

UNCLASSIFIED

AD NUMBER

ADA800185

CLASSIFICATION CHANGES

TO: unclassified

FROM: restricted

LIMITATION CHANGES

TO:  
Approved for public release; distribution is unlimited.

FROM:  
Distribution authorized to DoD only;  
Administrative/Operational Use; 26 FEB 1945.  
Other requests shall be referred to Office of  
Scientific Research and Development,  
Washington, DC. Pre-dates formal DoD  
distribution statements. Treat as DoD only.

AUTHORITY

E.O. 10501 dtd 5 Nov 1953; OSRD list no. 6 dtd  
8-12 Apr 1946

THIS PAGE IS UNCLASSIFIED

Reproduced by  
**AIR DOCUMENTS DIVISION**



**HEADQUARTERS AIR MATERIEL COMMAND**

**WRIGHT FIELD, DAYTON, OHIO**

*The*  
**U.S. GOVERNMENT**

**IS ABSOLVED**

FROM ANY LITIGATION WHICH MAY

ENSUE FROM THE CONTRACTORS IN-

FRINGING ON THE FOREIGN PATENT

RIGHTS, WHICH MAY BE INVOLVED.

REEL - C

756

A.T.I.

20593

**RESTRICTED**

Lewis, D.  
Flury, A. H.  
Godfrey, H. J.

Stress Analysis and Structures (7)  
Structural Testing (4)  
Cables, Aircraft control - Fatigue  
failure (14701.2)

20593

O.S.R.D. 4819

The corrosion-fatigue failure of aircraft control cables (N-101)

O.S.R.D., N.D.R.C., Div. 18, Washington, D. C.

U.S. Eng. Restr. Feb 45 60 photos, tables, diagr, graphs

The physical properties of aircraft control cables were investigated under test conditions designed to reproduce the effect of service conditions. Cable materials included 18-8 stainless steel and bright, galvanized, tinned, and lead-alloy-coated carbon steel. Results of fatigue tests with 1% loads showed that under the severe corrosive conditions of a salt atmosphere and at -65°F, 18-8 stainless steel cables were the most effective. The tinned cables had the lowest internal friction in the absence of corrosion.

Air Documents Division, T-2  
AMC, Wright Field  
Microfilm No.  
RC-756 F20593

N-101

RESTRICTED

NATIONAL DEFENSE RESEARCH COMMITTEE

of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

HEAVY METALLURGY DIVISION

20573

File 4819  
Div. 18.

Final Report

on

THE CORROSION-FATIGUE FAILURE OF AIRCRAFT CONTROL CABLES (N-101)

by

DARTREY LEWIS, A. H. FLORY, JR., AND R. J. GODFREY  
JOHN A. ROEBLING'S SONS COMPANY

COND. No. \_\_\_\_\_

Serial No. M-467

Copy No. \_\_\_\_\_

February 26, 1945

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U. S. C. 50; 31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

**RESTRICTED**

February 26, 1945

To: Dr. James B. Conant, Chairman  
National Defense Research Committee of the  
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

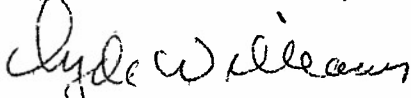
Subject: Final Report on the "Corrosion Fatigue Failure of  
Aircraft Control Cables (N-101)".

The attached final report, submitted by Dartrey Lewis, Technical Representative on NDRC Research Project NRC-15, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report presents the results of investigations of the physical properties of aircraft control cables under conditions of testing which were designed to reproduce service conditions, particularly those experienced by Naval Aircraft.

I recommend acceptance as the final report on the work under Contract OEMsr-492 with John A. Roebling's Sons Company.

Respectfully submitted,

  
Clyde Williams, Chief  
War Metallurgy Division, NDRC

Enclosure

**RESTRICTED**

# RESTRICTED

## PREFACE

This report is pertinent to the problems designated by the Office of the Coordinator of Research and Development, Navy Department, as N-101, and to the project designated by the War Metallurgy Committee as WMC-15.

The distribution of this report is as follows:

- Copies 1 thru 8 - Dr. Irvin Stewart, Executive Secretary, OSRD
- Copy No. 9 - Clyde Williams, Chief, War Metallurgy Division (Div. 18), NDRC  
and Chairman, War Metallurgy Committee
- Copy No. 10 - Office of the Executive Secretary, War Metallurgy Committee
- Copy No. 11 - V. H. Schnee, Chairman, Products Research Division,  
War Metallurgy Committee
- Copy No. 12 - H. W. Gillett, Member, Division 18, NDRC
- Copy No. 13 - S. D. Heron, Member, Division 18, NDRC
- Copy No. 14 - Zay Jeffries, Member, Division 18, NDRC
- Copy No. 15 - R. F. Mehl, Member, Division 18, NDRC
- Copy No. 16 - R. C. Tolman, Chairman, Subcommittee for Division 18, NDRC
- Copy No. 17 - Roger Adams, Member, Subcommittee for Division 18, NDRC
- Copy No. 18 - J. E. Jackson, Staff Aide for Division 18, NDRC
- Copies No. 19 thru 40 - Dr. Franklin S. Cooper, Senior Liaison Officer, Liaison  
Office, OSRD
- Copies No. 41 thru 54 - Army Air Forces, Commanding General, Wright Field  
Attn: Procurement Division, Materials & Processes  
Branch
- Copies No. 55 and 56 - Army Air Forces, Commanding General, Wright Field  
Attn: Major J. P. Auferter, NDRC Branch Liaison  
Officer
- Copy No. 57 - Army Air Forces, Headquarters, Assistant Chief of Air Staff  
Attn: Lt. Col. J. M. Gruitch, Air Ordnance Office
- Copy No. 58 - Army Air Forces Board, Orlando, Florida  
Attn: Secretary of the Board
- Copy No. 59 - Navy Department, Director, Naval Experimental Station,  
Philadelphia Navy Yard
- Copy No. 60 - G. W. Lewis, Director of Aeronautical Research,  
National Advisory Committee for Aeronautics
- Copy No. 61 - L. C. Strickland, Patent Advisor, War Metallurgy Committee
- Copy No. 62 - Dartrey Lewis, Technical Representative,  
NDRC Research Project NRC-15
- Copy No. 63 - A. H. Flury, Jr., Investigator, NDRC Research Project NRC-15
- Copy No. 64 - H. J. Godfrey, Investigator, NDRC Research Project NRC-15

### Project Liaison Officers

- Copy No. 65 - Army Air Forces, Commanding General, Wright Field  
Attn: J. B. Johnson, Chief, Materials Laboratory
- Copy No. 66 - Navy Department, Bureau of Aeronautics  
Attn: Lt. Comdr. W. P. Goepfert

# RESTRICTED

Members of the Project Committee

Copy No. 11 - V. H. Schnee, Chairman  
Copy No. 67 - Lt. Col. F. B. Fuller  
Copy No. 68 - J. L. Manson  
Copy No. 69 - R. R. Moore  
Copy No. 70 - E. S. Wellhofer

Members of the War Metallurgy Committee

Copy No. 71 - Carl Breer  
Copy No. 72 - Lyman J. Briggs  
Copy No. 73 - James H. Critchett  
Copy No. 74 - Col. R. S. A. Dougherty  
Copy No. 75 - Rudolph Furrer  
Copy No. 12 - H. W. Gillett  
Copy No. 13 - S. D. Heron  
Copy No. 76 - R. P. Heuer  
Copy No. 14 - Zay Jeffries  
Copy No. 77 - Col. G. F. Jenks  
Copy No. 65 - J. B. Johnson  
Copy No. 78 - John Johnston  
Copy No. 79 - T. L. Joseph  
Copy No. 80 - V. N. Krivobok  
Copy No. 81 - Frederick Laist  
Copy No. 82 - W. K. Lewis  
Copy No. 83 - Dean C. E. MacQuigg  
Copy No. 84 - C. L. McCuen  
Copy No. 15 - R. F. Mehl  
Copy No. 85 - Paul D. Merica  
Copy No. 86 - Col. S. B. Ritchie  
Copy No. 87 - Gilbert E. Seil  
Copy No. 88 - Mac Short  
Copy No. 89 - Capt. Lybrand Smith  
Copy No. 90 - Col. A. E. White  
F. W. Willard  
Copy No. 91 - R. S. Williams  
Copy No. 92 - Col. H. H. Zornig

Members of the Engineering Committee,  
Aircraft War Production Council, Inc.

Copy No. 93 - Boeing Aircraft Company, W. E. Beall  
Copy No. 94 - Consolidated-Vultee Aircraft Corp., Vultee Field Division,  
A. P. Fontaine  
Copy No. 95 - Douglas Aircraft Company, Incorporated, A. E. Raymond  
Copy No. 88 - Lockheed Aircraft Corporation, Factory "A", Mac Short  
Copy No. 96 - North American Aviation, Incorporated, Gordon Throne  
Copy No. 97 - Northrop Aircraft, Incorporated, R. A. Dutton  
Copy No. 98 - Ryan Aeronautical Company, B. T. Salmon

Members of the Plant Production Section,  
Aircraft War Production Council, Inc.

Copy No. 99 - Boeing Aircraft Company, H. O. West  
Copy No. 100 - Consolidated-Vultee Aircraft Corp., San Diego Div., H. Bowling  
Copy No. 101 - Lockheed Aircraft Corporation, Factory "A", George H. Prudden  
Copy No. 102 - North American Aviation, Incorporated, R. E. Dawe  
Copy No. 103 - Northrop Aircraft, Incorporated, Paul Buckner  
Copy No. 104 - Ryan Aeronautical Company, G. E. Barton

# RESTRICTED

## Members of the Testing and Research Panel, Aircraft War Production Council, Inc.

- Copy No. 93 - Boeing Aircraft Company, ... E. Beall
- Copy No. 105 - Consolidated-Vultee Aircraft Corp., Vultee Field Div., Harold Boyvey
- Copy No. 106 - Douglas Aircraft Company, Incorporated, J. R. Goldstein
- Copy No. 107 - Lockheed Aircraft Corporation, Factory "B", F. R. Shanley
- Copy No. 108 - North American Aviation, Incorporated, L. P. Spalding
- Copy No. 109 - Northrop Aircraft, Incorporated, T. E. Piper
- Copy No. 110 - Ryan Aeronautical Company, J. C. Scurlock

## Members of the Testing and Research Panel, Aircraft War Production Council, East Coast, Inc.

- Copy No. 111 - Bell Aircraft Corporation, Niagara Frontier Division, C. L. Fay
- Copy No. 112 - Curtiss-Wright Corporation, Airplane Division, Eric Dudley
- Copy No. 113 - Eastern Aircraft Division of General Motors Corp., W. F. Burke
- Copy No. 114 - Eastern Aircraft Division of General Motors Corp., D. J. Kaganov
- Copy No. 115 - Fairchild Engine & Airplane Corp., Fairchild Aircraft Division,  
M. J. Frank
- Copy No. 116 - Fairchild Engine & Airplane Corp., Ranger Aircraft Engines Division,  
T. Hammen, Jr.
- Copy No. 117 - Glenn L. Martin Company, G. L. Bryan, Jr.
- Copy No. 118 - Republic Aviation Corporation, Albert Epstein

## Members of the Airframes Production Committee, Central Aircraft Council

- Copy No. 119 - Aeronca Aircraft Corporation, V. Baltz
- Copy No. 120 - Chrysler Corp., DeSoto Division, H. E. Chesebrough
- Copy No. 121 - Ford Motor Company, Willow Run Bomber Plant, G. Scarlett
- Copy No. 122 - General Motors Corp., Fisher Cleveland Aircraft Div.,  
F. H. Hanson, Resident Manager
- Copy No. 123 - Goodyear Aircraft Corporation, A. DeYoung
- Copy No. 124 - Hayes Manufacturing Corporation, B. M. Smiling
- Copy No. 125 - Hudson Motor Car Company, J. J. Eskridge
- Copy No. 126 - Laister-Kauffman Aircraft Corp., J. J. Laister
- Copy No. 127 - McDonnell Aircraft Corporation, C. W. Drake
- Copy No. 128 - Murray Corporation of America, A. J. Scriven
- Copy No. 129 - Republic Aviation Corporation, H. J. MacDonald
- Copy No. 130 - Waco Aircraft Corporation, H. R. Perry
- Copy No. 131 - Woodall Industries, Inc., E. W. Higgins

## Members of the Engineering Policy Committee, Central Aircraft Council

- Copy No. 132 - Bendix Aviation Corporation, Charles Marcus
- Copy No. 133 - Chrysler Corporation, J. C. Zeder
- Copy No. 134 - Ford Motor Company, Willow Run Plant, Wm. F. Pioch
- Copy No. 135 - General Motors Corporation, Chevrolet Motor Div., J. M. Crawford

RESTRICTED

Members of the Engineering Policy Committee,  
Central Aircraft Council (Cont'd.)

- Copy No. 136 - Goodyear Aircraft Corporation, Karl Arnstein  
Copy No. 137 - Packard Motor Car Company, Colonel J. G. Vincent  
Copy No. 138 - Pesco Production Company, R. J. Minshall  
Copy No. 139 - Republic Aviation Corporation, D. R. Smith  
Copy No. 140 - Thompson Aircraft Production Company, A. T. Colwell  
Copy No. 141 - United Aircraft Corporation, F. W. Caldwell  
Copy No. 142 - Wright Aeronautical Corporation, R. J. Young, Chief Engineer

---

Allied Aviation Corporation

- Copy No. 143 - C. E. Wingo, Box 67, Cockeysville, Maryland

Beech Aircraft Corporation

- Copy No. 144 - Walter H. Beech, President, Wichita, Kansas  
Copy No. 145 - T. A. Wells, Vice President and Chief Engineer, Wichita, Kansas

Bell Aircraft Corporation

- Copy No. 146 - H. M. Poyer, Chief Engineer, Buffalo, New York  
Copy No. 147 - Robert J. Woods, Chief Design Engineer, Buffalo, New York

Boeing Aircraft Company

- Copy No. 148 - John K. Ball, Chief Design Engineer, Seattle, Washington

Brewster Aeronautical Corporation

- Copy No. 149 - R. D. MacCart, Chief Engineer, Long Island City, New York

Brunswick-Balke-Collender Company

- Copy No. 150 - J. A. Neagle, Chief Engineer, Muskegon, Michigan

Budd Manufacturing Company

- Copy No. 151 - Michael Watter, Chief Engineer, Philadelphia, Pennsylvania

Columbia Aircraft Corporation

- Copy No. 152 - John W. Kenny, President and General Manager, Valley Stream,  
Long Island, New York

# RESTRICTED

## Consolidated-Vultee Aircraft Corporation

- Copy No. 153 - James Kelley, San Diego Division, San Diego, California  
Copy No. 154 - M. F. Stoughton, Chief Design Engineer, Vultee Field Division,  
Vultee Field, California  
Copy No. 155 - D. N. Davis, Structure Supervisor, Vultee Field Division,  
Vultee Field, California

## Culver Aircraft Corporation

- Copy No. 156 - A. W. Mooney, Vice-President & Chief Designer, Wichita, Kansas

## Durtiss-Wright Corporation

- Copy No. 157 - R. C. Blaylock, Chief Engineer, Columbus Plant, Columbus, Ohio  
Copy No. 158 - G. H. Cartledge, Acting Chief of Materials, Buffalo, New York  
Copy No. 159 - C. C. Furnas, Director of Research, Buffalo, New York

## Douglas Aircraft Company

- Copy No. 160 - E. H. Heinemann, Chief Engineer, El Segundo, California  
Copy No. 161 - J. C. Buckwalter, Engineering Manager, Park Ridge, Illinois  
Copy No. 162 - L. A. Carter, Engineering Manager, Oklahoma City, Oklahoma  
Copy No. 163 - J. L. Whittier, Engineering Manager, Tulsa, Oklahoma  
Copy No. 164 - F. W. Herman, Chief Engineer, Long Beach, California  
Copy No. 165 - J. E. Schumann, Director of Tooling, Santa Monica, California  
Copy No. 166 - M. G. Simpson, Director of Quality, Santa Monica, California

## Fairchild Engine & Airplane Corporation

- Copy No. 167 - J. Carlton Ward, President, 30 Rockefeller Plaza,  
New York 20, N. Y.  
Copy No. 168 - Armand Thieblot, Chief Engineer, Hagerstown, Maryland

## Fleetwings Inc., Division of Kaiser Cargo, Inc.

- Copy No. 169 - Raymond Wiese, Admin. Engineer, Bristol 2, Pa.

## General Motors Corporation

- Copy No. 170 - L. A. Danse, Chairman, Metallurgical Committee, Detroit 2, Mich.

## Goodyear Aircraft Corporation

- Copy No. 171 - P. W. Litchfield, President, Akron, Ohio  
Copy No. 172 - C. J. Pennig, Administrative Engineer, Akron, Ohio  
Copy No. 173 - J. P. Lub, Manager of Engineering Division,  
Litchfield Park, Arizona

# RESTRICTED

Grumman Aircraft Engineering Corporation

- Copy No. 174 - Leroy R. Grumman, President, Bethpage, Long Island, New York  
Copy No. 175 - W. T. Schwendler, Chief Engineer, Bethpage, Long Island, New York

Howard Aircraft Corporation

- Copy No. 176 - B. D. DeWeese, President, Chicago, Illinois  
Copy No. 177 - D. W. Dressel, Project Engineer, Chicago, Illinois

Interstate Aircraft & Engineering Corporation

- Copy No. 178 - Don P. Smith, President, El Segundo, California

Lockheed Aircraft Corporation

- Copy No. 179 - R. E. Gross, President, Factory "B", Burbank, California  
Copy No. 180 - F. A. Smith, Chief Design Engineer, Factory "B", Burbank, Calif.  
Copy No. 181 - E. L. Hibbard, Chief Engineer, Factory "B", Burbank, California  
Copy No. 182 - J. McBrearty, Asst. Chief Structures Engineer, Factory "B",  
Burbank, California  
Copy No. 183 - L. H. Potter, Factory "B", AAF Material and Process Unit Repr.  
Copy No. 184 - R. R. Richolt, Mechanics and Hydraulics Staff Engineer,  
Burbank, California

Glenn L. Martin Company

- Copy No. 185 - G. T. Willey, Vice-Pres. & General Manager, Omaha, Nebraska  
Copy No. 186 - J. L. Bennett, Chief of Laboratories, Baltimore, Maryland  
Copy No. 187 - C. E. Roberts, Executive Engineer, Baltimore, Maryland  
Copy No. 188 - E. L. Zivi, Engineering Manager, Baltimore, Maryland  
Copy No. 189 - J. T. Thompson, Representative, National Aircraft Standards  
Committee

McDonnell Aircraft Corporation

- Copy No. 190 - G. C. Covington, Chief Engineer, St. Louis, Missouri  
Copy No. 191 - J. S. McDonnell, President, St. Louis, Missouri

North American Aviation, Inc.

- Copy No. 192 - F. B. Bolte, Experimental Research Laboratory Manager,  
Inglewood, California  
Copy No. 193 - E. Schmued, in Charge of Development, Inglewood, California  
Copy No. 194 - A. Wakeman, Materials Engineer, St. Louis, Missouri

# RESTRICTED

## Northrop Aircraft, Inc.

- Copy No. 195 - J. K. Northrop, Pres. & Chief of Design, Hawthorne, California
- Copy No. 196 - W. J. Cerny, Assistant Chief of Design, Hawthorne, California
- Copy No. 197 - T. A. Feeney, Control Design Engineer, Hawthorne, California
- Copy No. 198 - R. R. Nolan, Hawthorne, California

## Pratt & Reed Company

- Copy No. 199 - J. A. Gould, Chief Engineer, Deepriver, Connecticut

## Republic Aviation Corporation

- Copy No. 200 - Alexander Kartvelli, Chief Engineer, Farmingdale, New York
- Copy No. 201 - R. W. Miller, Executive Engineer, Farmingdale, New York

## John A. Roebling's Sons Company

- Copy No. 202 - A. J. Morgan, Chief Engineer, Wire Rope Division, Trenton 2, N. J.
- Copy No. 203 - C. M. Jones, Manager of Engineering, Trenton 2, New Jersey

## Ryan Aeronautical Corporation

- Copy No. 204 - T. C. Ryan, President, San Diego, California

## Standard Oil Company of New Jersey

- Copy No. 205 - C. W. Bohmer, Jr., Engineering Division, 26 Broadway, New York 4, N.Y.

## Standard Oil Development Company

- Copy No. 206 - J. C. Zimmer, Research Division, P. O. Box 243, Elizabeth, New Jersey

## Taylorcraft Aviation Corporation

- Copy No. 207 - J. C. Hart, President, Alliance, Ohio
- Copy No. 208 - R. H. Wendt, Chief Engineer, Alliance, Ohio

## Timm Aircraft Corporation

- Copy No. 209 - O. J. Timm, President & Chief Engineer, Van Nuys, California
- Copy No. 210 - N. V. Brower, Manager of Experimental Department, Van Nuys, Calif.

## Vought-Sikorsky Aircraft

- Copy No. 211 - I. I. Sikorsky, Engineering Manager, East Hartford, Connecticut

# RESTRICTED

Waco Aircraft Company

Copy No. 212 - A. F. Arcier, Chief Engineer, Troy, Ohio  
Copy No. 213 - C. J. Brukner, President, Troy, Ohio

War Production Board

Copy No. 214 - Maurice Nelles, Deputy Director, Office of Production Research  
and Development

---

Copy No. 215 -  
Copy No. 216 -  
Copy No. 217 -  
Copy No. 218 -  
Copy No. 219 -  
Copy No. 220 -  
Copy No. 221 -  
Copy No. 222 -  
Copy No. 223 -  
Copy No. 224 -  
Copy No. 225 -  
Copy No. 226 -  
Copy No. 227 -  
Copy No. 228 -  
Copy No. 229 -  
Copy No. 230 -  
Copy No. 231 -  
Copy No. 232 -  
Copy No. 233 -  
Copy No. 234 -  
Copy No. 235 -  
Copy No. 236 -  
Copy No. 237 -  
Copy No. 238 -  
Copy No. 239 -  
Copy No. 240 -  
Copy No. 241 -  
Copy No. 242 -  
Copy No. 243 -  
Copy No. 244 -  
Copy No. 245 -  
Copy No. 246 -  
Copy No. 247 -  
Copy No. 248 -  
Copy No. 249 -  
Copy No. 250 -  
Copy No. 251 -  
Copy No. 252 -  
Copy No. 253 -  
Copy No. 254 -  
Copy No. 255 -

# RESTRICTED

Copy No. 256 -  
Copy No. 257 -  
Copy No. 258 -  
Copy No. 259 -  
Copy No. 260 -  
Copy No. 261 -  
Copy No. 262 -  
Copy No. 263 -  
Copy No. 264 -  
Copy No. 265 -  
Copy No. 266 -  
Copy No. 267 -  
Copy No. 268 -  
Copy No. 269 -  
Copy No. 270 -  
Copy No. 271 -  
Copy No. 272 -  
Copy No. 273 -  
Copy No. 274 -  
Copy No. 275 -  
Copy No. 276 -  
Copy No. 277 -  
Copy No. 278 -  
Copy No. 279 -  
Copy No. 280 -  
Copy No. 281 -  
Copy No. 282 -  
Copy No. 283 -  
Copy No. 284 -  
Copy No. 285 -  
Copy No. 286 -  
Copy No. 287 -  
Copy No. 288 -  
Copy No. 289 -  
Copy No. 290 -  
Copy No. 291 -  
Copy No. 292 -  
Copy No. 293 -  
Copy No. 294 -  
Copy No. 295 -  
Copy No. 296 -  
Copy No. 297 -  
Copy No. 298 -  
Copy No. 299 -  
Copy No. 300 -

Total Number of Copies - 300

# RESTRICTED

RESTRICTED

FINAL REPORT

N.D.R.C. RESEARCH PROJECT NRC-15, CONTRACT NO. OEMsr-492  
THE CORROSION-FATIGUE FAILURE OF AIRCRAFT CONTROL CABLES (N-101)

(From May 1, 1942 to December 31, 1944)

Work done by:  
Development Engineering Laboratory  
John A. Roebling's Sons Company  
Trenton 2, New Jersey

Official Investigator:  
Dartrey Lewis

Full Time Project Engineer:  
A. H. Flury, Jr.

Report prepared by:  
H. J. Godfrey

January 15, 1945

RESTRICTED

TABLE OF CONTENTS

I.	Abstract	
II.	Report	
	Introduction.....	p 1
	Experimental Work	
	1. Procedure.....	p 3
	2. Data.....	p 8
	3. Discussion of Results.....	p 8
	Conclusions.....	p 22
III.	Tables	
	1. Acceptance Fatigue Tests on 5/32", 1/8" 7x19 Preformed Galvanized Aircraft Cable.....	p 25
	2. Effect of Load on Fatigue Life of AN-210 Micarta Sheaves.....	p 26
IV.	Figures	
	1. Diagrammatic View of Low Capacity Cable Fatigue Testing Machine.	
	2. Photograph of Low Capacity Cable Fatigue Testing Machine.	
	3. Cold Room with Low Capacity Fatigue Testing Machine.	
	4. Service Load Fatigue Testing Machine.	
	5. Diagrammatic View of Hydraulic Loading System for Service Load Machine.	
	6. Diagrammatic View of Internal Friction Testing Machine.	
	7. AN-210 Micarta and 24-ST Aluminum Alloy Sheaves.	
	8. Corrosion-Fatigue Tests on 18-8 Stainless Steel and Various Types of Carbon Steel Cables.	
	9. Corrosion-Fatigue Tests on Galvanized Steel Cables with Various Weights of Zinc Coating.	
	10. 18-8 Stainless Steel Cable after 12 Hour Salt Spray and 750,000 Reversals.	
	11. Hot Galvanized & Drawn Cable After 12 Hours Salt Spray and 750,000 Reversals.	
	12. Tinned Steel Cable After 12 Hours Salt Spray and 300,000 Reversals.	
	13. Fatigue Tests at -65°F on 18-8 Stainless Steel and Various Types of Carbon Steel Cables.	
	14. Fatigue Tests at -65°F on Galvanized Steel Cables with Various Weights of Zinc Coating.	
	15. Service Load Fatigue Tests on 18-8 and Galvanized Cables.	
	16. Internal Friction of Aircraft Cables at Room Temperature.	
	17. Internal Friction of Aircraft Cables at -65°F.	
	18. The Effect of Corrosion on the Internal Friction of Cables.	

TABLE OF CONTENTS (Cont.)

IV. Figures

19. The Effect of Fatigue on the Internal Friction of Cables.
20. The Effect of Temperature on the Fatigue Life of Cables with Various Types of Lubricants.
21. Corrosion-Fatigue Tests on Tinned and Galvanized Cable with Lubricants "A" and "H".
22. Fatigue Tests at  $-65^{\circ}\text{F}$  on Galvanized Cable with Lubricants "A" and "H".
23. Relation Between Fatigue Life and Loss of Lubricant Due to Heating to  $160^{\circ}\text{F}$ .
24. Fatigue Tests at  $-65^{\circ}\text{F}$  on Galvanized Cables with Lubricant "H", Before and After Heating to  $160^{\circ}\text{F}$ .
25. Fatigue Tests at  $-65^{\circ}\text{F}$  on Galvanized Cables with Lubricant "L", Before and After Heating to  $160^{\circ}\text{F}$ .
26. Effect of Paralketone on Corrosion-Fatigue Life of Tinned Cable with Lubricant "A".
27. Effect of Paralketone on Fatigue Life of Galvanized Cable at  $-65^{\circ}\text{F}$ .
28. The Effect of Temperature on the Internal Friction of Cables with Various Types of Lubricants.
29. The Internal Friction at Room Temperature of Galvanized Cables with Various Types of Lubricants.
30. The Internal Friction at  $-65^{\circ}\text{F}$  of Galvanized Cables with Various Types of Lubricants.
31. The Effect of Load on the Fatigue Life of Cable.
32. The Effect of Load on the Wire Breaks.
33. The Effect of Sheave Ratio on the Fatigue Life of Cable.
34. The Effect of the Shoave Ratio on the Critical Load Range.
35. The Effect of the Load on the Critical Sheave Ratio.
36. Relation Between the Maximum Number of Wire Breaks in one Cable Lay and the Average Loss in Strength.
37. The Expected Life of Aircraft Cable for a 10% Average Loss in Strength.
38. The Effect of "Trap Angle on the Fatigue Life of Aircraft Cable.
39. The Effect of Sheave Ratio on the Internal Friction of 7x19 Galvanized Cables.

## ABSTRACT

The physical properties of aircraft control cables have been investigated under conditions of test which were designed to reproduce the effect of service conditions, particularly those experienced by Naval aircraft.

The cable sizes investigated were 1/8", 5/32", 3/16", 5/16" and 1/4" diameters with a 7x19 construction, and 3/32" diameter with a 7x7 construction. The cable materials included 18-8 Stainless Steel and Bright, Galvanized, Tinned and Lead-Alloy-Coated Carbon Steel. The galvanized cables were made of wire with various weights of hot galvanized and electro-galvanized coatings. Standard commercial cable lubricants and special lubricants containing lithium soap grease, mineral oils, paralketone neutral base, rust preventive and extra pressure additives were studied. The effect of externally applied paralketone (AN-C-52) was also investigated.

The fatigue and internal friction properties of cable as affected by corrosion in a salt atmosphere and by temperatures ranging from +160°F to -65°F were studied. The fatigue properties of cables were investigated under normal laboratory conditions with sheaves and loads similar to those used in aircraft control systems.

The fatigue tests, in which climatic conditions were investigated, were made with two fatigue machines on which the cables were loaded by dead weights equal to 1% of the specified cable strength and tested with hardened steel sheaves having diameters 9 and 12 times the cable diameter. The service load fatigue tests were made with a large testing machine on which the cables were loaded by means of hydraulic jacks. Cable loads up to 60% of the specified cable strength were used in the latter tests with AN-210 micarta and 24-ST aluminum alloy sheaves having diameters from 12.1 to 28.7 times the cable diameter.

The relative fatigue properties of aircraft cables were evaluated by an inspection of the cables for broken wires and by determining the remaining strength of the cables after various numbers of reversals on the fatigue machine.

The internal friction of the cables was determined by the load necessary to start the cable in motion over hardened steel sheaves while under various tensions ranging from 25 to 200 pounds.

The results of the fatigue tests with 1% loads showed that under the severe corrosive conditions of a salt atmosphere and at  $-65^{\circ}\text{F}$ , 18-8 stainless steel cables were the most effective. Service load fatigue tests in the absence of corrosion have shown that 18-8 stainless steel cables had a considerably lower fatigue life than galvanized carbon steel cables. Heavy galvanized cables were the best of the carbon steel cables for corrosion-fatigue but had the poorest fatigue life at  $-65^{\circ}\text{F}$ . The tin, lead-alloy, and light zinc coatings did not materially improve the corrosion-fatigue life of bright carbon steel cables.

The tinned cables had the lowest internal friction in the absence of corrosion. Corrosion by salt spray increased the internal friction of tinned cables and decreased the internal friction of the heavy galvanized cables. The continuous flexing of the cables during fatigue test in the absence of corrosion lowered the internal friction of the galvanized cables but not sufficiently to equal that of the tinned cables. The internal friction of cables increased with an increase in cable tension and a decrease in sheave diameter.

The fatigue and internal friction of cables were improved by the use of lubricants. The effectiveness of lubricants was dependent upon the temperature and the protection they afforded against corrosion. The commercial cable lubricants were affected considerably by temperature, whereas some of the greases performed quite uniformly over the range of temperatures investigated. Externally applied paralketone (AN-C-52), was very effective in providing protection against corrosion but became brittle at  $-65^{\circ}\text{F}$  and flaked off the cable where it bent over a sheave.

The service load tests with nicarta and 24-ST sheaves indicated that for a given cable tension the fatigue life was satisfactory providing the ratio between the sheave diameter and cable diameter was above a critical amount. The critical sheave ratio increased with the cable tension. For a 1% load the critical sheave ratio for 7x19 galvanized cables was approximately 10, and for 10% and 20% loads was approximately 20 and 28 respectively. The relationship between the visible wire breaks and the average loss in strength was investigated. The relationship between the loss in strength and the number of reversals in fatigue under various load conditions was also investigated for 7x19 galvanized cables.

Abstract

pg. 3

The fatigue life of 7x7 construction cables with 1% loads was less than that of 7x19 construction with the same load and sheave ratio.

The AN-210 micarta pulleys operated satisfactorily under relatively low service loads but under higher loads failed by wear, splitting or bearing failures. The 24-ST sheaves equipped with large ball bearings operated satisfactorily under loads up to 60% of the specified cable strength.

RESTRICTED

FINAL REPORT

N.D.R.C. Research Project NRC-15, Contract No. OEMsr-492

THE CORROSION-FATIGUE FAILURE OF AIRCRAFT CONTROL CABLES (N-101)

(from May 1, 1942 to December 31, 1944)

From: John A. Roebling's Sons Company  
Development Engineering Laboratory

Report prepared by: H. J. Godfrey

INTRODUCTION

This investigation on the physical characteristics of aircraft cables was undertaken by the John A. Roebling's Sons Company for the Office of Scientific Research and Development, at the request of the Navy Department. Naval experience with 18-8 stainless steel control cables had not been satisfactory due to large variations in service life. Also, as a result of the scarcity of 18-8 stainless steel, carbon steel cables had been substituted. The problem of maintaining the carbon steel cables under severe corrosive conditions was therefore considered to be acute. It was the purpose of this investigation to study the corrosion-fatigue life of cables and to develop a carbon steel cable which would be the equivalent of a stainless steel cable, particularly in a salt atmosphere. The program included internal friction tests and fatigue tests as affected by temperatures ranging from +160°F to -65°F.

RESTRICTED

The performance of control cables with loads and sheaves similar to those used in actual service conditions was also investigated for the purpose of obtaining data which would be of use in the design of aircraft control systems.

The complete details of the investigation have been reported in the following Progress Reports, which are to be considered as the Appendix to the Final Report.

- Progress Report No. 1 - O.S.R.D. No. 1137, Serial No. M-31,  
"The Effect of Lubrication on the Fatigue Properties of Aircraft Control Cables"
- " " No. 2 - O.S.R.D. No. 1525, Serial No. M-83,  
"The Effect of Metallic Coatings and Lubricants on the Fatigue Properties of Aircraft Cables"
- " " No. 3 - O.S.R.D. No. 1610, Serial No. M-93,  
"The Effect of Sheave Diameter on the Fatigue Life of Aircraft Cables"
- " " No. 4 - O.S.R.D. No. 3746, Serial No. M-207,  
"The Effect of Metallic Coatings and Lubricants on the Fatigue & Internal Friction Properties of Aircraft Cables"
- " " No. 5 - O.S.R.D. No. 4543, Serial No. 439,  
"Aircraft Control Cables - Fatigue Tests Under Service Loads"
- " " No. 6 - O.S.R.D. No. 4602 Serial No. M-452,  
"Miscellaneous Tests on Aircraft Cables"

The above reports should be referred to if specific details relating to this investigation are required. The final report is a summary of the work included in the progress reports and may be read without reference to the progress reports.

The investigation was carried out under the direction of an Advisory Committee, the present members of which are as follows:

Dr. L. L. Wyman, Chairman  
Lt. Comdr. W. P. Goepfert, Bureau of Aeronautics, Navy Dept.  
Major F. B. Fuller, Army Air Corps, Wright Field, Dayton, Ohio  
Mr. J. B. Johnson, Materials Laboratory, Wright Field, Dayton, Ohio  
Mr. R. R. Moore, Naval Aircraft Factory, Philadelphia, Pennsylvania  
Mr. J. L. Manson, American Steel & Wire Company, New Haven, Conn.  
Mr. E. S. Wellhofer, American Chain & Cable Company, Wilkesbarre, Pa.

Acknowledgement is made to Dr. J. C. Zimmer and Mr. C. W. Bohmer, Jr., and their associates at the Standard Oil Development Company Laboratories, for their assistance in developing a special lubricant for aircraft cables.

Acknowledgement is also made to Mr. C. M. Jones, Manager of Engineering, and to Mr. A. J. Morgan, Chief Engineer, Wire Rope Division, John A. Roebling's Sons Company, for their continued assistance and advice.

EXPERIMENTAL WORK

1. PROCEDURE

(a) Test Methods

Three testing machines were constructed for the cable fatigue tests. Two of these machines were designed to test in accordance with Specification AN-RR-C-43 and AN-RR-C-48, and the third machine was designed to permit the testing of cables under service loads.

A diagrammatic view of a low capacity fatigue machine

is presented in Figure 1, and a photograph of a machine is shown in Figure 2. This type of machine was used to investigate cable materials and lubricants under various climatic conditions.

The corrosion-fatigue tests were made by first subjecting the cables to a 20% salt spray at 95°F for a definite period of time. They were then removed from the salt spray and while still wet, placed on a fatigue machine in a room where the humidity was maintained between 80 and 90% and the temperature approximately 75°F. Under these conditions the cables remained moist during the fatigue test. The low temperature fatigue tests were made in a cold room in which the temperature could be controlled between 70°F and -65°F. A photograph of the cold room with the fatigue machine is presented in Figure 3. The cable loads for the tests on the low capacity machines were 1% of the specified strength of the cable, as required by Specifications AN-RR-C-43 and AN-RR-C-48, and the cables were operated over hardened steel sheaves having a diameter 9 or 12 times the cable diameter.

A view of the large fatigue testing machine for the service load tests is shown in Figure 4 and a diagrammatic view of the hydraulic loading system is shown in Figure 5. The pressure on the hydraulic jacks was controlled by four Beggs Load Maintainers and the largest loading jack had a capacity of 8000 pounds. The large machine was also equipped with auxiliary

apparatus by which the wrap angle could be adjusted between 0° and 90°. Except for the wrap angle tests, all of the fatigue tests on the low capacity and service load machines were made with a wrap angle of 90°. AN-210 micarta and 24-ST aluminum alloy sheaves having diameters ranging from 12.1 to 28.7 times the cable diameter were used for the service load tests.

All of the fatigue machines were equipped to test 8 cables simultaneously. Each cable operated over two test sheaves and duplicate tests were usually made for each condition of test. The fatigue life of the cables was evaluated by inspecting the cables for broken wires and by determining the remaining strength of the cables after various numbers of reversals on the fatigue machine.

The internal friction tests were conducted with hardened steel sheaves on a test frame as shown in Figure 6. The internal friction was determined with cable loads ranging from 25 to 200 pounds and the amount of load necessary to start a cable in motion was used as a measure of the relative internal friction of the cables.

(b) Materials

The cables used in this investigation included the following general types:

7x19	Preformed	Galvanized Carbon Steel
7x19	"	Tinned Carbon Steel
7x19	"	Lead Alloy Coated Carbon Steel
7x19	"	Bright Carbon Steel
7x19	"	18-8 Stainless Steel
7x7	"	Galvanized Carbon Steel

A number of sizes of cables were tested and included 3/32", 1/8", 5/32", 3/16", 1/4" and 5/16" diameters. The galvanized cables included wire hot galvanized prior to final wire drawing, hot galvanized at final size and electro-galvanized prior to final wire drawing. The cables were furnished for the investigation by the following manufacturers:

American Chain & Cable Company  
 American Steel & Wire Company  
 John A. Roebling's Sons Company

The cables were lubricated with regular commercial cable lubricants and special lubricants containing lithium soap grease, mineral oil, paralketone neutral base, rust preventives and an E.P. additive. These lubricants were either placed in the cable during manufacture or after manufacture by a special pressure fitting. The effect of externally applied paralketone (AN-C-52) was also investigated.

# RESTRICTED

7.

A list of the cable lubricants referred to in this report is as follows:

Lubricant A - Standard Commercial Cable Lubricant

Lubricant B - Standard Commercial Cable Lubricant

Lubricant C - Standard Commercial Cable Lubricant

Lubricant D - Special Low Temperature Lubricant, manufactured by Standard Oil Company, trade name "Beacon Lubricant M-285"

Lubricant H - Special Lubricant containing lithium soap grease with a base mineral oil having a viscosity of approximately 500 seconds Saybolt Universal at 100°F, and containing rust preventive and extreme pressure additives. Manufactured by Standard Oil Company of New Jersey, and designated as "Lubricant No. 5414"

Lubricant H-1 - A mixture of 5 parts of Lubricant H and 4 parts of 500 second base mineral oil containing proper proportion of rust preventive and extreme pressure additives.

Lubricant L - 45% 500-second mineral oil, plus 55% paralketone neutral base

Lubricant H was developed by the Standard Oil Development Company for this investigation.

For the service load tests, AN-210 micarta and 24-ST aluminum alloy sheaves were used. The grooves in the 24-ST sheaves conformed to AN-210 specifications but the sheaves were fitted with larger ball bearings. A view of the AN-210 micarta and 24-ST sheaves is presented in Figure 7.

RESTRICTED

## 2. DATA

The data has been presented in detail in Progress Reports 1 to 6. In this final report, data representing the important findings on the fatigue life and internal friction of cables has been summarized under the following headings:

- a - The Effect of Materials
- b - The Effect of Lubricants
- c - The Effect of Load and Sheave Diameter

This data is presented in Figures 8 through 39 and in Tables I and II.

## 3. DISCUSSION OF RESULTS

### (a) The Effect of Materials

The corrosion-fatigue life of a number of types of carbon steel cables and an 18-8 stainless steel cable is presented in Figure 8. The fatigue life without corrosion was practically the same for all cables and is represented by the dotted curve on the graph. The best corrosion-fatigue life was obtained with the 18-8 stainless steel cable and the cable made with the wire hot galvanized and drawn had the best life of any of the carbon steel cables. The weight of zinc coating on this cable was considerably more than that on any of the other galvanized cables and probably accounted for the higher corrosion-fatigue life. The bright cable had the poorest

fatigue life and was not improved to any great extent by the use of tin, or light weight zinc coatings. The lead alloy coating was in one instance somewhat better than the lighter zinc coatings.

From the above results it may be assumed that the stainless steel cable is the best for operation in a salt atmosphere and would be more effective as the corrosion became more severe.

The effect of the weight of zinc coating on the corrosion-fatigue life is presented in Figure 9, where it is shown that the corrosion-fatigue life is improved by the use of a heavy zinc coating.

Photographs of 18-8 stainless steel, galvanized and tinned carbon steel cable after the corrosion-fatigue test are presented in Figures 10, 11 and 12, and illustrate the relative effectiveness of the three types of cable under fatigue when corrosion by a salt atmosphere is present.

The fatigue properties at  $-65^{\circ}\text{F}$  of various types of aircraft cables are presented in Figure 13. The 18-8 stainless steel cable was considerably better than any of the carbon steel cables at this low temperature and may be due to the stainless steel maintaining its toughness at sub-zero temperatures. The heavy galvanized cable had the poorest fatigue life, which is probably the result of its high internal friction at  $-65^{\circ}\text{F}$ .

The effect of the weight of zinc coating on the fatigue

life at  $-65^{\circ}\text{F}$  is presented in Figure 14 and shows that the fatigue life decreases as the weight of galvanizing increases.

The above corrosion-fatigue and low-temperature fatigue tests were made on steel sheaves with root diameters 12 times the cable diameter and with cable loads equal to 1% of the specified cable strength. Fatigue tests on 18-8 stainless steel and galvanized carbon steel cables with sheaves and loads similar to those used in present day aircraft are presented in Figure 15. The cable tension was equal to 10% of the specified cable strength and AN-210 5A micarta sheaves having a root diameter  $17\frac{1}{2}$  times the cable diameter were used. Under this relatively high load the fatigue life of the 18-8 stainless steel cable was considerably less than that of the galvanized carbon steel cable.

The low fatigue life of the stainless steel cable may be due to its low resistance to concentrated stresses which has been evidenced in tension tests. The 18-8 cables always show a lower tensile strength when using drum grips as compared to sockets, and break at the tangent point of the drum, whereas carbon steel cables do not show any difference in strength when tested by these two methods.

As a result of the fatigue tests on the various types of cable, the choice of cable should be determined by the conditions of service. The results of the tests indicate that if salt corrosion is of importance, 18-8 stainless steel cable

11.

should be the best cable. However, under heavy loads without corrosion, a carbon steel cable should be more effective.

The internal friction of aircraft cables was found to be affected by the type of material. Since the stresses in cables increase with an increase in the internal friction, this property has considerable influence on the fatigue life of cables. The internal friction also has a large effect on the sensitivity of the control of aircraft in flight.

The results of internal friction tests at room temperature and at  $-65^{\circ}\text{F}$  are presented in Figures 16 and 17. At both conditions of test the tinned cable had the lowest internal friction. The internal friction of the galvanized cables increased as the weight of zinc coating increased and the internal friction of all the cables was considerably higher at  $-65^{\circ}\text{F}$  than at room temperature. The increase in the internal friction at low temperature is due in part to the higher viscosity of the cable lubricants at this temperature. The internal friction was also proportional to the cable tension.

The internal friction of cables was found to change as they became corroded or were flexed during the fatigue tests. The effect of corrosion and fatigue are presented in Figures 18 and 19, and show that internal friction of the heavy galvanized cable was the highest as-manufactured and decreased as the period of corrosion and number of reversals increased. The internal friction of the tinned cables increased with corrosion and after

192 hours of salt spray, was equal to that of the heavy galvanized cable. The increase in the internal friction of the tinned cable was probably due to the pitting of the wires.

In the absence of corrosion the internal friction of the tinned cable during fatigue remained practically constant. The internal friction of the galvanized cable decreased somewhat during the fatigue test but was always higher than that of the tinned cable.

Where internal friction is of primary importance, the choice of cable will be influenced considerably by the expected service conditions. For normal exposure, a tinned cable would be desirable if sufficient protection could be provided against corrosion. In conditions of severe corrosion, the 18-8 stainless steel cable would probably have the lowest internal friction properties. The heavy galvanized cable would furnish protection against corrosion but would probably have the highest internal friction.

(b) The Effect of Lubricants

The results of fatigue and internal friction tests discussed above were obtained with cables lubricated with regular commercial cable lubricants. Since regular lubricants are affected to a large extent by temperature, several special lubricants were investigated for the purpose of securing one which would operate satisfactorily under all conditions.

# RESTRICTED

13.

The general effect of temperature between  $-65^{\circ}\text{F}$  and  $+120^{\circ}\text{F}$  on the fatigue life of aircraft cables is presented in Figure 20. These results show that regular commercial cable lubricants are best at room temperature but decrease in effectiveness with higher or lower temperatures. The special low temperature lubricant "D", however, maintained its lubricating value over the complete range of temperatures investigated. The cable with no lubricant had relatively low fatigue properties. Of the three commercial cable lubricants investigated, lubricant "A" was generally better than the two other lubricants, "B" and "C". The special lubricant, "D", maintained its consistency over a wide range of temperatures. The commercial lubricants, however, became very hard at low temperature and also tended to become fluid at high temperatures, and these characteristics were reflected in the fatigue properties of the cable.

The results of corrosion-fatigue tests on carbon steel cables with lubricants "A" and "H" are presented in Figure 21 and show a very marked improvement in corrosion-fatigue life by the use of the special lubricant "H". The value of lubricant "H" at  $-65^{\circ}\text{F}$  is also demonstrated by the fatigue tests presented in Figure 22. Lubricant "H" maintained its viscosity and provided the necessary lubrication over a wide range of temperature.

Aircraft are sometimes subjected to temperatures up to  $160^{\circ}\text{F}$ , particularly when on the ground, and the effect of

RESTRICTED

this high temperature on the cable lubricants was investigated. The test procedure consisted of first heating the cables to 160°F for a definite period of time and then testing on the fatigue machine under various conditions. The loss in the fatigue life due to the previous heating was found to have a relation to the amount of lubricant which drained from the cable during the heating. This relationship is shown in Figure 23 for lubricants A, H, H-1 and L. Lubricant "L" was a mixture of 45% 500 second oil plus 5% paralketone neutral base and had previously been very effective in corrosion-fatigue and low temperature fatigue tests. Lubricant "H-1" was a mixture of 4 parts of 500 second mineral oil containing the proper proportions of rust preventive and extreme pressure additives and 5 parts of lubricant "H". As lubricant "H" was a grease, it required a special pressure system to place the lubricant in the cable. Lubricant "H-1" was made so that it could be applied to the cable during manufacture in a normal manner. The above corrosion-fatigue tests show that lubricants "H" and "H-1" were the only lubricants that did not drain to any large extent from the cables when heated to 160°F. The cables with lubricants "A" and "L" had a considerably lower fatigue life after heating due to the loss of lubricant.

Fatigue tests at -65°F on cables with lubricants "H" and "L" are presented in Figures 24 and 25, and show that the

# RESTRICTED

15.

previous heating to 160°F had no effect on the cables with lubricant "H" but lowered the fatigue life of the cables with lubricant "L".

The above results have shown lubricant "H" to be very effective at low temperature and with corrosion. However, AN-RR-C-43 and AN-RR-C-48 Acceptance Fatigue Tests are made at room temperature without corrosion and the performance of cables lubricated with lubricants "H" and regular commercial lubricants under these conditions of test is presented in Table I. These tests indicated that lubricant "H" was not as effective as a standard commercial lubricant but the results may have been influenced somewhat by the fact that lubricant "H" was placed in the cable after manufacture. Fatigue tests reported in Progress Report No. 6 have indicated that when lubricants are applied to cables after manufacture, the lubricant does not penetrate fully into the center of the strands and results in a lower fatigue life.

The fatigue tests showed that, in general, lubricants "H" and "H-1" are the best lubricants in atmospheric conditions similar to those encountered in service. The use of lubricant "H-1" would allow the cables to be manufactured without resorting to a special pressure system for placing the lubricant into the cables.

The effect of externally applied paralkotone (AN-C-52) on the fatigue life of aircraft cables was investigated, as

RESTRICTED

this material is used extensively, particularly on Naval aircraft, to protect the cables from corrosion. The results of corrosion-fatigue and fatigue tests at  $-65^{\circ}\text{F}$  are presented in Figures 26 and 27 respectively. The corrosion-fatigue life of a tinned cable lubricated with a commercial lubricant was greatly improved by a coating of paralketone. At  $-65^{\circ}\text{F}$  the paralketone became very brittle and flaked off when the cables were bent over the test sheaves. The value of the paralketone for its resistance to corrosion would thus be nullified if the cables were also to be operated at low temperatures.

The internal friction of aircraft cables lubricated with various lubricants was investigated under a number of conditions. The effect of temperature on a number of lubricants is illustrated in Figure 28 and shows that the internal friction of the cables with the commercial lubricants increased very rapidly when the temperature went below  $0^{\circ}\text{F}$ . The internal friction of the cable with the low temperature lubricant "D" decreased slightly as the temperature decreased, and at  $-65^{\circ}\text{F}$  had the lowest internal friction of any of the lubricated cables. The cable with no lubricant had the lowest internal friction at sub-zero temperatures. Although lubricant "D" was beneficial at  $-65^{\circ}\text{F}$ , it resulted in considerably higher internal friction at temperatures above zero.

Lubricant "H", which was similar in nature to lubricant "D", proved to be very satisfactory at both room temperature and at  $-65^{\circ}\text{F}$ . The internal friction tests illustrating the performance of lubricant "H" and commercial lubricants at room temperature and at  $-65^{\circ}\text{F}$  are presented in Figures 29 and 30 respectively. The internal friction of the cable with lubricant "H" was approximately the same at  $-65^{\circ}\text{F}$  as at room temperature and was lower than any of the commercial lubricants. The internal friction of the cables containing commercial lubricants was considerably higher at  $-65^{\circ}\text{F}$ .

(c) The Effect of Load and Sheave Diameter

The above fatigue tests, which were conducted to study the effect of materials and lubricants under various climatic conditions, were made with low cable loads. For all these tests the cable tensions were approximately 1% of the cable strength, whereas in actual service the cable loads are considerably higher. As very little data are available on the fatigue life of aircraft cables under high loads, the effect of service loads and sheaves was included in this investigation.

AN-210 micarta sheaves were used wherever possible but when these failed too rapidly, 24-ST sheaves fitted with large ball bearings were used.

An example of the effect of cable loads ranging from 10% to 60% of the cable strength is shown in Figure 31. The

sheave diameter for this test was 28.7 times the cable diameter and under these conditions the cables operated satisfactorily with loads up to 20%. The fatigue life with a 40% load, however, was considerably lower. With a 60% cable tension the cables failed after relatively few numbers of reversals.

At the completion of each fatigue test the number of visible wire breaks were noted before determining the remaining strength of the cable. The results of these observations are shown in Figure 32 and also reflect the effect of cable tension on the life of the cable.

The effect of variations in the sheave diameter on the fatigue life is shown in Figure 33 for sheave ratios ranging from 16.1 to 28.7. The cable tension for these tests was 20%, and the results indicate that for this load, fatigue life was satisfactory with a sheave ratio of 28.7 but was seriously reduced with a sheave ratio of 23.4.

A large number of service load tests were conducted on 1/8", 3/16" and 1/4" diameter 7x19 galvanized cables and for each sheave size there was a critical load range below which the fatigue life of the cable was considered to be satisfactory. The effect of the sheave ratio on the critical load range is shown in Figure 34 and shows that the critical load increased with the sheave ratio. Similarly the critical sheave ratio increased as the cable tension increased and this relationship

is shown in Figure 35. It should be emphasized that the critical values are not points of sudden change. However, as the critical sheave size was exceeded the cable life increased rapidly, and as the critical load was exceeded the cable life decreased rapidly. The results indicated that a satisfactory fatigue life could be obtained with a sheave ratio above 10 if the cable loads were 1%. However, with cable loads of 10% it was necessary to have a sheave ratio above 20, and with cable loads of 20%, a sheave ratio above 28 was necessary.

The life of aircraft cables in service is generally determined by an inspection for broken wires. The relationship between the number of visible wire breaks and the remaining strength of the cable is therefore of importance. The data obtained from the service load tests showed considerable scatter, particularly after the cable had a large number of wire breaks. The maximum number of wire breaks in one cable lay has been found in wire rope practice to be a good guide for judging when the cable should be removed from service. The maximum number of broken wires in one cable lay has been observed in these tests and its relation to the average loss in strength is shown in Figure 36. The actual loss in strength may be either greater or less than shown on this curve.

The data showing the relationship between the number of reversals on the fatigue machine and the remaining strength

of the cable was also variable. This variation increases as the remaining strength decreases. With an average loss in strength of 10%, the tests indicated that the maximum loss in strength will, in general, not exceed 20%. With an average loss of strength in excess of 10%, the maximum loss of strength may be considerably greater. The life of aircraft cables corresponding to an average loss of strength of 10% is shown in Figure 37. This data was taken from the fatigue curves on 1/8", 3/16" and 1/4" 7x19 preformed galvanized cable. The individual points show some scatter and this should be taken into account. These curves are presented as a generalization of the information obtained and should be used only as a guide to the designer.

All of the fatigue tests discussed previously were made with a wrap angle of 90°. A limited number of tests were made on 3/16" 7x19 preformed galvanized cable in which the wrap angle ranged from 0 to 90°. The test results are presented in Figure 38 and indicate that the fatigue life decreased as the wrap angle increased from 0 to 20°. With a further increase in the wrap angle the strength of the cable after fatigue remained approximately the same as with the 20° angle tests.

The performance of aircraft cables as discussed above was obtained from tests on AN-210 micarta and 24-ST sheaves. The life of the micarta sheaves was found to be quite variable and failures occurred by wear, splitting, and bearing

failures. A summary of the observations made on AN-210 micarta sheaves is presented in Table II. With the exception of the 3A sheaves, the micarta sheaves operated satisfactorily with a cable tension equal to 10% of the smallest cable used on any particular sheave. In many cases micarta sheaves did not operate satisfactorily at higher loads. As cable tension was increased the life of the micarta sheaves decreased rapidly. The 24-ST sheaves proved to be satisfactory for high cable loads.

The fatigue life of cables with 1% loads was investigated and was reported in Progress Report No. 3. The results are not reproduced in the final report but indicated that the life of 7x7 cable construction was lower than that of 7x19 construction.

Internal friction tests discussed previously have shown that the internal friction of cables was proportional to the cable tension. The effect of sheave diameter on the internal friction of cables has also been investigated and these results are presented in Figure 39. For sheave ratios between 16 and 9 the internal friction of 7x19 preformed galvanized cables increased in inverse proportion to the sheave ratio. For a sheave ratio of 7, however, the internal friction was relatively higher than at the larger sheave ratios investigated.

CONCLUSIONS

1. Under cable loads of 1%, the best cable material for use in a salt atmosphere was 18-8 stainless steel.
2. Under service loads in the absence of corrosion, the fatigue life of galvanized carbon steel cables was considerably better than that of 18-8 stainless steel cables.
3. A heavy zinc coating, either hot galvanized or electro-galvanized, gave the best corrosion-fatigue life of the various types of carbon steel cables.
4. At  $-65^{\circ}\text{F}$  the 18-8 stainless steel cable had the best fatigue life and the heavy galvanized cable had the poorest fatigue life when tested with a 1% cable tension. The fatigue life of the galvanized cables at  $-65^{\circ}\text{F}$  improved as the weight of zinc coating decreased.
5. The tinned cable had the lowest internal friction and the heavy galvanized cable had the highest internal friction at room temperature and at  $-65^{\circ}\text{F}$ . The internal friction of the galvanized cables increased with the weight of coating.
6. The internal friction of galvanized cables decreased somewhat during fatigue testing in the absence of corrosion but remained higher than that of the tinned cable. The internal friction of the tinned cable remained constant during the fatigue test.
7. The internal friction of 18-8 stainless steel cable was not affected by salt spray corrosion whereas that of tinned cable increased and that of galvanized cable decreased.
8. Cable lubricants improve the fatigue life of cables under all conditions.
9. Commercial lubricants gave the best fatigue results at room temperature but resulted in lowered fatigue life at  $-65^{\circ}\text{F}$  and  $+120^{\circ}\text{F}$ .

(Continued)

## Conclusions (cont.)

10. Cables containing lubricant "H" had considerably better corrosion-fatigue life and fatigue life at  $-65^{\circ}\text{F}$  than cables containing commercial lubricants. The fatigue life of cables containing lubricant "H" was also better at room temperature following exposure to  $160^{\circ}\text{F}$  temperature.

11. The internal friction of cables lubricated with lubricant "H" was somewhat lower than cables with commercial lubricants at room temperature, and considerably lower at  $-65^{\circ}\text{F}$ . The internal friction of cables with commercial lubricants increased considerably at temperatures below  $0^{\circ}\text{F}$ , whereas cables with lubricant "H" were practically unaffected by temperatures down to  $-65^{\circ}\text{F}$ .

12. Lubricant "H" was not as effective as regular commercial cable lubricants in the AN-RR-C-43 acceptance fatigue tests. In order to obtain the best overall cable by means of special lubricants, the present specifications may have to be revised.

13. The corrosion-fatigue life of carbon steel cables was materially improved by the external application of paralketone (AN-C-52).

14. The service load fatigue tests indicated that in order to obtain long life (over 200,000 reversals) the ratio of sheave diameter to cable diameter for 7x19 preformed galvanized cable should be greater than the values shown below:

<u>Cable Load</u> <u>% of Specified</u> <u>Cable Strength</u>	<u>Sheave Ratio</u>
1	10
10	20
20	28

15. For long cable life (over 200,000 reversals) the following loads and sheave sizes were satisfactory in the service load tests:

(Continued)

Conclusions (cont.)

<u>Cable Size</u>	<u>Sheave Size</u>	<u>Cable Load % of Specified Cable Strength</u>
1/8" 7x19	AN-210-4A	10
3/16" 7x19	AN-210-5A	10
3/16" 7x19	AN-210-6A	20
1/4" 7x19	AN-210-6A	10

16. The serviceability of AN-210 micarta sheaves in the service load tests is shown in the following table. Sheave failure under high loads occurred by wearing, splitting and by bearing failures.

<u>Sheave Size</u>	<u>Cable Load % of Specified Cable Strength</u>	<u>Cable Size</u>	<u>Life</u>
AN-210 3A	10-20	1/8" 3/16"	Unsatisfactory
AN-210 4A	20	3/16"	Unsatisfactory
AN-210 4A	10	1/8" 3/16"	Limited
AN-210 4A	20	1/8"	Limited
AN-210 5A	10	3/16" 1/4"	Satisfactory
AN-210 6A	10	3/16" 1/4"	Satisfactory
AN-210 6A	20	3/16"	Satisfactory

17. 24-ST Aluminum alloy sheaves with large bearings operated satisfactorily with loads up to 60% of the specified cable strength.

18. The life of 7x19 preformed galvanized cables was a function of cable load and sheave diameter. The cable life for an average loss of strength of 10% was determined. (Fig. 37).

19. The fatigue life of 7x7 preformed galvanized cable was lower than that of 7x19 construction for the same sheave ratio and cable tension.

20. A limited number of tests on 3/16" 7x19 preformed galvanized cable with various wrap angles indicated that the fatigue life was reduced as the wrap angle was increased from 0 to 20°. Above 20° the wrap angle had no further effect on the fatigue life.

21. The internal friction of cables increased as the cable loads became greater and the sheave diameters became smaller.

TABLE I

AN-ER-C-43 Acceptance Fatigue Tests  
On  
5/32" and 1/8" 7x19 Preformed Galvanized Aircraft Cable

Material	Tensile Strength (pounds)		
	Before Fatigue	After Fatigue	Percent Remaining Strength
Reel #1 5/32", As Manufactured Lubricant "B"	2920	2660	
	<u>2930</u>	<u>2600</u>	
Average	2925	2630	90.0
Reel #1 5/32", Cleaned & Relubricated with Lubricant "H"		2125	
		1600	
		2060	
		<u>1870</u>	
Average		1914	65.5
Reel #2 5/32", As Manufactured Lubricant "B"	2950	2260	
	<u>2950</u>	<u>2570</u>	
Average	2950	2415	81.8
Reel #2 5/32" Cleaned & Relubricated with Lubricant "H"		2220	
		2310	
		1970	
		<u>2145</u>	
Average		2161	73.2
Reel #5 1/8", As Manufactured Lubricant "B"	2270	1300	
	2280	1220	
		1630	
		<u>1810</u>	
Average	2275	1490	65.7
Reel #5 1/8", Cleaned & Relubricated with Lubricant "H"		1200	
		1220	
		900	
		<u>1060</u>	
Average		1095	48.0

TABLE II

## EFFECT OF LOAD ON FATIGUE LIFE OF AN-210 MICARTA SHEAVES

Sheave Size	Cable Load lbs.	Cable Size in.	Condition of Sheaves				Average Reversals			
			% Good	% Worn	% Split	% Fearing Failure	Good	Worn	Split	Bearing Failure
3A	200	1/8		100				50,000		
3A	400	1/8		70	30			16,000	11,000	
3A	400	3/16		40	50	10		7,000	7,000	5,000
3A	800	3/16			100				6,000	
4A	200	1/8	71	18		11	210,000	200,000		250,000
4A	400	1/8	44	9	4	43	130,000	32,000	42,000	123,000
4A	400	3/16	31	39	8	22	150,000	130,000	120,000	140,000
4A	800	3/16	26	32	32	10	60,000	50,000	50,000	50,000
5A	400	3/16	100				240,000			
5A	700	1/4	46	45	6	3	170,000	430,000	230,000	100,000
6A	400	3/16	100				240,000			
6A	800	3/16	100				250,000			
6A	700	1/4	100				280,000			

RESTRICTED

# Diagrammatic View of AIRCRAFT Cable Fatigue Machine

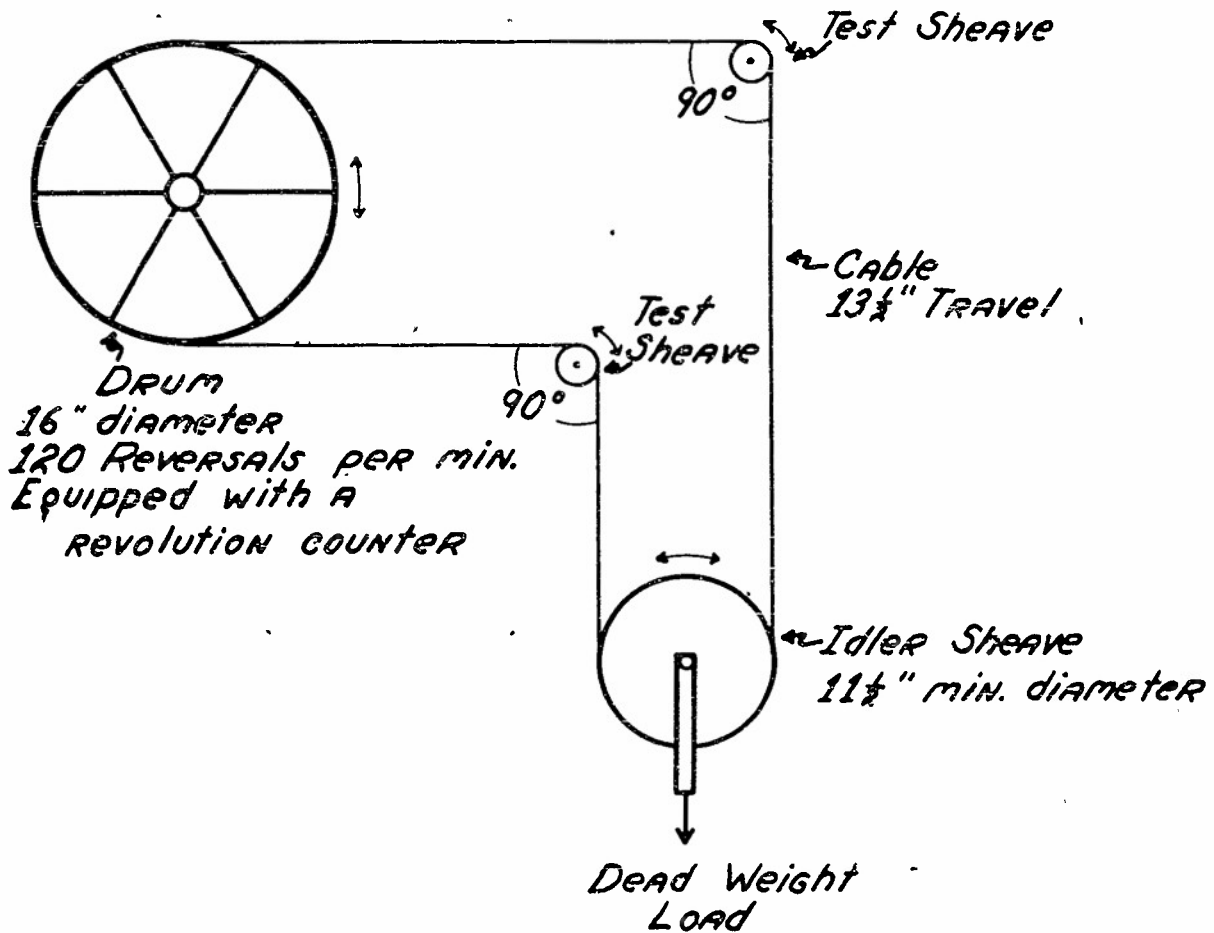
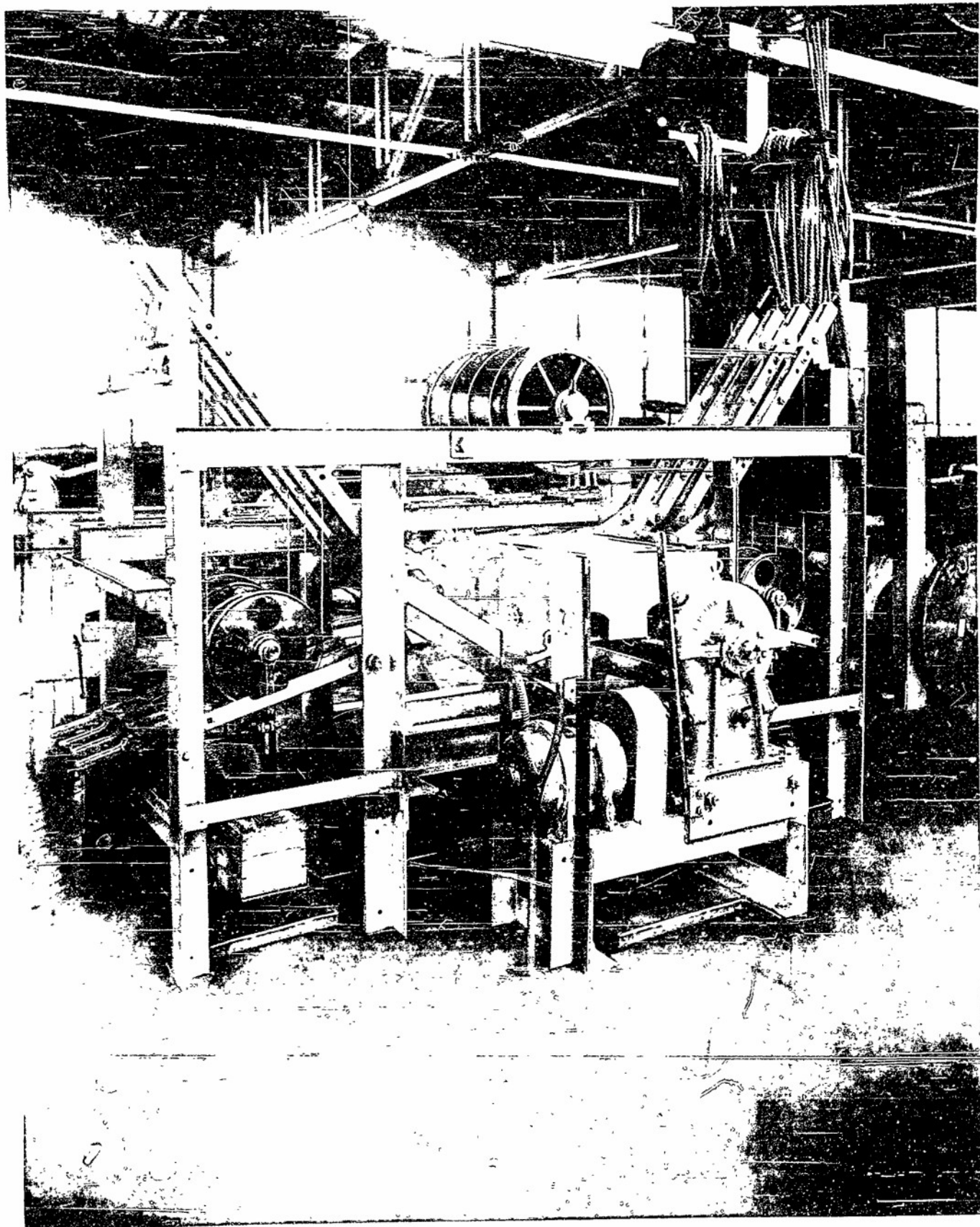


FIGURE 1  
11-16-44  
A. H. FLURY, JR.

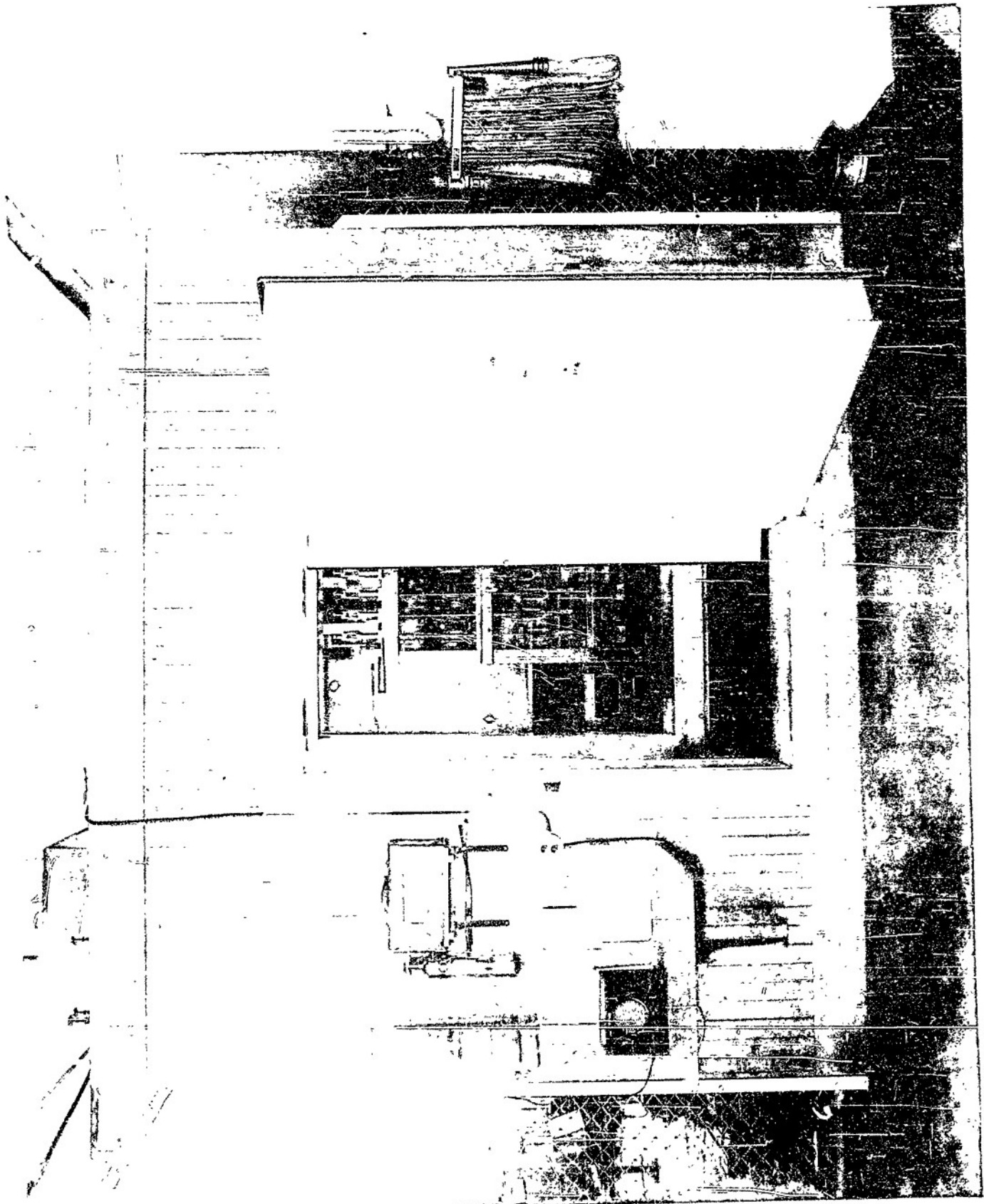
RESTRICTED



RESTRICTED

*FIGURE 2*

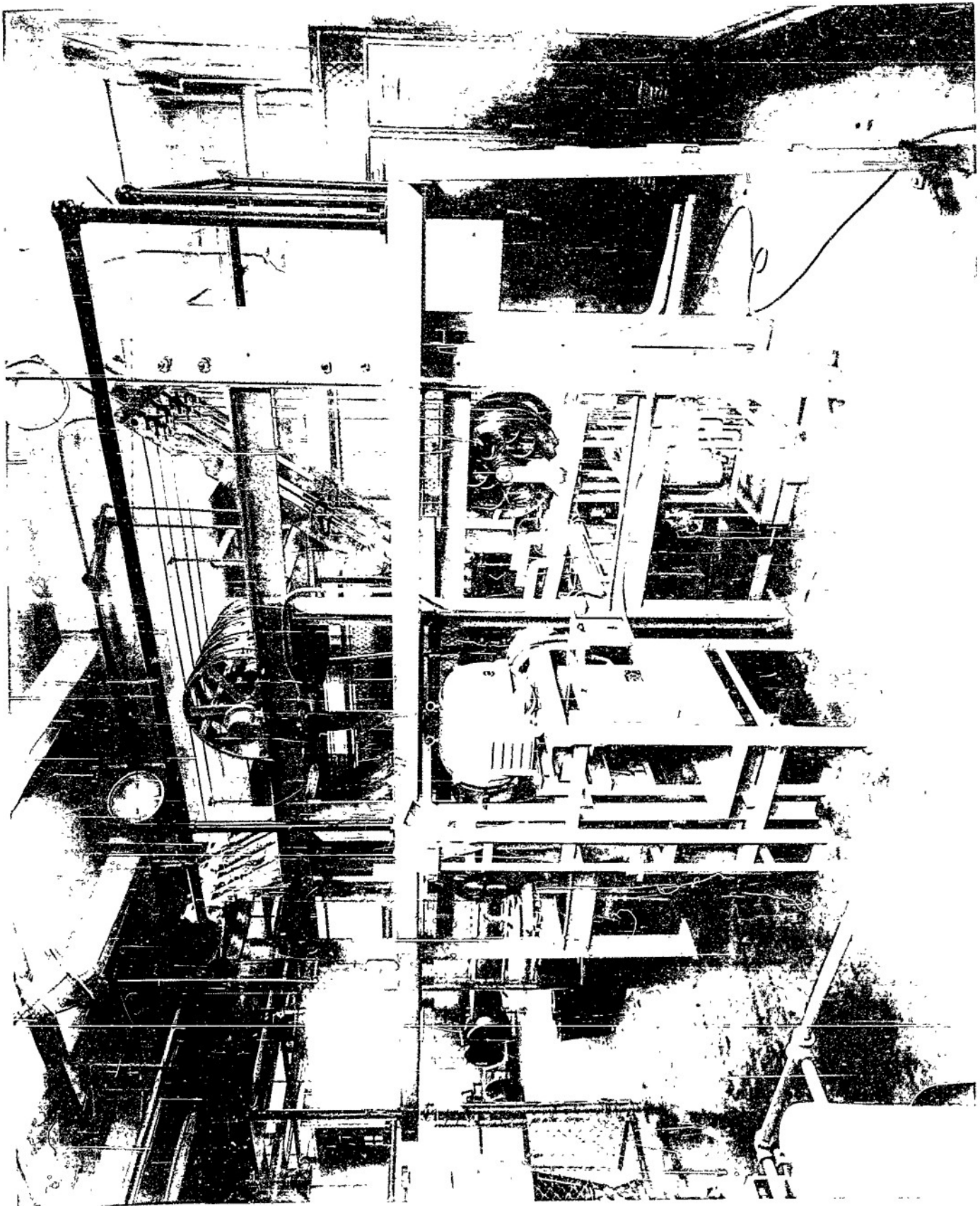
RESTRICTED



RESTRICTED

FIGURE 3

RESTRICTED

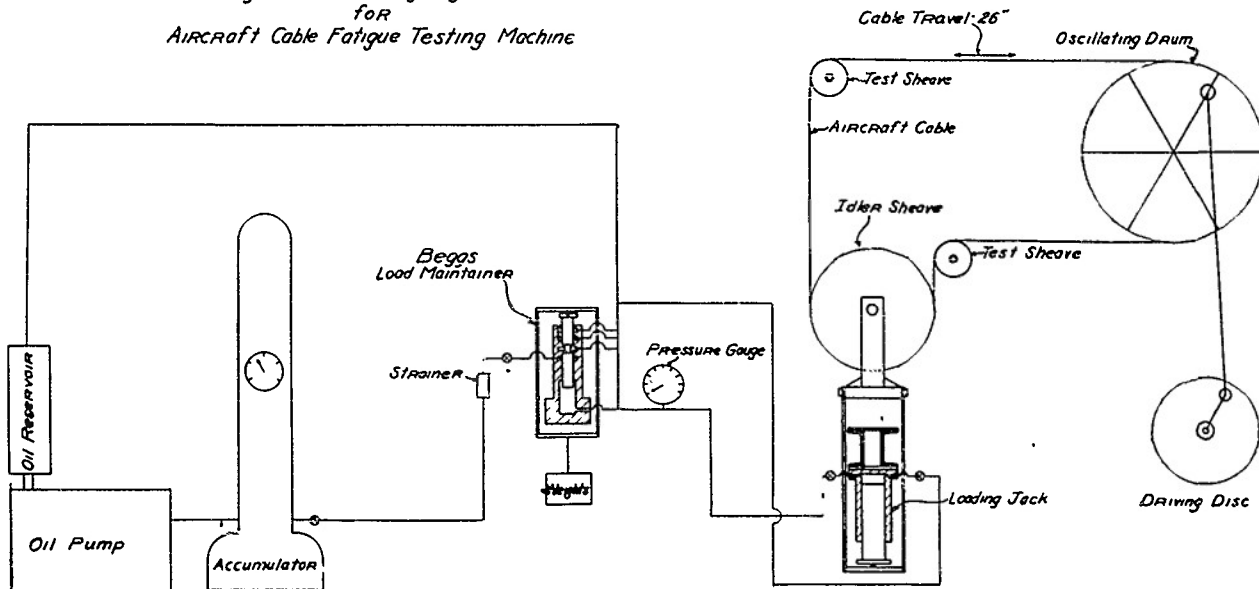


RESTRICTED

*Figure 4*

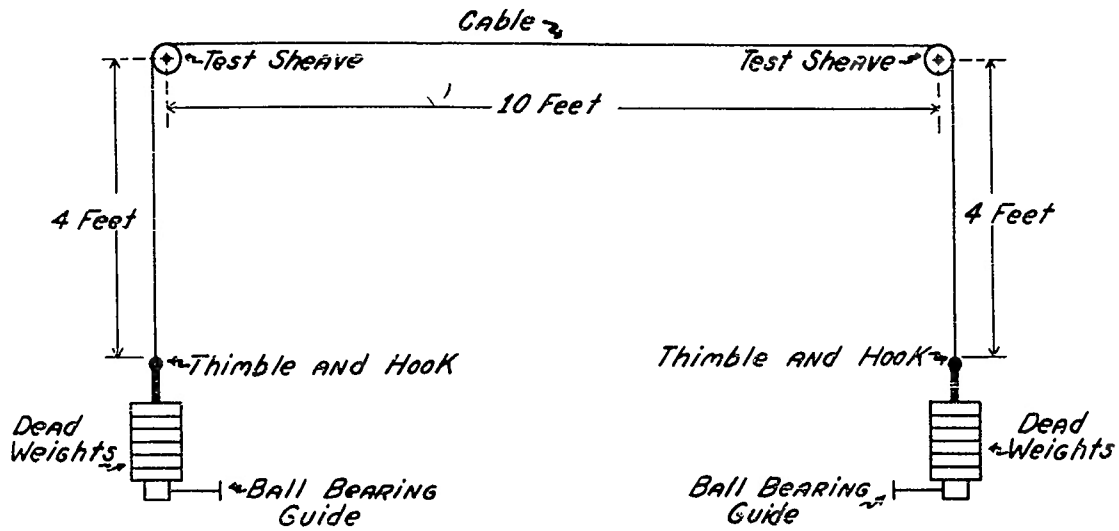
RESTRICTED

Hydraulic Loading System  
for  
Aircraft Cable Fatigue Testing Machine



EI-102  
Figure 5  
Oct 16, 1944  
HJG

INTERNAL FRICTION TEST FRAME



RESTRICTED

Figure 6  
11-16-44  
A. H. FLURY, JR.

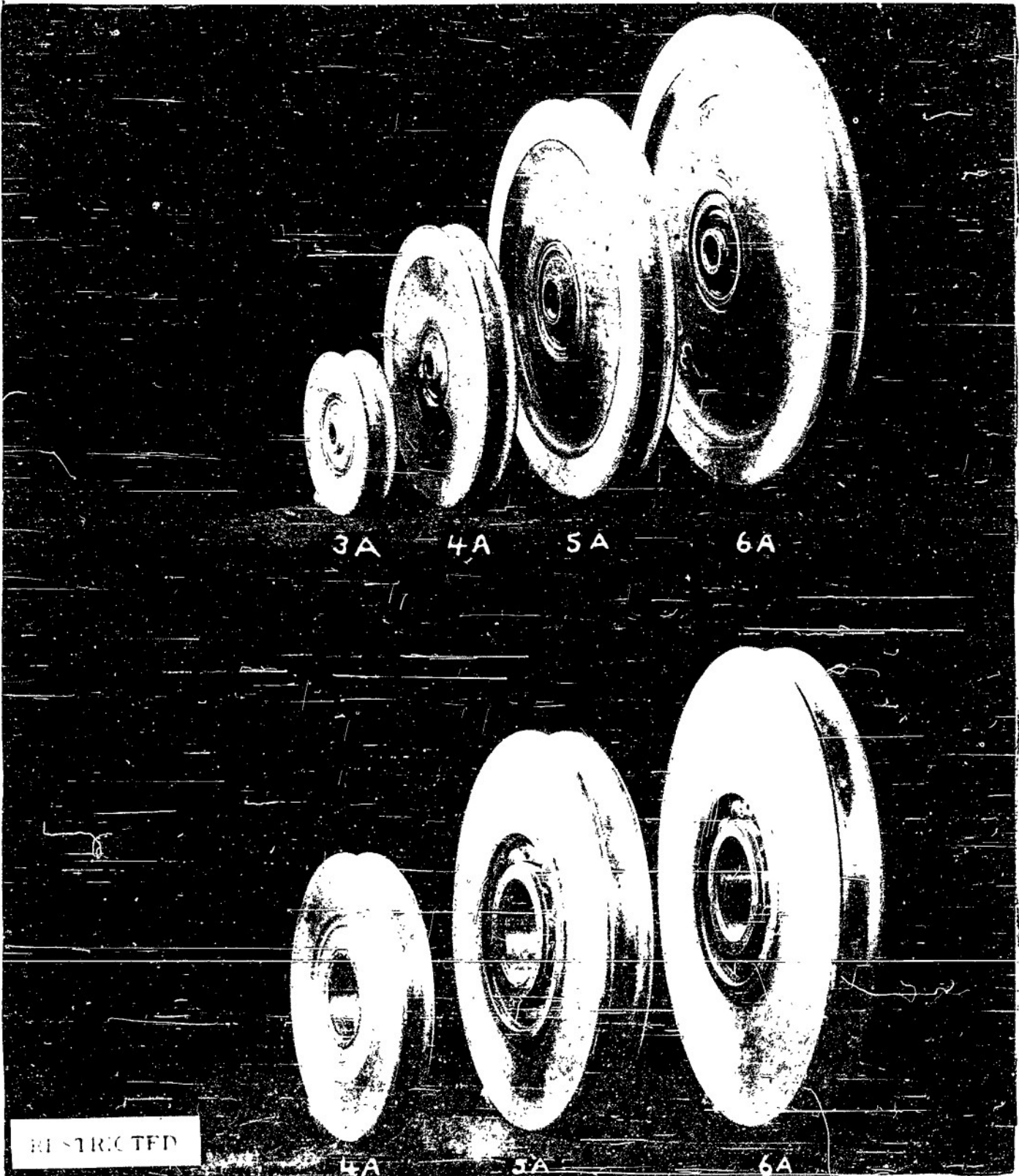
Top AN - 210 Micarta Sheaves 3A 4A 5A 6A      RESTRICTED

Bottom 24 ST Aluminum Alloy Sheaves 4A 5A 6A

Photo #3423

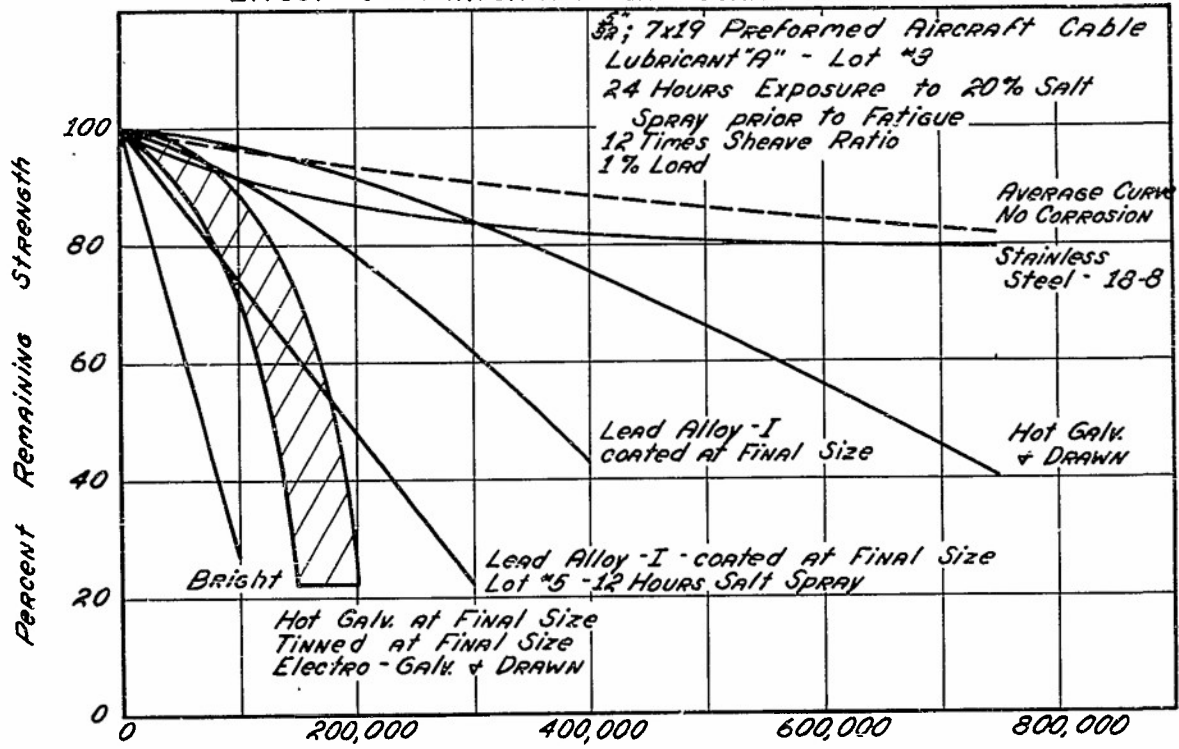
10/26/44

Approx. 2/3 X      Fig. 7



RESTRICTED

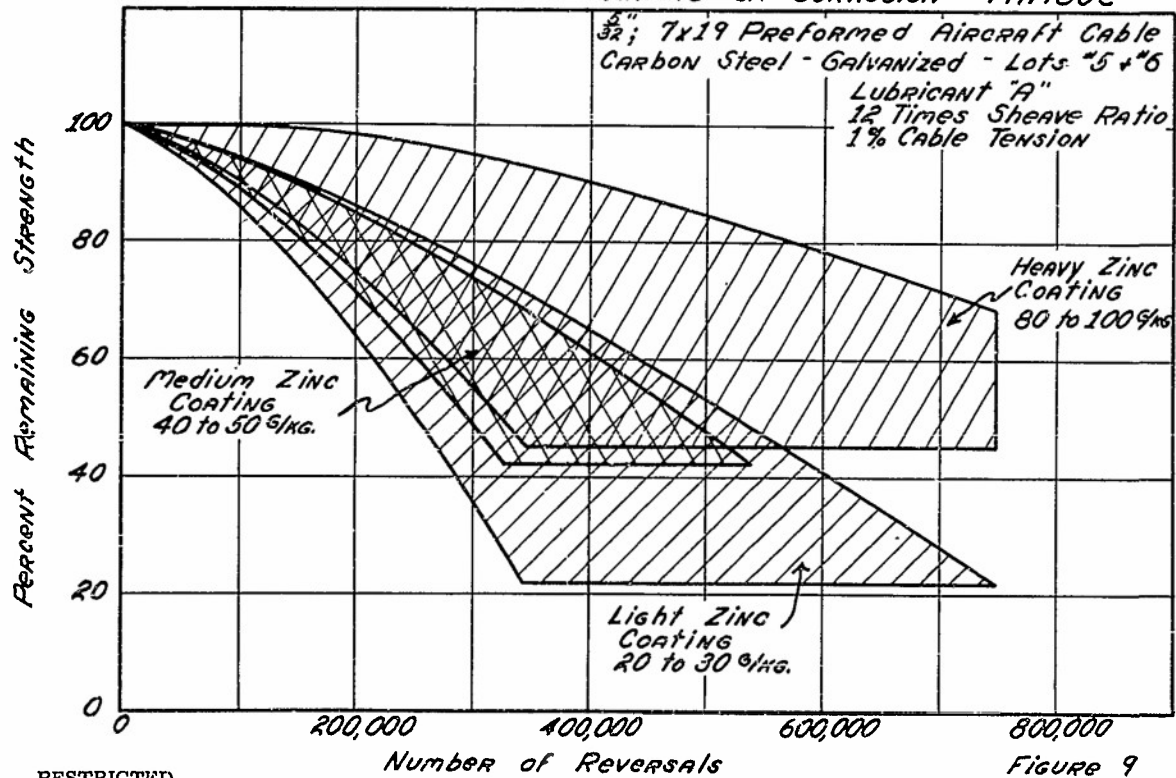
Effect of Materials on Corrosion - Fatigue RESTRICTED



Data from Progress Report No. 2 - Figures 14 + 15  
Progress Report No. 4 - Figure 5

FIGURE 8  
12-26-44  
A. H. FLURY, JR.

Effect of Weight of Zinc Coating on Corrosion - Fatigue



RESTRICTED

Data from Progress Report No. 4 - Figure 34

FIGURE 9  
12-26-44  
A. H. FLURY, JR.

RESTRICTED

18-8 STAINLESS STEEL  
12 Hours Salt Spray 750,000 Reversals--12x Sheaves.

Approx. x6

*Figure 10*



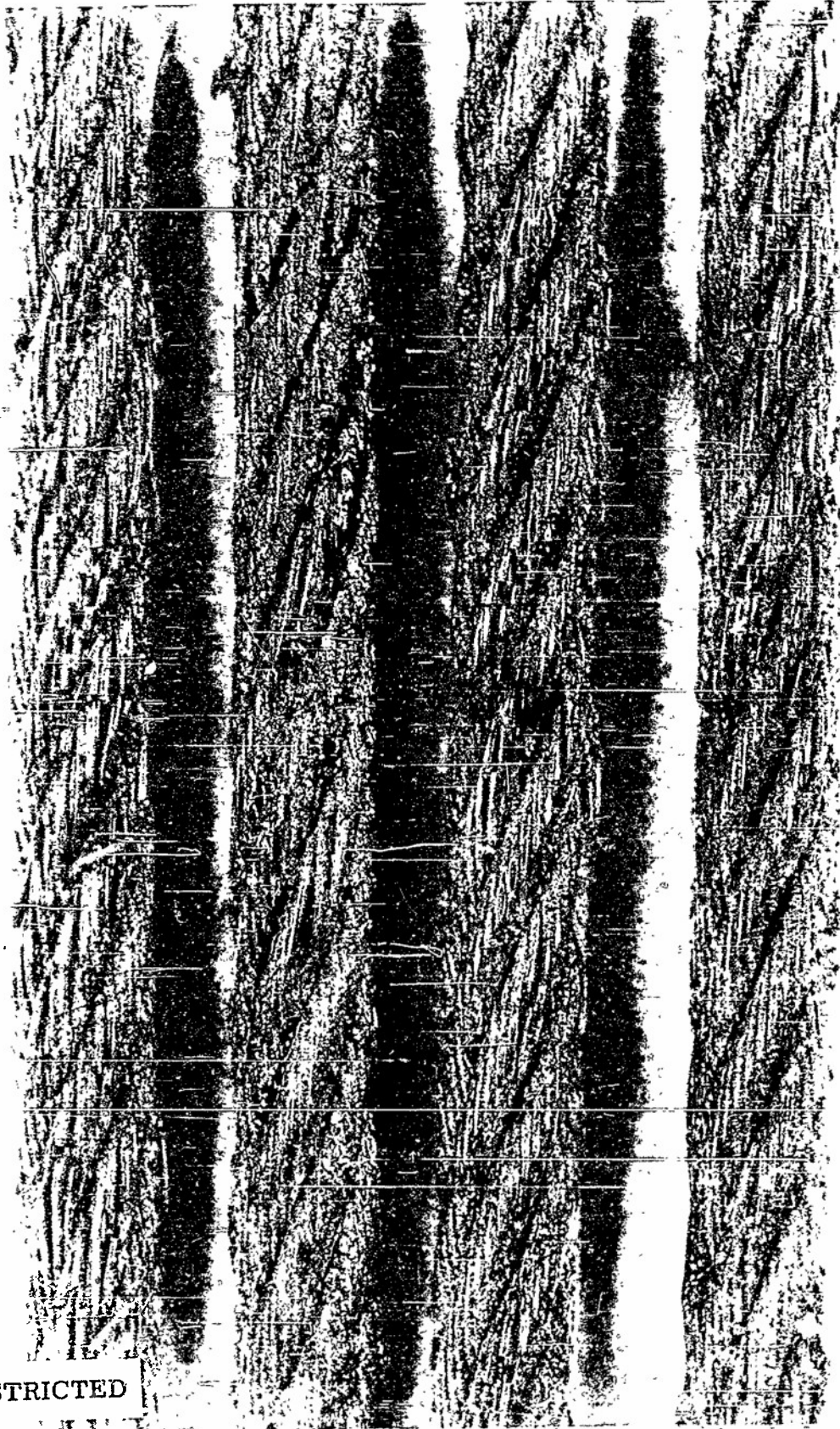
RESTRICTED

HOT GALVANIZED AND DRAWN  
12 Hours Salt Spray 750,000 Reversals--12x Sheaves.

RESTRICTED

Approx. x6

*Figure 11*



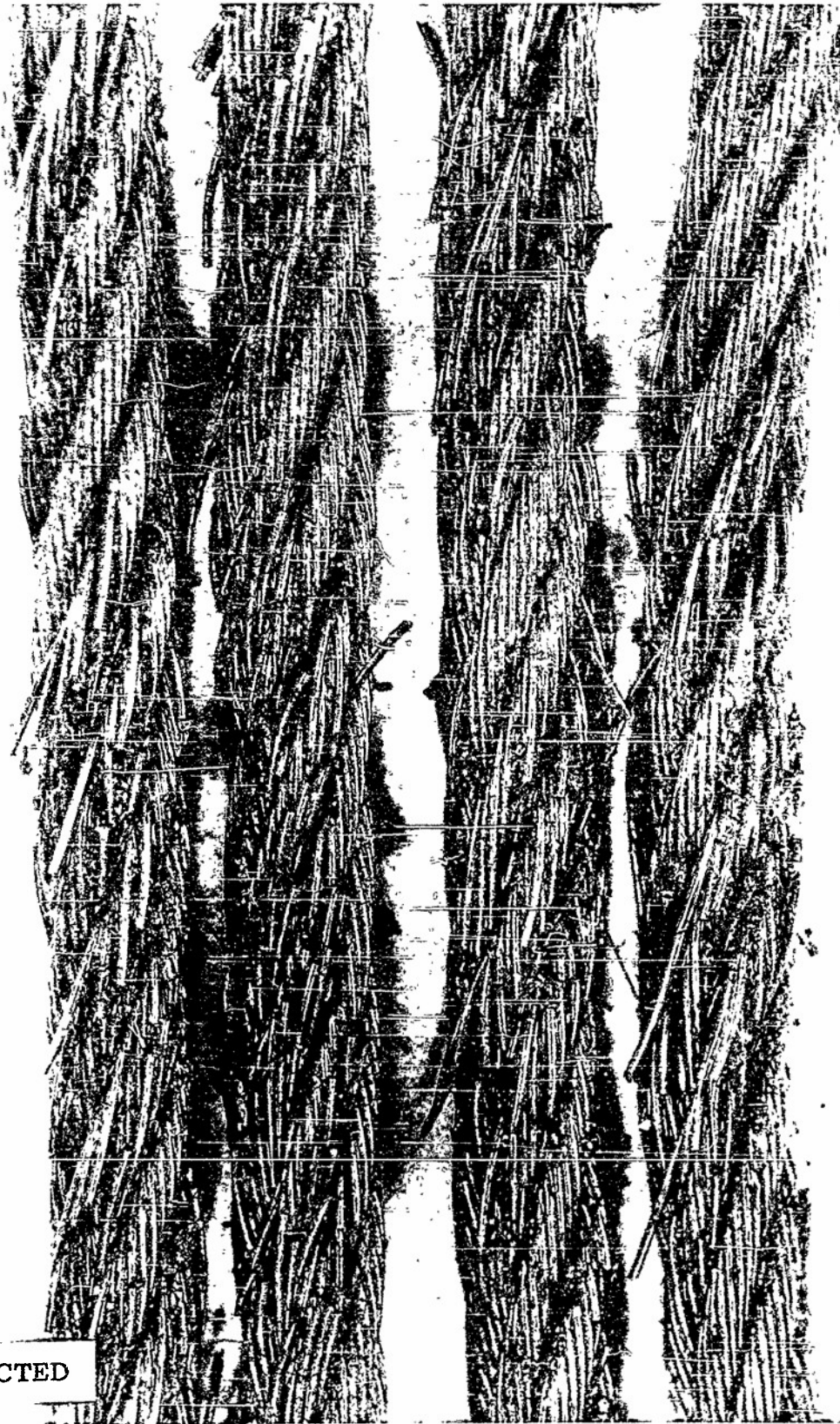
RESTRICTED

TINNED AT FINAL SIZE  
12 Hours Salt Spray 300,000 Reversals--12x Sheaves.

RESTRICTED

Approx. x6

*Figure 12*



RESTRICTED

RESTRICTED

Stainless and Carbon Steel at Service Loads

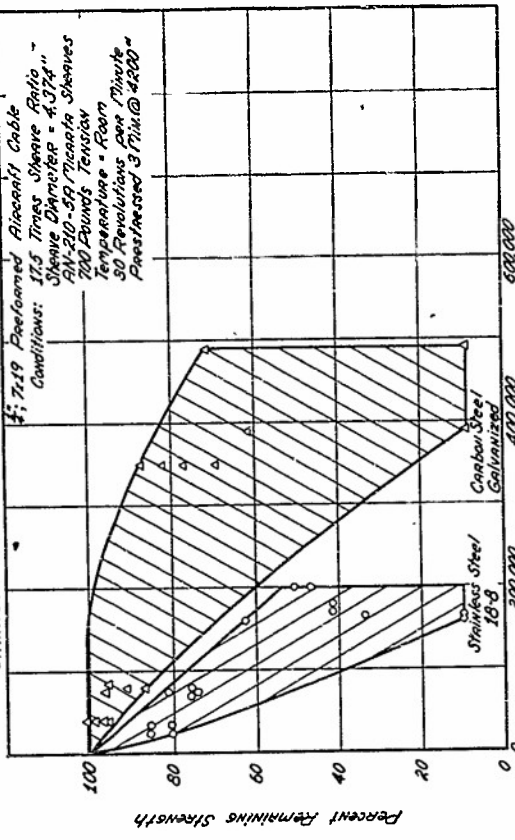


Figure 15  
 10-16-44  
 R.H. Flury, Jr.

Data from Progress Report No. 5 - Figure 67

Effect of Materials on Fatigue at -65°F

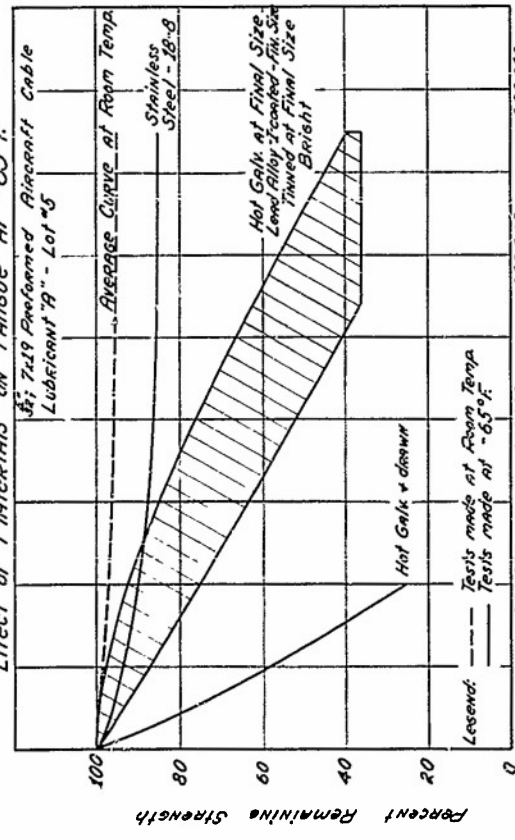


Figure 13  
 12-18-44  
 R.H. Flury, Jr.

Data from Progress Report No. 4 - Figures 3 & 7

Internal Friction Tests at Room Temperature

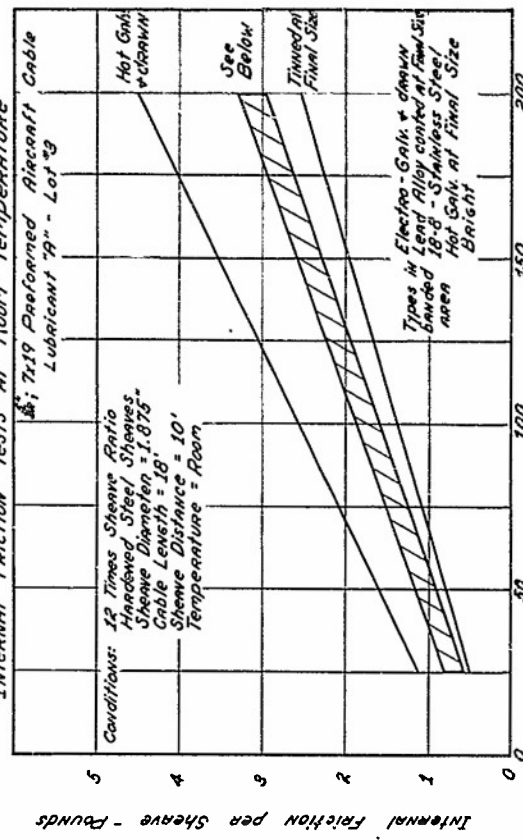


Figure 16  
 12-18-44  
 R.H. Flury, Jr.

Data from Progress Report No. 2 - Figure 29

Effect of Weight of Zinc Coating on Fatigue at -65°F

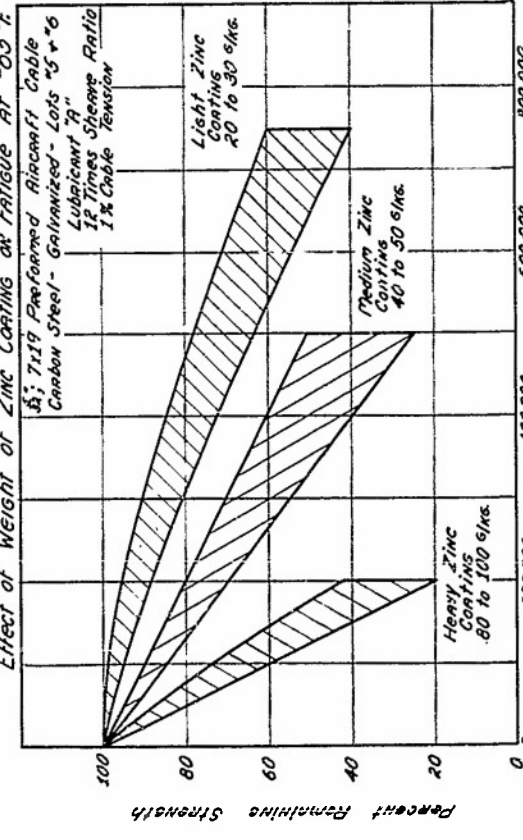


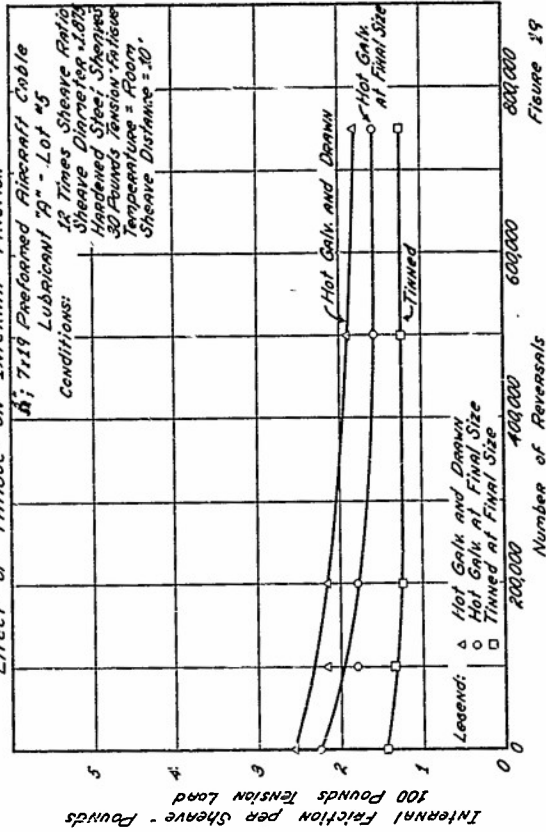
Figure 14  
 12-26-44  
 R.H. Flury, Jr.

Data from Progress Report No. 4 - Figure 32

RESTRICTED

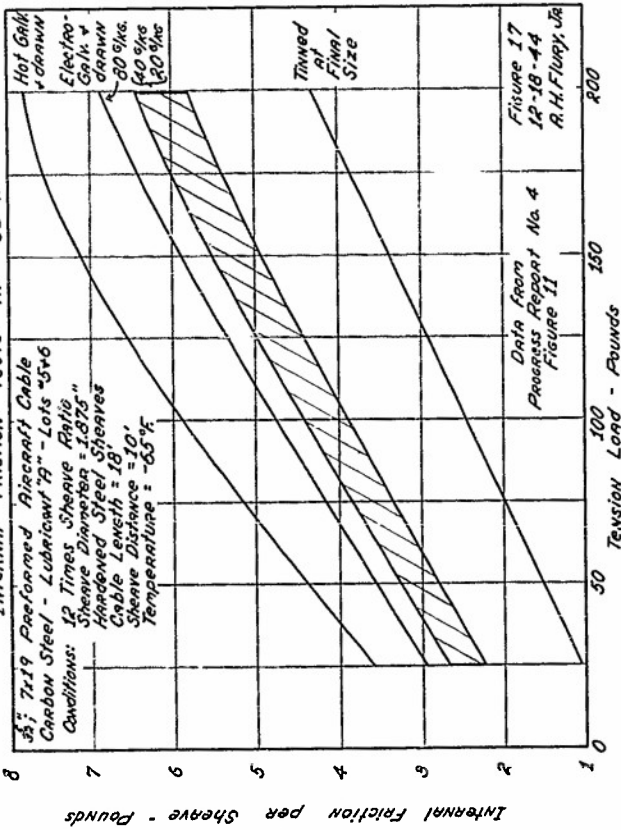
RESTRICTED

Effect of Fatigue on Internal Friction

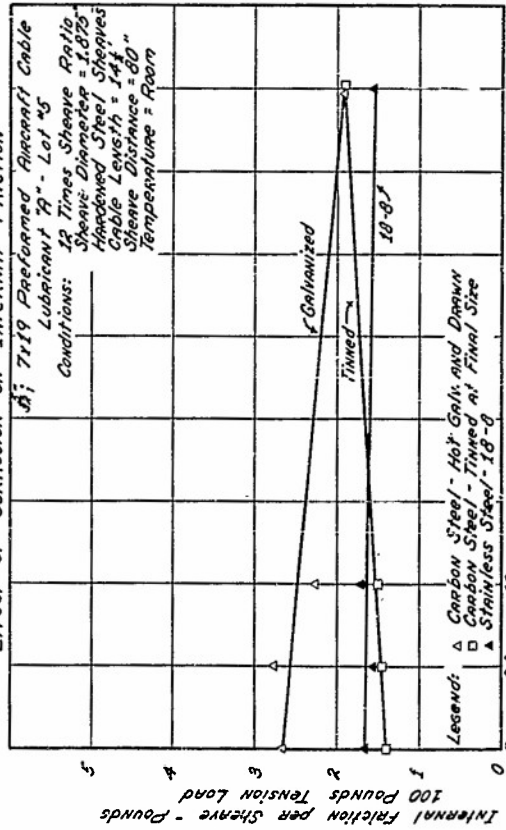


Data from Progress Report No. 6 - Figures 21, 23, & 23

Internal Friction Tests at -65°F

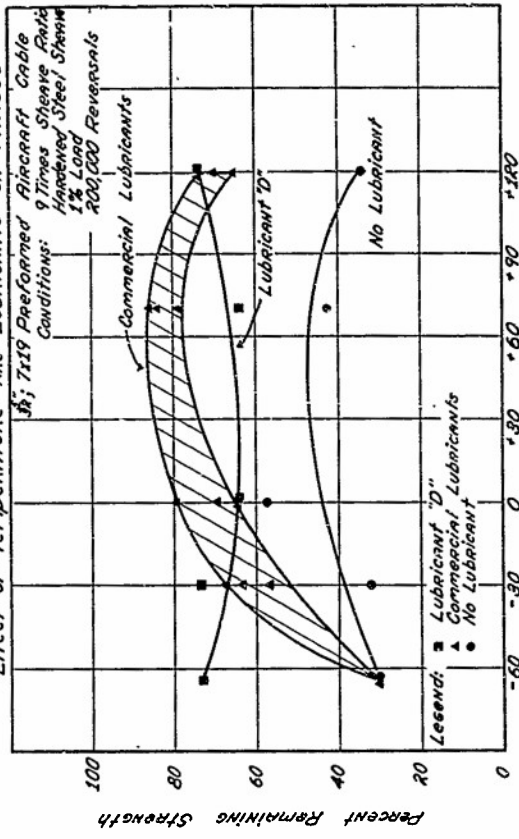


Effect of Corrosion on Internal Friction



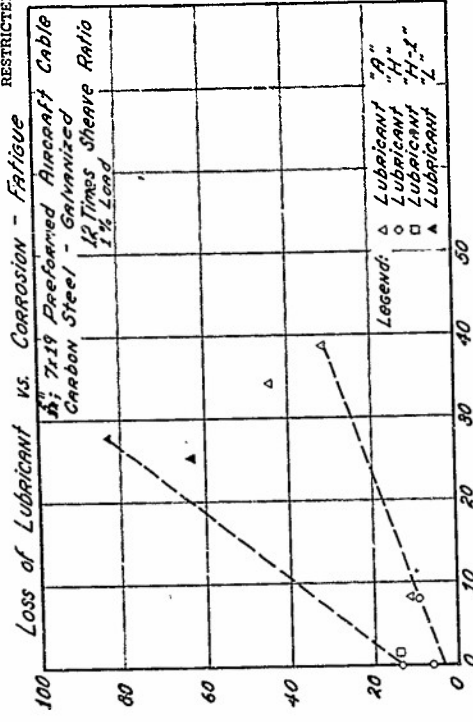
Data from Progress Report No. 4 - Figures 12, 13 & 15

Effect of Temperature and Lubricants on Fatigue



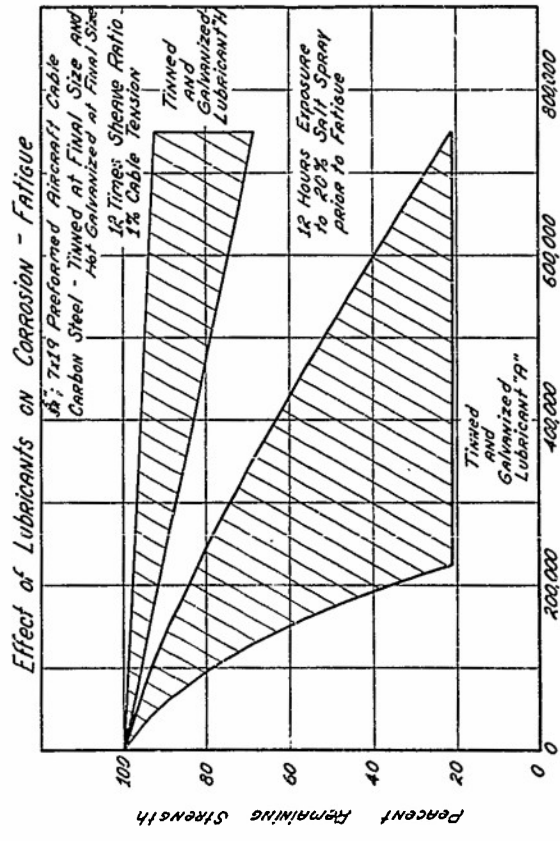
Data from Progress Report No. 1 - Figure 9

RESTRICTED

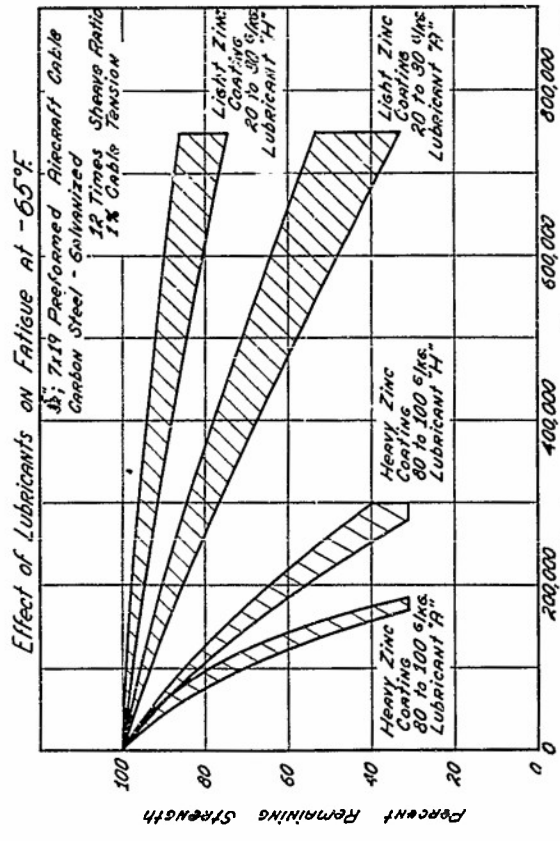


Percent Loss of Tensile Strength due to Heating 24 Hours at 160°F  
 - Corrosion Fatigue at 300,000 Reversals  
 Data from Progress Report No. 6  
 Figures 1, 8, 9, 13, 14, 15, 16 + 17  
 Figure 23  
 12-18-44  
 A.H. Flury, Jr.

Percent Loss of Lubricant due to Heating 24 Hours at 160°F

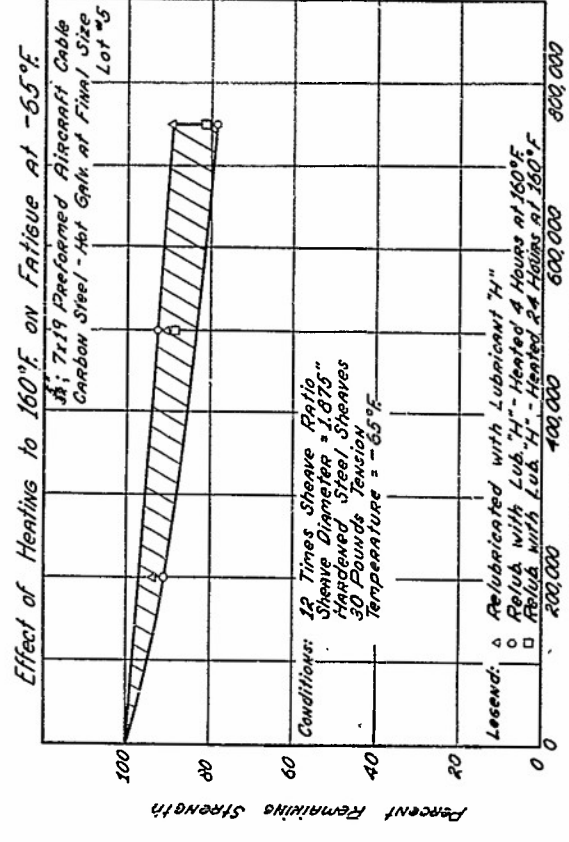


Data from Progress Report No. 4 - Figure 36  
 Figure 21  
 12-26-44  
 A.H. Flury, Jr.



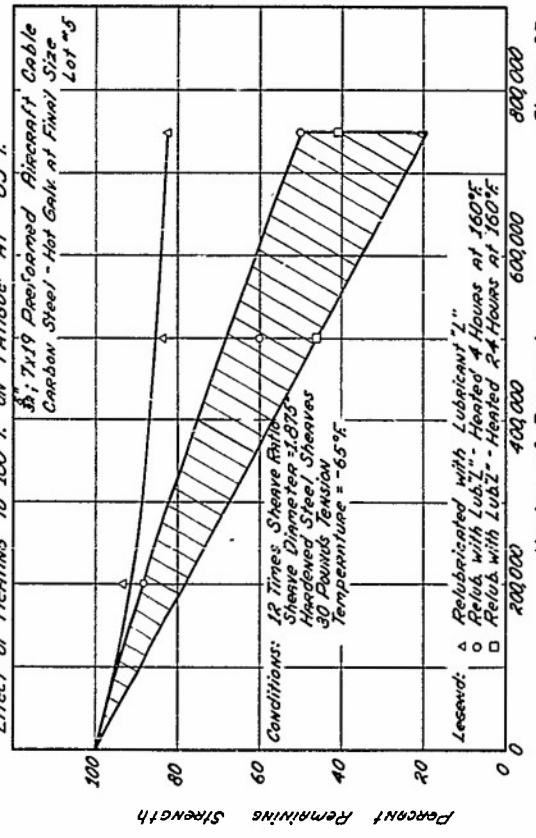
Data from Progress Report No. 4 - Figure 35  
 Figure 22  
 12-26-44  
 A.H. Flury, Jr.

RESTRICTED



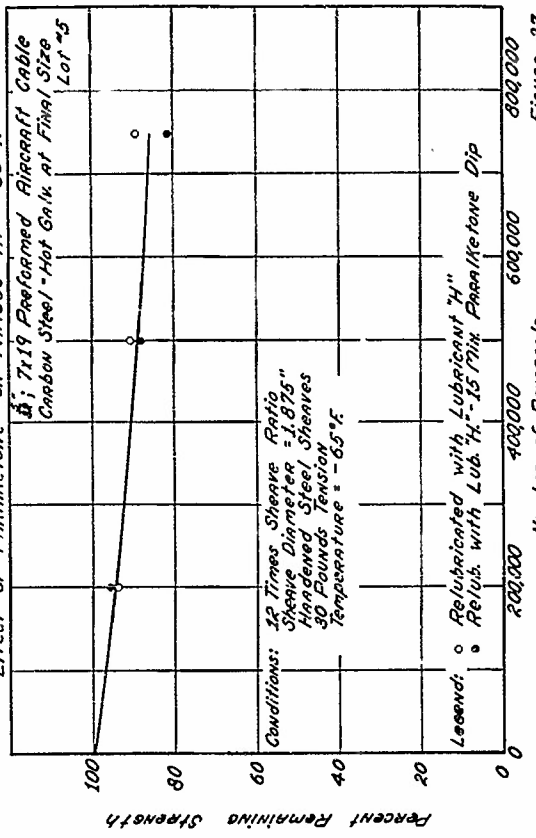
Data from Progress Report No. 6 - Figure 11  
 Figure 24  
 1-2-45  
 A.H. Flury, Jr.

Effect of Heating to 160°F on Fatigue at -65°F



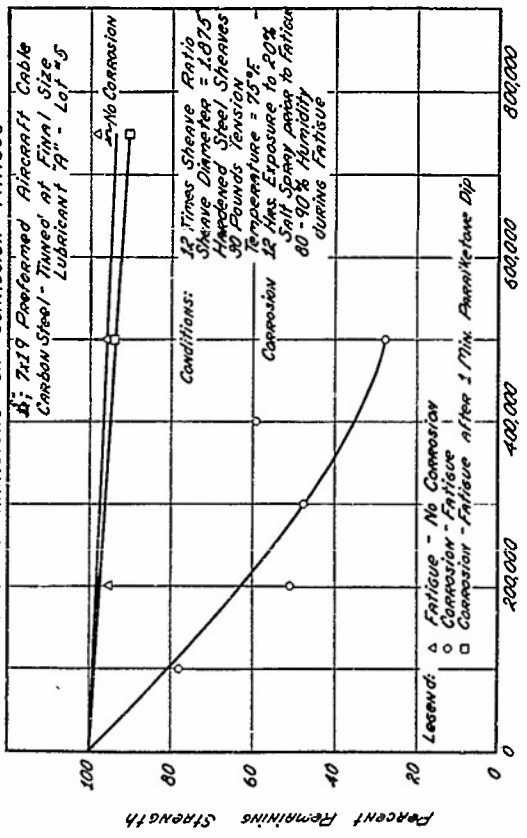
Data from Progress Report No. 6 - Figure 12  
Figure 15  
1-2-45  
A.H. Flury, Jr.

Effect of Paraffin on Fatigue at -65°F



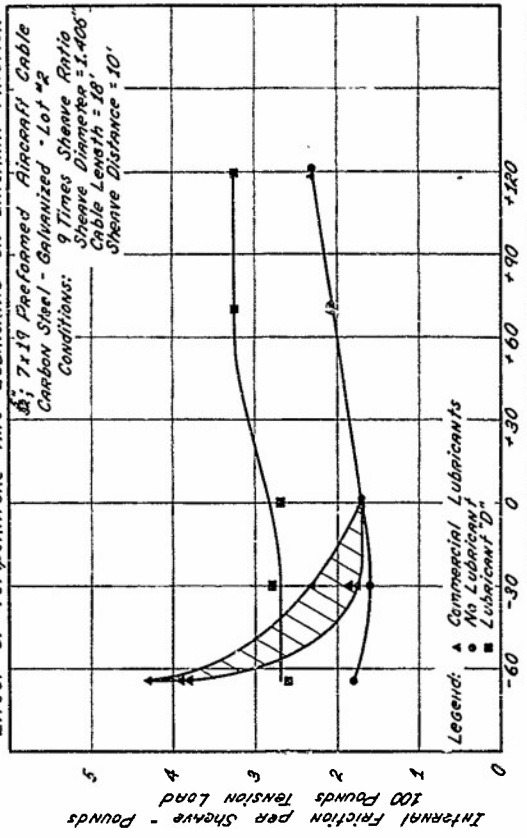
Data from Progress Report No. 6 - Figure 20  
Figure 27  
1-2-45  
A.H. Flury, Jr.

Effect of Paraffin on Corrosion Fatigue



Data from Progress Report No. 4 - Figure 26  
Figure 25  
12-26-44  
A.H. Flury, Jr.

Effect of Temperature and Lubricants on Internal Friction



Data from Progress Report No. 1 - Figure 15  
Figure 23  
12-26-44  
A.H. Flury, Jr.

RESTRICTED

RESTRICTED



RESTRICTED

Effect of Load on the Critical Sheave Ratio

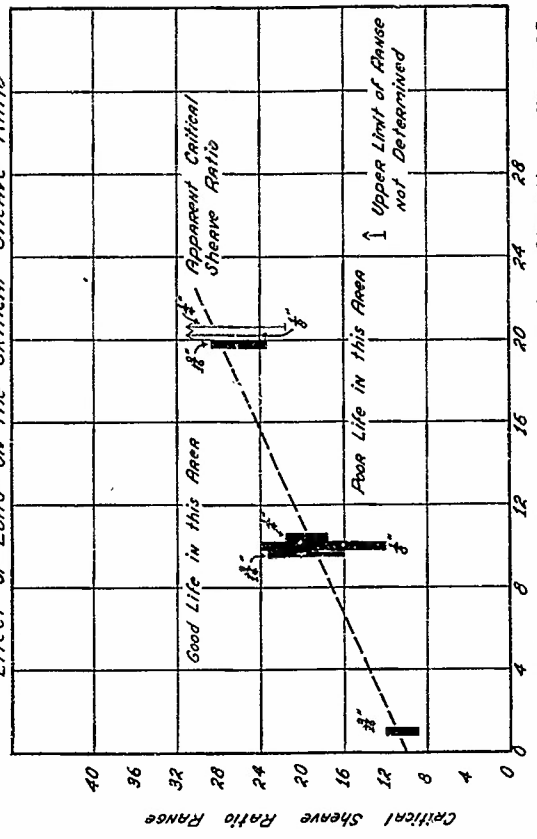


Figure 35  
1-2-45  
R.H. Flury, Jr.  
Data from Progress Report No. 5 - Figure 74

Effect of Sheave Ratio on Fatigue

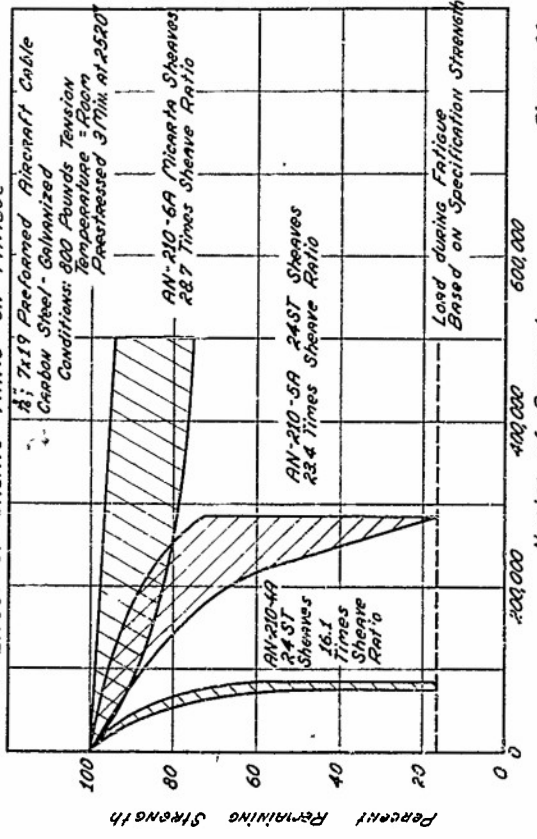


Figure 33  
1-2-45  
R.H. Flury, Jr.  
Data from Progress Report No. 5 - Figure 41

Visible Wire Breaks vs. Cable Strength

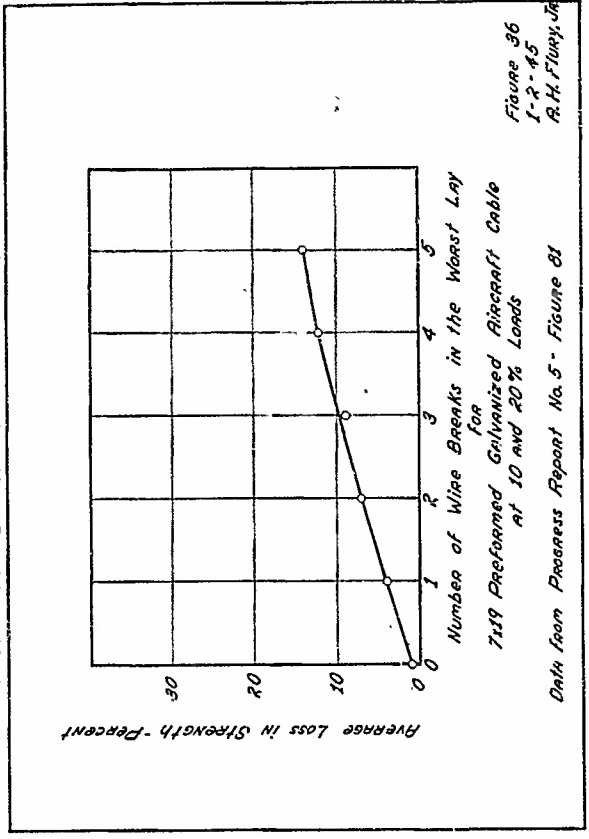


Figure 36  
1-2-45  
R.H. Flury, Jr.  
Data from Progress Report No. 5 - Figure 81

Effect of Sheave Ratio on the Critical Load

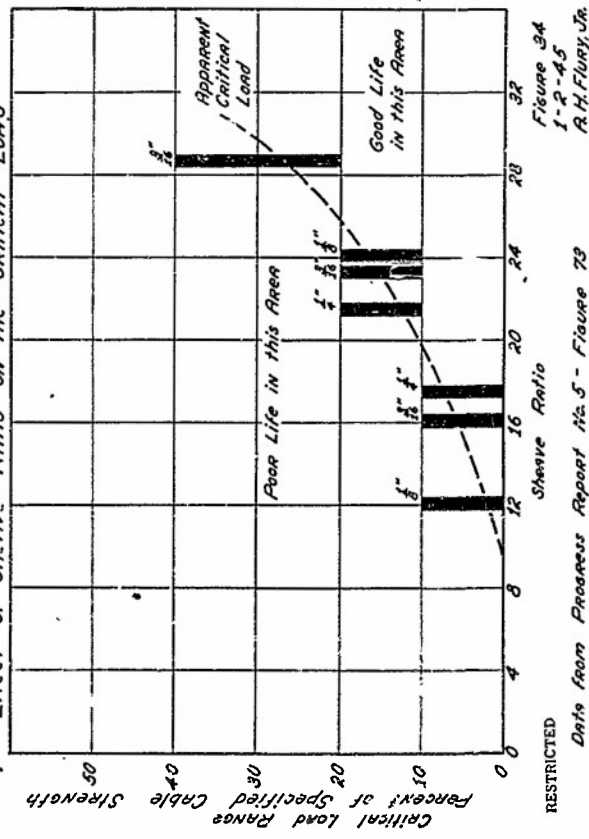
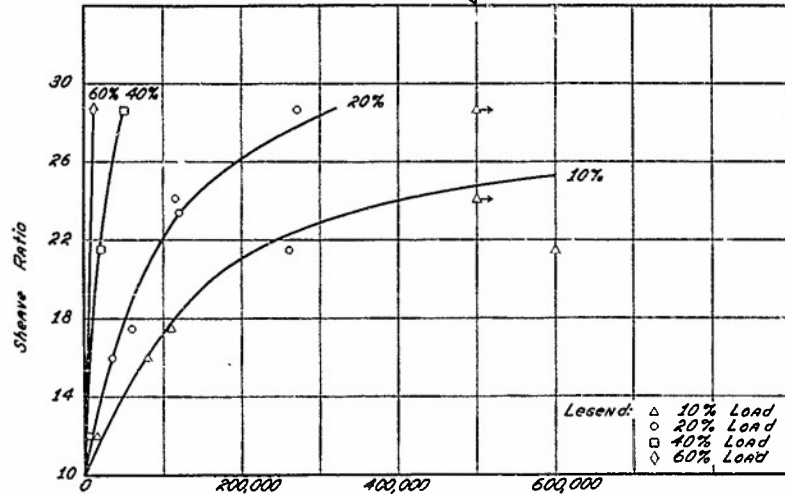


Figure 34  
1-2-45  
R.H. Flury, Jr.  
Data from Progress Report No. 5 - Figure 73

RESTRICTED

Life of 7x19 Preformed Galv Aircraft Cable



Reversals Corresponding to an Average Figure 37 of 10% Loss in Tensile Strength  
 Data from Progress Report No. 5 - Figure 32  
 1-2-45  
 R. H. Flury, Jr.

Effect of Wrap Angle on Fatigue

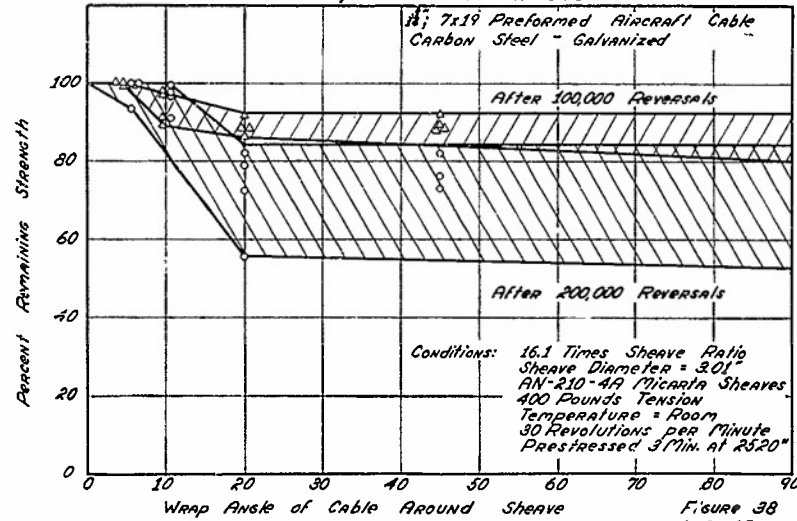
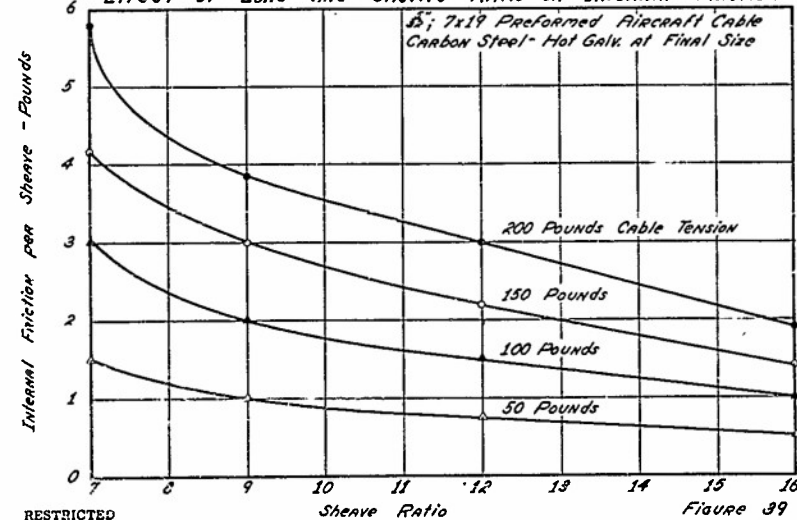


Figure 38  
 1-2-45  
 R. H. Flury, Jr.

Effect of Load and Sheave Ratio on Internal Friction



Data from Progress Report No. 3 - Figure 11

Figure 39  
 1-2-45  
 R. H. Flury, Jr.

REEL - C

756

A.T.I.

20593

RDTH FORM 69 A (13 MAR 47)

Lewis, D.  
Flury, A. H.  
Godfrey, H. J.

**RESTRICTED** P-7-4-13  
 DIVISION: Stress Analysis and Structures (7)  
 SECTION: Structural Testing (4)  
 CROSS REFERENCES: Cables, Aircraft control - Fatigue failure (14701.2)

265 650  
 ATI- 20593

ORIG. AGENCY NUMBER

O.S.R.D. 4819

REVISION

AUTHOR(S)

AMER. TITLE: The corrosion-fatigue failure of aircraft control cables (N-101)

P1/2 Aircraft Control Cables  
 FORG'N. TITLE: Corrosion

ORIGINATING AGENCY: O.S.R.D., N.D.R.C., Div. 18, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Restr.	Feb '45	60		photos, tables, diagr, graphs

**ABSTRACT**

The physical properties of aircraft control cables were investigated under test conditions designed to reproduce the effect of service conditions. Cable materials included 18-8 stainless steel and bright, galvanized, tinned, and lead-alloy-coated carbon steel. Results of fatigue tests with 1/8 loads showed that under the severe corrosive conditions of a salt atmosphere and at -65°F, 18-8 stainless steel cables were the most effective. The tinned cables had the lowest internal friction in the absence of corrosion.

CRST1 (PB 19835)

AD-A800 185

T-2, HQ., AIR MATERIEL COMMAND

AIR TECHNICAL INDEX  
 RESTRICTED

WRIGHT FIELD, OHIO, USAAF

WF-O-21 MAR 47 22,500

APR 8 1946 16

FORM 89 A (13 MAR 47)

RESTRICTED

P-7-4-13

ATI- 20593

Lewis, D.  
Flury, A. H.  
Godfrey, H. J.

DIVISION: Stress Analysis and Structures (7)

SECTION: Structural Testing (4)

CROSS REFERENCES: Cables, Aircraft control - Fatigue failure (14701.2)

ORIG. AGENCY NUMBER

O.S.R.D. 4819

REVISION

AUTHOR(S)

AMER. TITLE: The corrosion-fatigue failure of aircraft control cables (N-101)

FORG'N. TITLE:

ORIGINATING AGENCY: O.S.R.D., N.D.R.C., Div. 18, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N. CLASS.	U. S. CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Restr.	Feb '45	60		photos, tables, diagr, graphs

## ABSTRACT

The physical properties of aircraft control cables were investigated under test conditions designed to reproduce the effect of service conditions. Cable materials included 18-8 stainless steel and bright, galvanized, tinned, and lead-alloy-coated carbon steel. Results of fatigue tests with 1% loads showed that under the severe corrosive conditions of a salt atmosphere and at -65°F, 18-8 stainless steel cables were the most effective. The tinned cables had the lowest internal friction in the absence of corrosion.