AD-770 959

A STUDY OF NOLARO CABLE FOR USE WITH TETHERED BALLOONS

Joseph S. Ford, et al

Air Force Cambridge Research Laboratories
L. G. Hanscom Field, Massachusetts

12 October 1973

Unclassified
Security Classification

AD 770959

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Air Force Cambridge Research Laboratories (LCB) L.G. Hanscom Field Bedford, Massachusetts 01730	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
A STUDY OF NOLARO CABLE FOR USE WITH TETHERED BALLOONS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Scientific. Interim.

5. AUTHOR(S) *(First name, middle initial, last name)*
Joseph S. Ford, Major, USAF
Don E. Jackson, Capt, USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
12 October 1973	17	none

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) AFCRL-TR-73-0636
b. PROJECT, TASK, WORK UNIT NOS. 66650901	
c. DOD ELEMENT 62101F	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. DOD SUBELEMENT 681300	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Presented at the 7th AFCRL Scientific Balloon Symposium, Wentworth-by-the-Sea, Portsmouth, New Hampshire, 25 September 1972.	Air Force Cambridge Research Laboratories (LCB) L.G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

The purpose of this program was threefold: 1)to identify the mode of failure of the cable, 2) to investigate means of improving the cable, and 3)to establish operating procedures which would prevent future operational cable failures.

This paper presents the results of this testing program to date. The experimental set-up used to duplicate the cable/winch interface is discussed and the results of testing segments of the cable in this device are given. Laboratory failutes closely resembling that experienced in field conditions are shown and a theoretical model of the observed failure mechanism is discussed.

Additional areas of the investigation are discussed including microscopic study of fiber damage following cyclic loading of the cable over a fixed sheave, an evaluation of the cable against various sheave surfaces, the influence of foreign matter in the cable/sheave interface, and the design of instrumentation for the measurement of dynamic cable loads under field conditions.

KEYWORDS: Aerostats, Balloons, Balloon cable, Cable, Cable failure mode, Kite balloon, NOLARO cable, Tethered balloons, Tethers, Winch, Winch-cable interface

22

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Contents

PROCEEDINGS, SEVENTH AFCRL SCIENTIFIC BALLOON SYMPOSIUM

1. A Study of NOLARO Cable for Use With Tethered Balloons

J.S. Ford, Maj, USAF
United States Air Force Academy
Colorado Springs, Colorado

D.E. Jackson, Capt, USAF
AFCRL
Bedford, Massachusetts

1-1. INTRODUCTION

During field operations of a tethered balloon system in May of 1971, failure of the flying line resulted in loss of the balloon. Cable testing after the failure indicated no significant loss of break strength in portions of the cable near the operational failure. Winch testing using a weight and pulley system showed damage to the cable at the same point on the winch as the original failure. It appeared that the failure was due to wearing during balloon operations and not to a weak section of the cable. Laboratory testing was necessary to thoroughly understand all aspects of this failure mode. To accomplish this, AFCRL has undertaken a program with the Engineering Mechanics Department at the Air Force Academy to investigate the incident. This program has the short term goal of isolating and studying the cause of failure and thus taking appropriate steps to prevent future occurrence.

(Received for publication 15 December 1972)

The ultimate goal of the program is to study tether cables, both present designs and promising new ones.

The failure in the field occurred while using a 100,000-ft^3 kite balloon and a 0.52-inch diameter NOLARO cable; NOLARO is an acronym for NO LAY ROPE. It is manufactured by Columbian Rope Company and consists of prestretched polyester yarns contained in an extruded polyetheline jacket.

The 0.52-inch diameter NOLARO cable used in the field operations and this test program has 60 yarns and a nominal jacket thickness of 40 mils. This cable has a rated break strength of 11,500 pounds and weighs 90 pounds per 1000 feet.

The winds at the time of failure were averaging an estimated 40 knots with maximum gusts to 50 knots. These winds were sufficient to cause much sand and dirt to be blown around in the area of the winch. After holding the balloon at 1000 feet above ground level for 2 hours under these conditions, the cable failed at the first wrap on a nonrotating sheave of the winch.

The failure mode seen in the field has been isolated and studied in the laboratory. In studying this failure mode, other modes of wear and damage have also been investigated. This paper describes the tests conducted to date and the results. Also, future plans of the test program are discussed.

1-2. BASIC ASSUMPTION FOR NOLARO TEST PROGRAM

An assumption in the initial test program was that the critical condition for NOLARO is a holding operation with the tether line subjected to cyclic loads superimposed on a basic preload. During a holding condition, which is typical of tethered balloon operations, the material is subjected to traction loads over a short segment of the length for considerable time, whereas the point of application of these loads is continually changing during winching. Cyclic loads, in addition to the basic load due to the balloon, will be present during operation in high wind conditions. These cyclic loads are due to balloon aerodynamics, as well as the dynamic response of the cable.

1-3. PRELIMINARY TENSILE STRENGTH TESTS

The initial steps in the test program were to establish base line data for the static strength of the material and to develop in-house capability to make high-quality eye splices. The material used for the tests was 0.52 inch diameter NOLARO taken from the reel which was in use at the time of the operational failure. Ten 12-foot specimens were tested in tension using a hydraulic Universal Test Machine. The specimens were fabricated with an eye splice at each end and with a thimble inserted in the eye to protect the fibers. Test values between 9500 and 11,800 pounds were obtained, with the higher values occurring during later tests as splicing techniques were improved. Initial fiber failure occurred in all tests at the beginning of the eye splice, indicating that splicing is a limiting factor in the development of NOLARO breaking strength. These test results are in agreement with those obtained by other researches with like material as described in the reference documents.

1-4. CYCLIC LOAD TEST PROGRAM

After the initial tensile tests were completed, a test program was initiated to investigate the NOLARO/winch interface and the mechanism by which loads were transferred between the two. A test fixture (shown in Figure 1-1) was constructed to simulate a 90° NOLARO/winch interface. The test section consisted of sheave segments of identical geometry and material to that of the Fair Site dual capstan winch. A cross section of a sheave segment is shown in Figure 1-2. The segment is made of aluminum with a molded polyurethane coating. A solid aluminum sheave segment of identical geometry was also manufactured for the test fixture.

The fixture was mounted in an Instron Universal Test Machine as shown in Figures 1-3 and 1-4. To more closely duplicate the boundary conditions existing in actual operations, the primary load cell was extended 4 feet above the normal location on top of the test machine. A clamping fixture was installed on the splices to prevent slip between the polyethylene jacket and the polyester load fibers at those points. A 12,000-pound capacity strain-gauge load cell was mounted on the rear extention arm of the fixture to monitor load behavior in the NOLARO after passing over the 90° sheave section.

During initial testing with this fixture it was observed that the traction available from the 90° sheave segment was not a function of the load but remained at approximately 2000 pounds over a range of primary loads from 3000 to 9000 pounds. Slipping of the NOLARO jacket on the sheave could be observed at the higher loads. Dissection of test specimens which had been loaded to 9000 pounds around the sheave revealed no damage to either the jacket or the fibers. Static tests of specimens which had been tested to 9000 pounds around the sheave resulted in failure loads within the range of previous tensile tests. Specimens loaded to failure around the 90° sheave segment failed at comparable loads, and in the same manner, that is, initial fiber failure occurred at the beginning of the splice. Dissection of these specimens revealed no damage in the sheave area other than the usual hockling of fibers which had failed at the splice.

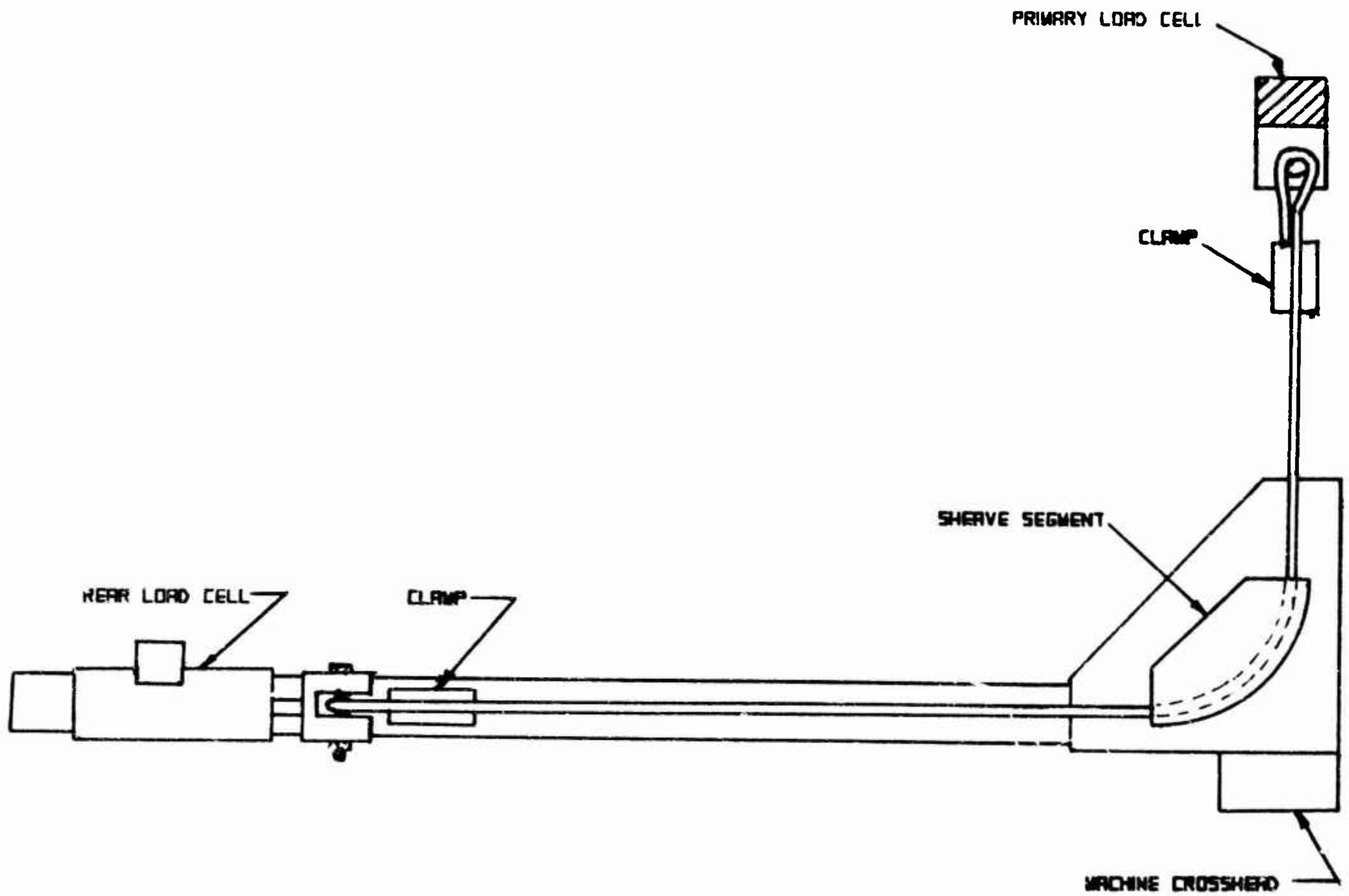

Figure 1-1. Schematic of Test Fixture

Figure 1-2. Cross Section of Test Sheave Segment

A series of cyclic load tests were performed next with a preload of 5000 pounds and a variable load of ±1000 pounds. This loading was considered typical of tether line behavior under moderate to high wind conditions. Duration of the tests varied with the maximum number of cycles attained at this loading condition being 13,500. Rear load cell readings remained almost constant during the cycling tests at a value 2000 pounds less than the upper load limit. No failures of either the NOLARO jacket or the polyester fibers occurred. Fibers were removed from the specimens after tests and compared with untested strands from a similar section of NOLARO under a stereo microscope. Some discoloration and slight abrasion of the fibers which had been in contact with the jacket material was noted; however, tensile tests on these fibers did not indicate that any reduction in strength had occurred.

For the next series of tests, sand with a sieve rating of 15 was introduced into the interface between the NOLARO and the fixed sheave. Since the operational failure had occurred during a sandstorm, it was considered highly probable that

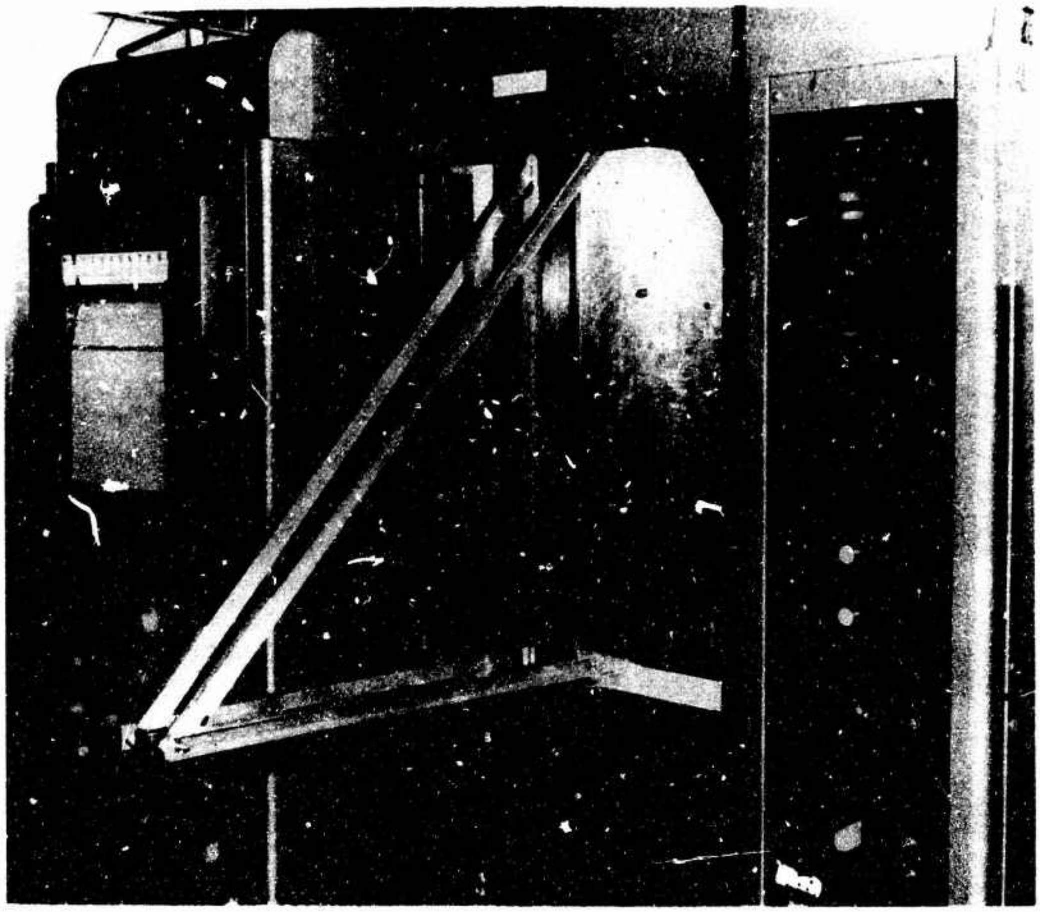

Figure 1-3. Test Fixture in Instron Test Machine (Front)

sand was present in the interface at the time. The introduction of the sand drastically changed the behavior of the NOLARO. Extreme elongations of the jacket material were evident at the point of tangency with the sheave during the initial application of load. Jacket failure occurred at this point after relatively few load cycles. Fiber abrasion and subsequent fiber failure occurred as load cycling continued.

Other friction producing materials, namely commercial belt dressing compound and small spherodized glass beads, were introduced during later tests with similar results. These materials were selected to produce friction without the sharp cutting edges of the sand. Fiber abrasion was less pronounced during tests with these materials; however, the initial jacket failure occurred in the same manner.

The failures observed in the tests with friction materials are considered to be representative of the one experienced in the field; namely, they occurred at the

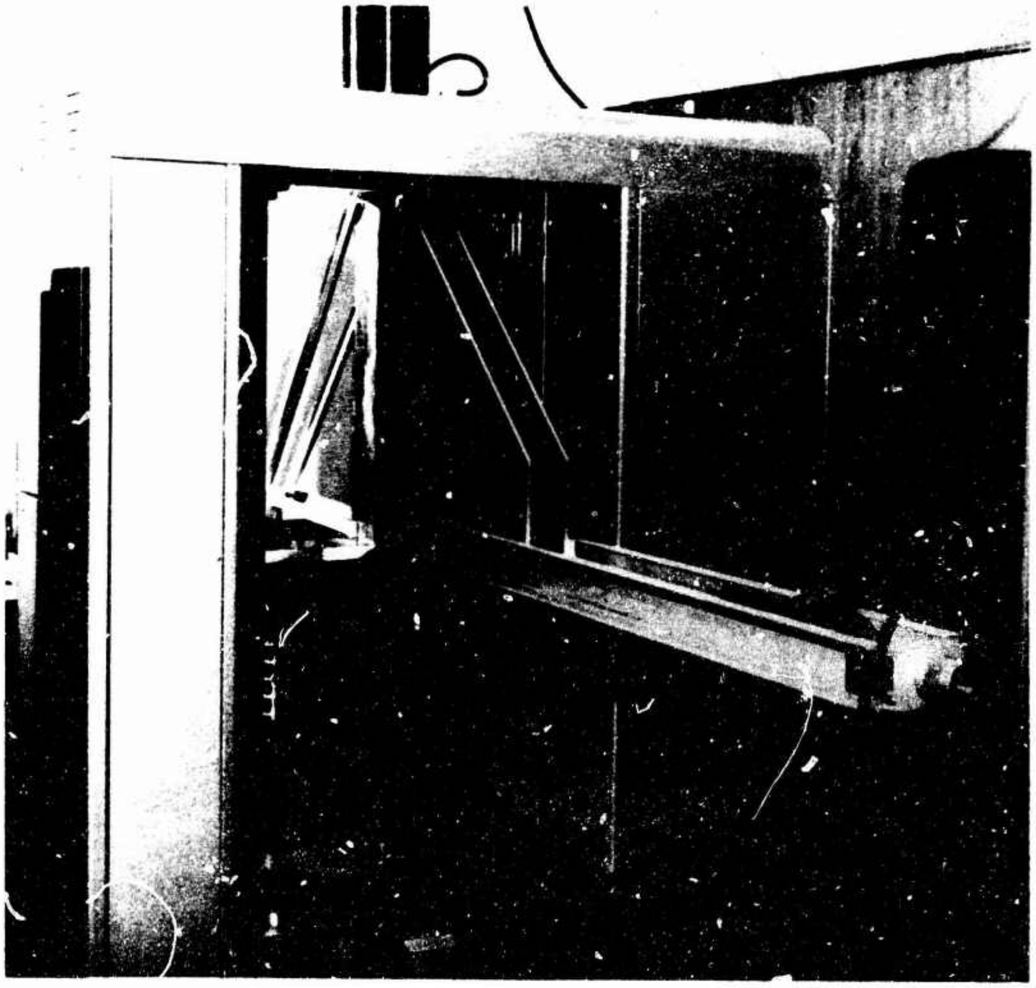

Figure 1-4. Test Fixture in Instron Test Machine (Rear)

initial contact point with the traction drive and were produced by cyclic loads with friction producing material along the interface. A brief explanation of the failure mechanism is presented next. The development of the theoretical model is supplemented with strain data obtained from the NOLARO jacket during cyclic tests with sand.

1-5. EXPLANATION OF FAILURE MECHANISM

The model used in this discussion is shown in Figure 1-5. It is essentially the same as the test fixture used for the cyclic tests. The coordinate(s) is measured from the loading end of the test specimen, and the point of application of the

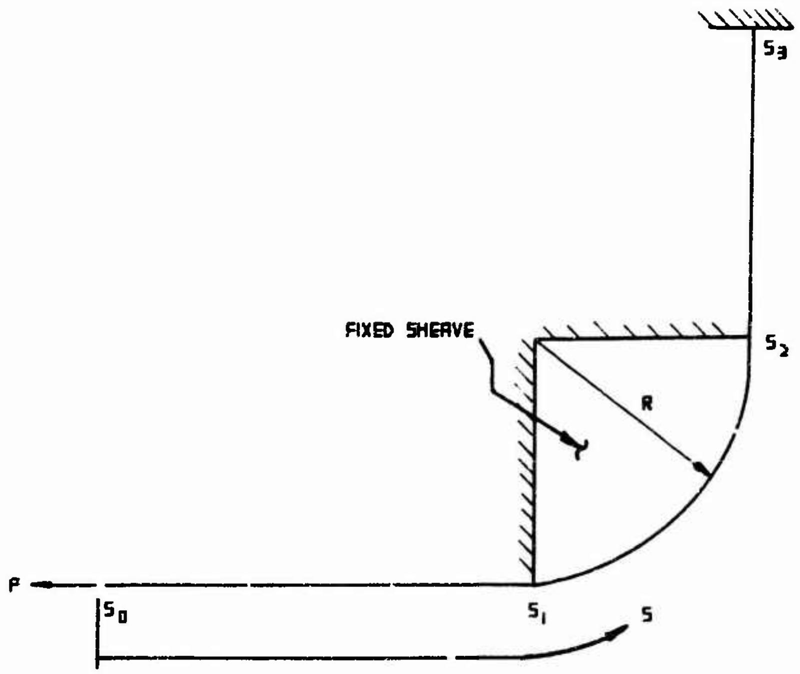

Figure 1-5. Schematic of Test Condition

load (P) is considered to be sufficiently removed from the sheave to represent the boundary conditions of a flying tether line. Friction forces (F) are transmitted to the fibers by means of shear forces in the jacket. The applied load (P) is resisted by these friction forces and by the load at the fixed end of the specimen.

The polyester stress-strain relationship can be considered linear within the range of loading considered; hence, the strain in the polyester bundle as it passes over the 90° sheave section is assumed to vary in proportion to the load in the fibers. Although actual fiber strain measurements were not made, a linear strain distribution along the sheave can be assumed since the fiber/jacket interface through which the friction forces are transmitted is not affected by the surface condition of the sheave. The total elongation of the fibers in the test section can therefore be expressed as the integral of the strains or simply the area under the solid curve in Figure 1-6 which shows assumed fiber strains versus position along the test section.

The jacket strains along the free sections of NOLARO between s_0-s_1 and s_2-s_3 are the same as those of adjacent fibers due to the low modulus of the polyethylene and the molded interface between the two. Friction along the area of contact with the sheave between s_1 and s_2 restrains the motion of jacket and results in a relative slip between the fibers and the polyethylene. The magnitude of this relative motion between the fibers and the jacket is small in the case of a clean sheave,

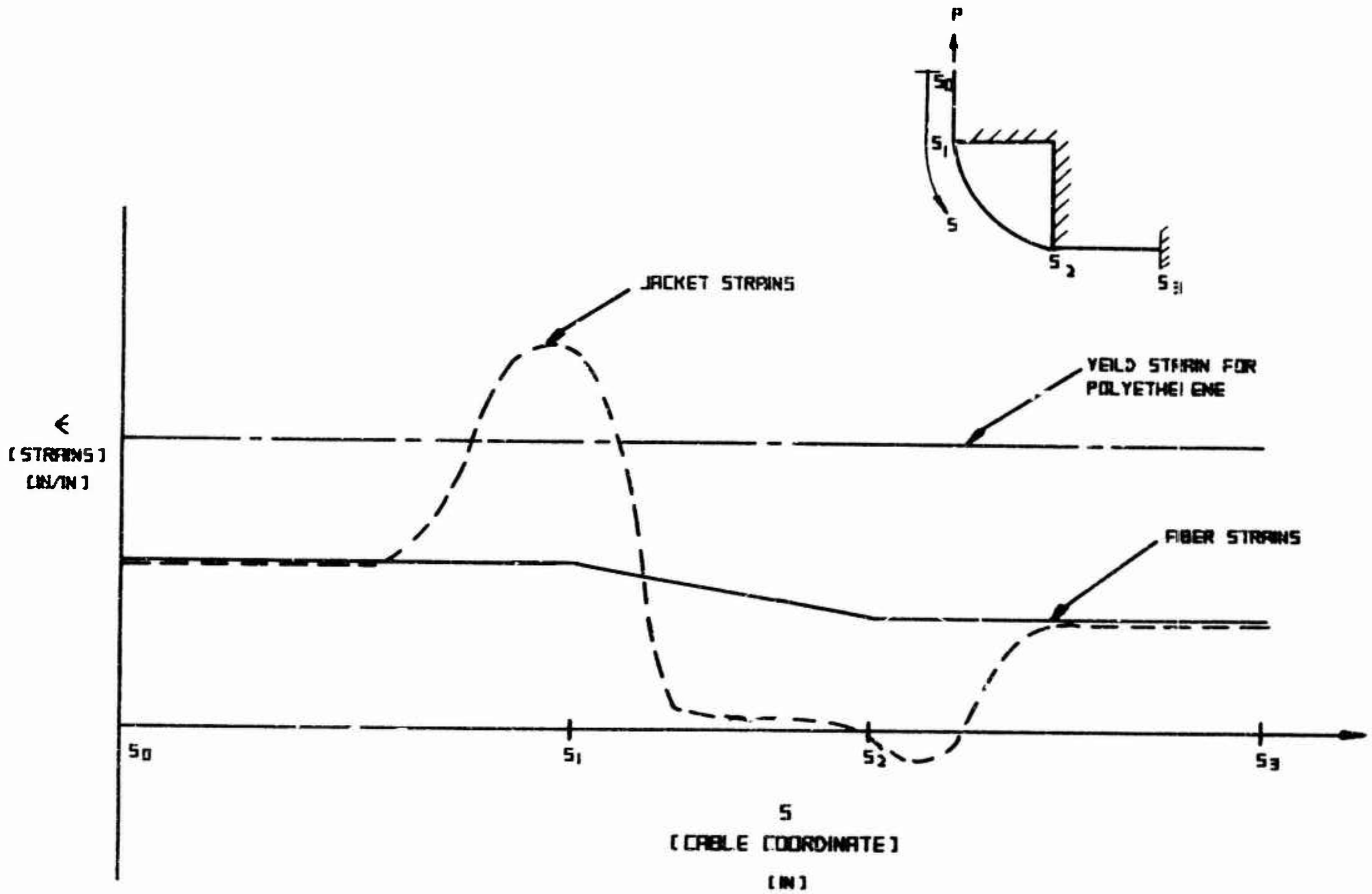

Figure 1-6. Strain in Jacket and Fibers vs Positions

but becomes very large when the jacket is restrained to almost no slip on the sheave by sand or other friction producing materials.

The real significance of the restraint of the polyethylene jacket by high friction on the fixed sheave is seen when the total elongation of the test section is considered. Point s_0 on Figure 1-6 is considered representative of a point on the flying cable sufficiently removed from the sheave. At this point the total elongation of the fibers and the jacket from point s_3, or the fixed end of the NOLARO, must be the same. In other words, the integral of the jacket strains between s_0 and s_3 must equal the integral of the fiber strains over the same length. The dashed line on Figure 1-6 shows measured jacket strains from tests on NOLARO with sand. The curve shows low jacket strains occurring along the contact surface, and more significantly, the very large strains in the jacket which occur as the cable separates from the sheave. These strains, which result from the total displacement condition, considerably exceed the yield condition for the polyethylene. Cyclic loading at this condition produces successive plastic deformation in the jacket at a localized area until rupture occurs.

The jacket failure sequence is clearly shown in Figures 1-7, 1-8, and 1-9. Figure 1-7 shows the specimen in the test fixture after a 2000-pound load was applied. The test marks on the NOLARO were placed at 1/2-inch intervals on the unloaded cable. Figure 1-8 shows the specimen after the application of a 6000-pound load. Over 100 percent elongation in the jacket has occurred locally and jacket failure can be seen on one side of the cable. Figure 1-9 shows the cable after

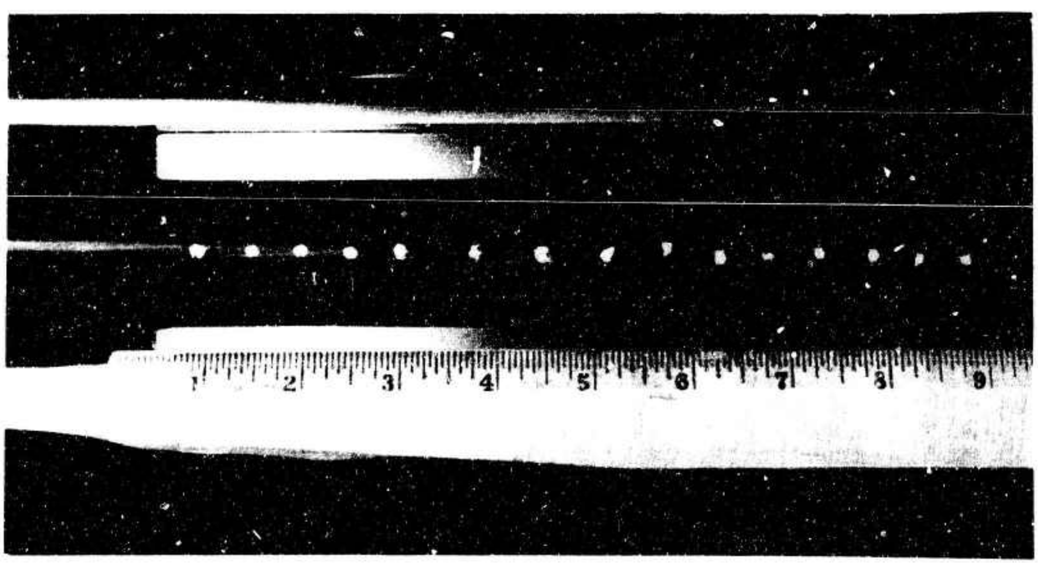

Figure 1-7. Specimen in Test Fixture – 2000-Pound Load (Sand in Interface)

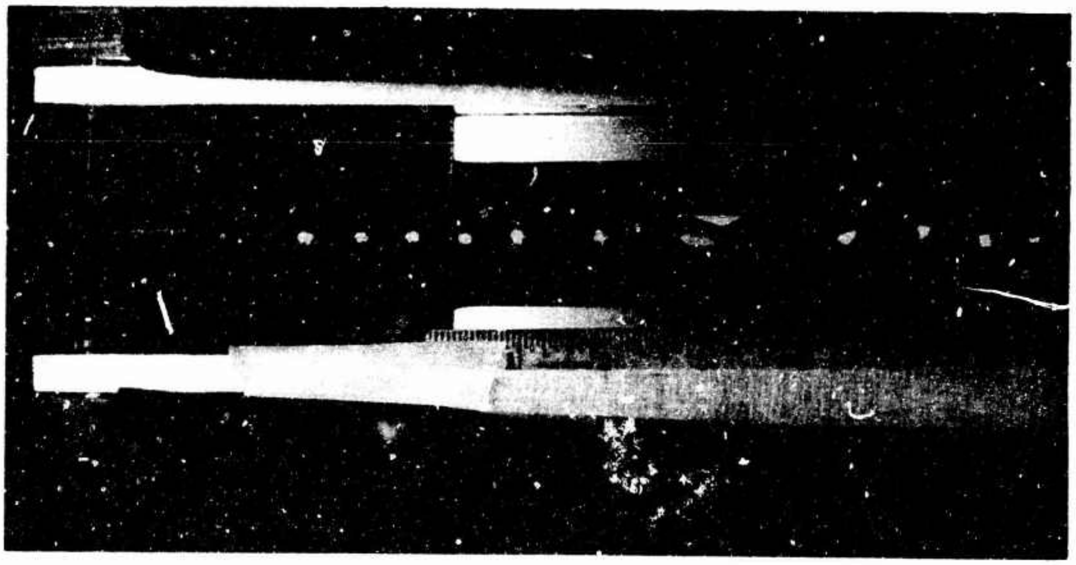

Figure 1-8. Specimen in Test Fixture – 6000-Pound Load (Sand in Interface)

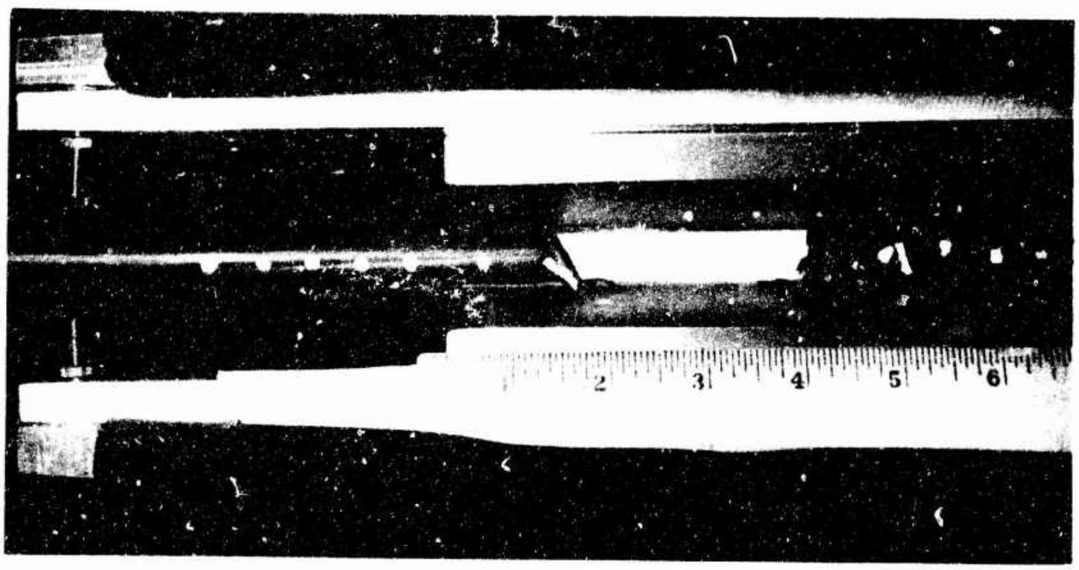

Figure 1-9. Specimen in Test Fixture – After Five Load Cycles 4000 ± 2000 Pounds (Sand in Interface)

five load cycles of 4000 ± 2000 pounds. Considerable separation has occurred at the jacket failure and several fibers have failed due to abrasion. Figure 1-10 shows the failed section of the NOLARO after removal from the test fixture. Severe damage to the fibers as well as the thinning of the jacket at the failure point is evident in the photograph.

Figure 1-10. Failed Section of NOLARO Removed from Test Machine

The preceding discussion, as well as the measured data and the photographs, applies only to the case of high friction in the area of initial contact with the sheave. As noted before, similar tests under clean conditions did not produce failures of this type. In these tests noticeable slip between the NOLARO jacket and the sheave could be observed, and the large jacket strains at the point of tangency were not present.

1-6. ADDITIONAL TESTING PROGRAMMED

Tests to date have been restricted in the total number of load cycles obtainable due to the relatively low cycling rate of the Instron machine. A new test fixture is currently under construction which will permit the accumulation of a large number of test cycles in a shorter period. This fixture utilizes a 3000-pound force magnetic exciter to provide the cyclic load. Preload of the cable is maintained by hydraulic actuators, and this preload is isolated from the exciter armature by pneumatic springs. A schematic drawing of the design is shown in Figure 1-11. The versatility of the magnetic exciter will provide for a wide range of frequency and load spectrum variations.

The three-wheel tensiometer shown in Figure 1-12 has been developed for use on line during flight operations with NOLARO. This tensiometer has a sensitivity

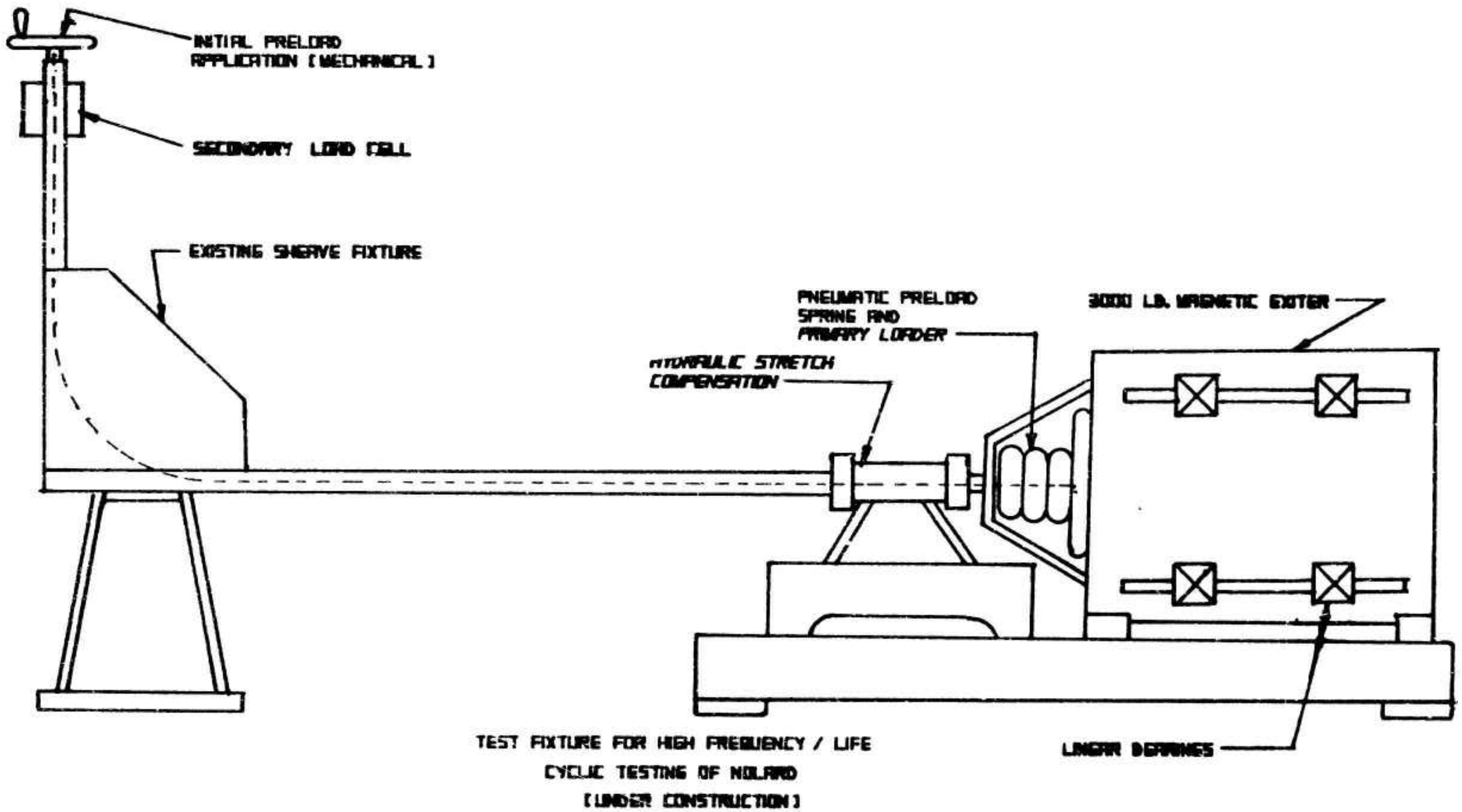

Figure 1-11. Schematic of Proposed High-Frequency Test Fixture

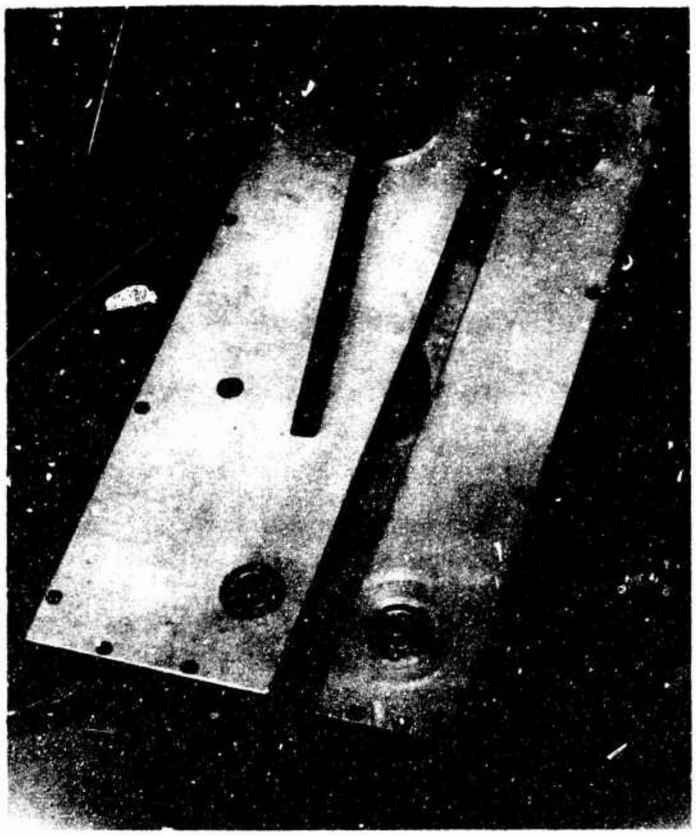

Figure 1-12. Three-Wheel Tensiometer Designed for Measuring NOLARO Loads During Flight Operations

of 1 mV/lb and a frequency response from dc to 1500 Hz. It functions over a range of 500 to 10,000 pounds. Dynamic cable loads during future flights will be measured and recorded on magnetic tape. The data will be analyzed for spectral content as well as used directly as an input to the magnetic exciter.

The tensiometer and test fixture are designed to measure and simulate flight operating conditions as closely as possible, with the primary objective being to determine life expectancy of NOLARO during holding operations. Temperature tests on NOLARO are also planned using an environmental chamber. Tests will be conducted between -60°F and +200°F. The chamber is of sufficient size to permit evaluation of the cable over a partial sheave segment.

I-7. CONCLUSIONS FROM TESTS PERFORMED ON NOLARO TO DATE

1. Limited cyclic loading of NOLARO against a fixed sheave under clean conditions does not appreciably degrade the strength of the cable. Tests have shown this to be true for load conditions of 50 ±20 percent of rated cable strength and up to 15,000 cycles. Test results are identical for both polyurethane and hardened aluminum sheave surfaces.

2. The introduction of foreign matter, in particular sand, into the sheave/cable interface results in a failure of the jacket after relatively few load cycles and subsequent fiber failures due to abrasion of the unprotected polyester.

3. Due to Conclusion 2, field operation with NOLARO should not be conducted under conditions of wind-blown sand unless the winch installation is enclosed. Frequent inspection of the winch surfaces should be made to ensure that a build-up of friction producing foreign matter does not occur. This is particularly important for the first groove on a multiple-groove dual-capstan winch of the type commonly used with NOLARO.

4. Holding operation with NOLARO should be programmed to move the cable frequently by small amounts, thus shifting the critical point along a section of the jacket and preventing accumulative plastic deformation.

5. NOLARO offers a high strength-to-weight ratio necessary for critical applications. The material must be handled with more care than steel cable, but this appears to be a small penalty to pay for the advantages to be gained in increased altitude and payload capability in tethered balloon operations.

6. Further testing of NOLARO is required to determine life expectancy under cyclic loading. Additional testing must be conducted to determine effects of temperature on cable properties.

References

Product Bulletin #R-1a, Columbian Rope Company, Auburn, New York, 1 June 1969.

Tests on NOLARO Tether, Telta Project, Unpublished test data, Patrick AFB, Florida, 20 June 1970.

angles. Knowledge of the aerodynamic characteristics of tethered balloons in this operating mode is needed to design the optimum system configuration.

Wind tunnel tests in the United States in the early 1900's were mainly of high fineness ratio bodies with application to airship design (Abbott, 1931). Some testing has been conducted in England on barrage balloons for tethered applications (Simonds, 1963). Recently, extensive pressure and force tests have been conducted in the United States of a natural shape and a kite balloon (Sherburne, 1968; Haak, 1971). However, the above tests have been conducted for a limited range of angle of attack (α), seldom exceeding 20°. A preliminary wind tunnel test of two kite-balloon models in a small subsonic facility provided the first balloon aerodynamic data at $\alpha > 20°$ (Swarthout, 1967). This test indicated the desirability of conducting a more extensive test program in a production facility. This paper presents the results of that subsequent program.

Natural shape, Class C, barrage, and Vee balloon models were tested in an 8- by 12-foot wind tunnel at the University of Washington. Lift, drag, and pitching moment are presented for an angle-of-attack range from -12° to +102°, and a nominal Reynolds Number (R. N.) of 10^6 ft^{-1}. The use of each balloon configuration as a tethered balloon is discussed. The data will be useful for selecting the optimum balloon shape for logging service.

2-2. NOMENCLATURE

α	pitch angle of attack, degrees
α_L	limit angle of attack, degrees
B	buoyant lift, pounds
C_D	drag coefficient, $2D/\rho V^2 \forall^{2/3}$
C_L	lift coefficient, $2L/\rho V^2 \forall^{2/3}$
C_m	pitching moment coefficient, $2M/\rho V^2 \forall^{2/3} \ell$
D	drag, pounds
γ	flight path angle, degrees
ℓ	reference length, feet
L	aerodynamic lift, pounds
L/D	aerodynamic lift-to-drag ratio, C_L/D_D
M	aerodynamic pitching moment about center of moments, ft-lb
M_V	pitching moment about tether point due to relative wind, ft-lb