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COLD-WEATHER FLIGHT TESTS OF AN OH-58
HELICOPTER EQUIPPED WITH AN ELASTOMERIC-
BEARING MAIN ROTOR

C. H. Fagan

Bell Helicopter Company

Prepared for:

Army Air Mobility Research and Development
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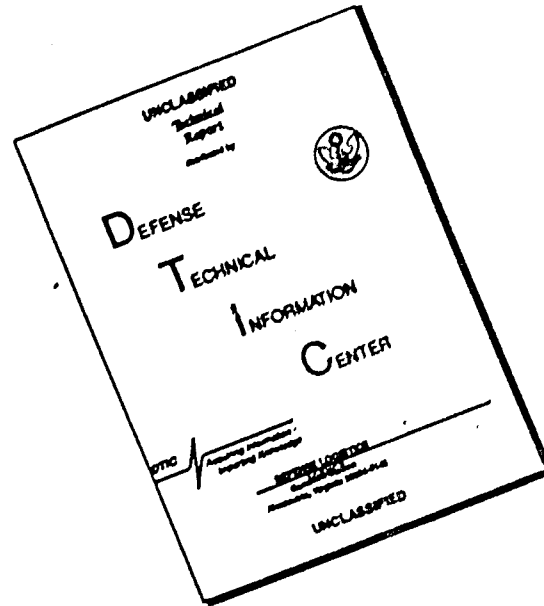
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13. ABSTRACT The report contains the results of a flight test program conducted to investigate the characteristics of a main rotor equipped with elastomeric bearings operating at low temperatures. The helicopter used was an OH-58A, and the main rotor tested had elastomeric bearings in the pitch-change and flapping axes. The tests were conducted at Fort Wainwright, Alaska, and operation at temperatures of 48°F, 5°F, -9°F, -13°F, -29°F, and -52°F was evaluated. Normal rotor control was obtained down to temperatures of -13°F. At lower temperatures, elastomer stiffening causes increased control system loads, which limit operation. Additional testing is needed to establish the precise minimum temperatures at which there are no control limitations, and to investigate pitch-change bearings made from elastomers other than natural rubber. Also, consideration needs to be given to operational procedures, or other means of "warming" the bearings, to minimize bearing stiffening.			

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This report was prepared by the Bell Helicopter Company, a Division of Textron Inc., under the terms of Contract DAAJ02-73-C-0024. It documents the results of flight tests conducted to evaluate the operational flight characteristics of an all-elastomeric bearing OH-58 main rotor in extreme cold-weather conditions.

The all-elastomeric bearing OH-58 main rotor hub was previously tested under extreme cold temperatures in the Eglin AFB Climatic Hangar in June 1972. The results of that program indicated that control loads increased significantly as temperatures dropped due to the stiffening of the elastomer in the bearing. It was determined that a flight test effort was needed to investigate the magnitude of combined bearing stiffness loads and loads created by in-flight rotor dynamics and other phenomena concerning flight characteristics of rotors equipped with elastomeric bearings.

Adverse weather conditions, ice-fog, and aircraft equipment problems precluded the acquisition of sufficient data to fully investigate the flight characteristics of the elastomeric bearing or to establish a limiting operating temperature. However, the limited data acquired is deemed to be of sufficient value to the aviation community to be reported.

The conclusions contained herein are concurred in by this Directorate.

The technical monitor for this contract was Mr. John W. Sobczak of the Military Operations Technology Division.

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COLD-WEATHER FLIGHT TESTS OF AN OH-58 HELICOPTER
EQUIPPED WITH AN ELASTOMERIC-BEARING MAIN ROTOR

Bell Helicopter Report 299-099-644

By

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Prepared by

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Fort Worth, Texas

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

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SUMMARY

Presented in this report are the results of a program designed to test the low-temperature flight characteristics of a helicopter main rotor equipped with elastomeric bearings. Prior to these tests, no flying with these bearings had been accomplished at temperatures below 0°F. The main rotor (designated Bell Helicopter Company (BHC) Model 640), which uses conic elastomeric bearings in the pitch-change axis and radial elastomeric bearings in the flapping axis, was flown on an OH-58 helicopter at Fort Wainwright, Alaska. Data are presented for operation at temperatures of 48°F, 5°F, -9°F, -13°F, -29°F, and -52°F.

Results of low-temperature tests of an identical main rotor in the Climatic Laboratory at Eglin Air Force Base, Florida, indicated that the main rotor control loads would increase with reductions in temperature below 0°F, but would remain normally operable to about -35°F. These conclusions were not fully substantiated in Alaska. Because of engine problems and adverse atmospheric conditions, insufficient data were acquired to establish a limiting cold-temperature level.

Hydraulic boost-off operation was found to be normal for the -13°F temperature flight. However, control system loads approached the endurance limit for the cyclic boost links. At some temperature between -13°F and -52°F, elastomer stiffening in the pitch-change bearings will increase the control system loads to an unacceptable level unless operational procedures can be defined to "warm" the bearing or reduce bearing stiffness. Additional cold-weather flight-test data are needed to determine the specific minimum temperature for flight operations with this particular configuration and to continue the development of elastomeric bearings for rotor application.

FOREWORD

This report was prepared under Contract DAAJ02-73-C-0024 (Project IF163209DB38), "Cold-Weather Flight Evaluation of an OH-58 Helicopter Equipped with an Elastomeric-Bearing Main Rotor," with the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory (USAAMRDL). Contract work was initiated on 1 December 1972, and the helicopter and test equipment were shipped to Fort Wainwright, Alaska, on 9 January 1973. The elastomeric-bearing main rotor flight tests were conducted on a noninterference basis on the OH-58 helicopter that was undergoing elastomeric-bearing tail rotor tests under USAAVSCOM Contract DAAJ01-72-A-0015 (P2E), D.O. 0001.

This program was under the technical cognizance of Messrs. L. Bartone, J. Daniel, and J. Sobczak of the Military Operations Technology Division of the Eustis Directorate. Principal Bell personnel associated with this program were Messrs. L. Arrick, W. Cresap, and T. Gardner.

The writer expresses his appreciation and that of all BHC personnel for the cooperation and assistance of the Fort Wainwright personnel.

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INTRODUCTION

Elastomeric bearings (E.B.'s) have been investigated for application to helicopter rotors at Bell Helicopter Company (BHC) for the past eight years. During that time, several main and tail rotor configurations, which used E.B.'s in the flapping and pitch-change axes, have been flight evaluated (References 1 and 2).

E.B.'s installed in the rotor system show advantages over conventional bearings, because they need no lubrication. They can be visually inspected without hub disassembly; they can provide longer service lives; and the gradual deterioration of the elastomer provides early warning to enhance the flight safety of the aircraft. However, low-temperature stiffening of the elastomer in the pitch-change bearing causes increased loads in the control system, and is a factor which should be considered during the initial design phases for new applications.

An all-elastomeric-bearing main rotor, BHC Model 640, was flight tested on an OH-58A helicopter in 1971 at normal Texas climatic conditions. In addition, low-temperature tests were conducted on an OH-58A equipped with the Model 640 rotor in the Climatic Laboratory at Eglin Air Force Base, Florida, in June 1972. Rotor and control loads are reported in Reference 3 for helicopter ground-run operations at temperatures of 70°F, 0°F, -25°F, -35°F, -45°F, -55°F, and -65°F. Control system load data shows that the loads increase with reduction in temperature for operation below 0°F. The higher loads were caused by an increase in the pitch-change bearings torsional spring rate as the temperature was reduced.

Prior to the tests discussed in this report, no flying had been accomplished with E.B. rotors at temperatures below 0°F. With this program, the Model 640 rotor, which uses conic E.B.'s in the pitch-change axis and radial E.B.'s in the flapping axis, was tested during forward flight in ambient temperatures of 48°F, 5°F, -9°F, and -13°F and during hover maneuvers at -29°F and -52°F. The low-temperature flight tests were conducted at Fort Wainwright, Alaska.

DESCRIPTION

TEST VEHICLE

A production OH-58A helicopter equipped with experimental main and tail rotors was used as the test vehicle. The two-bladed main rotor was equipped with elastomeric bearings in the flapping and pitch-change axes. The tail rotor tested was the same as a production tail rotor except for elastomeric bearings in the flapping axis. Additional equipment consisted of a main rotor brake and an experimental winterization kit.

TEST ROTOR

A Bell Helicopter Company Model 640 main rotor was evaluated. Blades for this rotor are the same as production OH-58A blades except for an inboard modification to pick up two hub bolts, giving a rotor diameter of 35.3 feet. The flexbeam type hub is equipped with two conic E.B.'s in each grip to carry all blade loads and to allow blade pitch motions. Also, the rotor is equipped with two radial E.B.'s in the flapping axis to carry the rotor thrust and drive loads and to accommodate flapping motions. Details of the flexbeam hub with one grip assembled are shown in Figure 1. The conic pitch-change and flapping bearings, both with a quarter section removed, are shown in Figures 2 and 3, respectively.

During this program the main rotor pitch-change bearings were indexed for no torsional load at 12 degrees up from minimum collective. This is four more degrees up collective than the previous indexing of the 640 rotor. The change in indexing reduces the steady loads at the pilot's collective lever by about 20 pounds for any flight condition except autorotation.

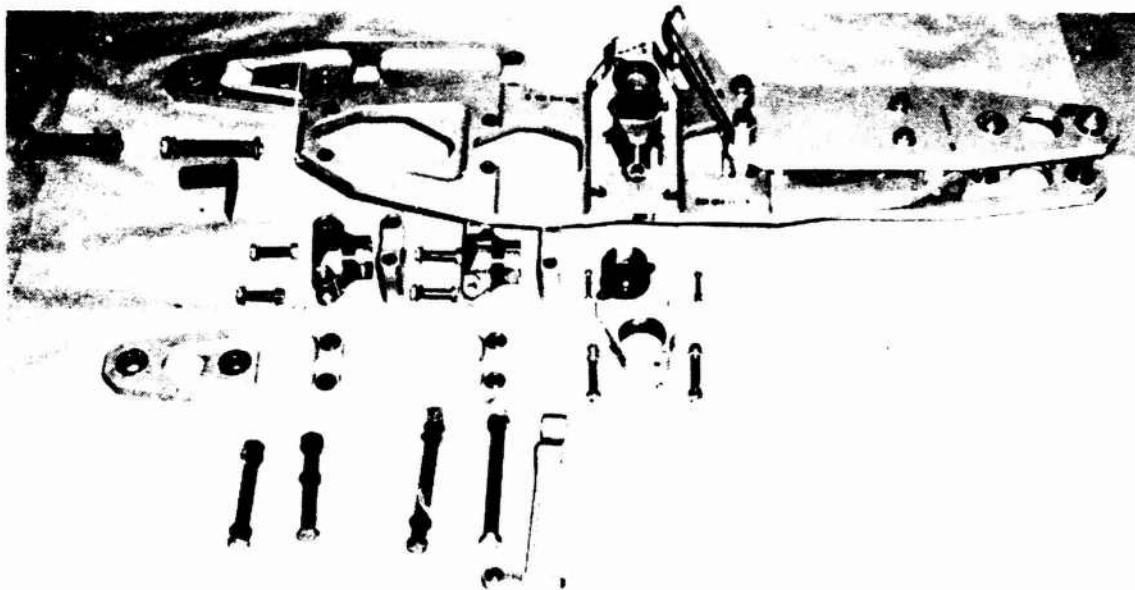


Figure 1. All-Elastomeric-Bearing Hub.

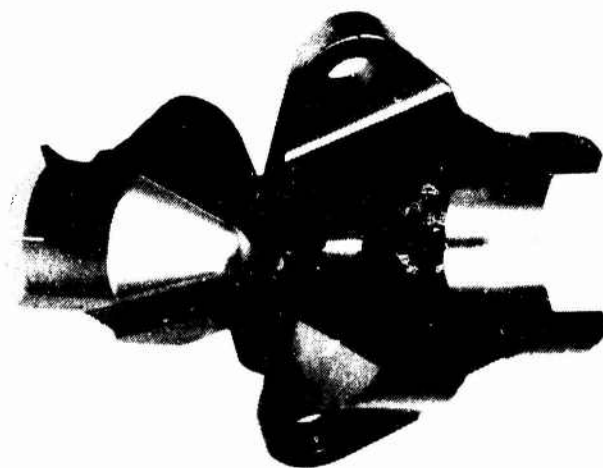


Figure 2. Main Rotor Pitch-Change Bearing.

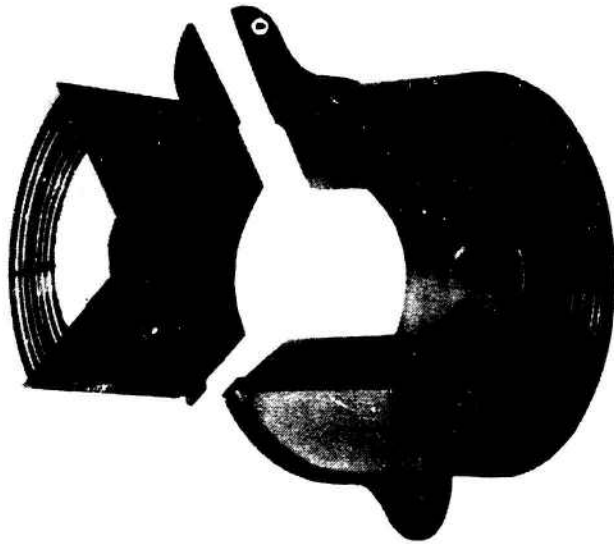


Figure 3. Main Rotor Flapping Bearing.

DISCUSSION OF TESTS

OPERATING PROCEDURES

During cold soak, the helicopter was left in an open, unprotected area of the flight ramp. Two 100-watt electric light lamps were placed in the wooden enclosure which housed the instrumentation package. These lights were used to provide heat during cold-soak periods to minimize warm-up time for the oscillographs. Also, an auxiliary power unit, shown in Figure 4, was used to furnish electrical power for a small heater to warm the fuel controls and to provide power for starting the helicopter engine. The combustion cabin heater was operated before engine start to accelerate warm-up time for the oscillographs and to provide heat for the helicopter cabin. Special arctic clothing, as shown in Figures 5 and 6, was worn by the test crew during operation outside the hangar. In addition to the clothing shown in Figure 5, cloth face masks were available and used at extreme low temperatures (below about -30°F). The added clothing increased the time necessary to perform minor tasks, such as the removal and replacement of a bolt. In fact, the collective control boost tube was disconnected, to remove any preload introduced by the pitch-change E.B.'s, during recording of the no-load instrumentation record. This operation was required before and after each flight.

After the helicopter was started and operating speed was reached, main rotor and throttle controls were exercised for 3 to 5 minutes to investigate control motion limits prior to flight. An effort was made by the pilot to conduct all maneuvers at the same rate to provide comparative load data.

ENGINE HOT START

During an attempted engine start on February 1, 1973, after a cold-soak period of 24 hours (Figure 6) at a temperature of -36°F , a severe engine overheat condition was experienced. Although the pilot's throttle was closed, sufficient fuel had accumulated in the engine to cause the damaging overheat. Subsequent investigations revealed that fuel would leak past the engine fuel control and accumulate in the engine when the fuel pump was operated to provide fuel for the cabin heater.

PILOT EVALUATION

The pilot investigated cyclic and collective control stick loads prior to each flight during ground run operation. Control inputs were executed to determine the effects of low-temperature stiffening of the pitch-change E.B.'s on limiting



Figure 4. Helicopter Preflight.



Figure 6. Helicopter Cold Soak.

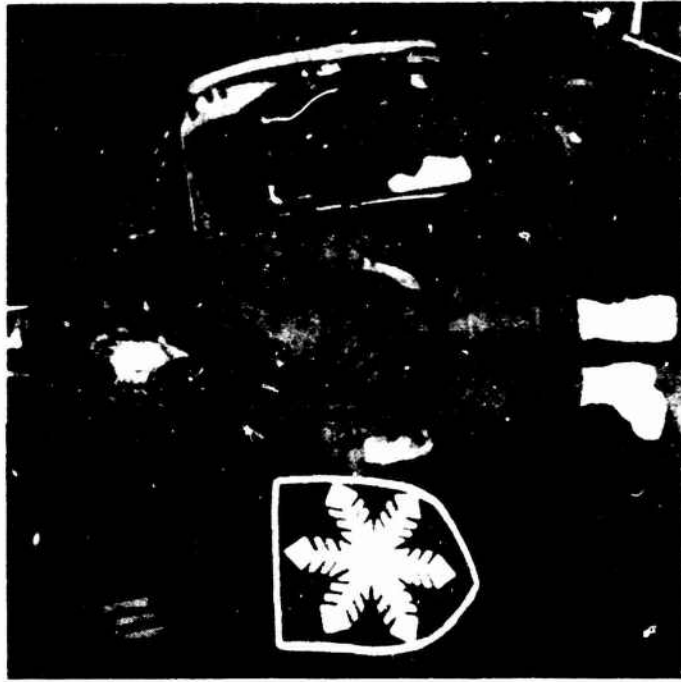


Figure 5. Arctic Clothing.

travel of the sticks and possible feedback loads. During Flight 50 (-13 F temperature conditions), all operations except the acceleration to 60 knots were conducted with the hydraulic boost off. Although feedback loads were present, the helicopter was completely controllable at all times. A 100% engine-out hover was demonstrated, and the maximum upward pull that the pilot could pull resulted in 115 horsepower. The maximum downward pull was limited to hover in ground effect. The maximum feedback load was 37 pounds on a 100% engine-out hover.

Flight 51 was conducted at a temperature of -13 F. The engine-out hover was demonstrated, and the maximum upward pull that the pilot could pull resulted in 115 horsepower. The maximum downward pull was limited to hover in ground effect. The maximum feedback load was 37 pounds on a 100% engine-out hover. The engine-out hover was limited to 100% engine-out hover, and the maximum upward pull that the pilot could pull resulted in 115 horsepower. The maximum downward pull was limited to hover in ground effect. The maximum feedback load was 37 pounds on a 100% engine-out hover.

At a temperature of -13 F, Flight 52 was conducted at a temperature of -13 F. The engine-out hover was demonstrated, and the maximum upward pull that the pilot could pull resulted in 115 horsepower. The maximum downward pull was limited to hover in ground effect. The maximum feedback load was 37 pounds on a 100% engine-out hover. Because of the probable recurrence of this problem and for support on the tail rotor investigation, the H.P. rotor was temporarily removed and a propeller rotor was installed.

The tail rotor was reinstalled on Flight 53, 47, and 48 were conducted. The rotor was reinstalled and Flights 49 and 50 were conducted at temperatures of -9 F and -13 F, respectively. Flight 51 was a ground run and low-level hover to test a new engine installed after the original engine was damaged due to a hot start. Because temperature conditions were higher than in the previous tests, only one additional flight (No. 52) was conducted, which was at +5 F.

TABLE I. FLIGHT TESTS CONDUCTED

Date	Flight No.	Ambient Temp. (°F)	Soak Time (hr)	Flight Time (min)	Center of Gravity Sta (in.)	Gross Weight (lb)	Comments
21 Dec 1972	41	+48	-	-	110.1	2785	Maneuvers and level flt. to 100 kt.*
22 Dec 1972	42	+46	-	48	106.5	3083	Maneuvers and level flt. to 132 kt.*
12 Jan 1973	44	-29	0.5	18	107.0	2600	Hover, turns, and sideward flts. Flt. aborted because of ice-fog.
16 Jan 1973	45	-52	23	18	110.1	2585	Hover, turns, and sideward flts. Flt. aborted because of ice-fog and feed-back loads.
30 Jan 1973	49	-9	3	42	110.1	2585	Maneuvers and level flt. to 100 kt.
31 Jan 1973	50	-13	24	42	110.1	2785	Maneuvers and level flt. to 100 kt.
6 Feb 1973	52	+5	48	30	110.1	2500	Maneuvers and level flts. to 120 kt.

*Flights conducted at BHC test facility, Fort Worth, Texas.

DATA ACQUISITION

Loads for the instrumentation channels as listed in Table II were recorded on photosensitive paper by an oscillograph. Data were recorded at time intervals selected by the pilot and flight test engineer to obtain records of specific flight operations. After each flight the paper was removed from the oscillograph and developed for permanent records. Locations of the instrumentation gages are given in Figure 7.

TABLE II. MAIN ROTOR CONTROLS INSTRUMENTATION		
Item	Parameter	Units*
Collective Link	axial load	lb
L.H. Cyclic Link	axial load	lb
R.H. Cyclic Link	axial load	lb
Pitch Link (Red)	axial load	lb
Pitch Link (White)	axial load	lb

*Link in compression for minus values.

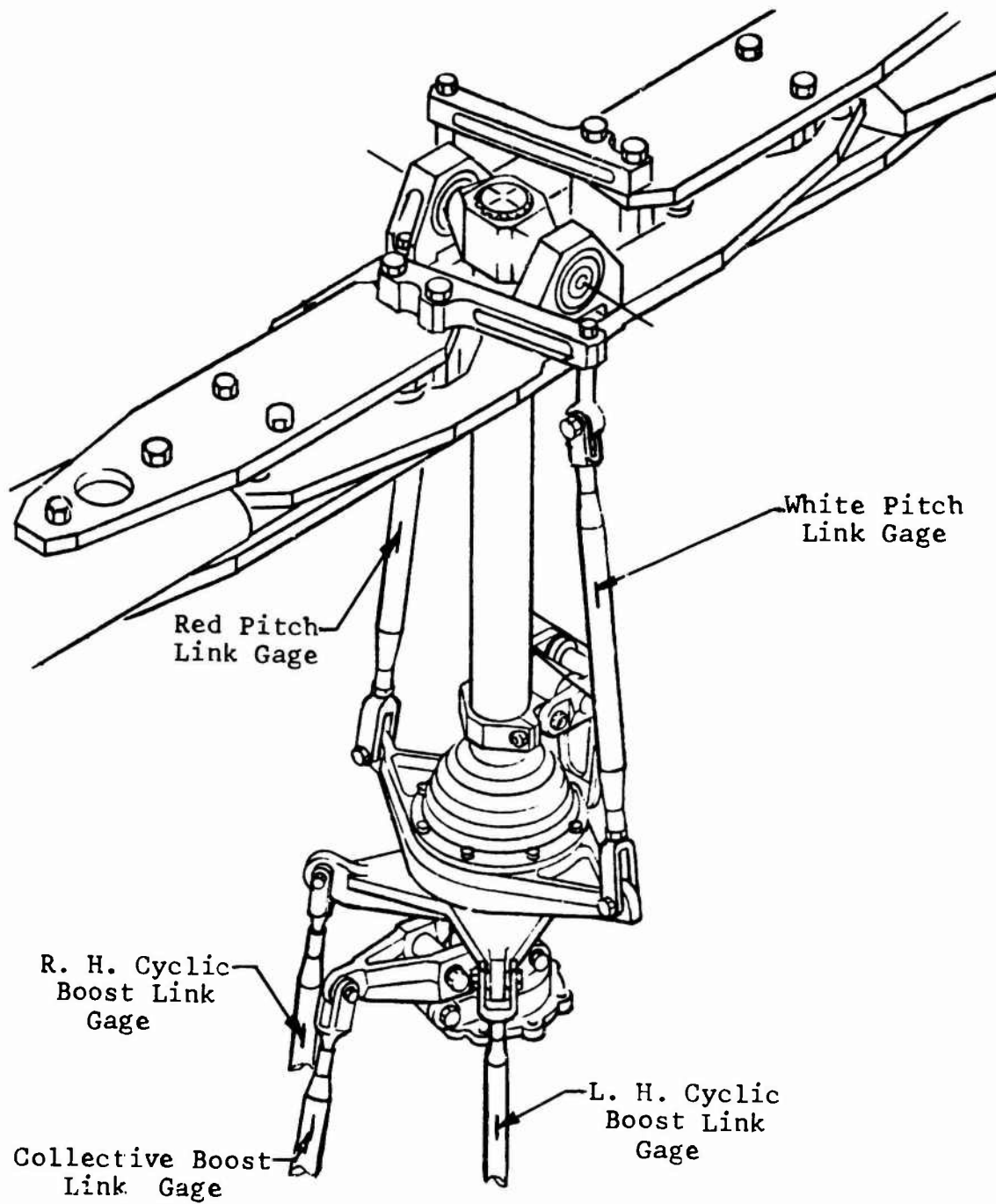


Figure 7. Main Rotor Hub and Controls Instrumentation.

DISCUSSION OF RESULTS

Listed in Figures 8 through 12 are loads data presented graphically for the main rotor control links. These data are the recorded maximum values for stabilized level flight at 354 main rotor rpm and at ambient temperatures of 48°F, 5°F, -9°F, and -13°F. Additional data are presented in Tables III through VIII for maneuvers conducted in ambient temperatures from 48°F to a low of -52°F. An effort was made by the pilot to execute all control inputs at a constant rate.

Collective boost link loads are compared in Figure 8 for temperatures ranging from 48°F to -13°F. The comparison shows an increase of about 20 percent in both steady and oscillatory loads for the lower temperature. Collective link loads were not considered to be excessively high even for operation at -52°F, as shown in Table V and Figure 15 (approximately 50-percent increase over loads for operation at 70°F). The data at 70°F were obtained from the IR&D Test Program.

Cyclic-boost link loads versus airspeed are presented in Figures 9 and 10. They show an increase of approximately 25 percent in oscillatory loads for the temperature range from 48°F to -13°F. However, the fact that the load increase was less at 100 knots than at 80 knots indicates that the pitch-change E.B.'s experienced some beneficial warm-up during the higher speed (increased cyclic motion) conditions. Mean loads in the right-hand cyclic-boost link increased almost 100 percent over the temperature range, causing high peak loads. Infinite life endurance limits for the lower cyclic-boost link, ±265 pounds (±238 pounds measured in the instrumented upper link) were exceeded during a 120-knot level flight at a temperature of +5°F. Maneuver load limits, calculated to be ±595 pounds in the instrumented link, were never reached. However, boost locking capability in the right cyclic cylinder was exceeded during a recovery from right sideward flight at -52°F temperature (Table V record number 675). For that maneuver, a load of -335 ±454 pounds was recorded, resulting in a compression peak load in the link of 789 pounds. A load on this link greater than 735 pounds will exceed the locking capability of the boost system and allow loads to feed back to the cyclic stick. Due to the mechanical linkage, loads at the pilot's cyclic stick will be 25 percent of the loads in excess of the boost locking capability, or in this instance, 14 pounds.

Red and white pitch-link load data versus airspeed are presented graphically in Figures 11 and 12. In Figures 13 through 15 the pitch-link and boost link data obtained during this program are compared with the data from ground-run operation in

the Climatic Laboratory as reported in Reference 3. The Climatic Laboratory data (scatter band) were taken with a 6-degree cyclic pitch input in an attempt to simulate cruise level flight. In-flight data for 70°F temperature were taken from the results of a previous Model 640 rotor test program. Although only a small temperature range was covered during the Alaska flight tests, the data tend to validate the results from the Climatic Laboratory.

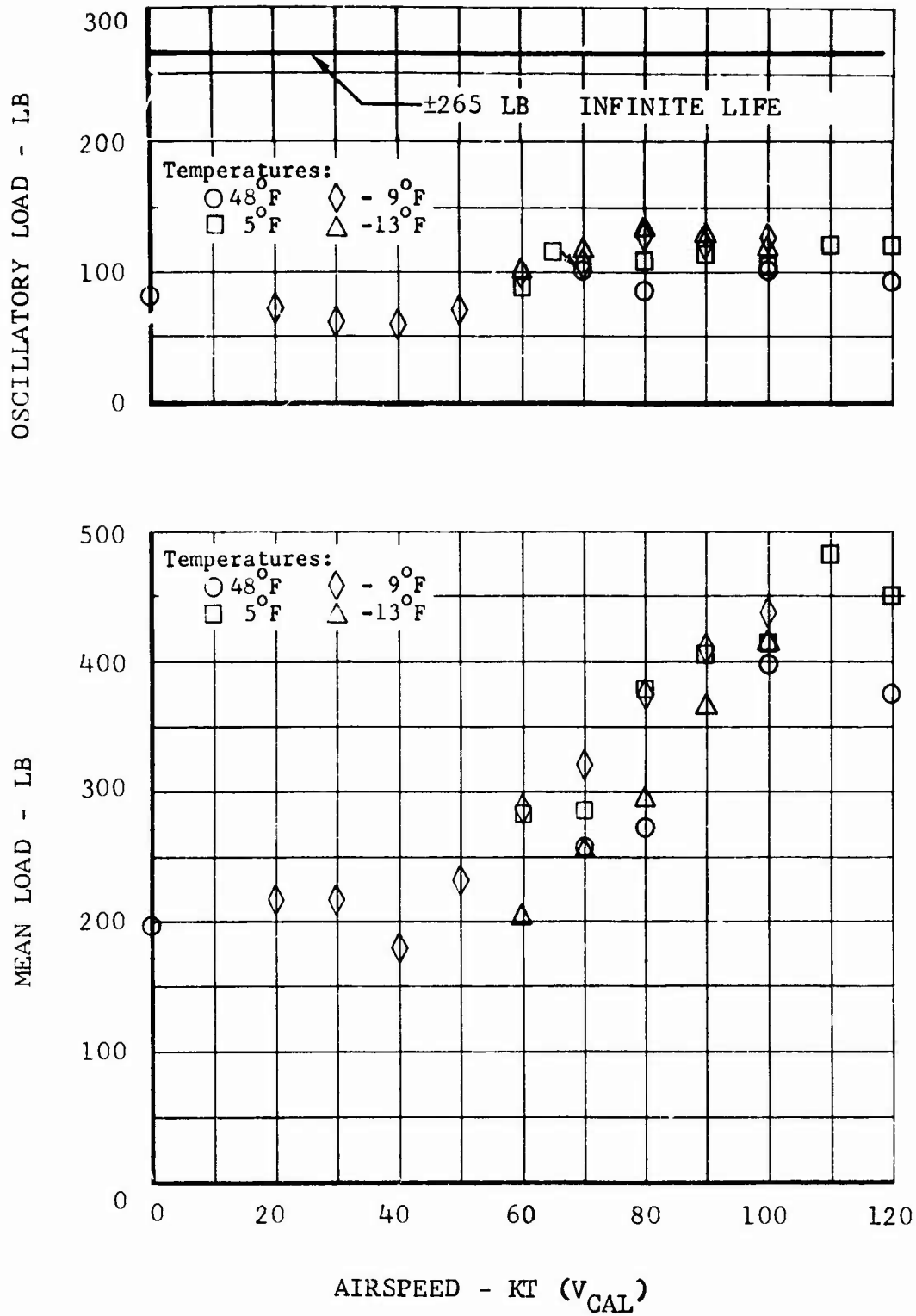


Figure 8. Collective Boost Link Load Versus Airspeed.

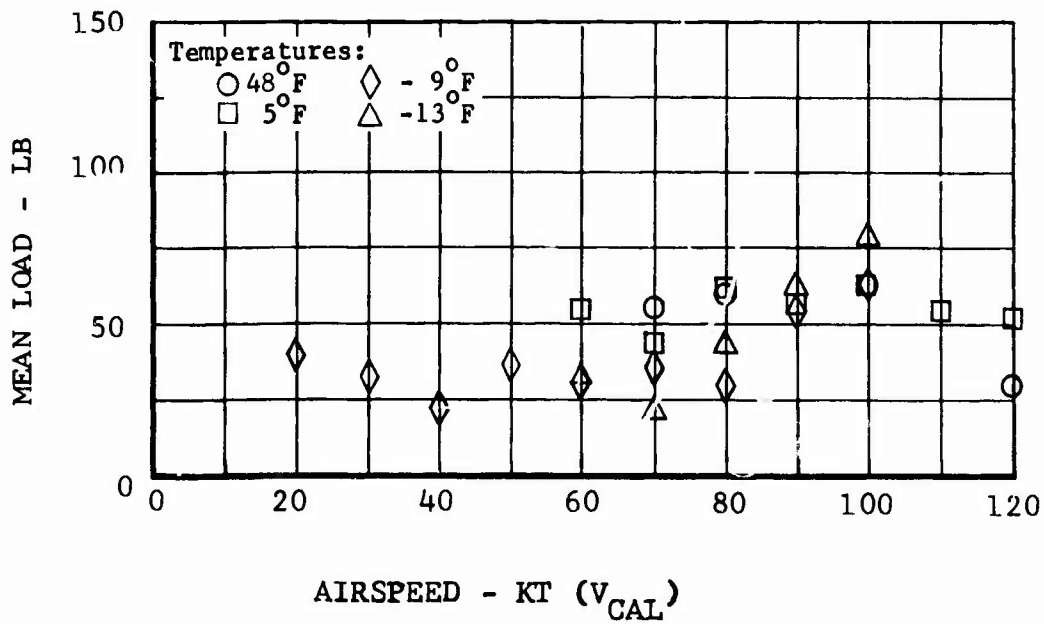
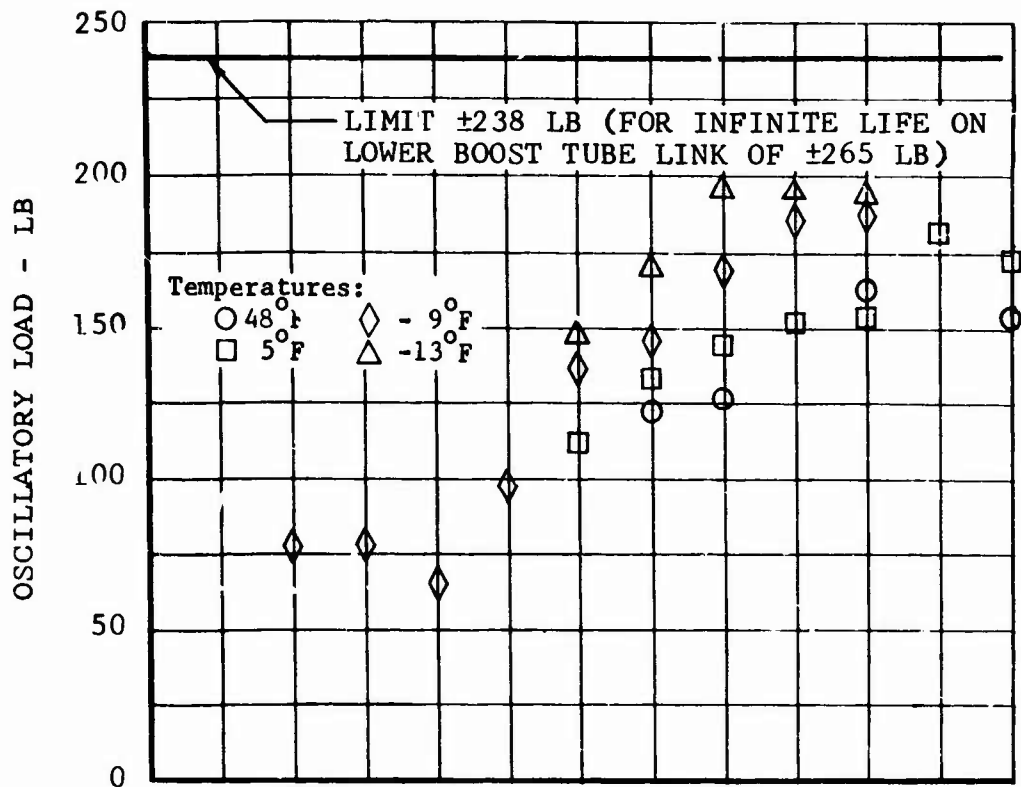


Figure 9. Left-Hand Cyclic-Boost Link Load Versus Airspeed.

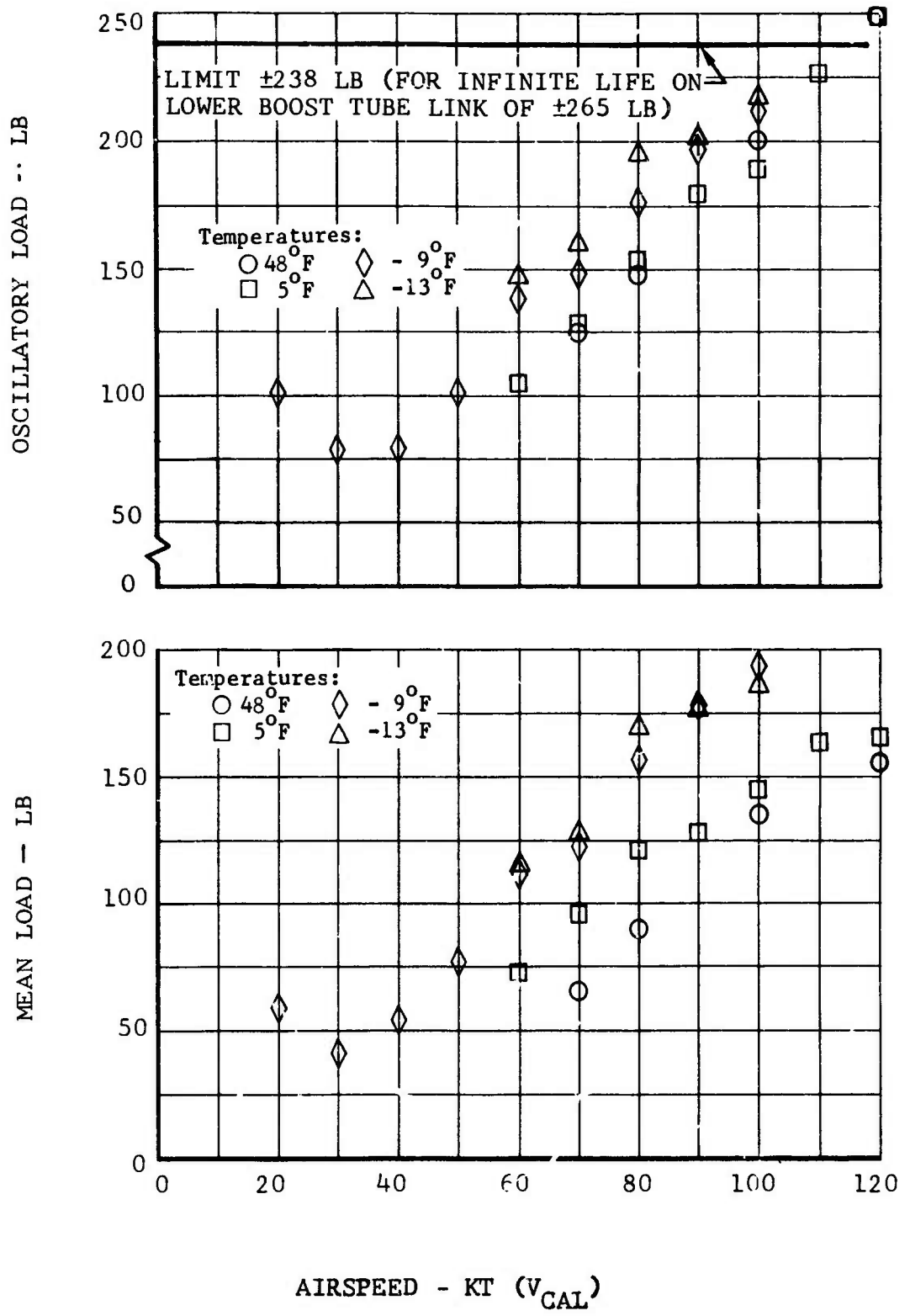


Figure 10. Right-Hand Cyclic-Boost Link Load Versus Airspeed.

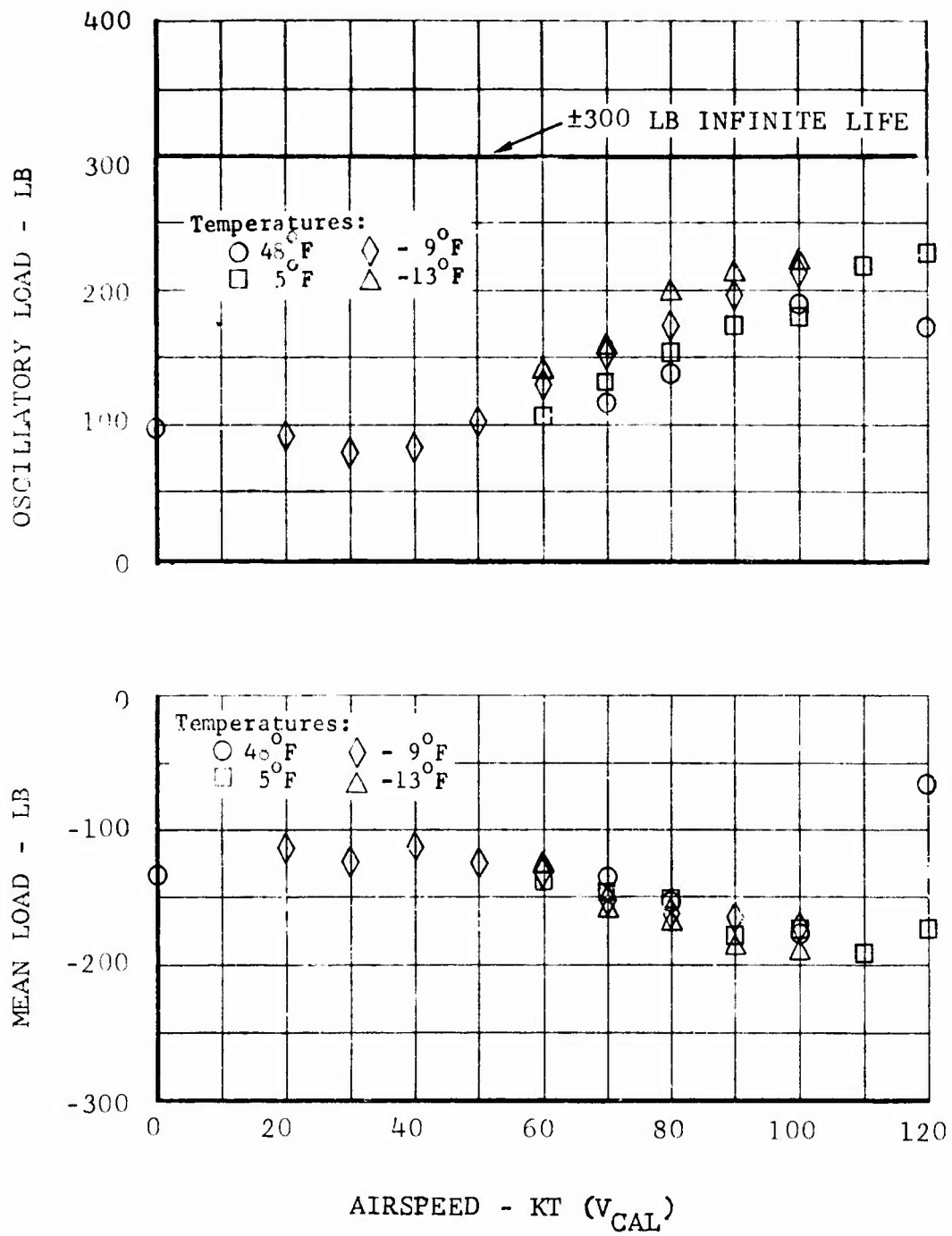


Figure 11. Red Pitch-Link Load Versus Airspeed.

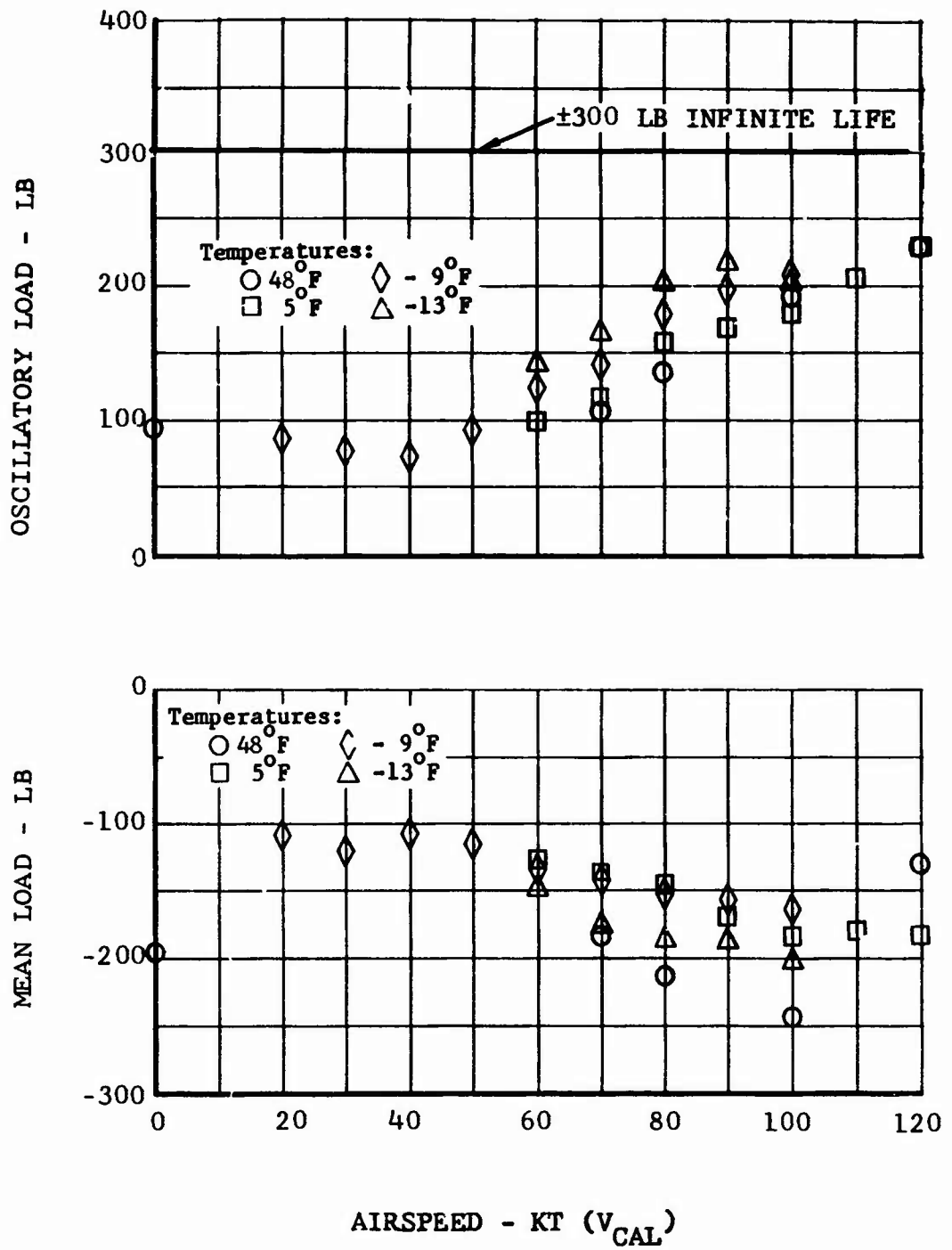


Figure 12. White Pitch-Link Load Versus Airspeed.

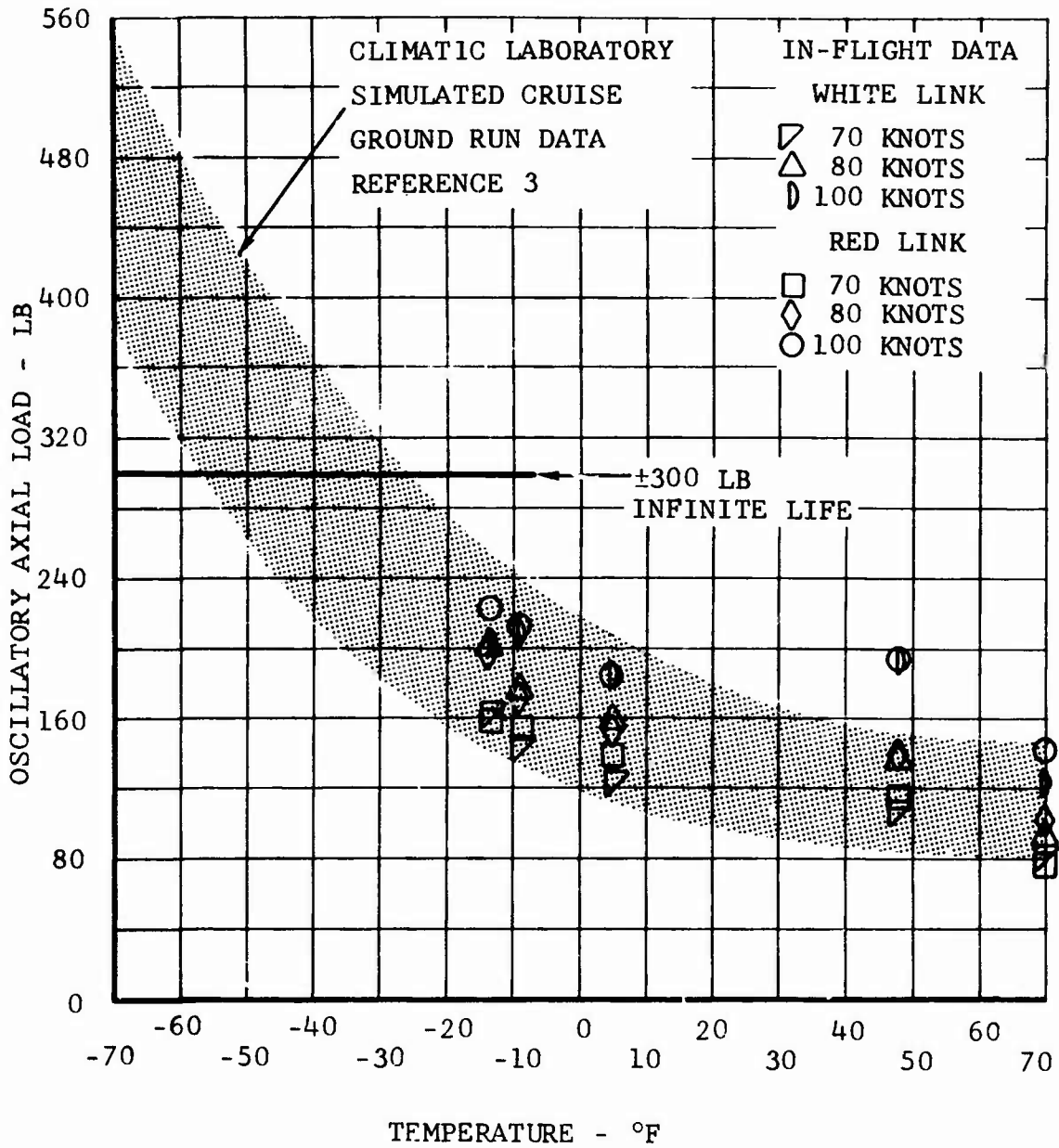


Figure 13. In-Flight and Climatic Laboratory Main Rotor Pitch-Link Loads Versus Temperature.

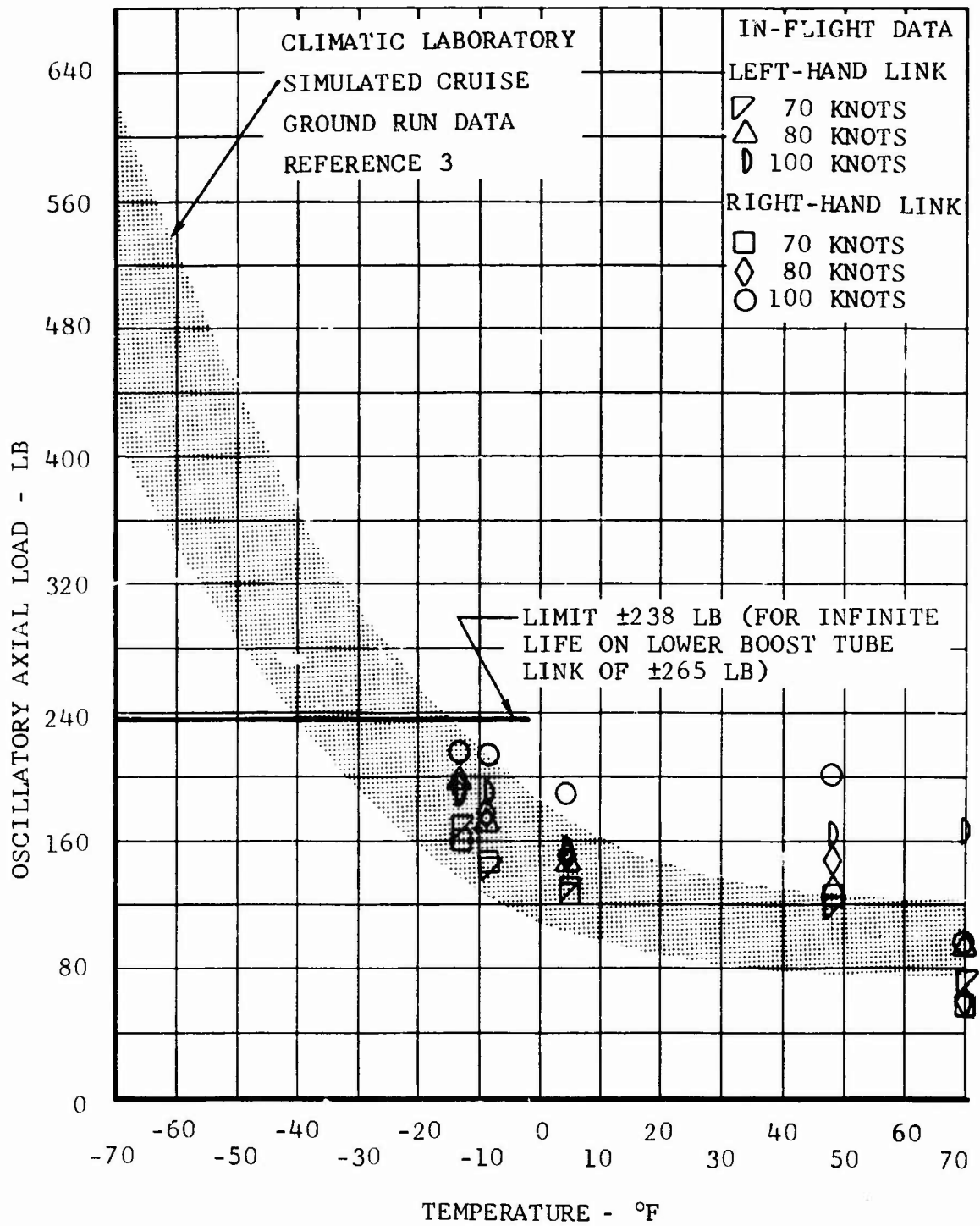


Figure 14. In-Flight and Climatic Laboratory Cyclic-Boost Link Loads Versus Temperature.

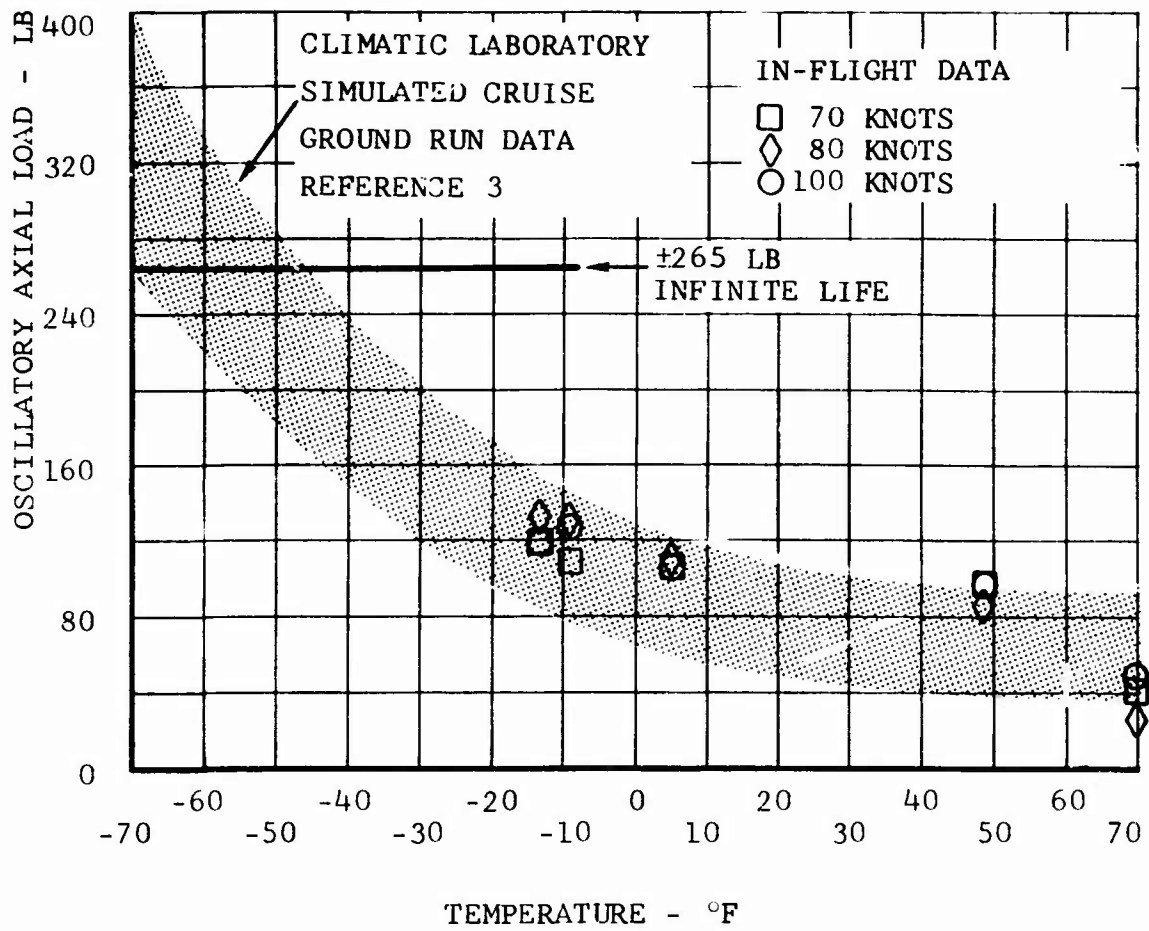


Figure 15. In-Flight and Climatic Laboratory Collective Boost Link Loads Versus Temperature.

TABLE III. MAIN ROTOR CONTROL LOADS FOR FLIGHTS NOS. 41 AND 42

Rec- ord No.	Flight Condition	L.H. Cyclic- Boost-Link Load (lb)		R.H. Cyclic- Boost-Link Load (lb)		Collective Boost-Link Load (lb)		Red Pitch- Link Load (lb)		White Pitch- Link Load (lb)	
		Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.
444	Hover I.G.E.	43	83	36	109	197	83	-136	98	-195	94
445	Accel. 0-60 kt	23	110	63	109	288	105	-166	105	-235	105
446	Climb - MC power	37	90	56	102	332	79	-188	105	-249	97
447	Level flt. 70 kt	53	120	66	125	258	101	-139	117	-209	108
448	Level flt. 80 kt	60	126	89	148	271	87	-154	139	-217	137
449	Level flt. 100 kt	57	163	135	201	398	101	-177	192	-242	191
470	Hover - left turn	-53	99	-82	82	69	139	-102	117	-129	114
471	Hover - right turn	155	76	-89	89	-139	113	-117	94	-147	97
472	Hover-F/A control	-36	168	-122	122	91	152	-98	120	-143	150
473	Hover-lat. reversal	-23	135	-89	108	121	173	-98	113	-143	114
474	Hover-pedal rev.	-33	99	-99	99	91	126	-113	98	-143	114
475	L. sideward flt.	26	158	-131	125	52	147	-102	139	-129	150
476	R. sideward flt.	-49	115	-62	141	39	152	-109	154	-139	147
484	Level flt. 120 kt	30	155	158	250	372	95	-60	173	-132	232
485	Level flt. 132 kt	13	237	191	296	390	130	-105	256	-150	236

NOTE: Records Nos. 444 through 449 were acquired during Flight 41 at 48°F,
and Nos. 470 through 485 are for Flight 42 at 46°F, main rotor
rpm 354

TABLE IV. MAIN ROTOR CONTROL LOADS FOR FLIGHT NO. 44

Rec- ord No.	Flight Condition	L.H. Cyclic- Boost-Link Load (lb)		R.H. Cyclic- Boost-Link Load (lb)		Collective Boost-Link Load (lb)		Red Pitch- Link Load (lb)		White Pitch- Link Load (lb)	
		Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.
644	Flat Pitch-flt. idle	-20	40	30	56	-66	48	11	34	-4	40
645	Hover I.G.E.	-43	37	-27	46	175	26	-196	38	-217	36
647	Hover-left turn	50	70	23	83	275	74	-188	75	-202	79
648	Hover-right turn	-13	68	50	63	275	57	-192	64	-206	69
649	Hover-pedal rev.	46	73	-30	83	249	66	-200	87	-231	87
650	L. sideward flight	40	106	-103	96	157	87	-184	117	-220	112
651	R. sideward flight	3	163	179	179	358	131	-181	173	-213	184
652	Hover autorotation	-56	123	-83	109	415	118	-339	98	-267	116

NOTE: Ambient temperature -29°F, main rotor rpm 354.

TABLE V. MAIN ROTOR CONTROL LOADS FOR FLIGHT NO. 45												
Rec- ord No.	Flight Condition	L.H. Cyclic- Boost-Link Load (lb)		R.H. Cyclic- Boost-Link Load (lb)		Collective Boost-Link Load (lb)		Red Pitch- Link Load (lb)		White Pitch- Link Load (lb)		
		Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	
666	Flat pitch	10	56	-96	43	-159	47	53	68	36	57	
667	Hover I.G.E.	-133	193	-209	189	-9	121	-241	196	-257	193	
669	Hover-left turn	-113	239	7	232	254	134	-271	279	-268	247	
670	Hover-right turn	-106	199	156	229	328	112	-215	230	-236	229	
671	Hover-pedal rev.	-169	216	-212	225	9	112	-226	233	-232	232	
672	Hover-F/A control	-153	359	-345	358	-177	246	-136	354	-161	368	
673	Hover-lat. reversal	239	339	56	335	164	190	-256	377	-272	365	
674	L. sideward flt.	73	266	-348	288	4	142	-218	316	-236	300	
675	R. sideward flt.	-349	415	-335	454	-328	267	-256	422	-261	418	
676	Hover throt. chop	-302	282	-60	312	-4	168	-245	282	-279	279	
677	Ground-rt.fwd.cyc.	-216	468	394	461	138	276	-23	482	-36	500	
678	Hover F/A cyc.	-116	402	365	418	401	254	-207	448	-172	436	
679	Ground-lt.aft cyc.	206	392	-411	358	-17	241	-181	429	-189	418	
680	Max. pwr. boost off	-10	183	139	219	297	142	-83	203	-107	214	

NOTE: Ambient temperature -52°F, main rotor rpm 354.

TABLE VI. MAIN ROTOR CONTROL LOADS FOR FLIGHT NO. 49

Rec- ord No.	Flight Condition	L.H. Cyclic- Boost-Link Load (lb)		R.H. Cyclic- Boost-Link Load (lb)		Collective Boost-Link Load (lb)		Red Pitch- Link Load (lb)		White Pitch- Link Load (lb)	
		Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.
895	Flat pitch	3	49	22	48	-67	51	26	47	42	42
897	Hover I.G.E.	6	45	-58	45	173	46	-179	47	-170	45
899	Hover-left turn	-6	71	-93	67	139	63	-186	69	-170	73
900	Hover-right turn	13	90	-100	80	143	84	-183	102	-173	97
901	Hover-F/A cyc.rev.	-58	141	-122	109	88	131	-182	117	-176	128
902	Hover-lat.cyc.rev.	147	154	-77	148	109	135	-153	146	-163	156
903	Hover-pedal rev.	-96	103	3	93	147	72	-186	106	-173	104
905	Accel. 0-60 kt	29	131	112	144	362	109	-193	135	-176	142
909	Level flt. 50 kt	35	99	77	103	232	72	-124	102	-114	93
910	Level flt. 60 kt	32	135	112	138	286	101	-131	131	-131	125
911	Level flt. 70 kt	35	144	122	148	320	109	-153	153	-142	142
912	Level flt. 80 kt	32	173	157	177	375	131	-161	175	-152	180
913	Level flt. 90 kt	67	183	186	205	429	152	-164	201	-156	204
915	Level flt. 100 kt	58	186	193	212	438	126	-172	215	-163	211
926	Decel. 60-0 kt	77	167	64	186	307	122	-153	153	-149	170

NOTE: Ambient temperature -9°F, main rotor rpm 354.

TABLE VII. MAIN ROTOR CONTROL LOADS FOR FLIGHT NO. 50

Rec- ord No.	Flight Condition	L.H. Cyclic- Boost-Link Load (lb)		R.H. Cyclic- Boost-Link Load (lb)		Collective Boost-Link Load (lb)		Red Pitch- Link Load (lb)		White Pitch- Link Load (lb)	
		Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.
938	Low col.cyc.stk.stir	-179	186	73	169	-195	119	-7	210	-14	221
939	Accel. 0-60 kt	51	192	185	204	438	149	-224	202	-242	208
940	Level flt. 60 kt	32	147	115	147	204	102	-127	141	-149	142
941	L. turn at 60 kt	45	135	89	134	208	98	-130	130	-135	121
942	Low pwr. let down	58	90	42	73	55	55	-76	90	-80	87
943	Max. pwr. climb	93	176	153	185	412	132	-195	174	-215	187
944	Level flt. 70 kt	22	170	128	160	255	119	-159	159	-176	163
947	Level flt. 80 kt	42	196	169	195	293	132	-170	199	-187	201
950	Level flt. 90 kt	61	196	176	201	365	128	-188	210	-187	215
953	Level flt. 100 kt	77	192	185	217	416	119	-192	221	-201	201
954	L. turn at 100 kt	71	199	192	217	382	128	-174	224	-197	225
955	R. turn at 100 kt	45	173	179	198	365	128	-181	195	-197	204
956	Climb at 60 kt	90	179	160	192	429	115	-210	188	-228	180
957	Flat pitch-cyc in.	96	244	214	240	38	174	58	246	45	239
958	Shut dn.max.up col.	45	103	86	105	106	98	-29	116	14	111

NOTE: Ambient temperature -13°F, main rotor rpm 354.

TABLE VIII. MAIN ROTOR CONTROL LOADS FOR FLIGHT NO. 52												
Rec- ord No.	Flight Condition	L.H. Cyclic- Boost-Link Load (lb)		R.H. Cyclic- Boost-Link Load (lb)		Collective Boost-Link Load (lb)		Red Pitch- Link Load (lb)		White Pitch- Link Load (lb)		
		Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	Mean	Osc.	
973	Hover I.G.E.	-13	32	0	32	295	25	-219	36	-204	45	
974	Hover-F/A cyc.	35	202	153	179	425	147	-204	175	-187	180	
975	Hover-lat. cyc.	157	163	-99	150	324	147	-212	168	-204	163	
976	Hover-throt. chop	-19	83	-80	67	219	59	-328	73	-311	83	
977	R. sideward flt.	13	218	-198	166	93	202	-201	179	-190	183	
978	L. sideward flt.	106	131	96	166	354	126	-157	157	-156	149	
979	Accel. 0-60 kt	48	163	118	169	463	126	-204	161	-197	163	
980	Climb-MC power	83	160	128	173	530	118	-219	175	-218	170	
981	Level flt. 60 kt	54	112	73	105	290	88	-142	106	-128	100	
982	Level flt. 70 kt	42	131	96	128	282	105	-146	139	-139	125	
983	Level flt. 80 kt	61	144	121	153	379	109	-153	153	-145	159	
986	Level flt. 90 kt	54	151	128	179	408	114	-179	172	-170	170	
987	Level flt. 100 kt	58	154	144	189	417	105	-175	183	-183	183	
989	Level flt. 120 kt	51	173	166	249	450	122	-172	230	-183	232	
990	Low pwr. let down	32	90	32	70	118	51	-106	77	-90	69	

NOTE: Ambient temperature 5°F, main rotor rpm 354.

CONCLUSIONS

Satisfactory operation of an OH-58A helicopter equipped with a Model 640 all-elastomeric-bearing main rotor was demonstrated at low temperatures to -13°F . Also, some flight testing was conducted down to -52°F .

No problems were encountered with the flapping elastomeric bearings, and it appears that they are satisfactory for operation at low temperatures to -52°F . However, elastomer stiffening with reductions in temperature increased the torsional stiffness of the pitch-change bearings and caused problems with the rotor control system. At some low temperature, the control system loads will increase to a point where they cause fatigue damage, rate-limit control inputs, and generate feedback loads at the pilot's controls. Due to time constraints and adverse climatic conditions, a thorough investigation of the in-flight characteristics of the blade feathering elastomeric bearings was not accomplished. No attempts were made to determine operational procedures that might be used to reduce the bearing stiffness and accompanying high control loads to an acceptable operational level. Additional tests are needed to establish the minimum temperature at which there are no control limitations, and to investigate the cold-weather operation of pitch-change bearings made from elastomers other than natural rubber.

For future helicopter rotor systems using elastomeric bearings, stiffening of the elastomer at cold temperatures should be a design consideration for the bearing, for the rotor hub (configuration), and for the control system.

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