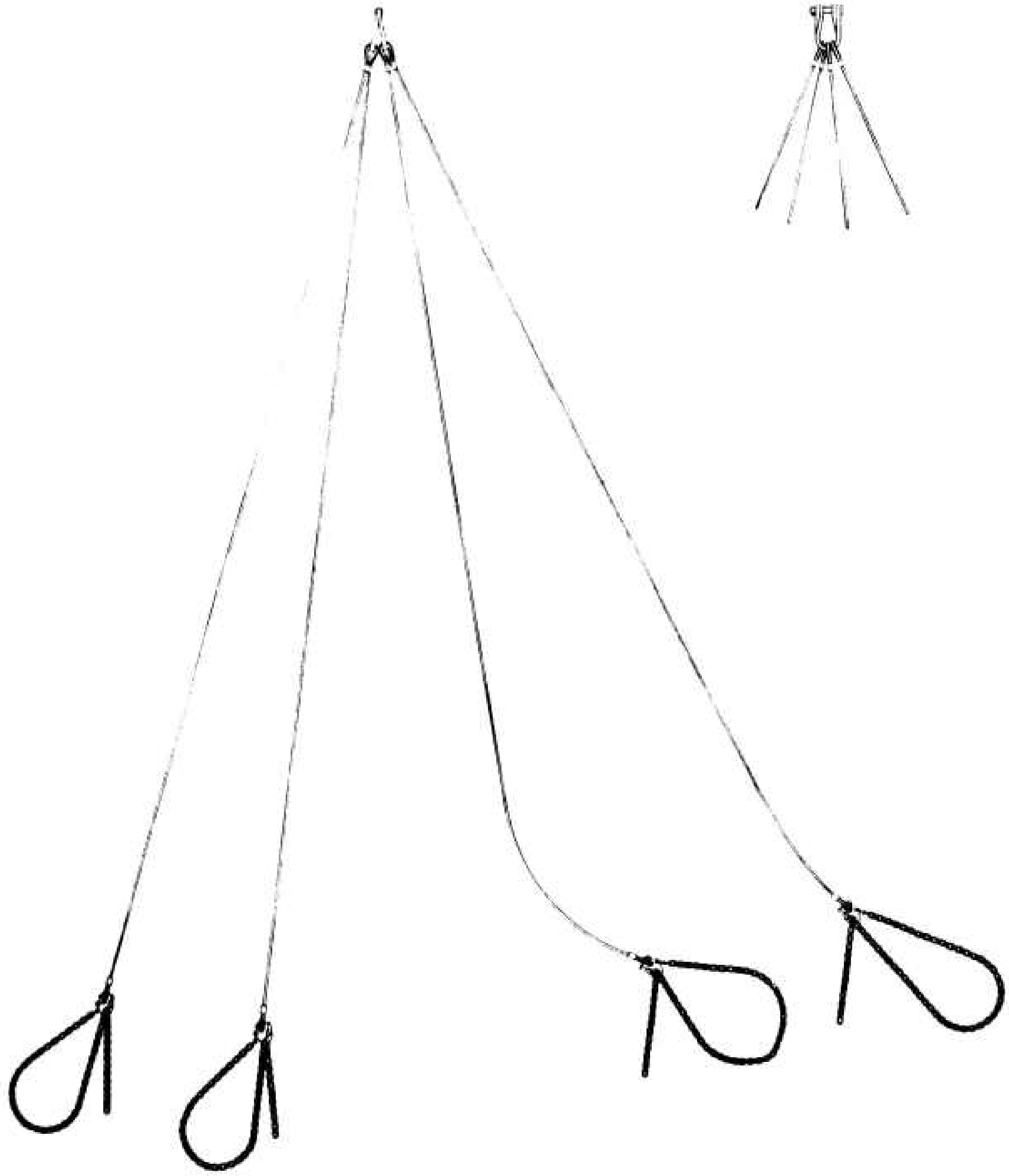


Figure 23. Typical Prototype 18- to 22-Foot Wire Rope Sling.

Figure 24. Typical Prototype 18- to 22-Foot Nylon Rope Sling.

either wire ropes with standard thimbles or textile ropes with polyurethane tube thimbles. Either type of rope can thus be used on the same shackle design. The apex fitting assembly for the 60K sling size is made up from a regular weldless forged alloy steel master-link, of oval shape (e.g., Crosby-Laughlin A-342), and four regular galvanized steel safety chain shackles (e.g., Crosby-Laughlin G-2150). The latter must be replaced by larger shackles with sleeved bolts if textile ropes are substituted for wire ropes.

The wire rope assemblies are of 7 x 19 or 6 x 41 IWRC regular lay stainless steel type 302/304. At each end is a flemish eye splice secured by a stainless steel sleeve and lined by a galvanized steel thimble (e.g., Crosby-Laughlin G-414).

The nylon rope assemblies are of double-braided construction as specified in Reference 10, coated with polyurethane to prevent ingress of abrasives and to protect against ultraviolet radiation. At each end is a standard eye splice which is covered by a thick-walled polyurethane tubing to act as a load bearing-thimble, to reduce the rate of wear in this highly critical area.

The grab hook assemblies provide a means for attaching the wire ropes to the chains and for varying the length of the chains. The grab hook itself is a steel forging. The upper part is a yoke which can carry a pin and spacer to attach the sling lower eye. The bottom part has an eye at one side for attachment of one end of the chain using a connecting link (e.g., Crosby-Laughlin G-336). At the other side is a hook into which any selected link in the chain can be inserted, according to the length of chain loop required. The chain link is retained in the grab hook by a spring-loaded keeper. The same spring is used on all three sizes.

The grab hook assemblies for the nylon rope slings are similar to those used on the corresponding size of wire rope sling except where dimensional growth is necessary in order to accommodate bulkier sling eyes. Hence the grab hook yokes are wider and deeper, and the keepers are therefore slightly longer. Also, the spacers are eccentrically bored tubes with an outside diameter large enough to provide adequate bend radius for the nylon ropes. They also reinforce the grab hook pins so that the same diameter pins can be used as on the wire rope sling grab hooks, despite the increased span.

The chains for both wire rope and nylon rope slings are welded steel alloy, conforming dimensionally to Federal Spec. RR-C-271a Type 1, Grade C Class 1, but with breaking loads about 10% higher. The bar size of material is correspondingly high, but still within the limits permitted by the specification. Chains for all three sizes of sling are nominally 8 feet long, thus providing length adjustment from 0 to 4 feet. They are attached as described under grab hook assemblies.

6K Wire Rope Sling

Principal dimensions, weight estimates, and design criteria for the main assemblies are given in Tables IX, X, XII, XIV, Column 1.

The total estimated weight for the 6K wire rope sling is 78.95 lb. This is 6% higher than the preliminary design, mainly due to the grab hook redesign.

6K Nylon Rope Sling

Principal dimensions, weight estimates, and design criteria for the main assemblies are given in Tables IX, XI, XIII, XIV, Column 1.

The total estimated weight for the 6K nylon rope sling is 83.79 lb.

25K Wire Rope Sling

Principal dimensions, weight estimates, and design criteria for the main assemblies are given in Tables IX, X, XII, XIV, Column 2.

The total estimated weight for the 25K wire rope sling is 174.00 lb. This is 7% higher than the preliminary design, mainly due to the grab hook redesign.

25K Nylon Rope Sling

Principal dimensions, weight estimates, and design criteria for the main assemblies are given in Tables IX, XI, XIII, XIV, Column 2.

The total estimated weight for the 25K nylon rope sling is 173.70 lb.

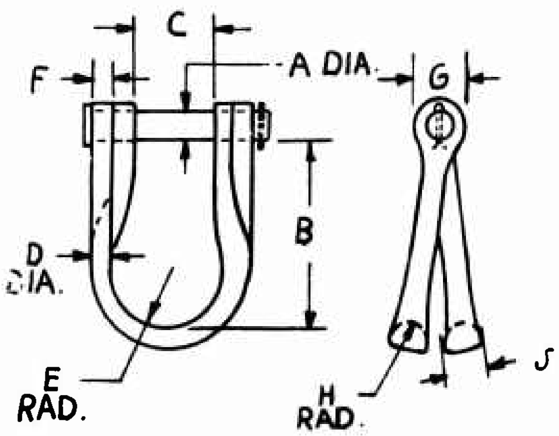
60K Wire Rope Sling

Principal dimensions, weight estimates, and design criteria for the main assemblies are given in Tables IX, X , XII, XIV, Column 3.

The total estimated weight for the 60K wire rope sling is 480.46 lb. This is 9% higher than the preliminary design, mainly due to the apex fitting redesign.

TABLE IX. SLING APEX FITTING ASSEMBLY DATA				
		Sling Capacity		
		6K	25K	60K *
(A) Top Pin Diameter	in.	1.125	1.500	2.000
(B) Hook Clearance Vertical	in.	7.50	7.62	9.80
(C) Hook Clearance Horizontal	in.	2.75	3.26	3.26
(D) Stock Diameter	in.	.75	1.12	1.37
(E) Shackle Loop Radius	in.	2.00	2.50	3.18
(F) Shackle Lug Thickness	in.	.62	.87	1.20
(G) Shackle Lug Diameter	in.	1.74	2.50	3.24
(H) Rope Bearing Radius	in.	.75	1.00	1.44
(J) Rope Bearing Width	in.	1.30	1.95	2.25
Estimated Weight	lb	8.47	20.66	45.00
Safety Factor		1.50	1.50	1.50
Flight Load Factor		5.28	2.96	2.96
Required Ultimate	lb	47,520	111,000	266,400

* No hardware was made for this design. Standard commercial items as shown below were substituted.



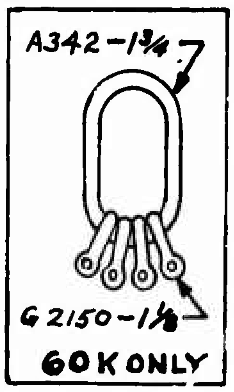


TABLE X. WIRE ROPE SLING-WIRE ROPE LEG ASSEMBLY DATA

		Sling Capacity		
		6K	25K	60K
(A) Rope Diameter	in.	1/2	3/4	1-1/8
(B) Length Between Eyes	in.	216.	216.	216.
Estimated Weight	lb	9.66	22.34	61.57
Leg Factor		.60	.60	.60
Flight Load Factor		5.78	2.87	2.87
Required Ultimate	lb	20,800	43,000	103,300

The above data refer to a four-legged sling.

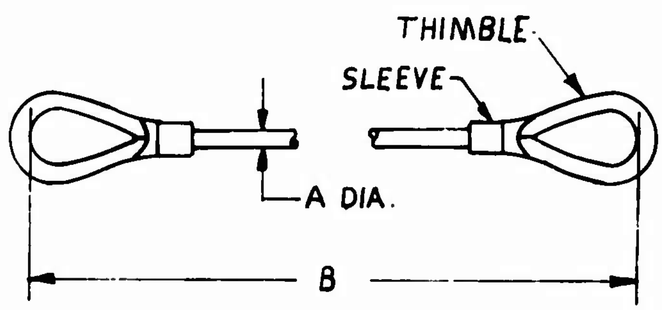


TABLE XI. NYLON ROPE SLING-NYLON ROPE LEG ASSEMBLY DATA

		Sling Capacity		
		6K	25K	60K *
(A) Rope Circumference	in.	3-1/4	4-1/2	7
(B) Rope Diameter, Nom.	in.	1-1/16	1-1/2	2-1/4
(C) Eye Pin Diameter, Min.	in.	2.3	2.4	2.6
(D) Length Between Eyes	in.	216.	216.	216.
Estimated Weight	lb	10.5	20.7	55.0
Leg Factor		.60	.60	.60
Flight Load Factor		5.78	2.87	2.87
Ultraviolet Factor		.85	.85	.85
Temperature Factor		.94	.94	.94
Required Ultimate, Spliced	lb	26,000	53,800	129,300

* No hardware was made for this design.

The above data refer to a four-legged sling.

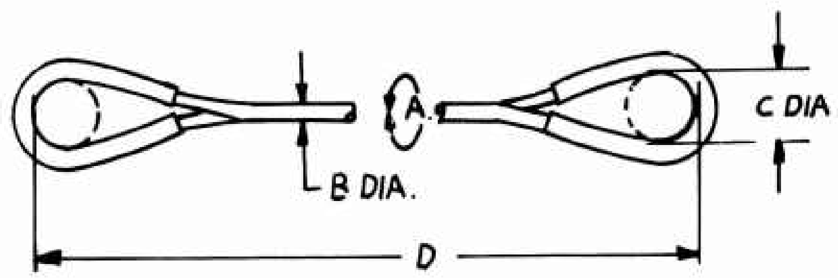


TABLE XII. WIRE ROPE SLING-GRAB HOOK ASSEMBLY DATA

		Sling Capacity		
		6K	25K	60K
(A) Top Pin Diameter	in.	.50	.75	1.00
(B) Rope Space Vertical	in.	.90	1.37	2.10
(C) Rope Space Horizontal	in.	.90	1.31	1.90
(D) Lower Eye Diameter	in.	.50	.65	1.00
(E) Chain Slot Radius	in.	.18	.25	.38
(F) Yoke Lug Thickness	in.	.38	.50	.80
(G) Yoke Lug Diameter	in.	1.25	1.50	2.50
(H) Hook Section Depth, Min.	in.	.90	1.10	1.70
(J) Hook Section Width	in.	.50	.62	.75
(K) Spacer Horizontal	in.	1.84	1.25	1.84
(L) Spacer Outside Diameter	in.	1.00	1.50	2.50
(M) Spacer Inside Diameter	in.	.83	1.33	2.33
Estimated Weight	lb	1.51	3.22	10.15
Leg Factor		.60	.60	.60
Flight Load Factor		5.78	2.87	2.87
Required Ultimate	lb	20,800	43,000	103,300
Connecting Link Size	in.	1/4	3/8	5/8

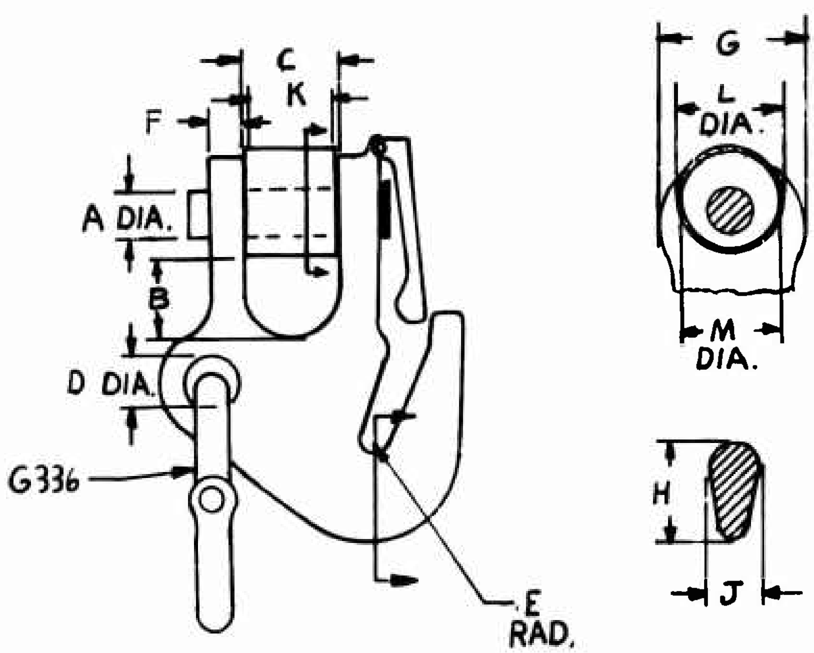


TABLE XIII. NYLON ROPE SLING-GRAB HOOK ASSEMBLY DATA

		Sling Capacity		
		6K	25K	60K *
(A) Top Pin Diameter	in.	.50	.75	1.00
(B) Rope Space Vertical	in.	1.50	2.25	3.25
(C) Rope Space Horizontal	in.	1.70	2.60	3.75
(D) Lower Eye Diameter	in.	.50	.65	1.00
(E) Chain Slot Radius	in.	.18	.25	.38
(F) Yoke Lug Thickness	in.	.38	.50	.80
(G) Yoke Lug Diameter	in.	1.25	1.50	2.50
(H) Hook Section Depth	in.	.90	1.10	1.70
(J) Hook Section Width	in.	.50	.62	.75
(K) Spacer Horizontal	in.	1.63	2.54	3.68
(L) Spacer Outside Diameter	in.	1.50	2.00	2.50
(M) Spacer Inside Diameter	in.	.51	.76	1.01
Estimated Weight	lb	2.13	4.56	14.2
Leg Factor		.60	.60	.60
Flight Load Factor		5.78	2.87	2.87
Required Ultimate	lb	20,800	43,000	103,300
Connecting Link Size		1/4	3/8	5/8

* No hardware was made for this design. The data given are provisional.

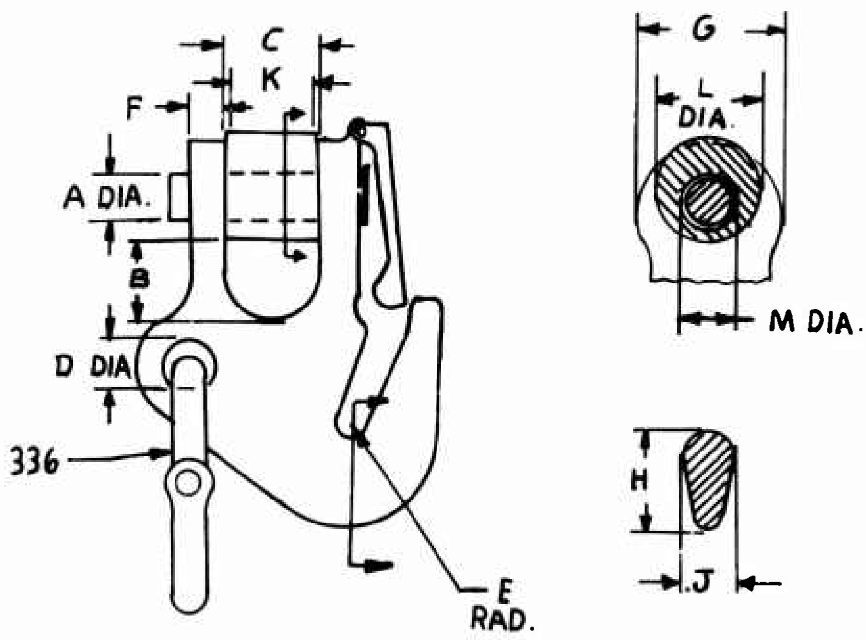
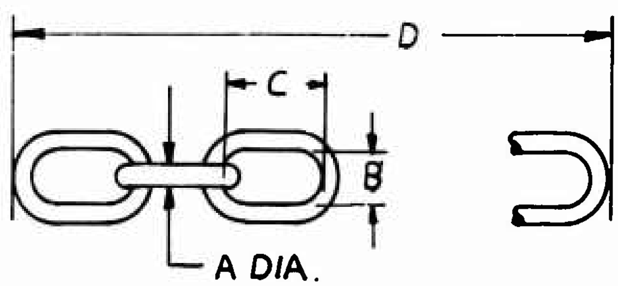


TABLE XIV. SLING CHAIN DATA

		Sling Capacity		
		6K	25K	60K
(A) Material Diameter, Nom.	in.	.250	.375	.625
(B) Link Inside Width, Max.	in.	.455	.650	.975
(C) Link Inside Length, Max.	in.	.975	1.333	1.820
(D) Length Overall, Nom.	in.	96.	96.	96.
Estimated Weight	lb	6.2	13.0	35.0
Leg Factor		.60	.60	.60
Flight Load Factor		5.78	2.87	2.87
Required Ultimate	lb	10,400	21,500	51,650



PENDANTS

Discussion

The differences between the recommended preliminary designs and the prototype designs are outlined below.

The apex fitting was intended to take the form of a thimble-reinforced eye splice on the pendant rope itself, but owing to a change in the rope specification and the impossibility of accommodating the rather bulky rope satisfactorily on all the relevant helicopter cargo hooks, a metal apex fitting was designed. At the top of the apex fitting are a steel bolt and spacer, which forms the load transfer point at the helicopter cargo hook. Their dimensions must be compatible with all the cargo hooks with which the pendant is to engage. At the bottom of the apex fitting is an aluminum saddle which forms the load transfer point for the pendant rope. Its upper surface is curved to provide an adequate bearing surface for the eye of the rope. The bolt and saddle are connected by side plates of sufficient length to provide vertical clearance for the tip of the longest cargo hook load beam when it swings down after release.

The recommended pendant rope material, namely, coated square-braided nylon rope, was replaced by a subsequently developed double-braided nylon rope. This has advantages in respect of elasticity, constructional symmetry, and coating facility as explained in Design Study.

The swivel hook remained substantially as recommended. The detail design and manufacture were executed by Eastern Rotorcraft Corporation. An added feature is a safety lock to prevent inadvertent release when loaded beyond a specified value.

The release system remained the same in principle, consisting of a mechanical cable routed through a duct on the pendant rope from the hook release lever to a handle at the apex fitting. To allow for expansion and contraction of the pendant rope, a take-up mechanism for the release cable (more complex than the system originally planned) was designed. The addition of the lock-on feature for the hook enabled the take-up mechanism to be divorced from the hook (where it was difficult to accommodate) and transferred to the apex fitting.

Further generic details of the prototype pendants are given below. Figure 25 gives a breakdown of pendant drawings. Figure 26 shows a typical prototype pendant assembly.

The apex fitting assemblies for both pendant sizes are fabricated from aluminum alloy side plates with a steel bolt and spacer at the top, to engage the aircraft hook, and an aluminum

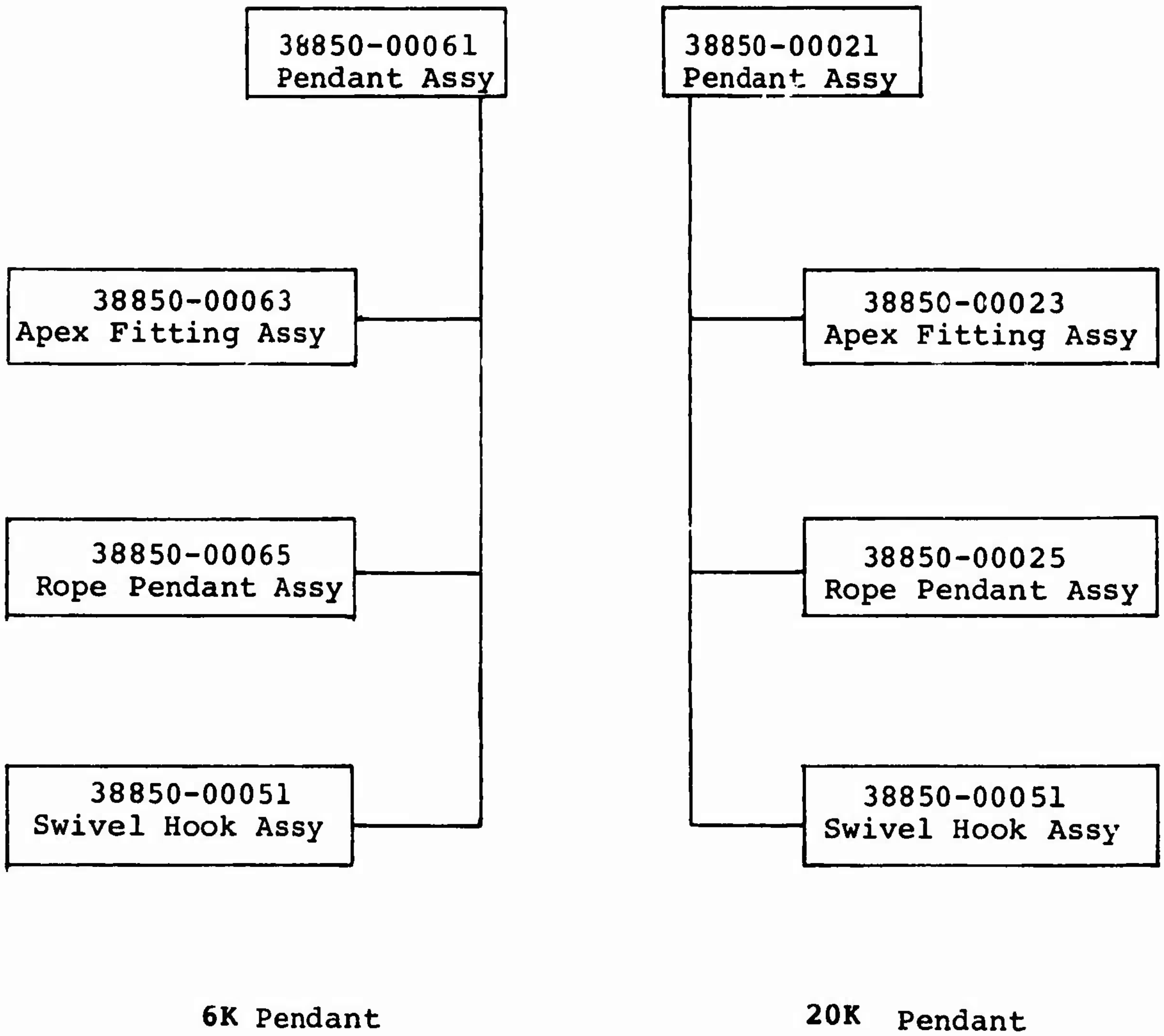


Figure 25. **Pendant Drawing Breakdown.**

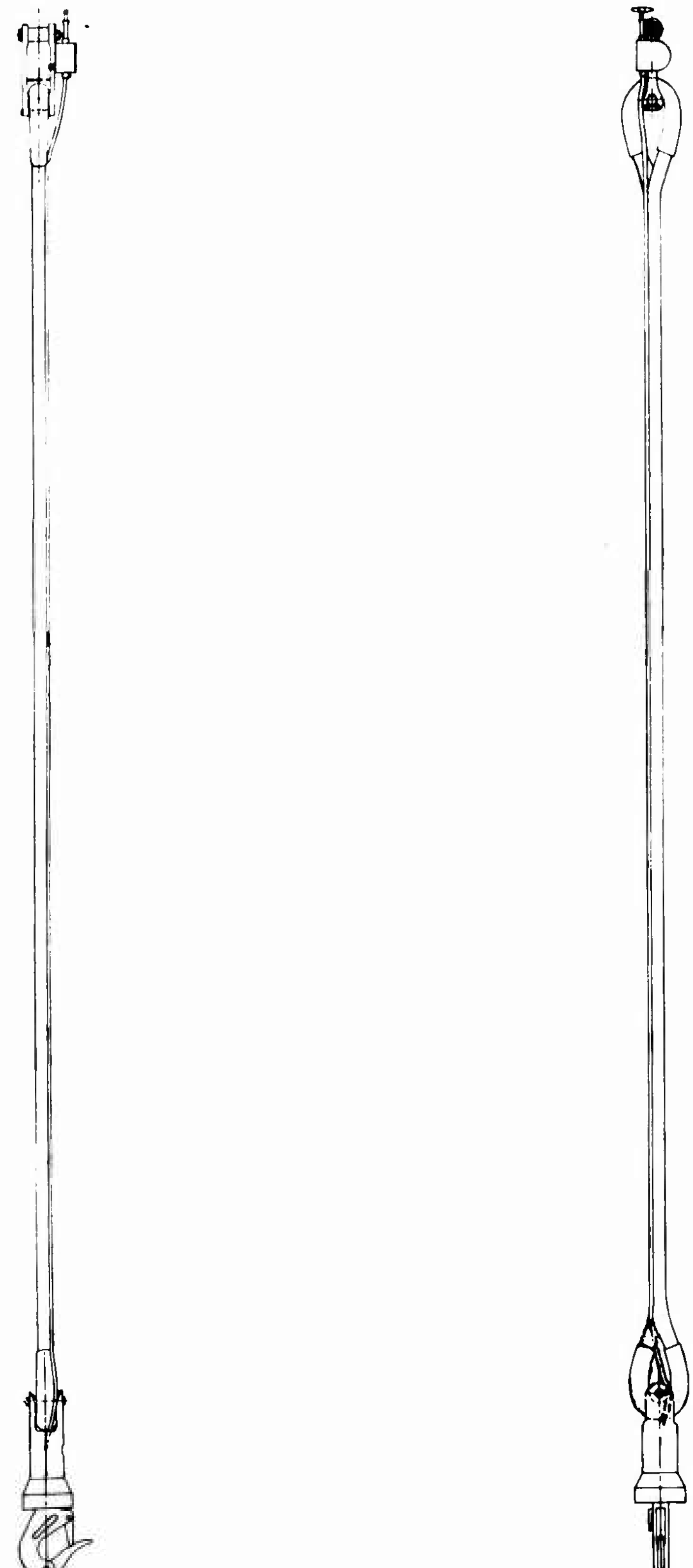


Figure 26. Typical 14- to 17- Foot Prototype Pendant Assembly.

alloy saddle at the bottom, to support the eye of the rope. Two small-diameter bolts secure the side plates at the bottom. An aluminum alloy cross bar spans the side plates at an appropriate distance above the bottom fitting to prevent accidental misplacement of the rope. A release cable take-up mechanism, which also provides stowage for the release handle, is attached to one side plate. This mechanism permits the pendant rope to stretch without pulling the cable.

The nylon rope assemblies are of double-braided construction, as specified in Reference 10, and are coated with polyurethane to prevent ingress of abrasives and protect against ultraviolet radiation. At each end is a standard eye splice which is covered by a thick-walled polyurethane tube to act as a load-bearing thimble. A 3/8-inch-bore polyurethane tube runs the full length of the rope, to form a duct for the release cable, and is attached by means of the aforementioned urethane coating. It then extends a few inches beyond the eyes, into the hook housing and take-up mechanism.

The swivel hook assemblies are based on an Eastern Rotorcraft Corporation design modified to a Sikorsky Specification Control Drawing. Release is accomplished by upward withdrawal of a detent from a vertical extension of the load beam. The withdrawal mechanism is actuated by a cable routed up through the release cable tube attached to the pendant rope, and terminating at the take-up mechanism. A ground release lever is also provided. The load beam is reset manually after release. Loads are attached to the hook by inserting the relevant fitting past a spring-loaded keeper. A single-row ball bearing provides the swivelling facility for the hook. The attachment to the pendant rope is by means of a pin and tube assembly. The hook incorporates a positive lock-on feature when under load.

The release system consists of the aforementioned release cable, a cable take-up mechanism, and a release handle. The cable is attached at its lower end to the swivel hook internal release lever, and its upper end is wound on a lever-mounted spool in the mechanism, such that it can be extended by 50 in. ±5 in. as the pendant rope stretches. A helical spring inside the spool provides retraction force. The release handle is connected by a safety cable, with a prescribed break strength, to a pivoted pawl which engages a ratchet on the spool periphery when the handle is pulled vertically approximately 1 in. This arrests the take-up mechanism, so that further upward movement of the handle lifts the locked spool and pulls the release cable. The same components are used on both sizes of pendant, except for the mechanism mounting plates, which are designed to fit the relevant apex fitting assembly.

6K Pendant

Principal dimensions, estimated weights, and design criteria for the main assemblies are given in Tables XV, XVI, XVII, XVIII, Column 1.

The total estimated weight for the 6K pendant is 73.34 lb. This is 170% more than the original design, mainly due to the extensive use of parts from the 20K pendant swivel hook.

20K Pendant

Principal dimensions, estimated weights and design criteria for the main assemblies are given in Tables XV, XVI, XVII, XVIII, Column 2.

The total estimated weight for the 20K pendant is 108.42 lb. This is 11% higher than the preliminary design, mainly due to the apex fitting redesign.

NONDESTRUCTIVE TESTER

The equipment used to perform nondestructive testing is made by Magnetic Analysis Corporation. It is described as an eddy current tester with phase and filter discrimination and has the trademark name of Minimac. It was designed to detect discontinuities in either ferrous or nonferrous wire, tubing, rod, bar stock, etc., where the inspection requirements are satisfied by a reasonable degree of discrimination ability. There are two components - a detector/control unit and a coil assembly - joined by a cable. The unit operates at a fixed frequency of 10 kHz. It utilizes a null detection system, which is phase and filter selective. The entire unit is solid state, and controls include balance, sensitivity, calibration, and an on/off switch. Flaw detection is indicated by a light. The coil assembly is a plastic annulus containing two flat coils separated by a distance which is optimized for the range of items to be tested. For the type of cables under consideration, the separation is 1/2 to 3/4 inch. The central hole of the unit must be able to accommodate the largest parts of the test cable (i.e., the thimbles) but after insertion, the aperture is then effectively closed down to about twice cable diameter by inserting split toroids of magnetic material.

In operation, the two coils are first "balanced" by simultaneous adjustment of the two balance controls until a null reading is obtained on the calibration meter. The sensitivity control is then set at a predetermined level so that the system will readily detect genuine flaws but will not produce spurious indications. (This level is established by experimentation with cables of the type to be tested and having specific flaws at known locations. Thus, if the requirement is to determine when a particular type of cable has been degraded to 90% of its original strength, a sample of such cable is made defective in various

TABLE XV. PENDANT APEX FITTING ASSEMBLY DATA

		Pendant Capacity 6K	20K
(A) Top Bolt Diameter	in.	.75	1.00
(B) Spacer Outside Diameter	in.	1.50	1.88
(C) Width Between Plates	in.	3.125	3.125
(D) Saddle Spindle Diameter	in.	.937	1.374
(E) Hook Clearance	in.	8.250	5.247
(F) Plate Thickness	in.	.38	.63
(G) Plate Width	in.	1.25	1.32
(H) Saddle Radius	in.	1.375	1.690
Estimated Weight	lb	5.31	8.42
Safety Factor		1.50	1.50
Flight Load Factor		5.28	2.96
Required Ultimate	lb	47,520	88,800

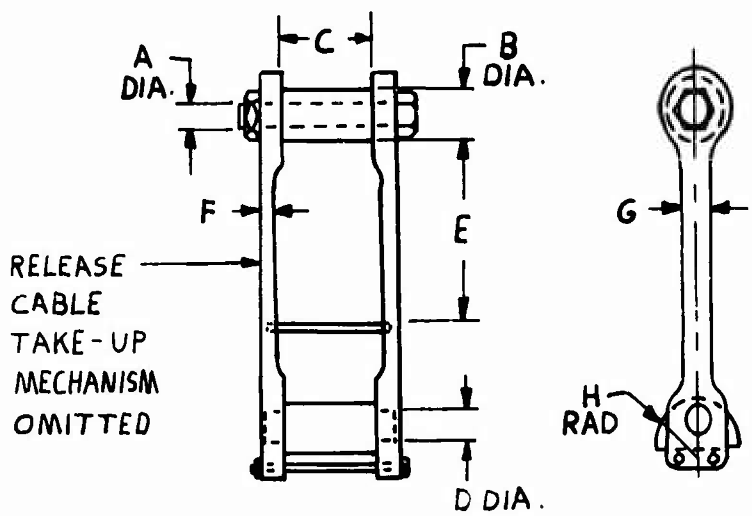


TABLE XVI. PENDANT NYLON ROPE ASSEMBLY DATA

		Pendant Capacity 6K	20K
(A) Rope Circumference	in.	4.5	6.5
(B) Rope Diameter, Nom.	in.	1.5	2.125
(C) Eye Pin Diameter, Min.	in.	2.50	3.00
(D) Length Between Eyes	in.	140.	180.
Estimated Weight	lb	16.00	38.00
Safety Factor		1.50	1.50
Flight Load Factor		5.28	2.96
Ultraviolet Factor		.85	.85
Temperature Factor		.94	.94
Required Ultimate, Spliced	lb	59,000	111,000
Required Spring Rate, Max.	lb/in.	2,000	4,000

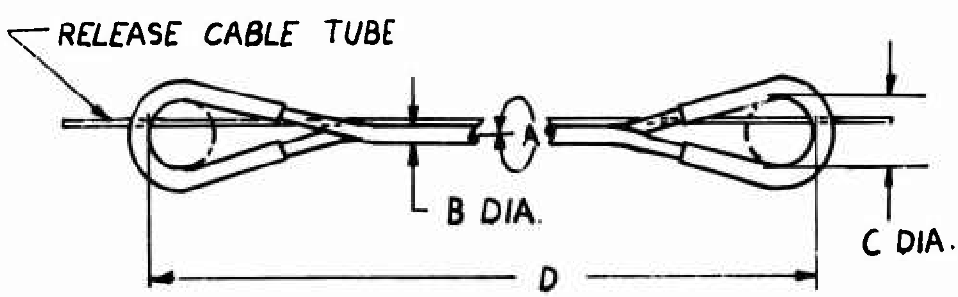


TABLE XVII. PENDANT SWIVEL HOOK ASSEMBLY DATA

		Pendant Capacity	
		6K	20K
(A) Top Pin Diameter	in.	2.50	3.00
(B) Rope Space Vertical	in.	2.00	2.80
(C) Rope Space Horizontal	in.	2.50	3.60
(D) Hook Acceptance Diameter	in.	2.00	2.60
(E) Load Beam Width, Max.	in.	1.66	2.53
(F) Load Beam Top Radius, Min.	in.	.75	1.12
Estimated Weight	lb	52.00	62.00
Safety Factor		1.50	1.50
Flight Load Factor		5.28	2.96
Required Ultimate	lb	47,520	88,800
Static Friction Torque, Min.	lb-ft	7.0	10.0
Lock on Load, Nom.	lb	900	2,000
Release Cable Load	lb	20-50	20-50

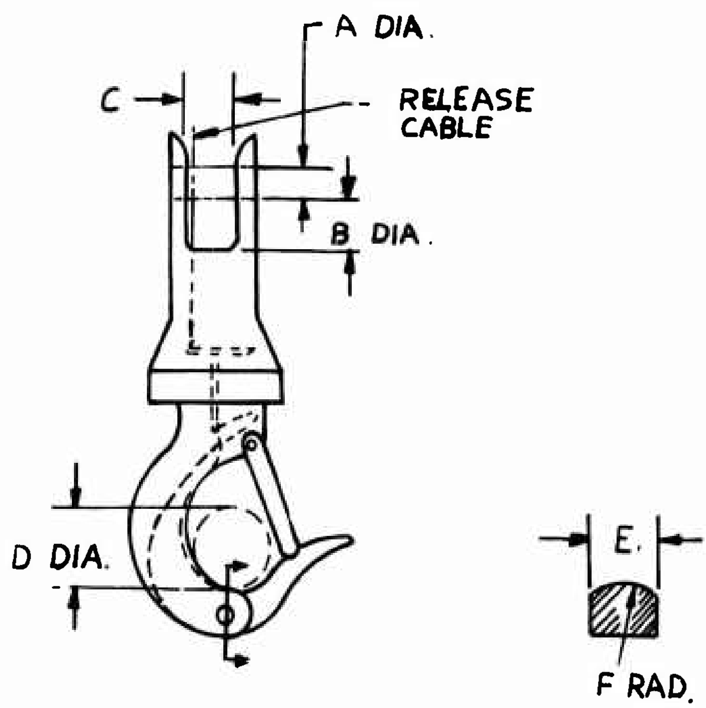
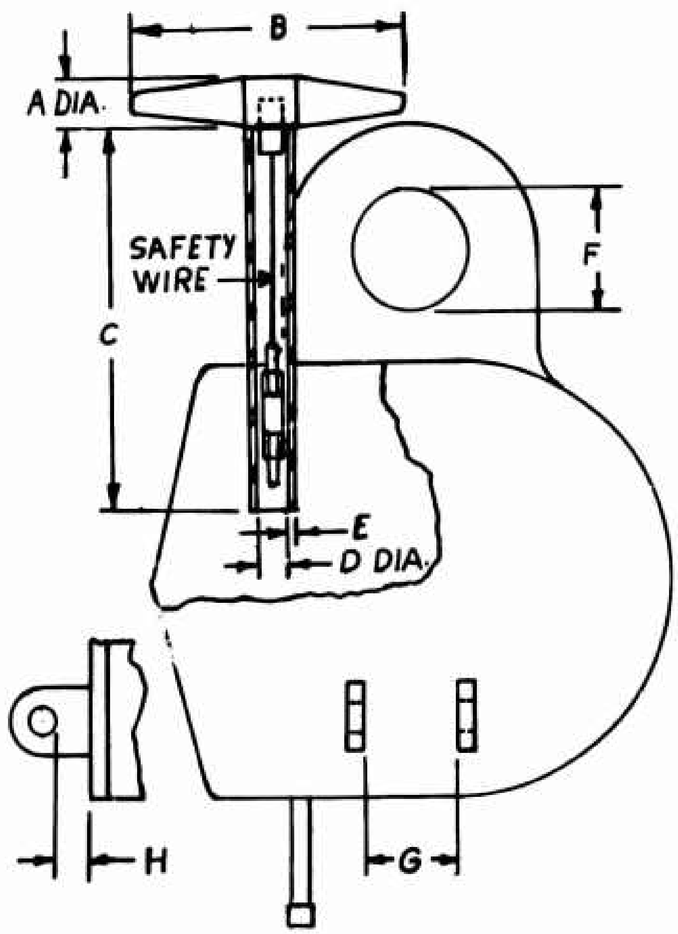


TABLE XVIII. PENDANT RELEASE SYSTEM DATA

		Pendant Capacity 6K	20K
(A) Handle Diameter	in.	.80 - .90	.80 - .90
(B) Handle Length	in.	2.80 - 3.00	2.80 - 3.00
(C) Tubing Length	in.	5.50 - 6.50	5.50 - 6.50
(D) Tubing Bore	in.	.38	.38
(E) Tubing Thickness	in.	.093	.093
(F) Mounting Hole Diameter	in.	.760	1.010
(G) Attachment Lug Spacing	in.	1.31	1.38
(H) Attachment Bolt Clearance	in.	.45	.70
Estimated Weight	lb	8.20	8.20
Safety Wire Ultimate	lb	80 - 130	80 - 130
Release Force	lb	30 - 50	30 - 50



ways, each of which would cause a 10% loss in strength. Submitting this sample to eddy current tests will enable the sensitivity appropriate to the requirement to be determined.) The test piece is then inserted in the coil and the appropriate inserts are fitted. Either the cable can be drawn through the coil, or it can be anchored at both ends and the coil moved along it. The latter method is more reliable, but it is important that the relative velocity be maintained at about 5 feet per second and that the cable does not oscillate radially in the coil. The indicator light will flash whenever a flaw such as a broken wire or a severe abrasion traverses the coil space.

FABRICATION OF TEST HARDWARE

PROOF AND ULTIMATE LOAD TESTS

Table XIX lists the sling and pendant components that were fabricated for proof and ultimate tests. The required proof loads and required ultimate loads are listed for each item.

TABLE XIX. SCHEDULE OF PROOF AND ULTIMATE TEST HARDWARE

Sling and Pendant Components	Qty.	Proof Load (lb) &	Ultimate Load (lb)
6K Sling Apex Fitting Assembly	1	17,500	47,520
25K Sling Apex Fitting Assembly	1	40,400	111,000
6K Wire Rope Assembly	1	8,320	20,800
6K Nylon Rope Assembly	1	9,700	26,000
25K Wire Rope Assembly	1	20,000	43,000
25K Nylon Rope Assembly	1	20,000	53,800
60K Wire Rope Assembly	1	48,000	103,300
6K Wire Rope Sling Grab Hook Assembly with Chain	1	8,320	20,800
25K Wire Rope Sling Grab Hook Assembly with Chain	1	20,000	43,000
60K Wire Rope Sling Grab Hook Assembly with Chain	1	48,000	103,300
6K Pendant Apex Fitting Assembly	1	19,000	47,520
20K Pendant Apex Fitting Assembly	1	40,000	88,800
6K Pendant Rope Assembly	1	22,000	59,000
20K Pendant Rope Assembly	1	41,000	111,000
6K Pendant Swivel Hook Assembly	1	19,000	47,520
20K Pendant Swivel Hook Assembly	1	40,000	88,800

A motion picture record was made of all the proof and ultimate tests.

ENVIRONMENTAL AND IMMERSION TESTS

Table XX lists the sling material specimens (all of 6K capacity but in short lengths) that were fabricated to evaluate the effect of exposure to adverse environments and immersion in corrosive fluids on the ultimate strength.

The control specimens were subjected to tensile tests to provide baseline figures for ultimate strength.

The environmental specimens were subjected to rain, fungus, salt, dust, temperature, humidity, and altitude, before being tensile tested. Each specimen was subjected to all the conditions sequentially. The tests were conducted to meet the intent

TABLE XX. SCHEDULE OF ENVIRONMENTAL AND IMMERSION TEST HARDWARE			
Specimens	Qty Wire Ropes	Qty Nylon Ropes	Qty Chains
Control	3	3	1
Environmental	3	3	1
Immersion	4	4	1
Total	10	10	3

of MIL-STD-810B except that the temperature range was -80°F to +160°F, the altitude range was 0 to 25,000 feet, and the humidity range was 95% at 75°F and 20% at 160°F.

The immersion specimens were subjected to JP-5, varsol, methyl ethyl ketone and MIL-H-5605 fuel before being tensile tested. One of each sling specimen (wire rope and nylon rope) was subjected to one of the four fluids, but the chain specimen was subjected to all the fluids sequentially. Immersion time in each case was 24 hours.

A motion picture record was made of all the tensile tests which were performed on the specimens subsequent to environmental and immersion treatment.

FUNCTIONAL TEST

One 6K wire rope sling leg assembly (comprising a cable assembly, a grab hook assembly, and a chain) was fabricated to assess the effect of icing conditions on the manual operability of the mechanical portions of the sling hardware. (Components assigned to the static tests were used.)

The assembly was water sprayed and then subjected to a temperature of -20°F for three hours. The usability of the sling leg was assessed, in particular the length adjustment facility provided by the grab hook and chain.

A motion picture record was made of the functional test.

STATIC TESTS

One 6K, one 25K, and one 60K wire rope sling were fabricated to validate the lifting techniques and rigging procedures.

The slings were used to lift, by means of a crane, over 30 representative loads, which were rigged in accordance with the relevant diagrams in the draft manual. Any necessary revisions to the procedures were recorded. All the static lifts were photographed, and a motion picture record was made during the course of the testing.

One 60K wire rope sling, in addition to the above, plus one spare apex fitting connecting link, were sent to Boeing Vertol for evaluation on a CH-62, in single-point and multi-point configuration.

NONDESTRUCTIVE TESTS

One Magnetic Analysis Minimac was fabricated to demonstrate the feasibility of nondestructive tests for wire ropes.

The test set (as described under Actual Prototype Designs) was applied to lengths of wire rope that had been rendered defective in various ways and degrees. Optimum procedures were established, and the ability of the equipment to determine residual strength was assessed.

The test setup is shown in Figure 27.

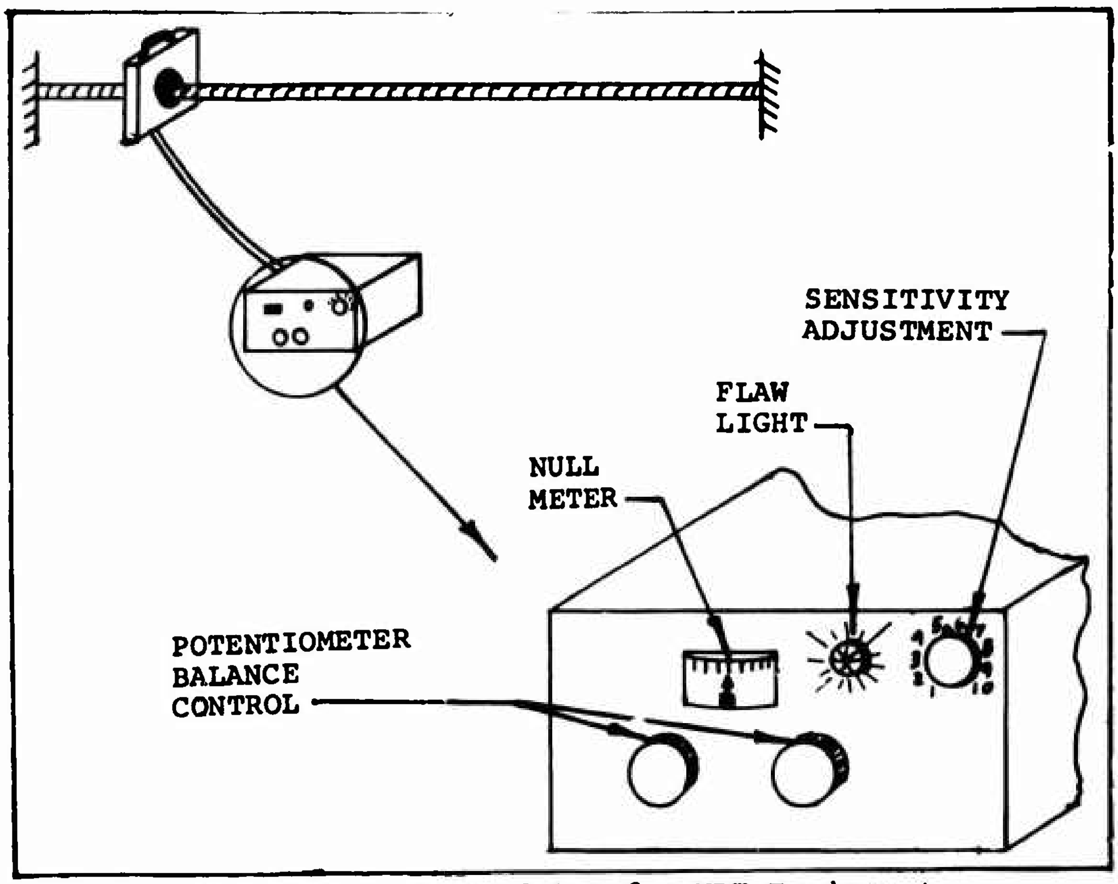


Figure 27. Test Setup for NDT Equipment

RESULTS OF TEST PROGRAM

PROOF AND ULTIMATE LOAD TESTS

Discussion

Proof and ultimate load tests were conducted at Sikorsky Aircraft for the following:

Sling Apex Fitting Assemblies	-	6K, 25K
Sling Grab Hook/Chain Assemblies	-	6K, 25K, 60K
Pendant Apex Fitting Assemblies	-	6K, 20K
Pendant Swivel Hook Assembly	-	6K

Proof and ultimate load tests were conducted at Eastern Rotorcraft Corp. for the following:

Pendant Swivel Hook Assembly	-	20K

Proof and ultimate load tests were conducted at Universal Wire Products for the following:

Sling Wire Ropes	-	6K, 25K, 60K

Proof and ultimate load tests were conducted at D. O'Connor & Sons, Inc., for the following:

Sling Nylon Ropes	-	6K, 25K
Pendant Ropes	-	6K, 20K

All components functioned normally after the 1-hour proof test, and all components met and surpassed their respective required ultimates.

Several items had been designed on the basis of a comparison with similarly configured standard hardware having well-established ultimates, since they would have needed considerably more strength to satisfy conventional structural theory. Despite this, some components proved to be overdesigned by a wide margin.

The sling apex fitting test results, for instance, indicate that these items might be adequate if made in aluminum alloy instead of steel. To test this hypothesis, aluminum alloy shackles in the 25K size were forged, using the same dies. For experimental purposes they were not bushed, and cotter pins replaced the retaining bolt. This assembly failed at 120,000 pounds. The excessive strength of the existing shackles is accounted for by the compromise made in the design to accommodate both wire rope and nylon rope sling eyes. The bearing criteria of the latter dictate a growth in the cross section of the shackle loop. Elimination of the nylon rope requirement would permit the use of shackles with a constant circular section.

The wire rope test results show no surprises. The apparently low margin on the 25K sling cable arises from the fact that the test machine reached its limit of stroke just before failure. It had actually surpassed the required ultimate, but after the machine was reset, the rope failed at a lower load than it had previously sustained. This demonstrates that deterioration occurs when a wire rope is relaxed after being loaded to near-ultimate.

The nylon rope test results are satisfactory, showing 10-25% margin. However, the splicing techniques had to be improved to achieve this.

The grab hook and chain test results also exhibit a degree of overdesign, despite some low margins shown in the structural analysis. The 60K grab hook failed by lateral bending of the hook, which was expected. On the other two assemblies the chains failed at the lower loading points. The margins were adequate, but the location of the failures spotlights the importance of load attachment point design.

The pendant apex fitting test results show 15-25% margin. Both sizes failed by shearing of the saddle which supports the rope. The side plates had been expected to fail in tension, at a much lower stress level.

The swivel hook test results are satisfactory. There is at present a high degree of component commonality for the two sizes, so there is obviously some overdesign in the 6K components.

Slings

Results of the proof and ultimate load tests are listed in Table XXI.

The 6K and 25K apex fitting assemblies failed when the pins had bent sufficiently to cause the small transverse retaining bolts to shear, due to their being pulled through the shackle eyes. The shackles themselves suffered little distortion. The 60K sling apex fitting assembly was not tested, since it is comprised of standard commercial items of established strength.

The 6K, 25K, and 60K cable assemblies failed at a splice in the usual manner, i.e., by progressive separation of wires at the base of the splice zone.

The 6K and 25K rope assemblies failed at a splice in the usual manner, i.e., by relative movement between fibers, leading to excessive heat.

The 6K and 25K grab hook/chain assemblies failed when the chain link at the load application point burst. The 60K grab hook/chain assembly failed when the hook had yielded enough laterally to release the chain link.

TABLE XXI. RESULTS OF PROOF AND ULTIMATE LOAD TESTS - SLINGS

Item	Proof Load (lb)	Required Ultimate (lb)	Failure Load (lb)	Mode of Failure
6K Apex Fitting Assy.	17,700	47,520	95,000	Pin bending
6K Cable Assy. (Wire Rope Sling)	8,320	20,800	24,000	Splice separation
6K Rope Assy. (Nylon Rope Sling)	9,700	26,000	32,250	Splice separation
6K Grab Hook/Chain Assy. (Wire Rope Sling)	8,320	20,800	23,150	Chain breakage
25K Apex Fitting Assy.	40,400	111,000	220,000	Pin bending
25K Cable Assy. (Wire Rope Sling)	20,000	43,000	43,050	Splice separation
25K Rope Assy. (Nylon Rope Sling)	20,000	53,800	66,850	Splice separation
25K Grab Hook/Chain Assy. (Wire Rope Sling)	20,000	43,000	51,700	Chain breakage
60K Cable Assembly (Wire Rope Sling)	48,000	103,300	105,000	Splice separation
60K Grab Hook/Chain Assy.	48,000	103,300	107,000	Hook bending

Pendants

Results of the proof and ultimate load tests are listed in Table XXII.

TABLE XXII. RESULTS OF PROOF AND ULTIMATE LOAD TESTS - PENDANTS

Item	Proof Load (lb)	Required Ultimate (lb)	Failure Load (lb)	Mode of Failure
6K Apex Fitting Assy.	19,000	47,520	59,800	Saddle shear
Rope Assy.	22,000	59,000	67,000	Splice separation
Swivel Hook Assy.	32,000	47,520	58,800	Bolt shear
20K Apex Fitting Assy.	40,000	88,800	101,500	Saddle shear
Rope Assy.	41,000	111,000	121,700	Splice separation
Swivel Hook Assy.	60,000	88,800	127,450	Bearing sleeve flange shear

The 6K and 20K apex fitting assemblies failed by shearing of the saddles just inboard of their lugs.

The 6K and 20K rope assemblies failed at a splice in the usual manner.

The 6K swivel hook assembly failed by shearing of the bolts securing the side plates to the main housings.

The 20K swivel hook failed by shearing of the flange in the sleeve which transfers load to the upper race of the swivel bearing.

ENVIRONMENTAL AND IMMERSION TESTS

Discussion

Environmental and immersion tests were conducted at Sikorsky Aircraft for the following:

Wire Rope Slings	-	6K (approx. 8-ft lengths)
Nylon Rope Slings	-	6K (approx. 8-ft lengths)
Chains	-	6K (approx. 8-ft lengths)

(Environmental exposures were carried out by Ogden Technology Laboratories, Inc.)

All the wire ropes and chains met the required ultimates after environmental and immersion treatments, but the nylon ropes showed some deterioration in strength from the baseline samples.

Wire Ropes

Results of the environmental and immersion tests are listed in Table XXIII.

TABLE XXIII. RESULTS OF ENVIRONMENTAL AND IMMERSION TESTS - WIRE ROPES

Specimen Details	Specimen No.	Failure Load (lb)
Baseline	15	21,300
Baseline	16	20,600
Baseline	17	20,800
Environmental - all elements	1	20,800
Environmental - all elements	2	21,400
Environmental - all elements	3	21,200
Immersion - JP5	7	21,200
Immersion - Varsol	8	20,600
Immersion - MEK	9	20,500
Immersion - MIL-H-5606	10	20,700

Nylon Ropes

Results of the environmental and immersion tests are listed in Table XXIV.

TABLE XXIV. RESULTS OF ENVIRONMENTAL AND IMMERSION TESTS - NYLON ROPES		
Specimen Details	Specimen No.	Failure Load (lb)
Baseline	18	19,500
Baseline	19	20,500
Baseline	20	19,500
Environmental - all elements	4	17,300
Environmental - all elements	5	17,800
Environmental - all elements	6	18,600
Immersion - JP5	11	18,300
Immersion - Varsol	12	18,600
Immersion - MEK	13	18,800
Immersion - MIL-H-5606	14	18,600

Chains

Results of the environmental and immersion tests are listed in Table XXV.

TABLE XXV. RESULTS OF ENVIRONMENTAL AND IMMERSION TESTS - CHAINS		
Specimen Details	Specimen No.	Failure Load (lb)
Baseline	23	16,500
Environmental - all elements	21	16,800
Immersion - all fluids	22	16,600

FUNCTIONAL TESTS

Discussion

Functional tests were conducted at Sikorsky Aircraft for the 6K wire rope sling only.

The operation of this size sling was satisfactory after it was subjected to an icing environment, and it is considered that the larger sizes would therefore operate satisfactorily after similar treatment.

Test Results

After spraying the 6K wire rope sling assembly with water and freezing at -20°F for 2 hours, the grab hook keeper was still sufficiently free to permit the insertion and removal of the chain. The other components of the sling were also unaffected.

STATIC TESTS

Discussion

Static tests were conducted at the United States Army Airborne Communications and Electronics Board, Fort Bragg, for the following:

Wire Rope Sling Assemblies - 6K, 25K, 60K

All sizes of slings functioned satisfactorily. The only major problem encountered was on a relatively minor item, namely, the chain connecting link. This has to be disassembled and re-assembled when rigging a load which requires an additional length of chain on one or more sling legs. The pin of the connecting link is retained by a split collar. Since this constitutes a frictional rather than a positive locking device, the manufacturers designed it to have exceptional tenacity. Driving the pin out, or in, requires tools that were not immediately available.

Connecting links have been in regular commercial use for many years, so there are evidently acceptable techniques for operating them. Given a drift of suitable diameter and length, there should be little difficulty. The addition of a bored anvil would facilitate the task still further.

There is an alternative design of connecting link which has a snap ring type of pin retainer. It is made by several different manufacturers, and is already in use with the 15,000-lb sling (FSN 1670-902-3082). This may be easier to operate, but unfortunately it is slightly larger throughout the range of sizes and cannot be used on the grab hooks as currently designed. However, since the requirement for extending a sling chain will be infrequent, there does not seem to be a strong case for changing the design.

Attachment of sling legs to various loads, locating the relevant chain link, and inserting the link in the grab hook presented no great difficulties on any of the three slings. Counting of chain links required less precision than was anticipated; most loads are sufficiently flexible to accommodate an error of ±1 link in the length of one leg relative to another.

The handling qualities of the 6K and 25K slings were considered satisfactory. The 60K sling was more manageable than anticipated, but the interim apex fitting, comprising a connecting link and four shackles, was a distinct handicap on this, the heaviest sling. Also, the shackles did not always position themselves properly when under load; situations sometimes arose in which the cable thimble was forced slightly out of line with its cable, due to interaction between shackles. These deficiencies would be eliminated by the introduction of a 60K twin-shackle apex fitting. (Results of ultimate tests indicate that it need not be much heavier than the existing 25K assembly, which is considerably overdesigned.)

The question of static discharge was raised during the trials, and it was concluded that any problems in this area could be resolved by existing methods involving the use of probes. No better techniques were known, but the procedures described in TM55-560-12, Chapter 5, Section 11, have been proved satisfactory.

Most of the loads were lifted without difficulty in accordance with the preliminary manual instructions. Some changes in sling leg lengths have been effected, mostly to refine the rigging rather than to correct defects in procedure. The articulated loads, involving combinations of M37 and M151 trucks with M416 and M101 trailers, were investigated thoroughly. Various techniques were tried, and the instructions have now been redrafted to produce optimized and standardized procedures for the four vehicles separately and in combination. Chains were tried as stabilizing links between the articulated vehicles, but were unsatisfactory. Nylon ropes, as recommended in the instructions, or nylon webbings are clearly superior, provided that they are cinched up to introduce a degree of preloading.

The AN/MPQ-4A radar set remains the most problematical load. Two alternative pairs of attachment points for the front sling legs were tried - one pair at high points on the folded outrigger legs, and the other pair at lifting lugs on the chassis. The former method is more stable but puts the edge of the antenna vulnerably close to the wire ropes. The latter method has been selected, as it provides better clearance for the sling components and agrees with the procedure shown in TM55-450-12, Section V, Figure 13-5. It should be borne in mind, however, that this configuration has marginal stability since the lift points are so far below the center of gravity.

The rigging of the rear sling legs on some of the six-wheeled trucks, e.g., M35, M36, M49, M51, will vary slightly according to whether or not they are equipped with sling guides. These take the form of notched plates or sometimes C-shaped bars welded to the edges of the chassis in line with the lifting pins on the centers of the rear springs. Trucks which are otherwise identical may differ with regard to this feature.

The only other commentaries arising from the static tests were not directly concerned with the slings. Where spreader bars were used, they performed better than expected. It was found unnecessary, for instance, to introduce any special devices to secure the bars to the sling legs since they tended to be self retaining once they had settled in position. For flight purposes, it will be sufficient to bind the spreader bars to the sling legs using ordinary nylon cord, Type III, 4-strand. Where padding was used (on spreader bars, sling legs, or vehicles), it was left unwrapped in order to expedite the trials. For flight purposes it would need to be protected as described in the manual, by covering with cloth such as canvas or plastic, to prevent disintegration in rotor downwash, wind or wet weather. An alternative type of vehicle padding was used on some lifts, namely, Pad, energy dissipating (FSN 1670-753-3928). This is a honeycomb material used extensively in air drop operations and is considered useful in many applications, e.g., to protect hoods, fenders, and similar soft structures on vehicles.

6K Wire Rope Sling

This sling was used to lift the following loads:

1. Generator Set, PU619M, Trailer Mounted
2. Radar Set, AN/MPG-4Q.
3. Set, Welder, Arc, Trailer Mounted.
4. Trailer, Cargo, 1/4 Ton, 2W 416.
5. Trailer, Tank, Water, 400 Gal. Capacity, M149.
6. Truck, Ambulance, Front Line, 1/4 Ton, 4 x 4, M718
7. Truck, Cargo, 1-1/4 Ton, 4 x 4, M715, Without Winch.
8. Truck, Cargo, M37, Without Winch, and Trailer, Cargo, 1/4 Ton, 2W M416.
9. Truck, Cargo, M37, Without Winch, and Trailer, Cargo, 3/4 Ton, 2W M101A.
10. Truck, Utility, 1/4 Ton, 4 x 4, M151A1, and Trailer Cargo, 1/4 Ton, 2W M416.

11. Truck, Utility, 1/4 Ton, 4 x 4, M151A1, and Trailer Cargo, 3/4 Ton, 2W M101A1.

Item 2 was trial lifted in two alternative ways. Items 8 and 9 were not available in "With Winch" form.

25K Wire Rope Sling

This sling was used to lift the following loads:

1. Ambulance, M725.
2. Grader, Road, Motorized, Air Transportable.
3. Howitzer, Light, Towed, 105MM, M102.
4. Howitzer, Medium, Towed, 155MM, M114A1.
5. Loader, Scoop Type, Diesel Driven, 4 Wheeled, 1-1/2 Cubic Yard, Air Transportable.
6. Mixer Concrete, Trailer Mounted, Gasoline Driven, 16 Cubic Feet, Model 16SM.
7. Semitrailer, Low Bed, 25 Ton, 4 Wheeled, M172A1.
8. Semitrailer, Van, Expandable, 6 Ton, 4 Wheeled, M313.
9. Semitrailer, Wrecker, 12 Ton, 4 Wheeled, M270A1.
10. Tractor, Full Tracked, Low Speed, Diesel Driven, Model D6B.
11. Truck, Cargo, 2-1/2 Ton, M35A1, With Winch.
12. Truck, Cargo, M36.
13. Truck, Cargo, M37, Without Winch.
14. Truck, Cargo, 1-1/4 Ton, 6 x 6, M561.
15. Truck, Dump, 5 Ton, 6 x 6, M51, With Winch.
16. Truck, Forklift, Diesel Driven, Pneumatic Tire, 6,000 Lb Capacity.
17. Truck, Tank, Gasoline, 2-1/2 Ton, 6 x 6, M49A2C, Without Winch.
18. Truck, Van, 2-1/2 Ton, 6 x 6, M109A3, Without Winch.

Item 3 was lifted without ammunition, due to nonavailability. Item 6 was rigged as if it was a Model HBG concrete mixer, since the latter was not available. Model 16SM is normally slung directly on a pendant or cargo hook.

60K Wire Rope Sling

This sling was used to lift the following loads:

1. Crane, Shovel, Crawler Mounted, 12.5 Ton, 3/4 Cubic Yard.

2. Truck, Tractor, 10 Ton, 6 x 6, M123A1C, With Winch.

NONDESTRUCTIVE TESTS

Discussion

Tests were conducted on the eddy current test apparatus (Minimac, by Magnetic Analysis Corp.), using 3/4-in.-diameter steel wire rope test samples. The device consists of a control unit and a twin-coil unit through which the cable passes. The coil unit can be fitted with variously sized inserts to accommodate different cables. The control unit has adjustment controls and a null meter for balancing two potentiometers, a sensitivity control, and a flaw detection light. There are also connection terminals for a buzzer or bell (to be triggered at the same time as the flaw detection light). The machine was factory set to detect damage which would cause a strength loss of 10% or more.

During the tests, two difficulties arose. First, the device is speed sensitive, and second, since the cable is somewhat free to move around in the coil unit while it passes through, false indications of flaws are recorded. The following operating technique was found to optimize detection of actual damage while minimizing false detection of flaws due to cable "noise". (The test setup is shown in Figure 27.)

1. Mount coil unit around rope sample.

2. Mount rope sample, taut but unloaded, in a horizontal position.

3. Set sensitivity at low end of scale (i.e., 1 or 2), but high enough so that null reading is close to maximum. Adjust potentiometers to obtain minimum null reading. Increase sensitivity in increments, repeating this procedure until sensitivity is maximum and null reading is minimum. Then reduce sensitivity to 5-1/2.

4. With setup procedure completed, move detection coil along length of rope, watching flaw detection light. Speed should be held constant at 1 to 1-1/2 feet per second.

5. If flaw light is triggered, repeat test several times in area of cable where indication occurred. Repeat of flaw indication both verifies existence of damage and helps determine location of damage.

The flaw light will not trigger if the coil unit is arrested immediately over the flaw. It has to traverse the flaw to generate an impulse.

Nondestructive Tester

Results of the tests on the Magnetic Analysis Minimac are listed in Table XXVI. The three 3/4-in.-diameter wire ropes were cut and abraded to a controlled extent as denoted in Table XXVII. The optimum sensitivity/coil speed combinations were determined by several runs over the same wire rope.

TABLE XXVI. RESULTS OF TESTS ON NDT EQUIPMENT

Wire Rope No.	Per-Cent Flaws	Test Run No.	Sensi-tivity	Speed of coil (ft/sec)	Results and Remarks
1	1-9	1	4-1/2	3.30	Too fast to produce signal
		2	5	2.00	No faults detected
		3	5-1/2	1.25	No faults detected
		4	6	.90	2.5% flaw detected
		5	6-1/2	-	Intermittent detection
2	10	1	4	4.00	Too fast to produce signal
		2	4-1/2	3.30	All flaws detected
		3	5	2.00	All flaws detected
		4	5-1/2	1.25	All flaws detected
		5	6	.90	All flaws detected
		6	6-1/2	.70	All flaws detected
3	0	1	5	2.00	Too fast
		2	5-1/2	1.25	No flaws detected
		3	6	.90	No flaws detected
		4	6-1/2	.70	No flaws detected

Best sensitivity/coil speed was found to be 5-1/2 at 1 to 1-1/2 feet per second.

TABLE XXVII. SCHEDULE OF FLAWED TEST WIRE ROPE *			
Wire Rope No.	Distance of Flaw From End (in.)	Per-cent Flaw	Description of Flaw
1	19	1.0	Two exterior wires from each of two diagonally opposite inner strands cut.
	27	2.5	Five wires of inner core of outer strand cut.
	36	1.0	Three exterior wires from inner stand cut.
	46	3.0	Complete center strand cut.
	50	6.8	Three inner strands cut.
	60	9.0	Four inner strands cut.
	70	6.0	Five wires on inside of outer strand, two filler wires, and one inner strand cut.
2	21	10.0	Twenty-eight wires on two adjacent outer strands heavily abraded.
	29	10.0	Twenty-eight wires around circumference heavily abraded for 1 inch.
	41	10.0	Twenty-eight wires around circumference heavily abraded for 1/2 inch.
	53	10.0	Fourteen wires on two adjacent outer strands cut.
3	-	-	Undamaged.

* 3/4-inch 6 x 25 Type "W" IWRC stainless steel

Core wire area $= .00176$ in.^{2}

Core strand area $= .00176 \times 7 = .01230$ in.^{2}

Outer wire area $= .00382$ in.^{2}

Filler wire area $= .00064$ in.^{2}

Outer strand area $= .00382 \times 19 + .00064 \times 6 = .07642$ in.^{2}

Total cable area $= .0123 \times 7 + .07642 \times 6 = .544$ in.^{2}

CONCLUSIONS AND RECOMMENDATIONS

All three wire rope slings, both nylon rope slings, and both pendants satisfied the requirements of the test program.

Wire rope is the preferred sling material, due to considerations of longevity and nondestructive test feasibility. End fittings should be attached via eye splices.

Nylon rope has some weight advantage in the larger sizes, but unfortunately the end fittings would be heavier (and these are the parts which have to be manhandled the most). It has superior handling qualities, until the necessary protective coatings are applied. It has greater elasticity - an essential attribute for pendants, but of minor significance for slings.

Finally, a consideration of all the cost elements (semi-raw material, splicing, coating, end fittings, inspection, maintenance) confirms the superiority of the chosen material.

The 60K sling will be greatly improved when the temporary apex fitting assembly is replaced by a twin-shackle type. The design of the latter will benefit from knowledge gained during the tests of the smaller twin shackles. The 6K and 25K apex fittings can be made at least 50% lighter, especially if they are designed for wire ropes only, and if a stronger retaining bolt is fitted.

The 6K and 25K grab hooks could be made about 10% lighter. The same keeper spring was used on all three sizes of grab hooks, for economy; and although it proved to be a good compromise, it should be replaced by springs with a more appropriate rate on the 6K and 60K sizes.

The 6K pendant swivel hook has many components in common with the 20K pendant swivel hook, in order to reduce costs. Consequently, the weight of the 6K hook grossly exceeded the original estimate, while the 20K hook was very close to the estimate. On a production basis, there is scope for at least 50% reduction in the weight of the 6K hook.

The release handle, which was originally conceived as a separate component stowed on the pendant apex fitting, became an addition to the release cable take-up mechanism when the latter was transferred from the hook to the apex fitting. It should now be redesigned as an integral part of the mechanism. Minor differences in the 6K and 20K pendant take-up mechanisms should be eliminated by changing the method of attachment to the apex fittings.

An additional spliced joint should be made in the release cable near its lower end to facilitate assembly of the pendant.

Only one practicable method of nondestructive testing for sling legs is available. An existing instrument, the Minimac, produced valid results once optimum operating techniques were established.

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APPENDIX I

STRUCTURAL ANALYSIS SUMMARY

DISCUSSION

The sling systems consist of four-legged sling assemblies (with three different nominal capacities - 6,000, 25,000 and 60,000 pounds) suspended either from pendant assemblies (with two different capacities - 6,000 and 20,000 pounds) or directly from the helicopter cargo hook.

Each four-legged sling assembly comprises three main subassemblies, namely, an apex fitting, four sling legs, and four grab hooks. Each grab hook carries a loop of appropriately sized chain. The sling legs of the 6,000- and 25,000-pound sizes may be of wire rope or nylon rope, and both versions are covered by this report. The apex fittings and chains associated with either version are, size for size, identical, but the grab hooks differ in certain features since the nylon ropes are bulkier than the wire ropes. Where appropriate, the analyses will be cross-referenced to features already covered. The 60,000-pound sling (which is in wire rope form only) has a different apex fitting from the other two sizes, being comprised of standard hardware. Apart from this, corresponding components for each sling size are similar in design, and the same stressing principles are therefore applicable.

Each pendant assembly comprises three main subassemblies, namely, an apex fitting, a pendant rope (made of nylon), and a swivel hook. (Attached to the apex fitting is a release cable take-up mechanism and a release handle. These are low-stressed items which are not subject to structural analysis, but the handle incorporates a safety break which has to be tested to ensure that it separates between prescribed load limits.) Corresponding components for each pendant size are similar in design, and the same stressing principles are therefore applicable.

In accordance with MIL-S-8698, the minimum ultimate factor of safety is taken as 1.5 for all sling and pendant components. Flight load factors, however, depend on the function of the component, the relevant helicopter load factors, and the type of load, as detailed in the text and as explained more fully under Design Criteria. From these and any other factors relevant to a particular component, the ultimate loads are established. Component design is based upon ultimate rather than yield strength. The significance of this is that some degree of automatic stress relieving occurs on certain components when they initially distort under load. For example, shackles and chain links contract laterally, thus reducing the moment arm; a point load tends to distribute as the degree of plastic deformation increases; a noncentral load on a beam moves toward center as the beam bends, thus producing a more equable end-load distribution. The validity of these assumptions will be checked by destructive tests which will be filmed to record the modes of failure. It is possible that some parts will distort in a stress-accentuating manner. For example, the hook may bend at a rate which increases the moment arm more effectively than the chain realignment reduces it, so producing a divergent situation. Imponderables of this type are resolved in the analysis by comparison with similarly configured standard hardware having well-established ultimates; for example, shackles, master links, and commercial grab hooks.

Table XXVIII lists the minimum margins of safety calculated in the report. Those exceeding unity are designated "High".

TABLE XXVIII. MINIMUM MARGINS OF SAFETY

Sling Components	Stress	6K	25K	60K
Apex Fitting Assy:				
Shackle - Lug	Tens. & Brg.	.73	.77	Master-
	Shear	High	High	link
- Side	Tensile	High	High	.002
- Loop	Tens. & Bend.	.41	.48	Shackle
Pin	Bending	.40	.18	.10
	Shear	High	High	
Rope Assy.(nylon rope sling)	Tensile	.11	.11	-
Cable Assy.(wire rope sling)	Tensile	0	0	.002
Grab Hook Assy:				
Hook - Pin Lug	Tens. & Brg.	High	.79	1.41
- Connecting Link Lug	Tens. & Brg.	High	High	High
- Hook Section	Bend. & Tors.	.50	.47	.06
Spacer (nylon rope sling)	Bending	High	High	-
Spacer (wire rope sling)	Bending	.50	.23	.05
Pin	Shear	.42	.54	.14
Chain	Tensile	.12	.07	.08

Pendant Components	Stress	6K	20K
Apex Fitting Assy:			
Side Plate Assy. - Top Lug	Tens. & Brg.	.57	.79
	Shear	.78	High
	Tens., Sust.	High	High
- Center Section	Bending	High	High
	Tensile	.030	.21
- Bottom Lug	Tens. & Brg.	.57	.79
	Shear	.78	High
Spacer	Bending	.16	.21
Top Bolt	Shear	.04	.59

TABLE XXVIII - Continued			
Pendant Components	Stress	6K	20K
Saddle - Center Section	Bending	.32	.26
- Lug	Bending	.23	.49
	Shear	.33	.54
	Bearing	High	High
Rope Assy.	Tensile	.020	.080
Swivel Hook Assy.			
All Components	All	.010	.002

The units of measure used throughout this report are as follows:

Length - inch

Load - pound

Stress - pounds/inch^2

6K WIRE ROPE SLING

Design Load Criteria

For the apex fitting assembly:

Ultimate load = 6,000 x 5.28 x 1.5

= 47,520 (1)

For the sling leg subassemblies:

Ultimate load = 6,000 x 5.78 x .6

= 20,800 (2)

6K Wire Rope Sling Apex Fitting Shackle (38850-00006-101)

Material: 4340

(F_{tu} = 150,000 F_{su} = 95,000)

Lug - Tensile and Bearing

Lower value of P_{au} = 41,821 (3)

Worst-case load, i.e., when the hook is offset by the maximum permitted by dimensions, and with the shackle at 45°, is given by:

P	= 47,520 x .72/2 cos 45°	
	= 24,197	(4)
Ultimate M.S.	= 41,821/24,197 - 1	
	= +.73	(5)

Lug - Shear

P_{au}	= 71,725	(6)
P	= 24,197	(7)
Ultimate M.S.	= 71,724/24,197 - 1	
	= +1.97 High	(8)

Side - Tensile

P_{au}	= 61,050	(9)
P	= 24,197	(10)
Ultimate M.S.	= 61,050/24,197 - 1	
	= +1.52 High	(11)

Loop - Tensile and Bending

P_{au}	= 47,500	(12)

Worst-case load, i.e., both cables hanging parallel, side by side, from the center of the loop with the shackle at 45°, is given by:

P	= 47,520/2 cos 45°	
	= 33,606	(13)
Ultimate M.S.	= 47,520/33,606 - 1	
	= +.41	(14)

6K Wire Rope Sling Apex Fitting Pin (388350-00008-101)

Material: 4340

(F_{tu} = 150,000 F_{su} = 95,000)

Pin - Bending

P_{au} = 66,354 (15)

P = 47,520 (16)

Ultimate M.S. = 66,354/47,520 - 1

= <u>+.40</u> (17)

Pin - Shear

P_{au} = 93,955 (18)

If 72% of the ultimate load is taken on one side, i.e., when the hook is offset by the maximum permitted by dimensions:

P = 34,214 (19)

Ultimate M.S. = 93,955/34,214 - 1

= <u>+1.75</u> High (20)

<u>6K Wire Rope Sling Cable Assembly</u> (38850-00010-041)

Material: Stainless steel wire rope Type 302/304

Rope - Tensile

P_{au} = 20,800 (21)

P = 20,800 (22)

Ultimate M.S. = 20,800/20,800 - 1

= <u>0</u> (23)

(Note: This is the margin at minimum specified strength.)

<u>6K Wire Rope Sling Grab Hook</u> (38850-00014-101)

Material: 4340

(F_{tu} = 150,000 F_{su} = 95,000)

Pin Lug - Tensile and Bearing

Lower value of P_{au} = 32,866 (24)

P = 10,400 (25)

Ultimate M.S. = 32,866/10,400 - 1

= <u>+2.16</u> High (26)

Connecting Link Lug - Tensile and Bearing

P_{tru} = 39,376 (27)

P = 10,400 (28)

Ultimate M.S. = 39,376/10,400 - 1

= +2.78 High (29)

Hook Section - Bending and Torsion

P_{au} = 15,600 (30)

P = 10,400 (31)

Ultimate M.S. = 15,600/10,400 - 1

= +.50 (32)

Note: This value depends on the side moment produced on the hook by the chain. It is influenced by the final attitude of the chain relative to the hook, which is difficult to predict.

6K Wire Rope Sling Grab Hook Spacer (38850-00016-101)

Material: 4130

(F_{tu} = 150,000)

Spacer - Bending

P_{au} = 31,103 (33)

P = 20,800 (34)

Ultimate M.S. = 31,103/20,800 - 1

= +.50 (35)

6K Wire Rope Sling Grab Hook Pin (MS20392-7C61)

Material: Steel

(F_{tu} = 145,000 Maximum double shear load = 29,440)

Pin - Shear

P_{au} = 29,440 (36)

P = 20,800 (37)

Ultimate M.S. = 29,440/20,800 - 1
= +.42 (38)

6K Wire Rope Sling Chain (38850-00053-102)

Material: Alloy Steel

Chain - Tensile

P_{au} = 12,000 (39)

P = 10,400 (40)

Ultimate M.S. = 12,000/10,400 - 1

= +.12 (41)

6K NYLON ROPE SLING

Design Load Criteria

For the apex fitting assembly:

Ultimate Load = 6,000 x 5.28 x 1.5

= 47,520 (42)

For the sling leg subassemblies:

Ultimate Load = 6,000 x 5.78 x .6

= 20,800 (43)

Appropriate environmental factors are applied to the nylon rope.

6K Nylon Rope Sling Apex Fitting Shackle (38850-00006-101)

Same as 6K Wire Rope Sling Apex Fitting Shackle.

6K Nylon Rope Sling Apex Fitting Pin (38850-00008-101)

Same as 6K Wire Rope Sling Apex Fitting Pin

6K Nylon Rope Sling Rope Assembly (38850-0009-041)

Material: Nylon rope, double braided MIL-R-24050A

Rope - Tensile

P_{au} = 29,000 (44)

P = 20,800/.85 x .94

= 26,000 (45)

Ultimate M.S. = 29,000/26,000 - 1

= +.11 (46)

6K Nylon Rope Sling Grab Hook (38850-00013-101)

Similar to 25K Wire Rope Sling Grab Hook

6K Nylon Rope Sling Grab Hook Spacer (388350-00015-101)

Material: 7075-Γ651

(F_{tu} = 77,000)

Spacer - Bending

P_{au} = 51,395 (47)

P = 20,800 (48)

Ultimate M.S. = 51,395/20,800 - 1

= +1.47 High (49)

6K Nylon Rope Sling Grab Hook Pin (MS20392-7C87)

Similar to 6K Wire Rope Sling Grab Hook Pin

6K Nylon Rope Sling Chain (38850-00053-101)

Same as 6K Wire Rope Sling Chain

25K WIRE ROPE SLING

Design Load Criteria

For the apex fitting assembly:

Ultimate load = 25,000 x 2.96 x 1.5

= 111,000 (50)

For the sling leg subassemblies:

Ultimate load = 25,000 x 2.87 x .6

= 43,000 (51)

25K Wire Rope Sling Apex Fitting Shackle (38850-00006-102)

Material: 4340

(F_{tu} = 150,000 F_{su} = 95,000)

Lower value of P_{au} = 90,060 (52)

Worst-case load, i.e., when the hook is offset by the maximum permitted by dimensions, and with the shackle at 45^o, is given by:

P = 111,000 x .65/2 cos 45^o

= 51,025 (53)

Ultimate M.S. = 90,060/51,025 - 1

= +.77 (54)

Lug - Shear

P_{au} = 140,410 (55)

P = 51,025 (56)

Ultimate M.S. = 140,410/51,025 - 1

= +1.75 High (57)

Side - Tensile

P_{au} = 139,950 (58)

P = 51,025 (59)

Ultimate M.S. = 139,950/51,025 - 1

= +1.74 High (60)

Loop - Tensile and Bending

P_{au} = 116,402 (61)

Worst-case load, i.e., both cables hanging parallel, side by side, from the center of the loop with the shackle at 45^o, is given by:

P = 111,000/2 cos 45^o

= 78,501 (62)

Ultimate M.S. = 116,402/78,501 - 1

= +.48 (63)

25K Wire Rope Sling Apex Fitting Pin (38850-00008-102)

Material: 4340

(F_{tu} = 150,000 F_{su} = 95,000)

Pin - Bending

P_{au} = 131,340 (64)

P = 111,000 (65)

Ultimate M.S. = 131,340/111,000 - 1

= +.18 (66)

Pin - Shear

P_{au} = 167,200 (67)

If 65% of the ultimate load is taken on one side, i.e., when the hook is offset by the maximum permitted by dimensions,

P = 111,000 x .65

= 72,150 (68)

Ultimate M.S. = 167,200/72,150 - 1

= +1.32 High (69)

25K Wire Rope Sling Cable Assembly (38850-00010-042)

Material: Stainless steel wire rope Type 302/304

Rope - Tensile

P_{au} = 43,000 (70)

P = 43,000 (71)

Ultimate M.S. = 43,000/43,000 - 1

= 0 (72)

(Note: This is the margin at minimum specified strength.)

25K Wire Rope Sling Grab Hook (38850-00014-102)

Material: 4340

(F_{tu} = 150,000 F_{su} = 95,000)

Pin Lug - Tensile and Bearing

Lower value of P_{au} = 38,446 (73)

P = 43,000 x .5

= 21,500 (74)

Ultimate M.S. = 38,446/21,500 - 1

= +.79 (75)

Connecting Link Lug - Tensile and Bearing

P_{tru} = 66,775 (76)

P = 21,500 (77)

Ultimate M.S. = 66,775/21,500 - 1

= +2.11 High (78)

Hook Section - Bending and Torsion

P_{au} = 31,680 (79)

P = 21,500 (80)

Ultimate M.S. = 31,680/21,500 - 1

= +.47 (81)

(Note: This value depends on the side moment produced on the hook by the chain. It is influenced by the final attitude of the chain relative to the hook, which is difficult to predict.)

25K Wire Rope Sling Grab Hook Spacer (38850-00016-102)

Material: 4130

(F_{tu} = 150,000)

Spacer - Bending

P_{au} = 52,734 (82)

P	= 43,000	(83)
Ultimate M.S.	= 52,734/43,000 - 1	
	= +.23	(84)

25K Wire Rope Sling Grab Hook Pin (MS20392-10C81)

Material: Steel

(F_{tu} = 145,000 Maximum double shear load = 66,280)

Pin - Shear

P_{au}	= 66,280	(85)
P	= 43,000	(86)
Ultimate M.S.	= 66,280/43,000 - 1	
	= +.54	(87)

25K Wire Rope Sling Chain (38850-00053-102)

Material: Alloy steel

Chain - Tensile

P_{au}	= 23,000	(88)
P	= 21,500	(89)
Ultimate M.S.	= 23,000/21,500 - 1	
	= +.07	(90)

25K NYLON ROPE SLING

Design Load Criteria

For the apex fitting assembly:

Ultimate load	= 25,000 x 2.96 x 1.5	
	= 111,000	(91)

For the sling leg subassemblies:

Ultimate load	= 25,000 x 2.87 x .6	
	= 43,000	(92)

Appropriate environmental factors are applied to the nylon rope.

25K Nylon Rope Sling Apex Fitting Shackle (38850-00006-102)

Same as 25K Wire Rope Apex Fitting Shackle.

25K Nylon Rope Sling Apex Fitting Pin (38850-00008-102)

Same as 25K Wire Rope Sling Apex Fitting Pin

25K Nylon Rope Sling Rope Assembly (38850-0009-042)

Material: Nylon rope, double braided MIL-R-24050A

Rope - Tensile

P_{au} = 60,000 (93)

P = 43,000/.85 x.94

= 53,817 (94)

Ultimate M.S. = 60,000/53,817 - 1

= +.11 (95)

25K Nylon Rope Sling Grab Hook (38850-00013-102)

Similar to 25K Wire Rope Sling Grab Hook

25K Nylon Rope Sling Grab Hook Spacer (388350-00015-102)

Material: 7075-T651

(F_{tu} = 77,000)

Spacer - Bending

P_{au} = 106,901 (96)

P = 43,000 (97)

Ultimate M.S. = 106,901/43,000 - 1

= +1.49 High (98)

25K Nylon Rope Sling Grab Hook Pin (MS20392-10C123)

Similar to 25K Wire Rope Sling Grab Hook Pin

25K Nylon Rope Sling Chain (388350-00053-102)

Same as 25K Wire Rope Sling Chain

60K WIRE ROPE SLING

Design Load Criteria

For the apex fitting assembly:

Ultimate load = 60,000 x 2.96 x 1.5

= 266,400 (99)

For the sling leg subassemblies:

Ultimate load = 60,000 x 2.87 x .6

= 103,300 (100)

60K Wire Rope Sling Apex Fitting Master Link (Crosby-Laughlin A342 - 1-3/4 in.)

Material: Alloy steel

(F_{tu} = 125,000)

Link - All stresses

P_{au} = 267,000 (107)

P = 266,400 (102)

Ultimate M.S. = 267,000/266,400 - 1

= +.002 (103)

60K Wire Rope Sling Apex Fitting Shackle (Crosby-Laughlin G2150-11/8)

Material: Alloy steel

(F_{tu} = 125,000)

Shackle - All stresses

P_{au} = 114,000 (104)

P = 103,300 (105)

Ultimate M.S. = 114,000/103,300 - 1

= +.10 (106)

<u>60K Wire Rope Sling Cable Assembly</u> (38850-00010-043)

Material: Stainless steel wire rope Type 302/304

Rope - Tensile

P_{au} = 103,500 (107)

P = 103,300 (108)

Ultimate M.S. = 103,500/103,300 - 1

= <u>+.002</u> (109)

(Note: This is the margin at minimum specified strength.)

<u>60K Wire Rope Sling Grab Hook</u> (38850-00014-102)

Material: 4340

(F_{tu} = 150,000 F_{su} = 95,000)

Pin Lug - Tensile and Bearing

Lower value of P_{au} = 124,633 (110)

P = 103,300 x .5

= 51,650 (111)

Ultimate M.S. = 124,633/51.650 - 1

= <u>+1.41</u> High (112)

Connecting Link Lug - Tensile and Bearing

P_{tru} = 136,766 (113)

P = 51,650 (114)

Ultimate M.S. = 136,766/51,650 - 1

= <u>+1.65</u> High (115)

Hook Section - Bending and Torsion

P_{au} = 54,495 (116)

P = 51,650 (117)

Ultimate M.S. = 54,495/51,650 - 1

= <u>+.06</u> (118)

(Note: This value depends on the side moment produced on the hook by the chain. It is influenced by the final attitude of the chain relative to the hook, which is difficult to predict.)

<u>60K Wire Rope Sling Grab Hook Spacer</u> (38850-00016-103)

Material: 4130

(F_{tu} = 150,000)

Spacer - Bending

P_{au} = 108,845 (119)

P = 103,300 (120)

Ultimate M.S. = 108,845/103,300 - 1

= <u>+.05</u> (121)

<u>60K Wire Rope Sling Grab Hook Pin</u> (MS20392-12C119)

Material: Steel

(F_{tu} = 145,000 Maximum double shear load = 117,820)

Pin - Shear

P_{au} = 117,820 (112)

P = 103,300 (123)

Ultimate M.S. = 117,820/108,300 - 1

= <u>+.14</u> (124)

<u>60K Wire Rope Sling Chain</u> (38850-00053-103)

Material: Alloy steel

Chain - Tensile

P_{au} = 56,000 (125)

P = 51,650 (126)

Ultimate M.S. = 56,000/51,560 - 1

= <u>+.08</u> (127)

6K PENDANT

Design Load Criteria

For all three main subassemblies:

Ultimate Load = 6,000 x 5.28 x 1.5

= 47,520 (128)

6K Pendant Apex Fitting Side Plate Assembly (38850-00063-041)

Material: 7075-T651

(F_{ty} = 66,000 F_{tu} = 77,000 F_{su} = 46,000)

Top Lug - Tensile and Bearing

Lower value of P_{au} = 49,956 (129)

If 67% of the ultimate load is taken on one side plate,

P = 47,520 x .67

= 31,838 (130)

Ultimate M.S. = 49,956/31,838 - 1

= +.57 (131)

Top Lug - Shear

P_{au} = 56,580 (132)

P = 31,838 (133)

Ultimate M.S. = 56,580/31,838 - 1

= +.78 (134)

Top Lug - Tensile due to bushing

F_{au} = 46,200 (135)

σ = 4.80 x .0024 x 10^6/.9393

= 12,264 (136)

Ultimate M.S. = 46,200/12,264 - 1

= +2.77 High (137)

Center Section - Bending

P_{au}	= 711,637	(138)
P	= 47,520	(139)
Ultimate M.S.	= 711,637/47,520 - 1	
	= <u>+10.86</u> High	(140)

Center Section - Tensile

P_{au}	= 32,880	(141)
P	= 31,838	(142)
Ultimate M.S.	= 32,880/31,838 - 1	
	= +.03	(143)

<u>6K Pendant, Apex Fitting Spacer</u> (38850-00063-102)

Material: 4130

(F_{tu} = 150,000)

Spacer - Bending

For worst-case load, i.e., center concentrated,

P_{au}	= 55,120	(144)
P	= 47,520	(145)
Ultimate M.S.	= 55,120/47,520 - 1	
	= +.16	(146)

<u>6K Pendant Apex Fitting Top Bolt</u> (AN12-54)

Material: Steel

(F_{tu} = 125,000 Maximum single shear load = 33,150)

Bolt - Shear

P_{au}	= 33,150	(147)
P	= 31,838	(148)
Ultimate M.S.	= 33,150/31,838 - 1	
	= +.04	(149)

<u>6K Pendant Apex Fitting Saddle</u> (33850-00063-104)

Material: 7075-T651

(F_{tu} = 77,000 F_{su} = 46,000 F_{bru} = 100,000)

Center Section - Bending

For semi-distributed load,

P_{au}	= 62,875	(150)
P	= 47,520	(151)
Ultimate M.S.	= 62,875/47,520 - 1	
	= <u>+.32</u>	(152)

Lug - Bending

P_{au}	= 29,274	(153)

If 50% of the ultimate load is taken on one lug,

P	= 47,520 x .50	
	= 23,760	(154)
Ultimate M.S.	= 29,274/23,460 - 1	
	= +.23	(155)

Lug - Shear

P_{au}	= 31,694	(156)
P	= 23,760	(157)
Ultimate M.S.	= 31,694/23,760 - 1	
	= +.33	(158)

Lug - Bearing

P_{au}	= 57,600	(159)
P	= 23,760	(160)
Ultimate M.S.	= 47,600/23,760 - 1	
	= +1.42 High	(161)

6K Pendant Rope Assy. (38850-00065-041)

Material: Nylon rope, double braided, MIL-R-24050A

Rope - Tensile

P_{au}	= 60,000	(162)
P	= 59,000	(163)
Ultimate M.S.	= 60,000/59,000 - 1	
	= +.02	(164)

6K Pendant Swivel Hook Assembly (38850-00051-041)

(Eastern Rotorcraft Design)

All components - All stresses

P_{au}	= 48,000	(165)
P	= 47,520	(166)
Ultimate M.S.	= 48,000/47,520 - 1	
	= +.01	(167)

20K PENDANT

Design Load Criteria

For all three main subassemblies:

Ultimate load	= 20,000 x 2.96 x 1.5	
	= 88,800	(168)

20K Pendant Apex Fitting Side Plate Assembly (38850-00023-041)

Material: 7075-T651

(F_{ty} = 66,000 F_{tu} = 77,000 F_{su} = 46,000)

Top Lug - Tensile and Bearing

Lower value of P_{au} = 84,140 (169)

If 53% of the ultimate load is taken on one side plate,

P	= 88,800 x .53	
	= 47,064	(170)
Ultimate M.S.	= 84,140/47,064 - 1	
	= +.79	(171)

Top Lug - Shear

P_{au} = 95,496 (172)

P = 47,064 (173)

Ultimate M.S. = 95,496/47,064 - 1

= +1.03 High (174)

Top Lug - Tensile due to bushing

F_{au} = 46,200 (175)

σ = 4.30 x .0024 x 10^6/1.1898

= 8,674 (176)

Ultimate M.S. = 46,200/8,674 - 1

= +4.33 High (177)

Center Section - Bending

P_{au} = 758,556 (178)

P = 88,800 (179)

Ultimate M.S. = 758,556/88,800

= +7.54 High (180)

Center Section - Tensile

P_{au} = 57,134 (181)

P = 47,064

Ultimate M.S. = 57,134/47,064 - 1

= +.21 (182)

20K Pendant, Apex Fitting Spacer (38850-00023-102)

Material: 4130

(F_{tu} = 150,000)

Spacer - Bending

For worst case load, i.e., center concentrated

P_{au}	= 107,560	(183)
P	= 88,800	(184)
Ultimate M.S.	= 107,560/88,800 - 1	
	= .21	(185)

<u>20K Pendant Apex Fitting Top Bolt</u> (NAS 1116-80)

Material: Steel

(F_{tu} = 160,000 Maximum single shear load = 74,600)

Bolt Shear

P_{au}	= 74,600	(186)
P	= 47,064	(187)
Ultimate M.S.	= 74,600/47,064 - 1	
	= +.59	(188)

<u>20 Pendant Apex Fitting Saddle</u> (38850-00023-104)

Material: 7075-T651

(F_{tu} = 77,000 F_{su} = 46,000 F_{bru} = 100,000)

Center Section - Bending

P_{au}	= 111,872	(189)
P	= 88,800	(190)
Ultimate M.S.	= 111,872/88,800 - 1	
	= +.26	(191)

Lug - Bending

P_{au}	= 66,349	(192)

If 50% of the ultimate load is taken on one lug,

P	= 88,800 x .50	
	= 44,400	(193)

Ultimate M.S. = 66,349/44,400 - 1

= +.49 (194)

Lug - Shear

P_{au} = 68,218 (195)

P = 44,400 (196)

Ultimate M.S. = 68,218/44,400 - 1

= +.54 (197)

Lug - Bearing

P_{au} = 118,800 (198)

P = 44,400 (199)

Ultimate M.S. = 118,800/44,400 - 1

= +1.70 High (200)

20K Pendant Rope Assy. (38850-00025-041)

Material: Nylon rope, double braided, MIL-R-24050A

Rope - Tensile

P_{au} = 120,000 (201)

P = 88,800/.85 x .94

= 111,000 (202)

Ultimate M.S. = 120,000/111,000 - 1

= +.08 (203)

20K Pendant Swivel Hook Assembly (38850-00051-042)

(Eastern Rotorcraft Design)

All components - All stresses

P_{au} = 89,000 (204)

P = 88,800 (205)

Ultimate M.S.	$= 89{,}000/88{,}800 - 1$	
	$= \underline{+.002}$	(206)

APPENDIX II

TECHNICAL DATA SUMMARY AND PHOTOGRAPHS

For reference purposes, the principal technical data for the wire rope slings, nylon rope slings, and pendants are summarized in Tables XXIX, XXX and XXXI, respectively.

TABLE XXIX. TECHNICAL DATA SUMMARY - WIRE ROPE SLINGS

		Nominal Capacity		
		6K	25K	60K
Apex fitting pin diameter	in.	1-1/8	1-1/2	1-3/4*
Apex fitting internal width	in.	7.50	7.62	10.87*
Wire rope diameter	in.	1/2	3/4	1-1/8
Chain size	in.	1/4	3/8	5/8
Sling length (nominal)	ft	18-22	18-22	18-22
Ultimate strength	lb	47,520	111,000	266,400
Weight (estimated)	lb	79	174	480

*Commercial apex fittings

TABLE XXX. TECHNICAL DATA SUMMARY - NYLON ROPE SLINGS

		Nominal Capacity		
		6K	25K	60K
Apex fitting pin diameter	in.	1-1/8	1-1/2	1-3/4*
Apex fitting internal width	in.	7.50	7.62	10.37*
Nylon rope diameter (nominal)	in.	1-1/16	1-1/2	2-1/4*
Chain size	in.	1/4	3/8	5/8
Sling length (nominal)	ft	18-22	18-22	18-22
Ultimate strength	lb	47,520	111,000	266,400
Weight (estimated)	lb	84	174	480*

*No components designed for this size

TABLE XXXI. TECHNICAL DATA SUMMARY - PENDANTS

		Nominal Capacity	
		6K	20K
Apex fitting pin diameter	in.	1.50	1.88
Apex fitting internal width	in.	3.125	3.125
Nylon rope diameter (nominal)	in.	1-1/2	2-1/4
Hook acceptance diameter	in.	2.00	2.60
Load beam width	in.	1.66	2.53
Pendant length (nominal)	ft	14	17
Spring rate	lb/in.	2,000	4,000
Ultimate strength	lb	47,520	88,800
Weight (estimated)	lb	73.34	108.42

Figure 28 is a photograph of a typical wire rope sling assembly. Photographs of the 6K, 25K and 60K slings in use during the static lift tests are included at Figures 29, 30 and 31, respectively, while Figure 32 is a photograph of a typical lift operation for an articulated load.

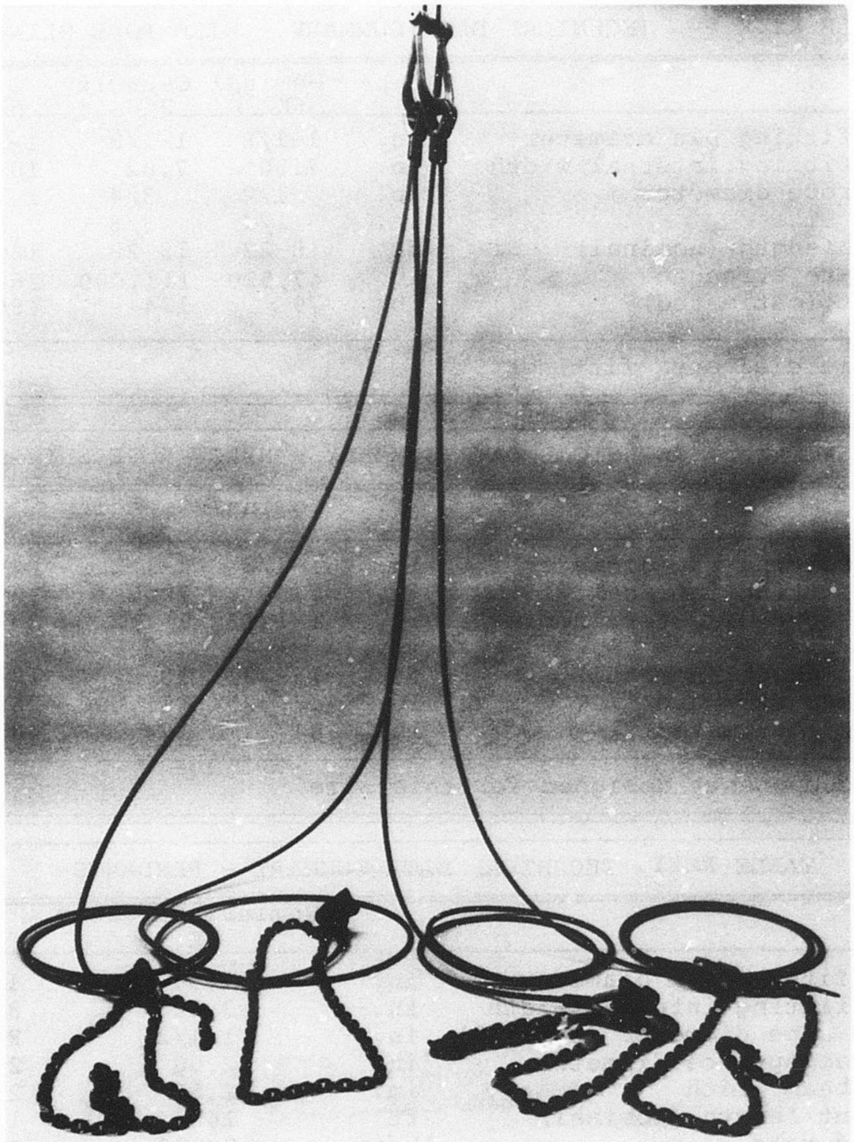

Figure 28. Typical Wire Rope Sling Assembly.

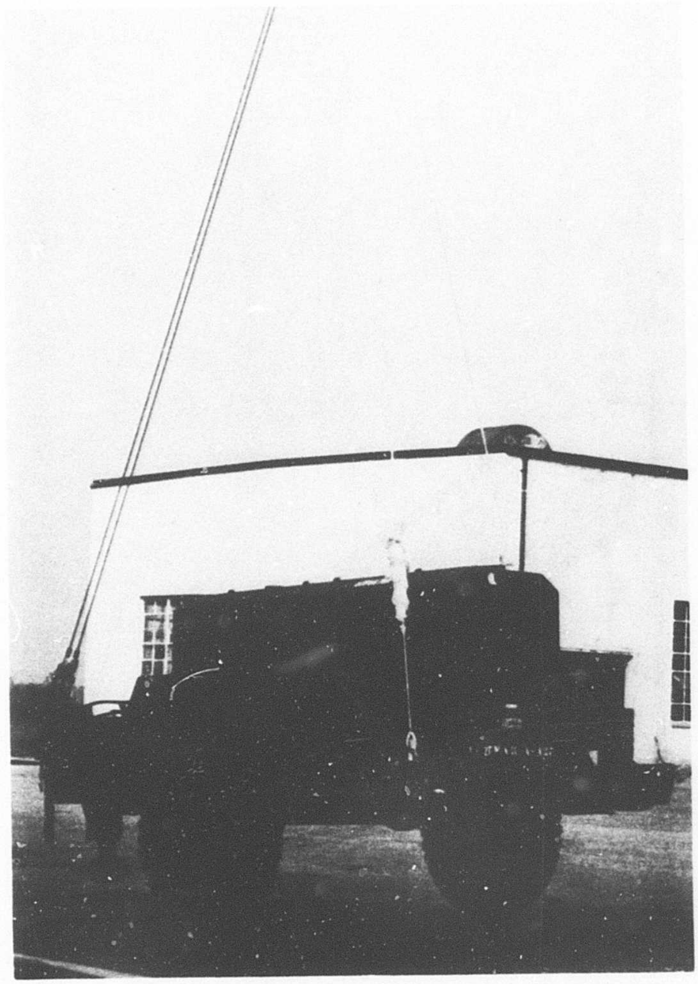

Figure 29. Typical Usage of 6K Wire Rope Sling

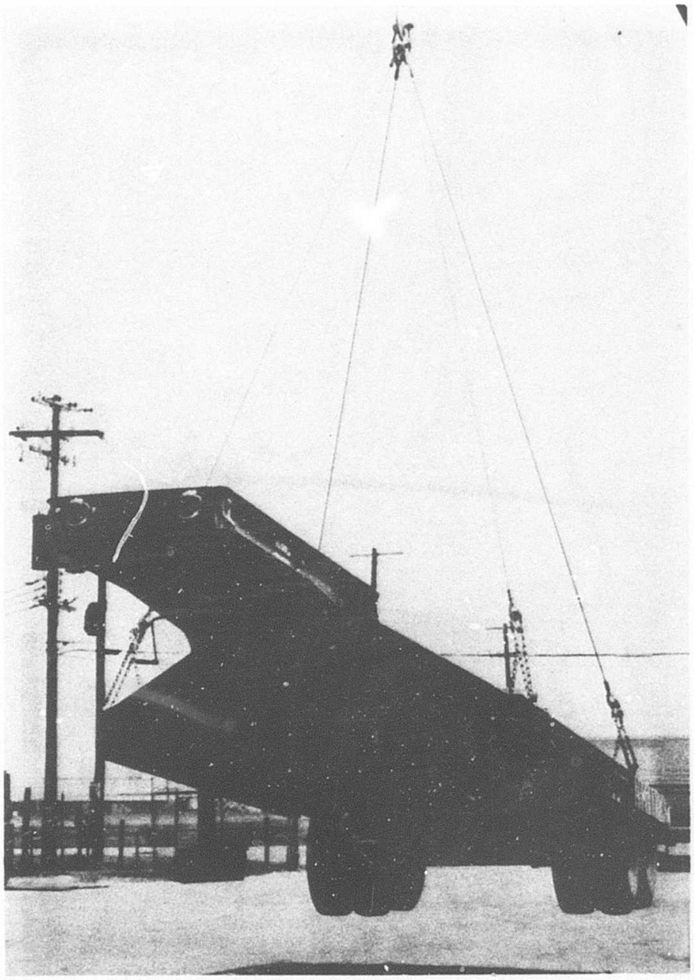

Figure 30. Typical Usage of 25K Wire Rope Sling

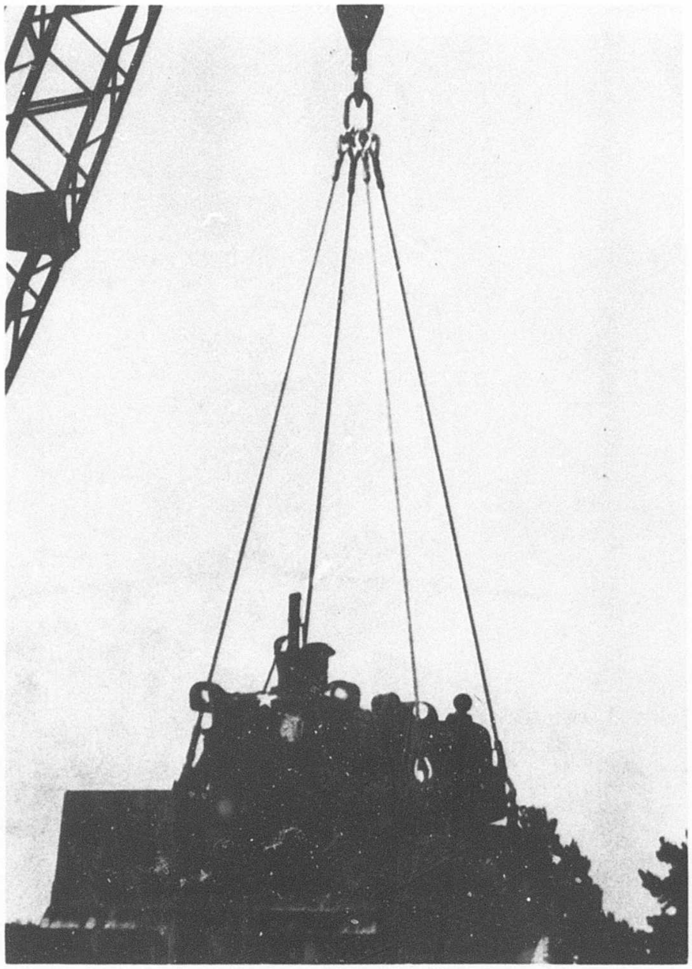

Figure 31. Typical Usage of 60K Wire Rope Sling

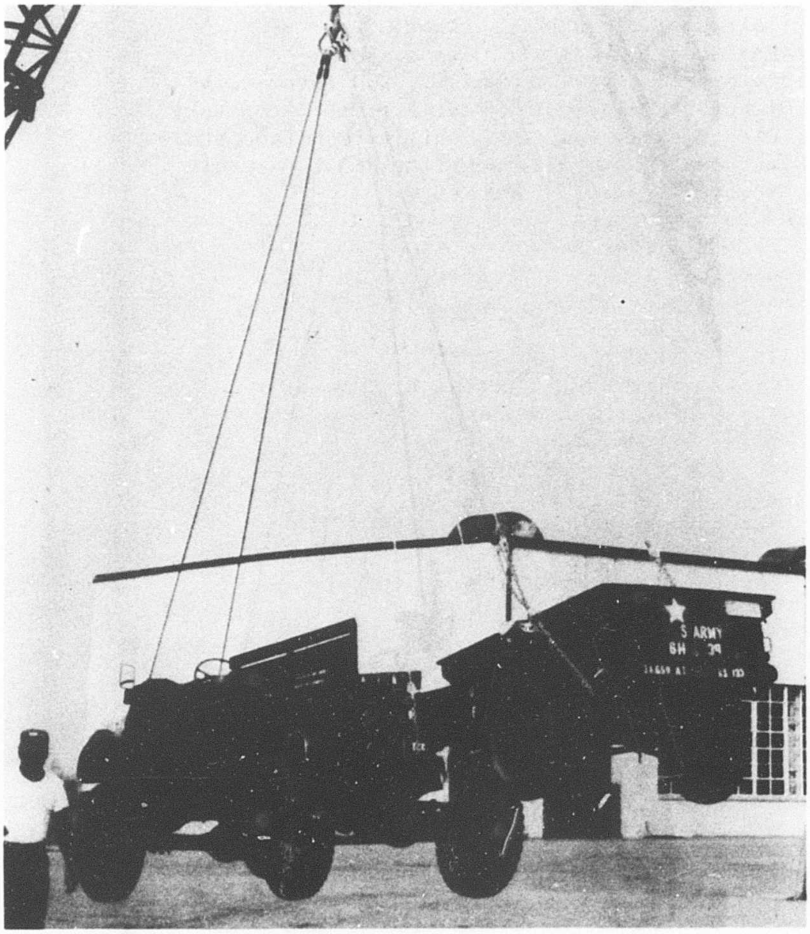

Figure 32. Typical Articulated Load Lift