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DESIGN AND DEVELOPMENT ENGINEERING HANDBOOK OF THERMAL EXPANSION PROPERTIES OF AEROSPACE MATERIALS AT CRYOGENIC AND ELEVATED TEMPERATURES

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DESIGN AND DEVELOPMENT ENGINEERING HANDBOOK OF THERMAL EXPANSION PROPERTIES OF AEROSPACE MATERIALS AT CRYOGENIC AND ELEVATED TEMPERATURES

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FOREWORD

The data contained in this handbook revise and update the original data issued in Rocketdyne Report No. R-3462. The data were developed under the direction of L. R. Williams, J. D. Young, E. H. Schmidt, and E. F. Green of the Materials and Processes Department. Data determinations were made by E. Kildow.

ABSTRACT

Thermal expansion data are presented for Aerospace materials commonly used in liquid propellant rocket engines. These data cover a range of temperature from -423 F to 2000 F (or lower if limited by melting point). Most of the data were determined at Rocketdyne.

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INTRODUCTION

The purpose of this handbook is to document thermal expansion vs temperature curves for liquid propellant rocket engine materials from -423 F to +2000 F. Due to the nonlinear relationship between thermal expansion and temperature for most materials, the use of thermal expansion coefficients is not sufficiently accurate to predict the expansion of critical parts subjected to large temperature changes. The curves presented in this handbook are intended to overcome the basic inaccuracy associated with using coefficients by allowing the engineer to determine the total thermal length change at specific temperatures with reference to any other temperature.

The materials reported in this handbook are either used in liquid propellant rocket engines or are under study for use therein. In the case of materials that are used at cryogenic temperatures, the curves extend from 70 F to -423 F, and those materials used in high temperature applications extend from 70 F or either 2000 F or their maximum use temperature, whichever occurs first.

Elevated temperature data curves were extended down to cryogenic temperatures where the data was available. The cryogenic portion is not of sufficient accuracy for detailed cryogenic comparisons; hence the user should refer to the cryogenic data curve which is plotted only over a range of 70 F to -320 F or -423 F. All curves presented in this handbook are plotted as total thermal length change from 70 F to a specific temperature vs temperatures in degrees Fahrenheit.

TEST PROCEDURES

MATERIALS AND SPECIMENS

The materials tested in this program are in the condition normally used in service (typically annealed, age hardened, solution treated, precipitation hardened, as cast, or as wrought). The individual charts record the specimen condition. All materials were prepared in accordance with Rocketdyne Materials and Processes Specifications or equivalent (government or ASTM).

The specimen used in this program is shown in detail in Fig. 1. The particular specimen geometry and finish were selected to comply with the Leitz dilatometers used in this investigation.

LEITZ DILATOMETER

Both the elevated temperature and cryogenic testing were performed on Leitz dilatometers. The Leitz dilatometer employs an electro-optical transducing system to measure the thermal expansion vs temperature response of the specimens. Figure 2 is a diagram of the dilatometer transducing and readout system. The specimen "A" is subjected to a uniform rate temperature change as measured by the thermocouple "B." This temperature change "T" results in a length change "L" in the specimen. A light source "D" is focused by a lens system "E" through a prism "C" onto a mirror "F" on a gold wire galvanometer. The light beam "I" is subsequently reflected from the mirror to a readout screen "J." Any length change in the specimen is transmitted through the linkage to the prism, which pivots, thus causing the light beam to strike the mirror in a different spot. The thermocouple output is coupled to the galvanometer in such a way that any EMF generated in the thermocouple causes a rotation of the mirror. The resultant rotation of the mirror and prism cause the light beam to move in a solid arc with the desired temperature expansion response.

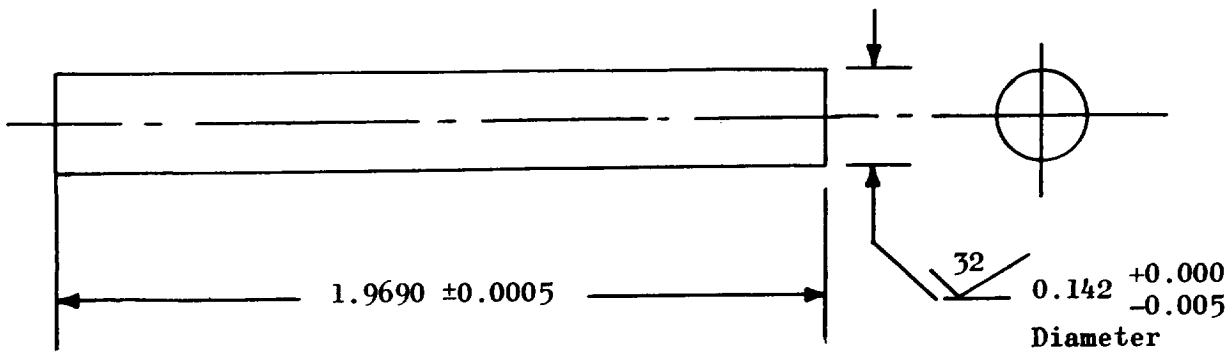


Figure 1. Dilatometer Specimen

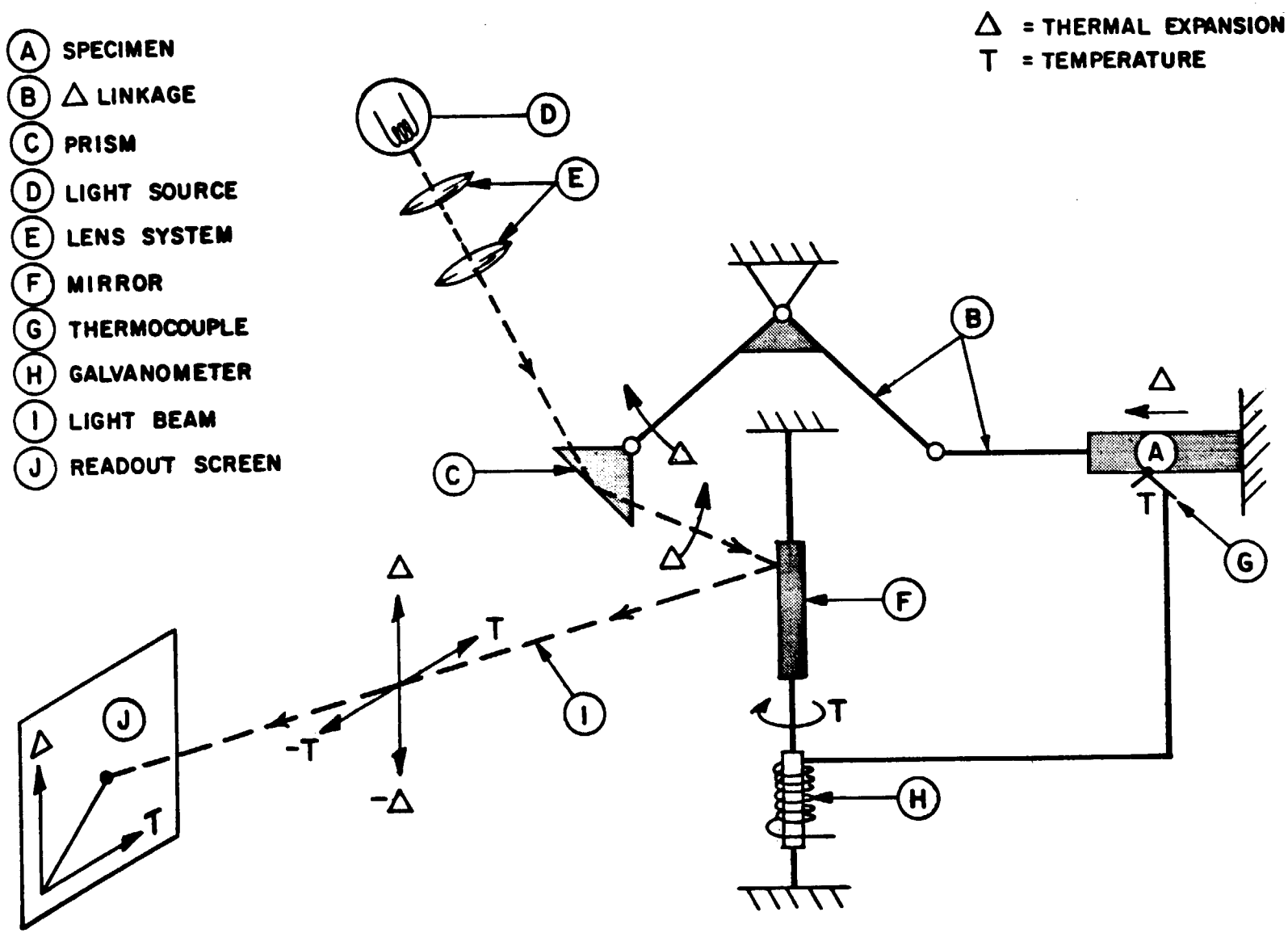


Figure 2. Schematic Diagram of Leitz Dilatometer

The dilatometer is calibrated by substituting a precision micrometer for the specimen, and an output potentiometer for the thermocouple. Thus, calibrated length changes and EMF signals can be put into the system.

ELEVATED TEMPERATURE TESTS

All elevated temperature tests were performed in a standard Leitz temperature chamber (Fig. 3). The chamber was so constructed that the vacuum or inert atmosphere could be maintained on the specimen. The furnace had a range to 2000 F. A special water-cooled mounting flange was provided to thermally isolate the furnace from the dilatometer.

To provide an efficient inert atmosphere at elevated temperatures, the chamber was subjected to a series of evacuations and argon purges prior to each test. In this way, any residual air left by one evacuation of the chamber was diluted with argon which removed this air during subsequent evacuations by an entrainment process.

All tests were performed at a heating rate of 7.5 F per minute. This rate was selected as being intermediate between an infinitely slow equilibrium process and a thermal shock environment. It should be noted here that there is a definite rate dependence for thermal expansion. In some high rate (thermal shock) situations, due to a low specific heat in some metals or ceramics, there will be a marked lag in thermal expansion, some of which will not be realized at the final temperature, because of the non-equilibrium heating rate.

CRYOGENIC TEMPERATURE TESTS

A special cryostat was constructed for the dilatometer to facilitate operation from room temperature to liquid hydrogen temperature. The cryostat was constructed to allow cooling of the sample at a uniform temperature rate from 70 F to -423 F. Figure 4 is a diagram of the cryostat. Figure 5 shows a photograph of the equipment.

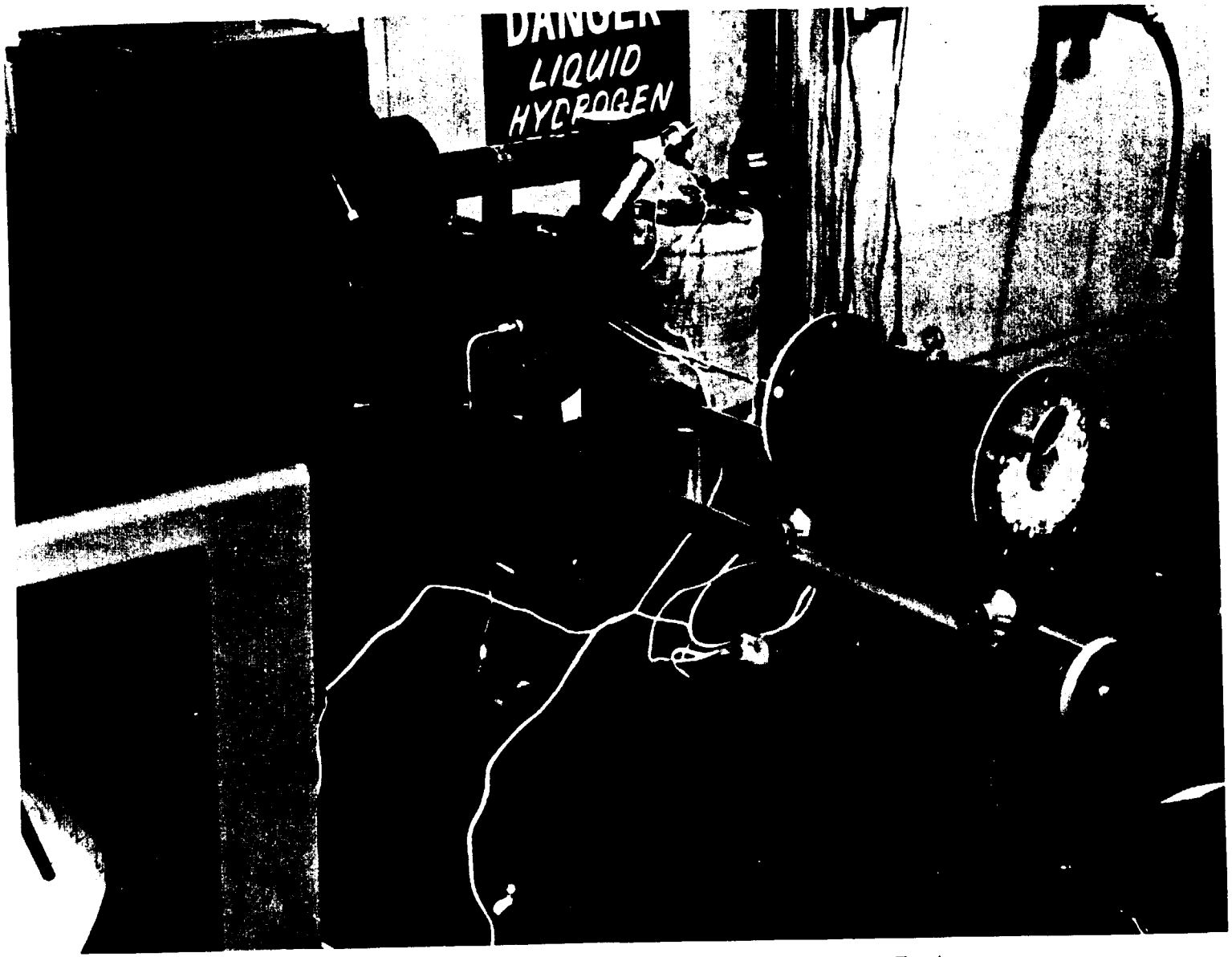


Figure 3. Leitz Dilatometer Elevated Temperature Test

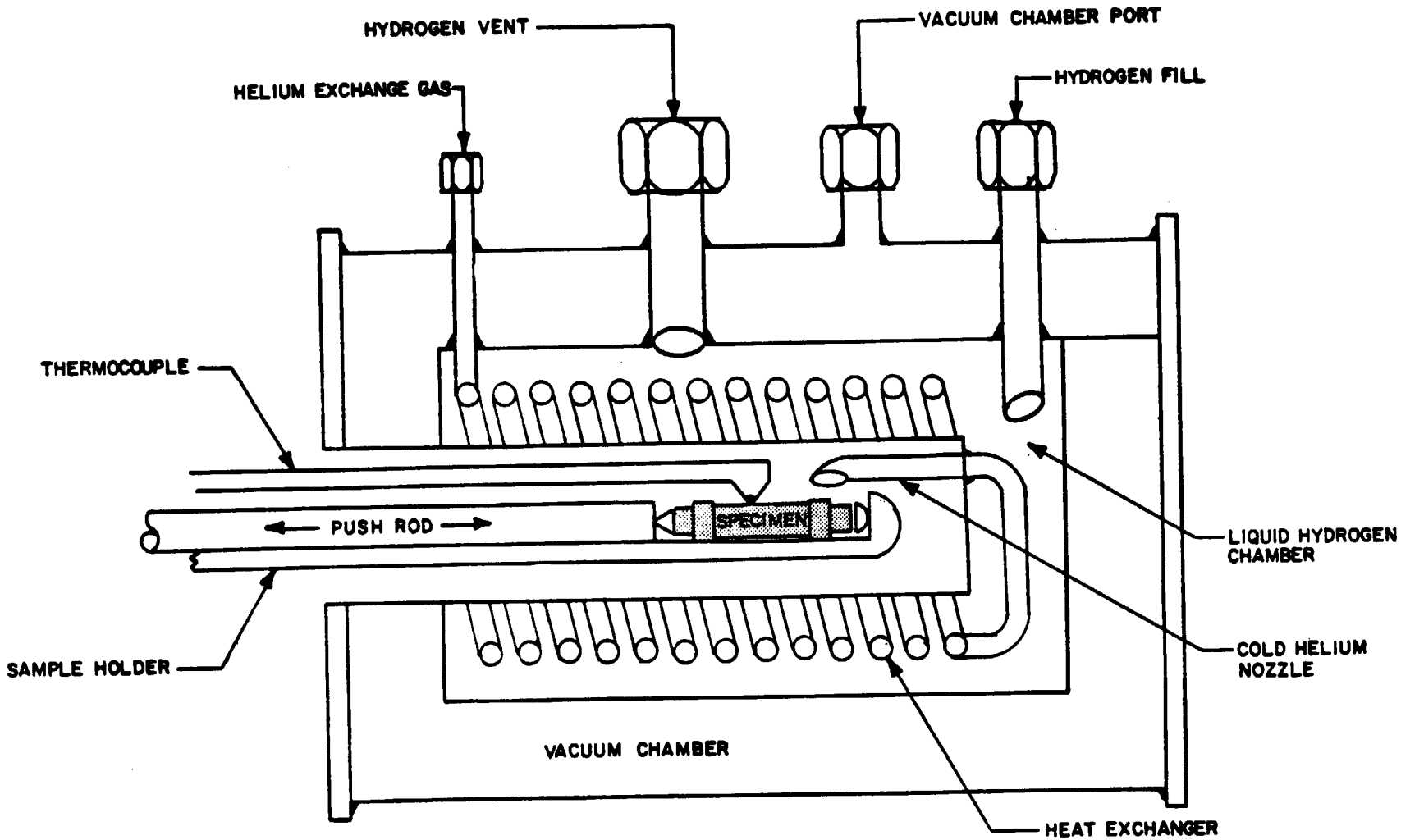


Figure 4. Cryogenic Temperature Chamber

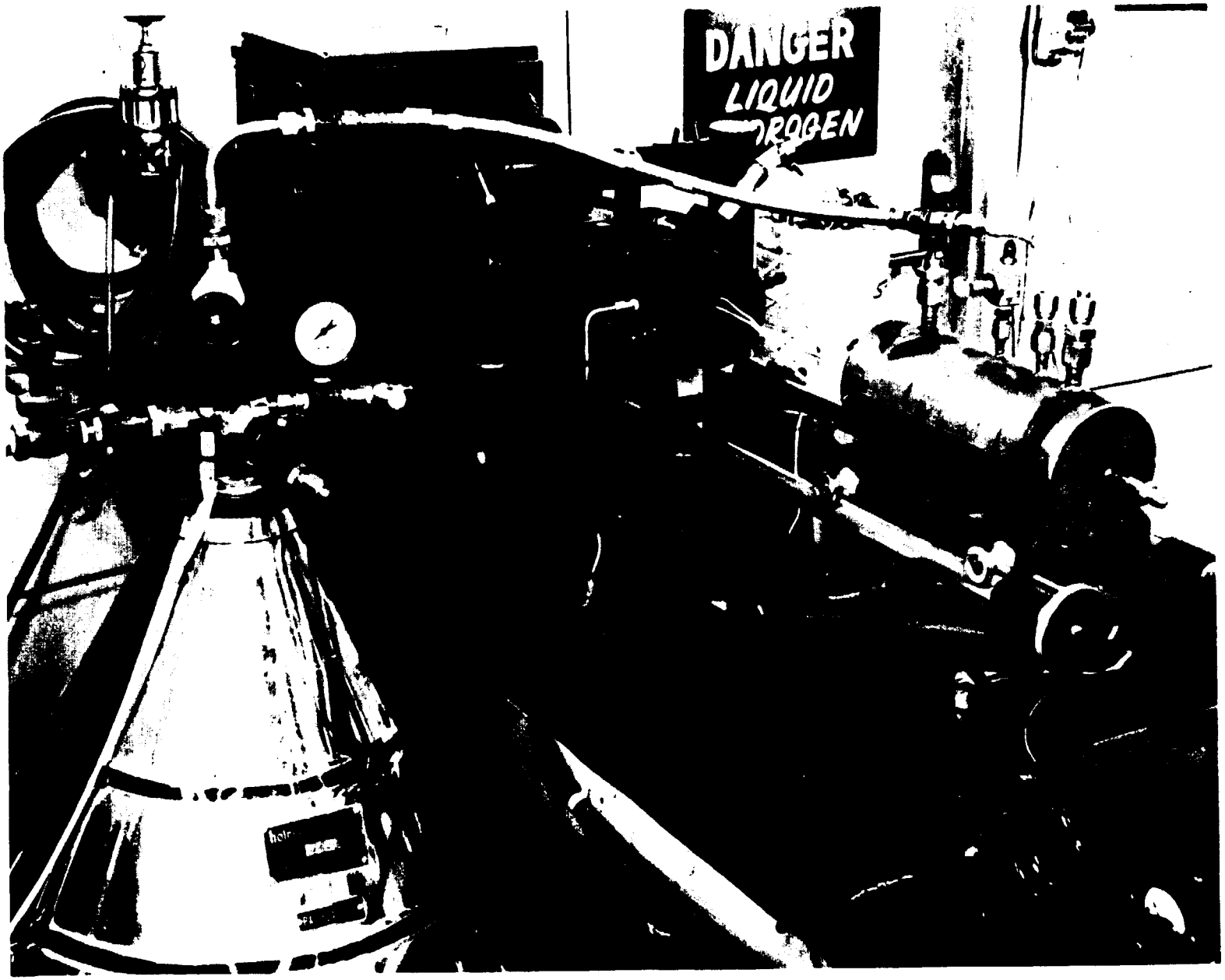


Figure 5. Leitz Dilatometer Cryogenic Temperature Test

The basic operation of the cryostat involves the controlled rate cooling of helium gas by a liquid hydrogen heat exchanger. The helium gas is introduced into the specimen chamber to cool the specimen. Since helium condenses at a lower temperature than the boiling point of liquid hydrogen, it will remain gaseous to -423 F and below.

A Research Inc. "Thermac A" temperature control system was used to maintain a uniform cooling rate by controlling the flow of liquid hydrogen to the heat exchanger. A constant flow of gaseous helium was maintained through the heat exchanger into the specimen chamber. A Skyvalve Corp. solenoid valve was used to meter the liquid hydrogen to the heat exchanger, the solenoid valve being controlled by the Thermac "A." A 70 F to -423 F range card was installed on the Thermac "A" and the Data-Trak programmer was programmed to maintain a 3-1/3 F per minute cooling rate by controlling the open and closed time of the LH_2 solenoid valve.

The helium gas flowing over the specimen satisfactorily cooled the specimen at the desired rate because of the small mass and the high specific heat of the gas.

ANALYSIS OF RESULTS

By introducing calibrated deflections into the dilatometer with a micrometer, and measuring the corresponding deflection of the light beam on the readout screen, a magnifying factor for the measurement system can be established, or

$$MF = \frac{\Delta L\ rs}{\Delta L\ m}$$, where Lm = deflection/micrometer
Lrs = deflection/readout screen

To obtain the thermal strain ϵ_T, the deflection on the readout screen must be divided by the specimen length L, and the magnifying factor, or

$$\epsilon_T = \frac{\Delta L\ rs}{L\ (MF)} = \text{thermal strain}$$

DISCUSSION

A literature search was made to compare published data with Rocketdyne data. Whenever small discrepancies were observed, it was felt that the Rocketdyne data was more reliable for the following reasons: Rocketdyne materials control and specimen preparation were generally more closely controlled than those in the literature. All Rocketdyne data was the result of two independent runs, on different specimens. An accurate calibration was maintained on the Leitz dilatometers used. If Rocketdyne data varied by a reasonable amount from published data (typically this occurred on only two curves, and to an extent of the order of 5 percent), the test was rerun. The accuracy of the dilatometric data is ±3 percent due to variations in equipment and charting of all data.

In all testing, two definite anomalies were observed. Both of these were at cryogenic temperatures below -300 F. One case concerned an ordering of magnetic domains by thermal strain in magnetic alloys, and the other concerns a strain induced martensitic reaction in stainless steels. The results on these tests were presented in the most reasonable analysis possible that would maintain a justifiable usefulness of these curves to the designer.

The list of charts, graphically illustrating the total thermal expansion data at elevated temperatures (Section I) and at cryogenic temperatures Section II), is presented as groups of material type.

A comparison of metals - total thermal length change in decreasing numerical order, 70 F to temperature, in./in. x 10^{-5} is presented in Table 1. A comparison of metals - total thermal length change grouped by material types, 70 F to temperature, in./in. x 10^{-5} is presented in Table 2.

In general, this handbook provides a comprehensive documentation of thermal expansion data for rocket engine materials accurately obtained and presented in a useful manner.

LIST OF CHARTS

Material Type	Material Name	Section I Elevated Temperatures Chart Number	Section II Cryogenic Temperatures Chart Number
1. Low Melting Point	Antimony	1.1.50	
	Lead		1.2.60
	Silver		1.3.60
	Tin		1.4.60
	Zinc		1.5.60
2. Aluminum	Aluminum		2.1.60
	356 Aluminum	2.2.50	
	2014		2.3.60
	2020	2.4.50	2.4.60
	2024	2.5.50	2.5.60
	2618	2.6.50	2.6.60
	6061	2.7.50	2.7.60
	6066	2.8.50	2.8.60
	7075	2.9.50	2.9.60
	Tens-50	2.10.50	2.10.60
4. Titanium	Ti-5Al-2.5Sn	4.1.50	4.1.60
	Ti-6Al-4V	4.2.50	4.2.60
5. Copper and Copper Base Alloys	OFHC Copper	5.2.50	5.2.60
	Beryllium Copper No.25		5.3.60
	Chromium Copper	5.4.50	5.4.60
	Aluminum Bronze		5.5.60
	Bearium B-10		5.6.60
	Bearium B-4		5.7.60
	Naval Brass		5.8.60
6. Iron and Low Alloy Steel	Iron		6.1.60
	1018	6.2.50	6.2.60
	4130	6.3.50	6.3.60
	4340	6.4.50	6.4.60
	88 X	6.5.50	6.5.60
	18% Ni (200) Maraging		6.6.60
	18% Ni (250) Maraging	6.8.50	6.8.60
	18% Ni (300) Maraging	6.9.50	6.9.50
	9310		6.10.60
	9 Ni - 4Co		6.11.60

Material Type	Material Name	Section I Elevated Temperatures Chart Number	Section II Cryogenic Temperatures Chart Number
7. Austenitic Stainless Steel	302 CRES	7.1.50	
	304L CRES		7.2.60
	310 CRES Cast	7.3.50	7.3.60
	310 CRES		7.3A.60
	316 CRES	7.4.50	7.4.60
	321 CRES	7.5.50	7.5.60
	330 CRES	7.6.50	
	347 CRES	7.7.50	7.7.60
	RA 333	7.8.50	
	29 Ni 20Cr	7.9.50	7.9.60
	35 Ni 15Cr	7.10.50	7.10.60
	ARMCO 21-6-9		7.11.60
8. Heat Treatable Stainless Steel	416 CRES	8.1.50	8.1.60
	430 FM CRES	8.2.50	8.2.60
	431 CRES	8.3.50	8.3.60
	440C CRES	8.4.50	8.4.60
	17-4PH CRES	8.5.50	8.5.60
	17-7PH CRES		8.6.60
	AM 355 CRES	8.7.50	8.7.60
	NS 355 CRES	8.8.50	8.8.60
	No. 5 Relay Steel		8.9.60
	Vanadium Permendur		8.10.60
9. Heat Resistant Alloys	A286 CRES	9.1.50	9.1.60
	Inconel B		9.2.60
	Inconel X-750	9.3.50	9.3.60
	Inconel 600	9.4.50	9.4.60
	Inconel 718	9.5.50	9.5.60
	Rene' 41	9.6.50	9.6.60
	Hastelloy B	9.7.50	9.7.60
	Hastelloy C	9.8.50	9.8.60
	Hastelloy X	9.9.50	9.9.60
	Rene' 62	9.10.50	
10. Cryogenic Alloys	K-Monel	10.1.50	10.1.60
	Invar 36	10.2.50	10.2.60
	Invar 36 (F.M.)		10.2A.60
	Nickel 200	10.3.50	10.3.60
	Udimet A	10.4.50	10.4.60
	Udimet 700	10.5.50	
11. Experimental and Refractory Alloys	Cb-10Ti-10Mo	11.2.50	
	Mo-0.5Ti-0.08Zr	11.4.50	11.4.60
	Indium		11.5.60
	Ta-10W	11.6.50	11.6.60
	Be-33Al	11.7.50	
	Ni-Be2		11.8.60

Material Type	Material Name	Section I Elevated Temperatures Chart Number	Section II Cryogenic Temperatures Chart Number
12. Graphites, Ceramics, Plastics	CDJ-97 Graphite	12.1.50	12.1.60
	P-03-XHT Graphite	12.2.50	12.2.60
	P-303-C Graphite	12.3.50	12.3.60
	No. 692 Graphite	12.4.50	12.4.60
	Silver Graphite		12.5.60
	K 162B (Ti_xCy - Ni)		12.6.60
	K 801 (W_xCy - Ni)		12.7.60
	K 601 (W_xCy - Ti_xCy)		12.8.60
	Tungsten Carbide	12.9.50	12.9.60
	Silica Glass		12.10.60
	Coor's Al_2O_3		12.11.60
13. Plastics	Kel-F Grade 81		13.1.60
	Kel-F/Glass Filled		13.2.60
	Kel-F/Bronze Filled		13.3.60
	Teflon		13.4.60
	Teflon/Asbestos Filled		13.5.60
	Teflon/Glass Filled		13.6.60
	Teflon/Glass Filled		13.7.60
	Teflon/Glass Filled		13.8.60
	Teflon/Bronze Filled		13.9.60
	Teflon/Graphite Filled		13.10.60
	F.E.P. Teflon		13.11.60
	F.E.P./Glass Filled		13.12.60
	F.E.P./Glass Filled		13.13.60
	Halon/TVS		13.14.60
	Halon/TVS		13.15.60
	VESPEL		13.16.60

TABLE 1

METALS - TOTAL THERMAL LENGTH CHANGE IN DECREASING NUMERICAL ORDER

70 F TO TEMPERATURE, IN./IN. X 10^{-5}

70 F/-423 F		70 F/-320 F		70 F/400 F		70 F/800 F		70 F/1200 F		70 F/1600 F	
Alloy	In./In.	Alloy	In./In.	Alloy	In./In.	Alloy	In./In.	Alloy	In./In.	Alloy	In./In.
Indium	-700	Indium	-600	Antimony	+810	Antimony	+1690	Antimony	+2540	CR Copper	+1670
Lead	-700	Zinc	-600	2024-T6	+470	6066-T6	+1160	2618-T6	+1700	321 CRES	+1640
Zinc	-680	Lead	-580	2020-T6	+460	2024-T6	+1110	Be-33 Al	+1340	347 CRES	+1570
7075-T6	-475	7075-T6	-440	Tens 50-T6	+460	Tens 50-T6	+1060	Cr Copper	+1180	A-286 CRES	+1570
6061-T6	-460	6061-T6	-420	2618-T6	+450	2020-T6	+1060	321 CRES	+1160	29Ni-20Cr	+1560
Bearium B-10	-440	Tens 50-T6	-407	6061-T4	+450	6061-T4	+1050	29Ni-20Cr	+1120	302 CRES	+1560
Tens 50-T6	-435	2014-T6	-395	6066-T6	+450	7075-T6	+1020	302 CRES	+1110	Cast 310 CRES	+1530
2014-T6	-430	Aluminum	-390	7075-T6	+420	2618-T6	+1000	347 CRES	+1110	316 CRES	+1500
Aluminum	-415	Bearium B-10	-387	356 Al-T6	+420	356 Al-T6	+1000	316 CRES	+1080	330 CRES	+1500
Silver	-410	6066-T6	-380	Be-33 Al	+340	Be-33 Al	+750	Cast 310 CRES	+1080	35Ni-15Cr	+1420
Bearium B-4	-405	2020-T6	-375	Cr Copper	+310	Cr Copper	+720	A-286 CRES	+1080	Inco X-750	+1420
2024-T3	-375	Silver	-370	88X	+300	321 CRES	+700	330 CRES	+1060	NS 355 CRES	+1400
Naval Brass	-360	2024-T3	-365	29Ni-20Cr	+300	302 CRES	+690	35Ni-15Cr	+1000	RA 333	+1400
Cr Copper	-360	Bearium B-4	-365	302 CRES	+300	A-286 CRES	+680	NS 355 CRES	+1000	Rene' 62	+1390
321 CRES	-335	2618-T6	-360	321 CRES	+300	29Ni-20Cr	+680	K-Monel	+980	Inco 718	+1390
304L CRES	-330	Naval Brass	-355	316 CRES	+290	K-Monel	+680	Ni 200	+970	Ni 200	+1380
347 CRES	-315	Cr Copper	-325	A-286 CRES	+280	316 CRES	+670	Inco X-750	+970	Rene' 41	+1380
316 CRES	-310	Al Bronze	-320	Hastelloy X	+270	88X	+670	Hastelloy X	+962	Udimet 700	+1380
Cast 310 CRES	-300	304L CRES	-305	Cast 310 CRES	+270	347 CRES	+660	RA 333	+960	OFHC Copper	+1380
OFHC Copper	-295	321 CRES	-300	330 CRES	+260	Cast 310 CRES	+640	Inco 718	+960	Hastelloy X	+1380
310 CRES	-290	347 CRES	-295	NS 355 CRES	+250	330 CRES	+640	Rene' 62	+960	430(FM) CRES	+1370
A-286	-285	316 CRES	-287	Udimet 700	+250	Hastelloy X	+605	Udimet 700	+960	Inco 600	+1320
21-6-9	-280	Be Cu	-280	430(FM) CRES	+240	35Ni 15Cr	+600	Rene' 41	+950	Hastelloy C	+1220
Inco X-750	-255	Cast 310 CRES	-280	35 Ni 15Cr	+240	Rene' 41	+600	OFHC Copper	+950	88X	+1200
Hastelloy X	-255	OFHC Copper	-280	4340	+240	Udimet 700	+590	430(FM) CRES	+950	Hastelloy B	+1170
K-Monel	-250	21-6-9	-270	4130	+240	Inco 718	+580	1018	+940	Invar 36	+1130
Inco 718	-250	310 CRES	-268	Inco 600	+240	1018	+580	4130	+910	416 CRES	+1100
Hastelloy C	-248	A-286 CRES	-263	Rene' 41	+240	RA 333	+580	Inco 600	+900	AM 355 CRES	+1060
Ni Be 2	-245	88X	-240	K-Monel	+230	NS 355 CRES	+580	4340	+860	Ti-6Al-4V	+1030
Ni 200	-230	29Ni 20Cr	-240	RA 333	+230	Ni 200	+580	440C CRES	+820	4130	+1030
Inco 600	-230	Hastelloy C	-240	Inco X-750	+230	Inco X-750	+580	Hastelloy C	+820	Ti-5Al-2.5 Sn	+1030
No. 5 Relay	-251	Hastelloy X	-237	Hastelloy B	+220	Rene' 62	+570	Hastelloy B	+790	Udimet A	+1025
9310	-215	Inco X-750	-235	Hastelloy C	+220	4130	+570	416 CRES	+770	1018	+1010
9Ni 4Co	-215	Inco 718	-230	Rene' 62	+220	OFHC Copper	+560	AM 355 CRES	+760	17-4PH(850)	+980
18Ni (200)	-210	K-Monel	-230	OFHC Copper	+220	4340	+560	17-4PH (850)	+740	4340	+980
NS 355 CRES	-202	Ni - Be 2	-230	440C CRES	+220	430(FM) CRES	+560	Invar 36	+740	431 CRES	+960
4130	-202	Ni 200	-220	17-4PH (850)	+220	Inco 600	+550	431 CRES	+740	440C CRES	+940
17-7PH (RH1050)	-200	Inco 600	-215	AM 355 CRES	+220	AM 355 CRES	+520	Ti-5A-2.5 Sn	+670	18Ni (300)	+820
Iron	-200			1018	+220	Hastelloy C	+510			18Ni (250).	+780
										Tungsten Carbide	+740

TABLE 1

(Concluded)

70 F/-423 F		70 F -320 F		70 F/400 F		70 F/800 F		70 F/1200 F		70 F/1600 F	
Alloy	In./In.	Alloy	In./In.	Alloy	In./In.	Alloy	In./In.	Alloy	In./In.	Alloy	In./In.
416 CRES	-195	No. 5 Relay	-205	Inco 718	+220	440C CRES	+500	Ti-6Al-4V	+660	TA-10 W	+630
17-4PH (H900)	-195	18Ni (200)	-200	Udimet A	+210	416 CRES	+480	88X	+640	Cb-10Ti-10Mo	+480
440C CRES	-195	9Ni 4Co	-200	347 CRES	+202	Hastelloy B	+480	18Ni (300)	+610	Mo-0.5Ti-0.08Zr	+480
430(FM) CRES	-180	Rene' 41	-200	Ni 200	+202	431 CRES	+470	18Ni (250)	+590		
18Ni (300)	-180	9310	-200	18Ni (250)	+200	Udimet A	+460	Udimet A	+540		
V.Permendur	-175	17-7PH(RH1050)	-195	18Ni (300)	+200	17-4PH (850)	+460	Tungsten Carbide	+480		
Ti-6Al-4V	-165	NS355 CRES	-190	416 CRES	+200	18Ni (250)	+450	TA-10W	+440		
Ti-5Al-2.5 Sn	-165	Iron	-190	431 CRES	+200	18Ni (300)	+430	Cb-10Ti-10Mo	+360		
18Ni (250)	-150	4130	-185	Ti-6Al-4V	+170	Ti-6Al-4V	+390	Mo-0.5Ti-0.08Zr	+340		
Invar 36	-60	V.Permendur	-185	Ti-5Al-2.5Sn	+170	Ti-5Al-2.5Sn	+380				
		4340	-182	Tungsten Carbide	+140	Invar 36	+350				
		430(FM) CRES	-182	Mo-0.5Ti-0.08Zr	+120	Tungsten Carbide	+300				
		416 CRES	-180	TA-10W	+120	TA-10W	+270				
		440C CRES	-180	Cb-10Ti-10Mo	+120	Cb-10Ti-10Mo	+220				
		Hastelloy B	-180	Invar 36	+50	Mo-0.5Ti-0.08Zr	+220				
		AM355 CRES	-177								
		17-4PH (H900)	-177								
		Udimet A	-176								
		35Ni-15Cr	-175								
		1018	-175								
		18Ni (300)	-172								
		Ti-6Al-4V	-155								
		Ti-5Al-2.5Sn	-150								
		18Ni (250)	-135								
		431 CRES	-125								
		Tungsten Carbide	-123								
		TA-10W	-104								
		Mo-0.5Ti-0.08Zr	-82								
		Invar 36	-75								

TABLE 2

METALS - TOTAL THERMAL LENGTH CHANGE GROUPED BY MATERIAL TYPES

70F TO TEMPERATURE, IN./IN. x 10^{-5}

Material		-423 F In./In.	-320 F In./In.	400 F In./In.	800 F In./In.	1200 F In./In.	1600 F In./In.
Type	Name						
Low Melting Point	Antimony	- -	- -	+810	+1690	+2540	- -
	Lead	-700	-580	- -	- -	- -	- -
	Silver	-410	-370	- -	- -	- -	- -
	Tin	- -	-55(-150F)	- -	- -	- -	- -
	Zinc	-680	-600	- -	- -	- -	- -
Aluminum	Aluminum	-415	-390	- -	- -	- -	- -
	356 Al - T6	- -	- -	+420	+1000	- -	- -
	2014 - T6	-430	-395	- -	- -	- -	- -
	2020 - T6	- -	-375	+460	+1060	- -	- -
	2024 - T6	-375	-365	+470	+1110	- -	- -
	2618 - T6	- -	-360	+450	+1000	+1700	- -
	6061 - T6	-460	-420	+450	+1050	- -	- -
	6066 - T6	-- -	-380	+450	+1116	- -	- -
	7075 - T6	-475	-440	+420	+1020	- -	- -
	Tens 50-T6	-435	-407	+460	+1060	- -	- -
Titanium	Ti-5Al-2.5Sn	-165	-150	+170	+380	+670	+1030
	Ti-6Al-4V	-165	-155	+170	+390	+660	+1030
Copper & Copper-Base Alloys	Copper	-320	-305	- -	- -	- -	- -
	OFHC Copper	-295	-280	+220	+560	+950	+1380
	Be Cu No. 25	- -	-280	- -	- -	- -	- -
	Cr Cu	-360	-325	+310	+720	+1180	+1670
	Al Bronze	- -	-320	- -	- -	- -	- -
	Naval Brass	-360	-355	- -	- -	- -	- -
	Bearium B-4	-405	-365	- -	- -	- -	- -
	Bearium B-10	-440	-387	- -	- -	- -	- -

TABLE 2

(Continued)

Material		-423 F In./In.	-320 F In./In.	400 F In./In.	800 F In./In.	1200 F In./In.	1600 F In./In.
Type	Name						
Iron & Low Alloy Steels	Iron	-200	-190	- -	- -	- -	- -
	1018	- -	-175	+220	+580	+940	+1010
	4130	-202	-185	+240	+570	+910	+1030
	4340	- -	-182	+240	+560	+860	+980
	88 X	- -	-240	+300	+670	+640	+1200
	18 Ni (200)	-210	-200	- -	- -	- -	- -
	18 Ni (250)	-150	-135	+200	+450	+590	+780
	18 Ni (300)	-180	-172	+200	+430	+610	+820
	9310	-215	-200	- -	- -	- -	- -
	9Ni - 4Co	-215	-200	- -	- -	- -	- -
Austenitic Stainless Steels	302 CRES	- -	- -	+300	+690	+1110	+1560
	304L CRES	-330	-305	- -	- -	- -	- -
	Cast 310 CRES	-300	-280	+270	+640	+1080	+1530
	310 CRES	-290	-268	- -	- -	- -	- -
	316 CRES	-310	-287	+290	+670	+1080	+1500
	321 CRES	-335	-300	+300	+700	+1160	+1640
	347 CRES	-315	-295	+202	+660	+1110	+1570
	330 CRES	- -	- -	+260	+640	+1060	+1500
	RA 333	- -	- -	+230	+580	+960	+1400
	29 Ni 20Cr	- -	-240	+300	+680	+1120	+1560
	35 Ni 15Cr	- -	-175	+240	+600	+1000	+1420
	Armco 21-6-9	-280	-270	- -	- -	- -	- -
Heat Treatable Stainless Steels	416 CRES	-195	-180	+200	+480	+770	+1100
	430 (FM) CRES	-180	-182	+240	+560	+950	+1370
	431 CRES	- -	-125	+200	+470	+740	+960
	440C CRES	-195	-180	+220	+500	+820	+940

TABLE 2

(Concluded)

Material		-423 F	390 -320 F	330 400 F	730 800 F	1130 1200 F	1550 1600 F
Type	Name	In./In.	In./In.	In./In.	In./In.	In./In.	In./In.
Heat Treatable Stainless Steels	17-4PH(H900)CRES	-195	-177	+220	+460	+740	+980
	17-7PH(RH1050)CRES	-200	-195	- -	- -	- -	- -
	AM 355 CRES	- -	-177	+220	+520	+760	+1060
	NS 355 CRES	-202	-190	+250	+580	+1000	+1400
	No. 5 Relay Steel	-215	-205	- -	- -	- -	- -
	V. Permendur	-175	-185	- -	- -	- -	- -
Heat Resistant Alloys	A-286 CRES	-285	-263	+280	+680	+1080	+1570
	Inconel X-750	-255	-235	+230	+580	+970	+1420
	Inconel 600	-230	-215	+240	+550	+900	+1320
	Inconel 718	-250	-230	+220	+580	+960	+1390
	Rene' 41	- -	-200	+240	+600	+950	+1380
	Hastelloy B	- -	-180	+220	+480	+790	+1170
	Hastelloy C	-248	-240	+220	+510	+820	+1220
	Hastelloy X	-255	-237	+270	+605	+962	+1380
	Rene' 62	- -	- -	+220	+570	+960	+1390
Cryogenic & Refractory Alloys	K-Monel	-250	-230	+230	+68	+980	- -
	Invar 36	-60	-75	+50	+350	+740	+1130
	Ni 200	-230	-220	+202	+580	+970	+1380
	Udimet A	- -	-176	+210	+460	+540	+1025
	Udimet 700	- -	- -	+250	+590	+960	+1380
	Ni - Be 2	-245	-230	- -	- -	- -	- -
Experimental & Refractory Alloys	Cb-10Ti-10Mo	- -	- -	+120	+220	+360	+480
	Mo-.5Ti-.08Zr	- -	-82	+120	+220	+340	+480
	Indium	-700	-600	- -	- -	- -	- -
	Ta - 10W	- -	-104	+120	+270	+440	+630
	Be - 33AL	- -	- -	+340	+750	+1340	- -
	Tungsten Carbide	- -	-123	+140	+300	+480	+740

SECTION I

THERMAL EXPANSION PROPERTIES OF AEROSPACE MATERIALS AT ELEVATED TEMPERATURES

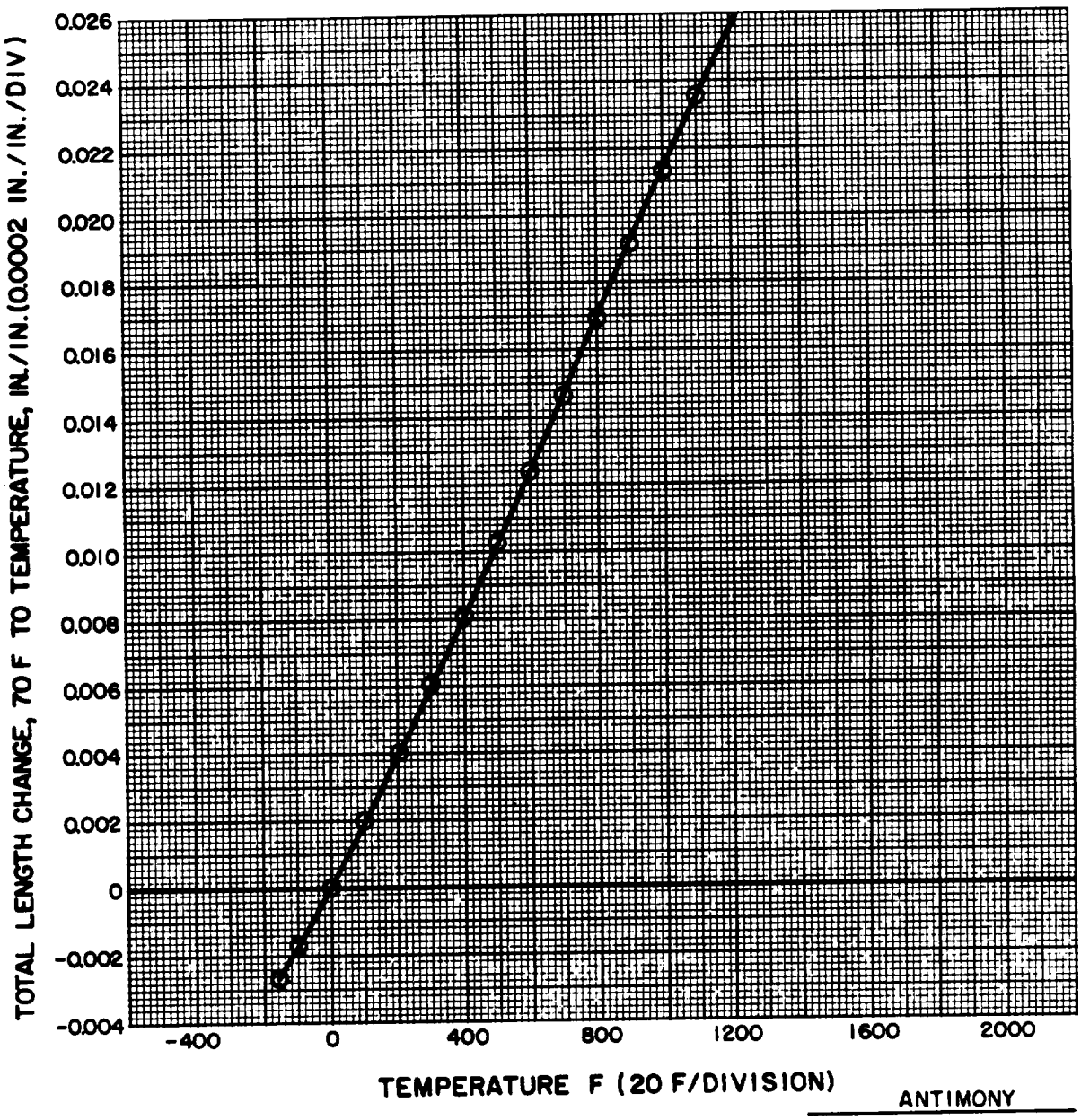
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE TRANSACTIONS A.S.M

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 1·1·50
MATERIAL ANTIMONY
FORM CASTING
CONDITION AS CAST
SPECIFICATION –
DATE JUNE 1965

NOTES:



ANTIMONY

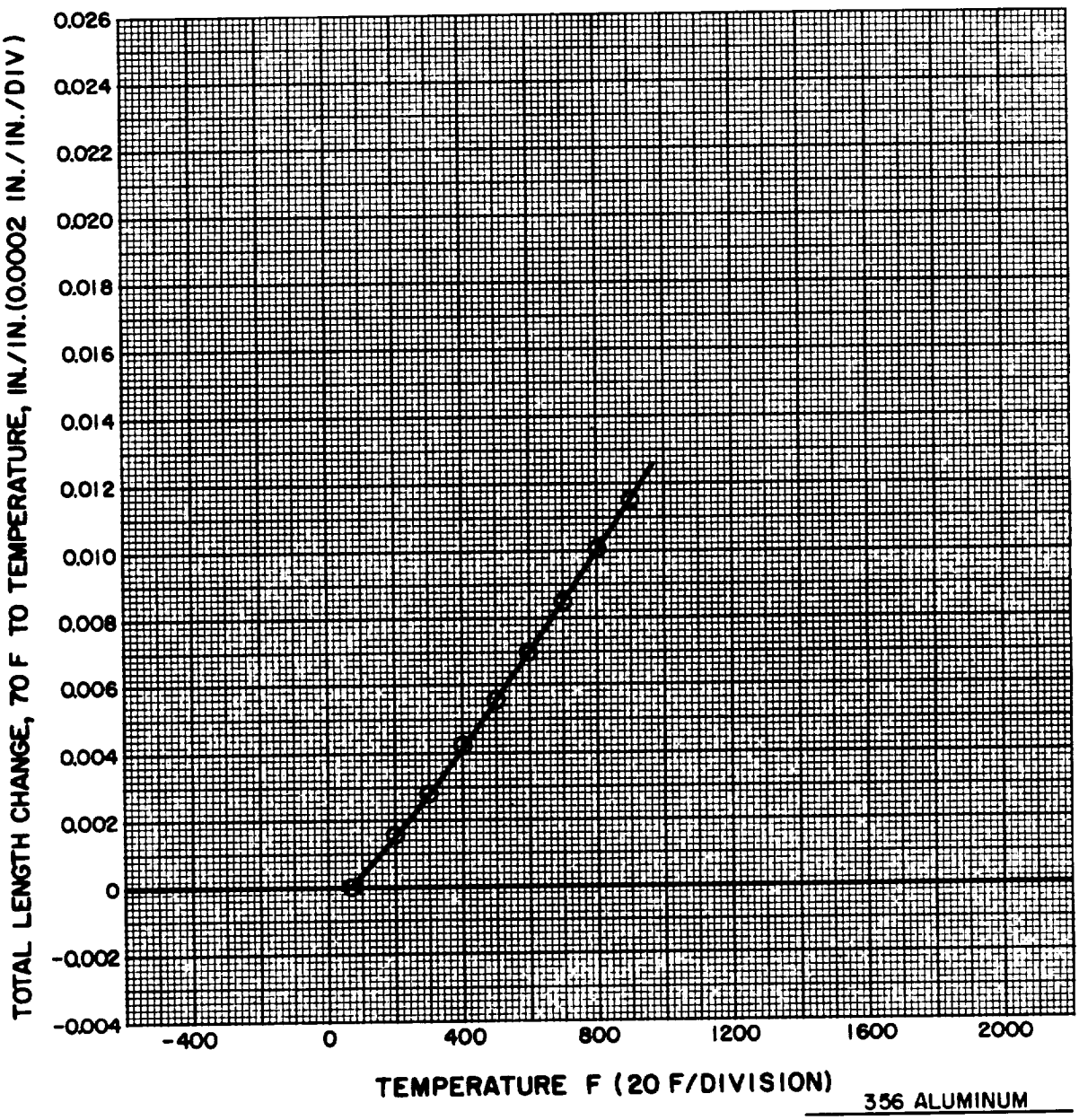
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE R-3462
APPROVED
REFERENCE NORTHROP DATA

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 2·2·50
MATERIAL 356 ALUMINUM
FORM CASTING
CONDITION T6
SPECIFICATION RB0170-006,7,9,10
DATE JUNE 1965

NOTES:



356 ALUMINUM

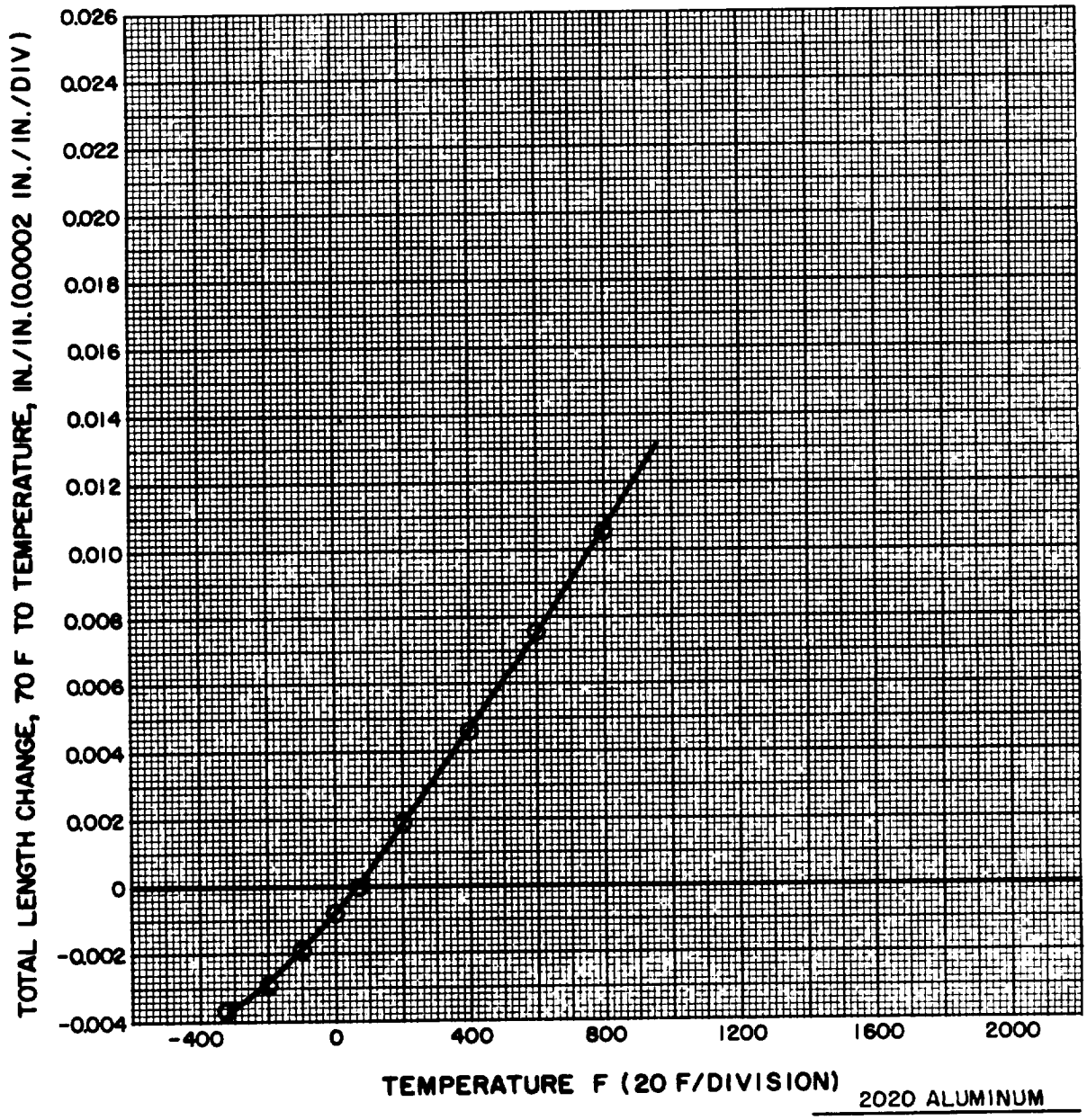
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 2·4·50
MATERIAL 2020 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION -
DATE JUNE 1965

NOTES: 4Cu – BALANCE Al



2020 ALUMINUM

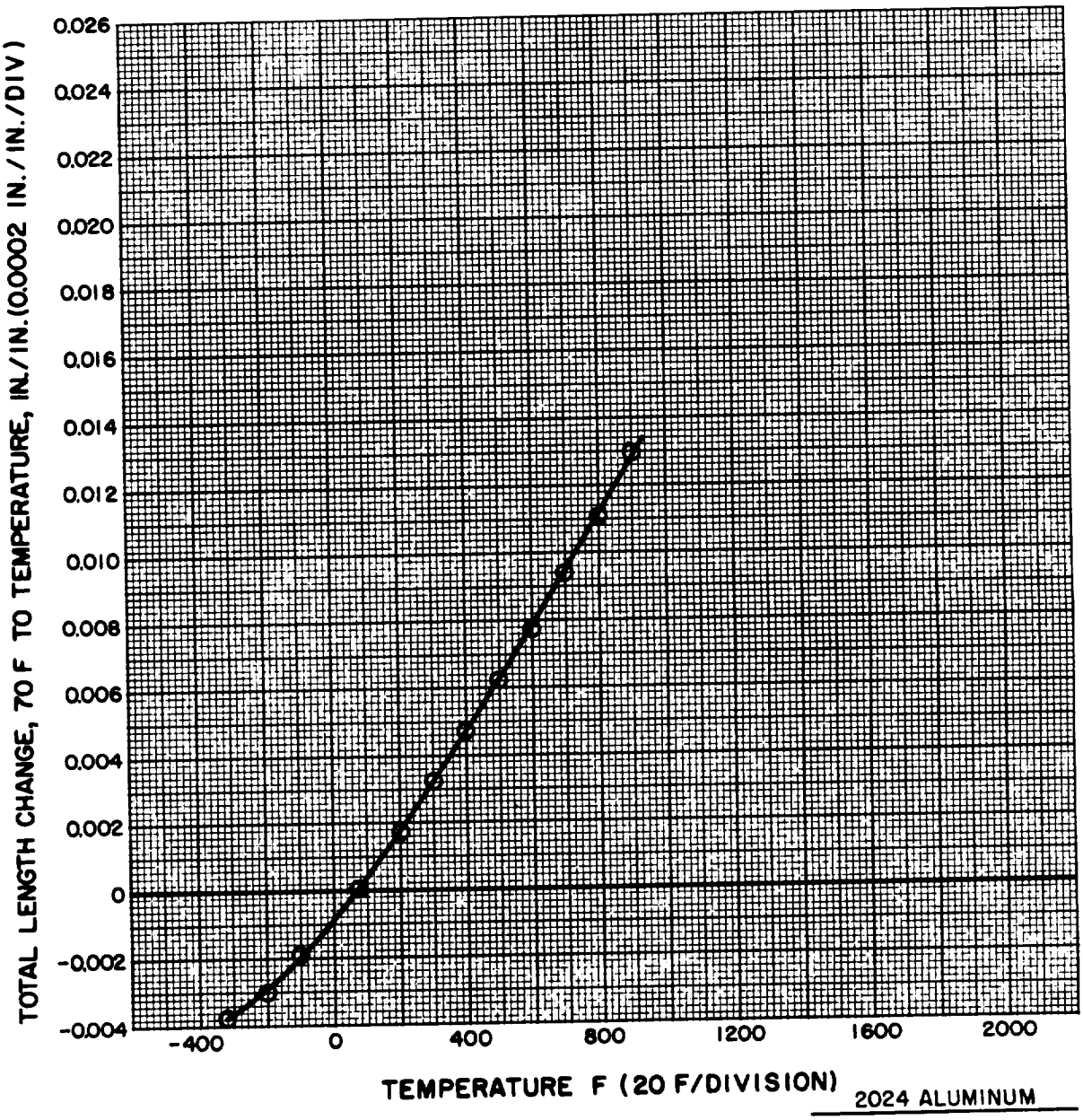
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION
PROPERTIES
AT
ELEVATED TEMPERATURES

CHART NO. 2·5·50
MATERIAL 2024 ALUMINUM
FORM BAR
CONDITION T4
SPECIFICATION QQ-A-268
DATE JUNE 1965

NOTES:



2024 ALUMINUM

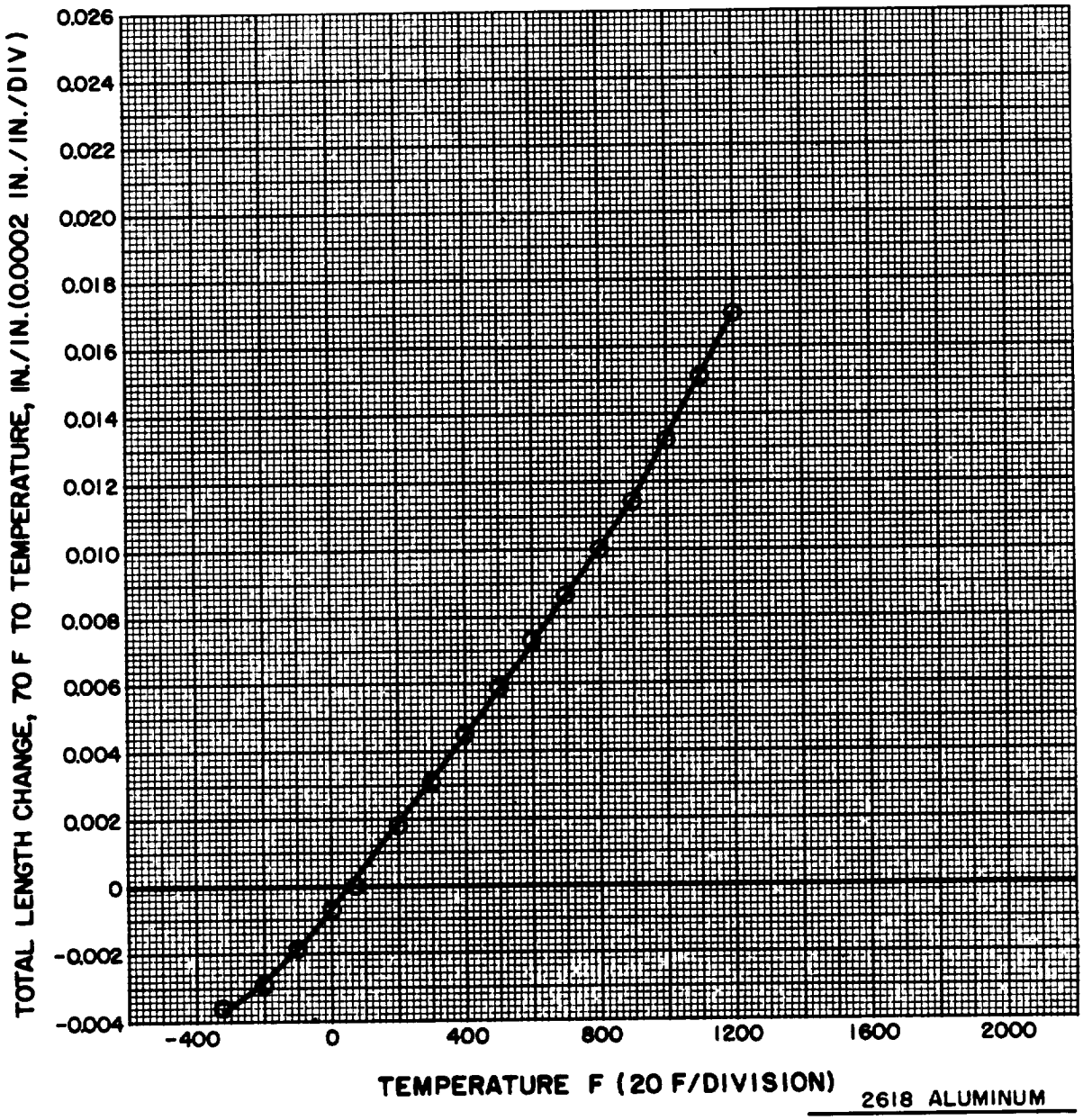
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 2·6·50
MATERIAL 2618 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION NA2-7158
DATE JUNE 1965

NOTES:



2618 ALUMINUM

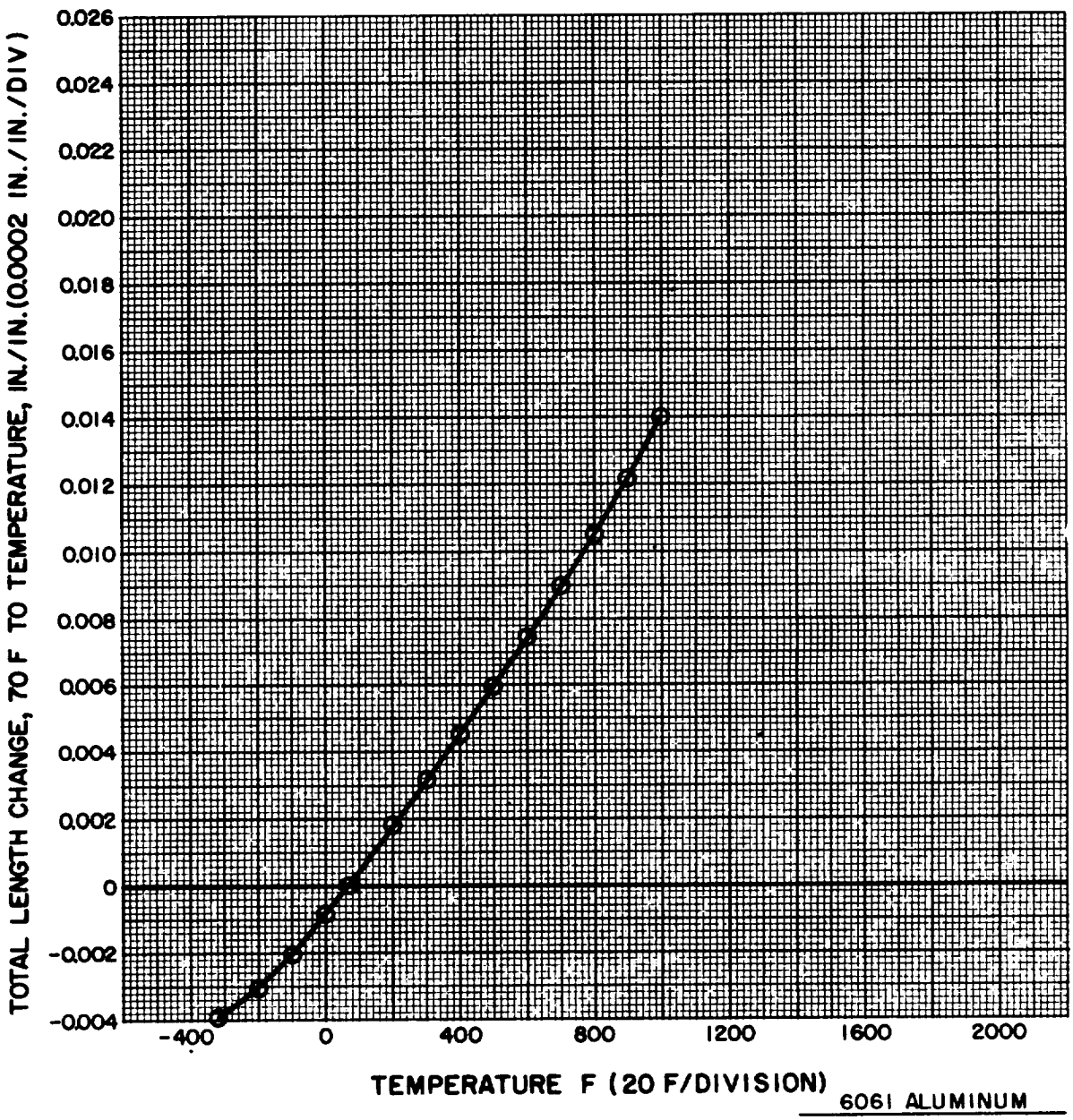
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION
PROPERTIES
AT
ELEVATED TEMPERATURES

CHART NO. 2-7-50
MATERIAL 6061 ALUMINUM
FORM WROUGHT
CONDITION T4
SPECIFICATION AMS 4146
DATE JUNE 1965

NOTES:



6061 ALUMINUM

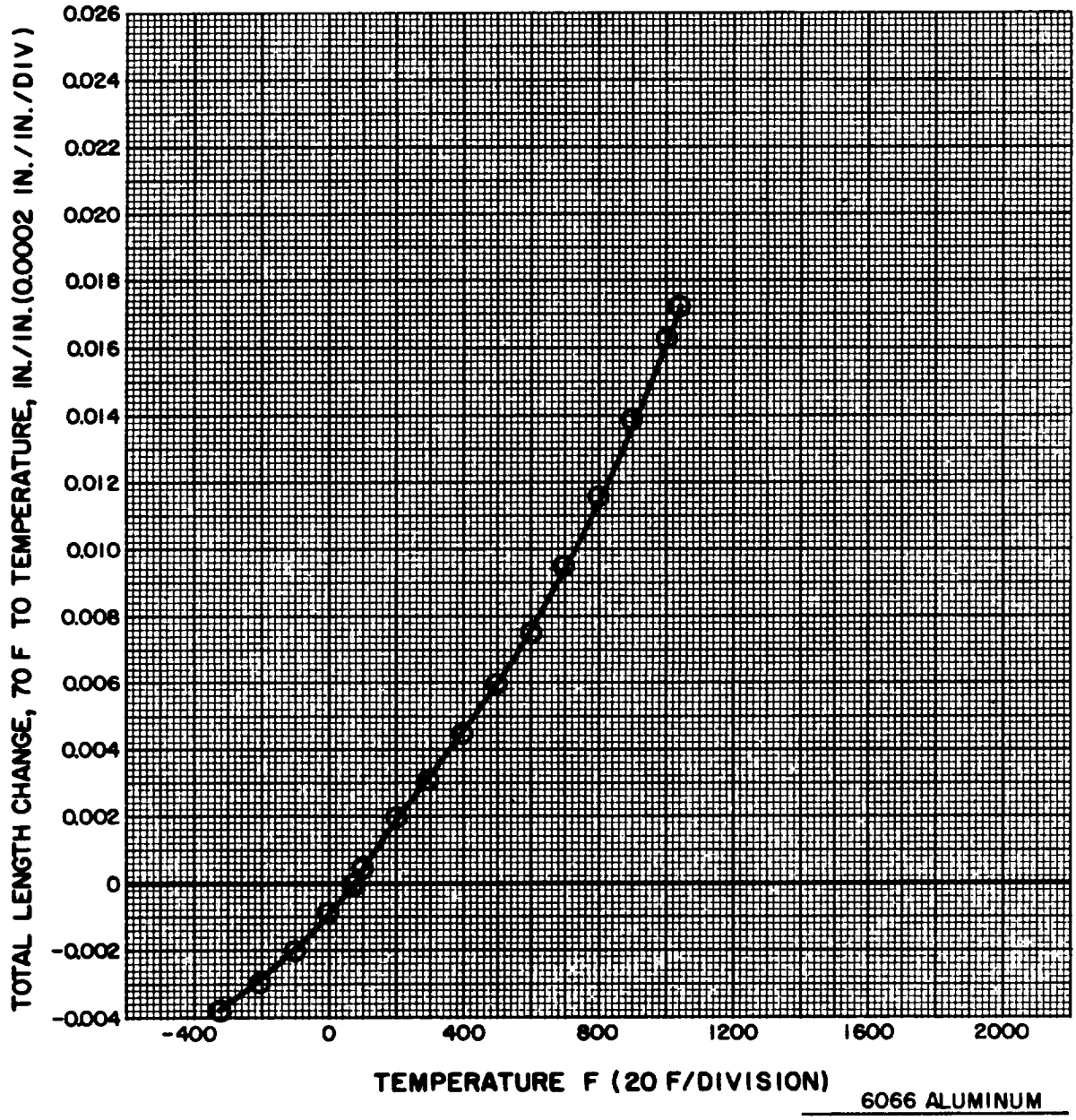
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 2-8-50
MATERIAL 6066 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION MIL-A-25493
DATE JULY 1965

NOTES:



6066 ALUMINUM

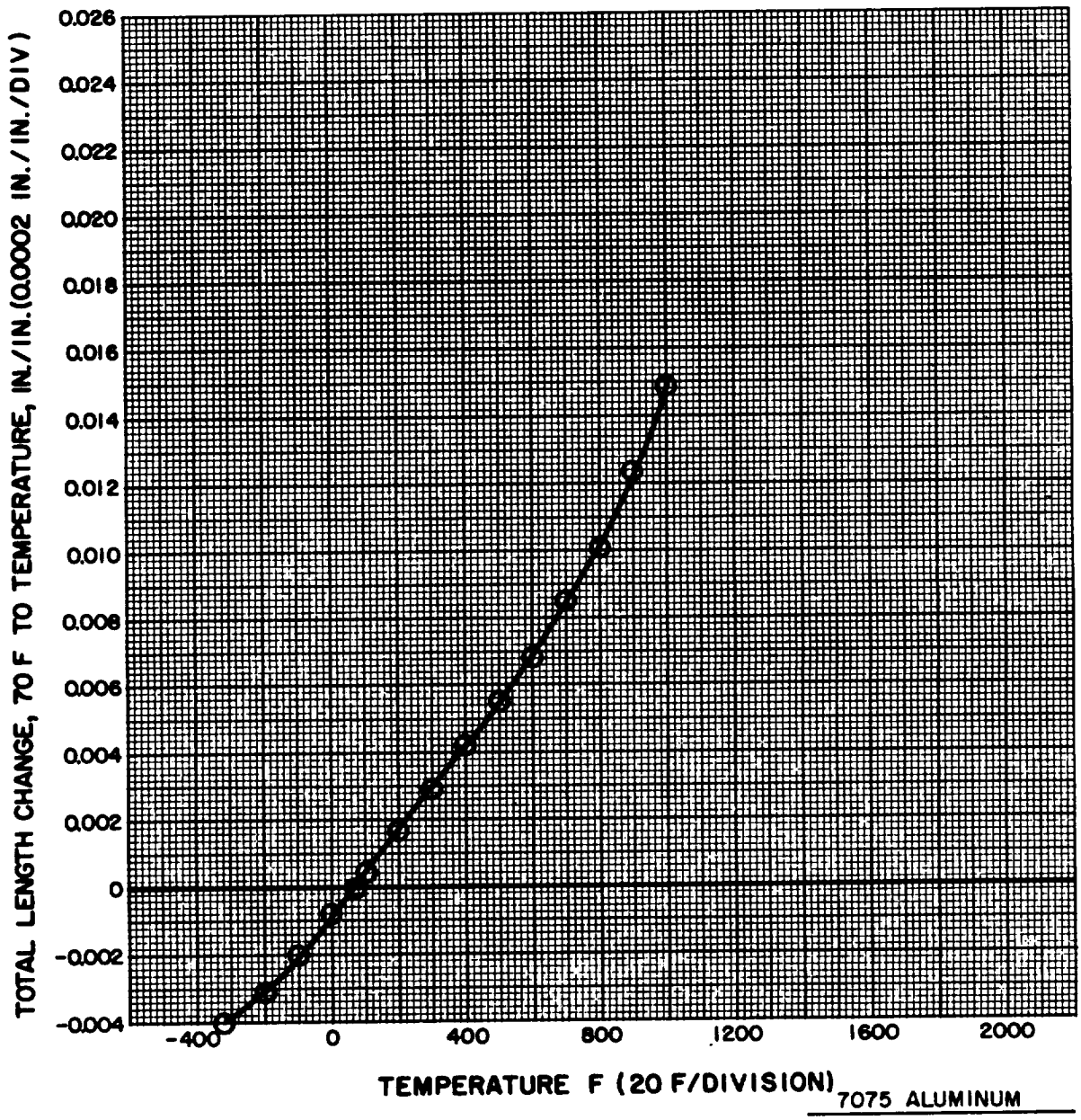
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 2·9·50
MATERIAL 7075 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION MIL-A-22771
DATE MARCH 1962

NOTES:



7075 ALUMINUM

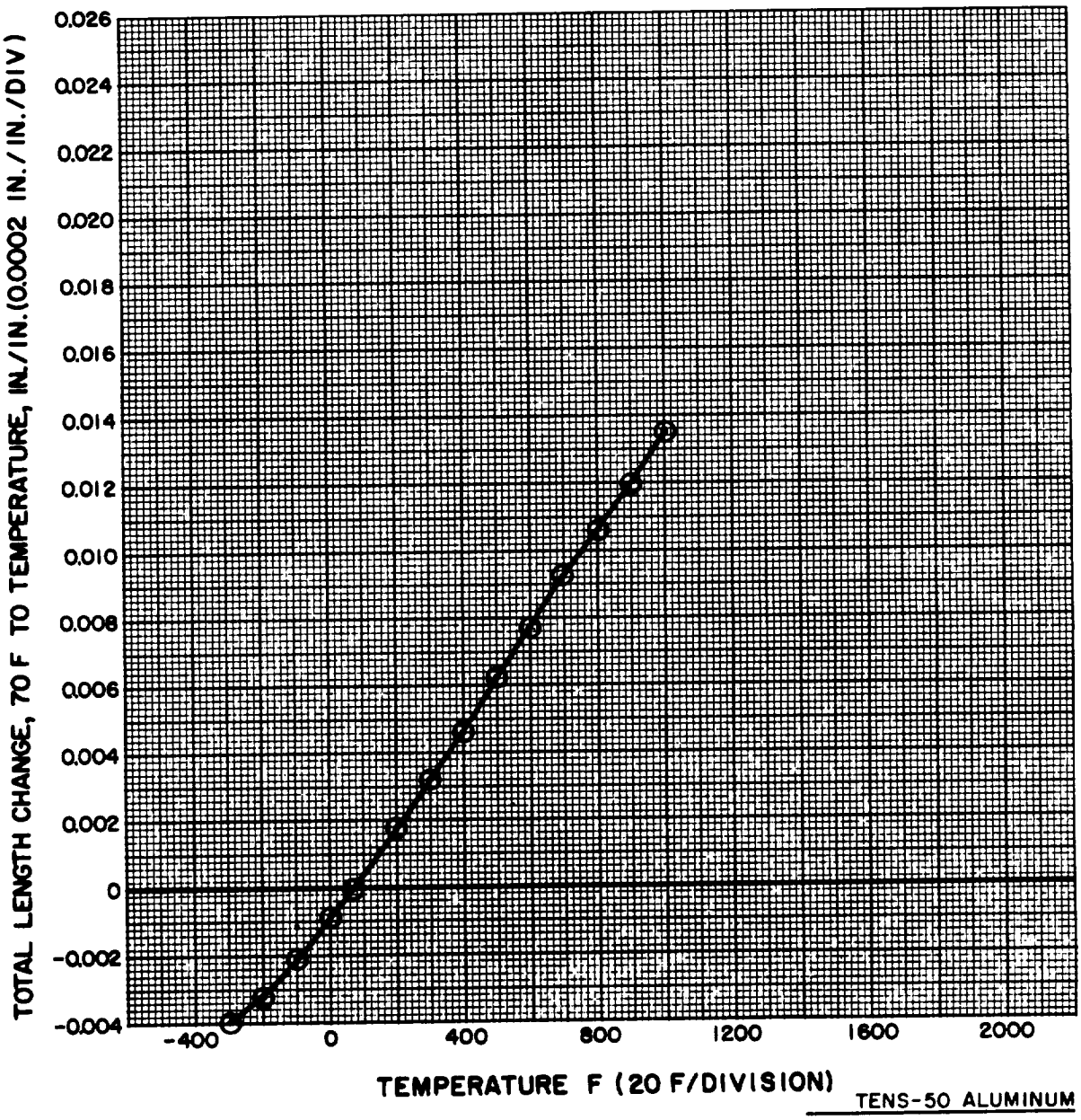
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 2·10·50
MATERIAL TENS-50 ALUMINUM
FORM CAST
CONDITION T6
SPECIFICATION RBO 170-008
DATE MARCH 1962

NOTES: 8 Si-.5 Mg-.2 Fe-.15 Be-.15 Ti BALANCE Al



TENS-50 ALUMINUM

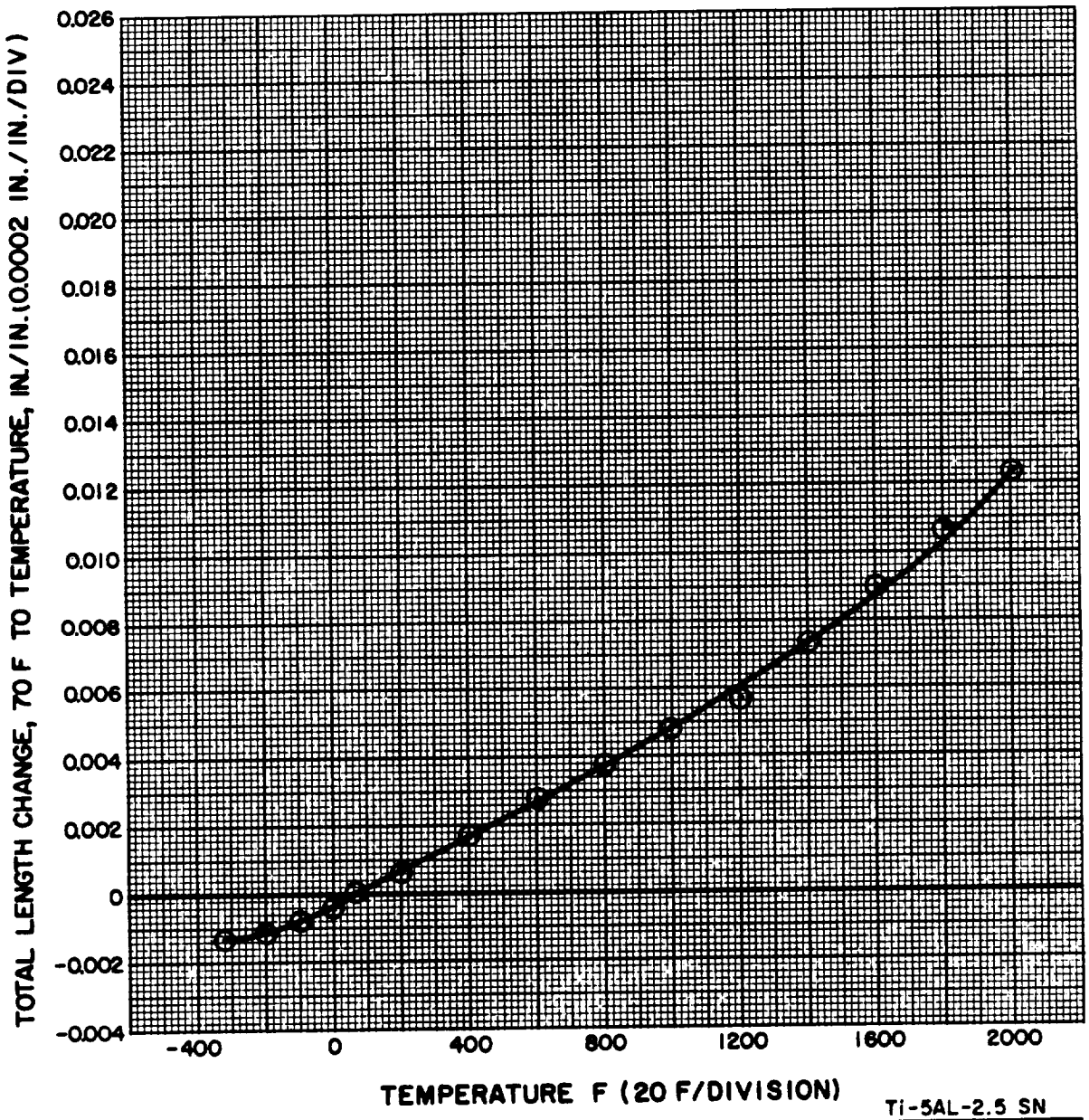
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 4·1·50
MATERIAL Ti-5AL-2.5 SN
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 170-079
DATE AUGUST 1965

NOTES:



Ti-5AL-2.5 SN

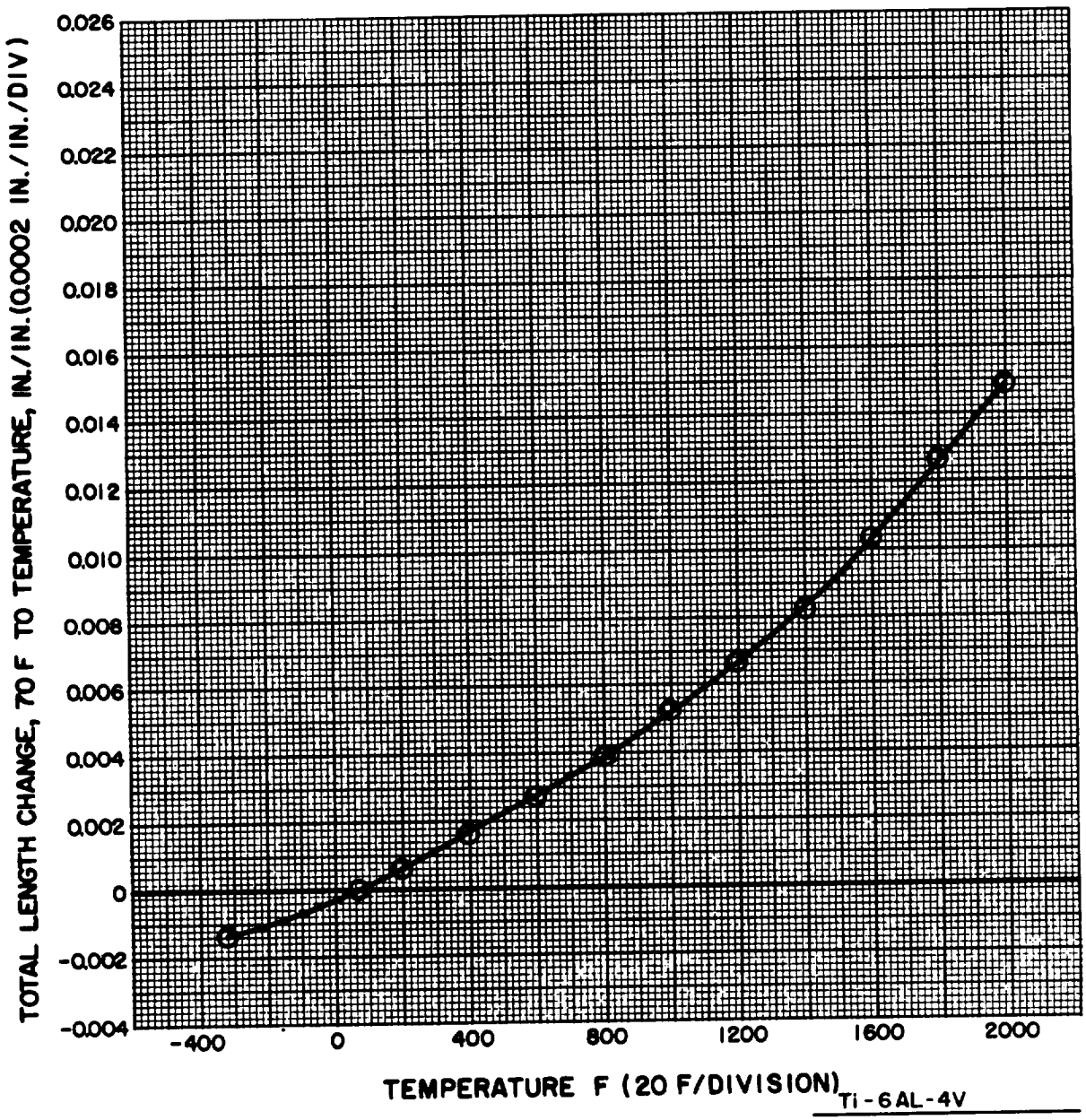
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 4·2·50
MATERIAL Ti-6 AL-4V
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 170-054
DATE MARCH 1962

NOTES:



Ti-6AL-4V

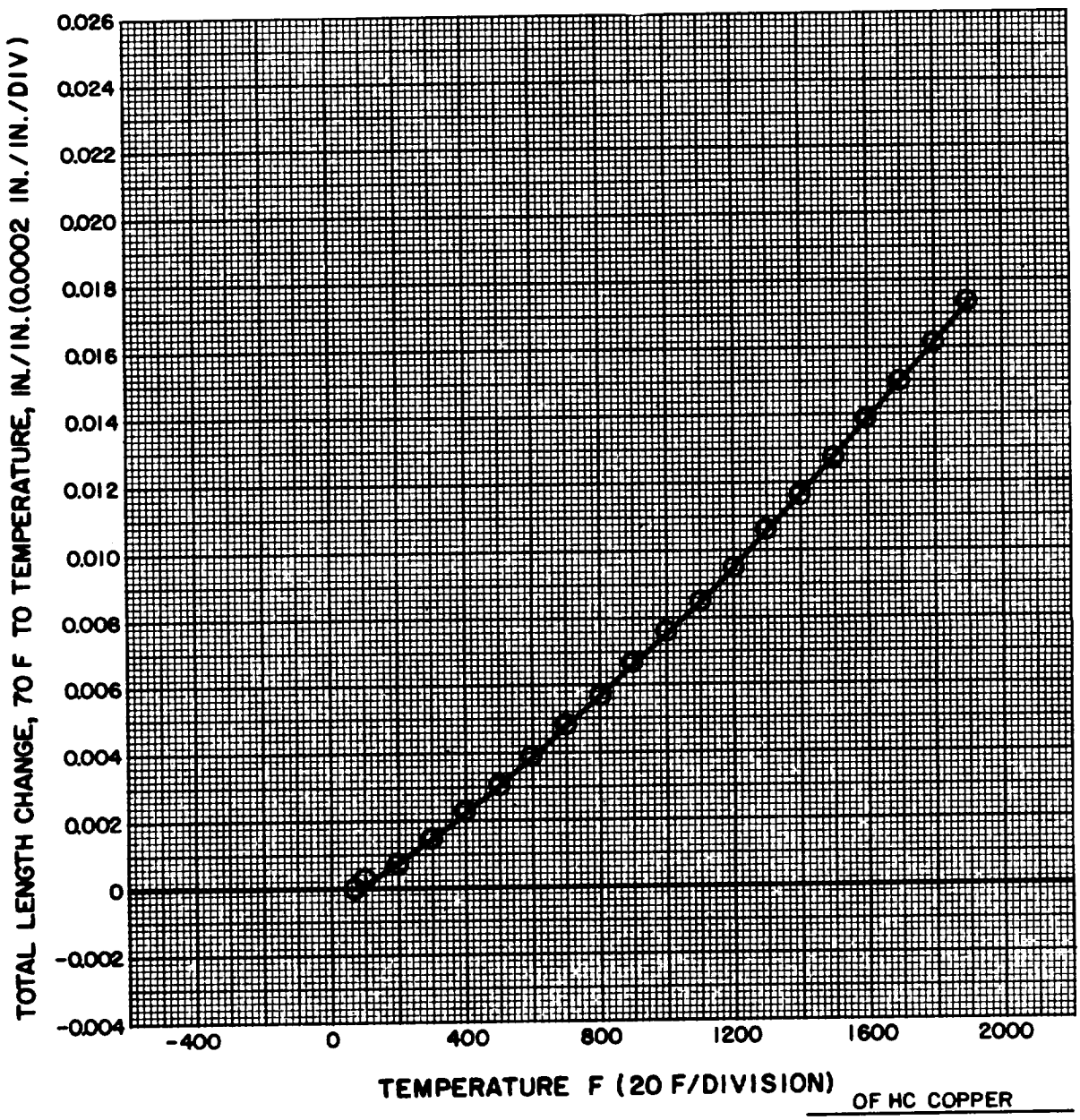
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 5·2·50
MATERIAL OF HC COPPER
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 170-047
DATE JULY 1965

NOTES:



OF HC COPPER

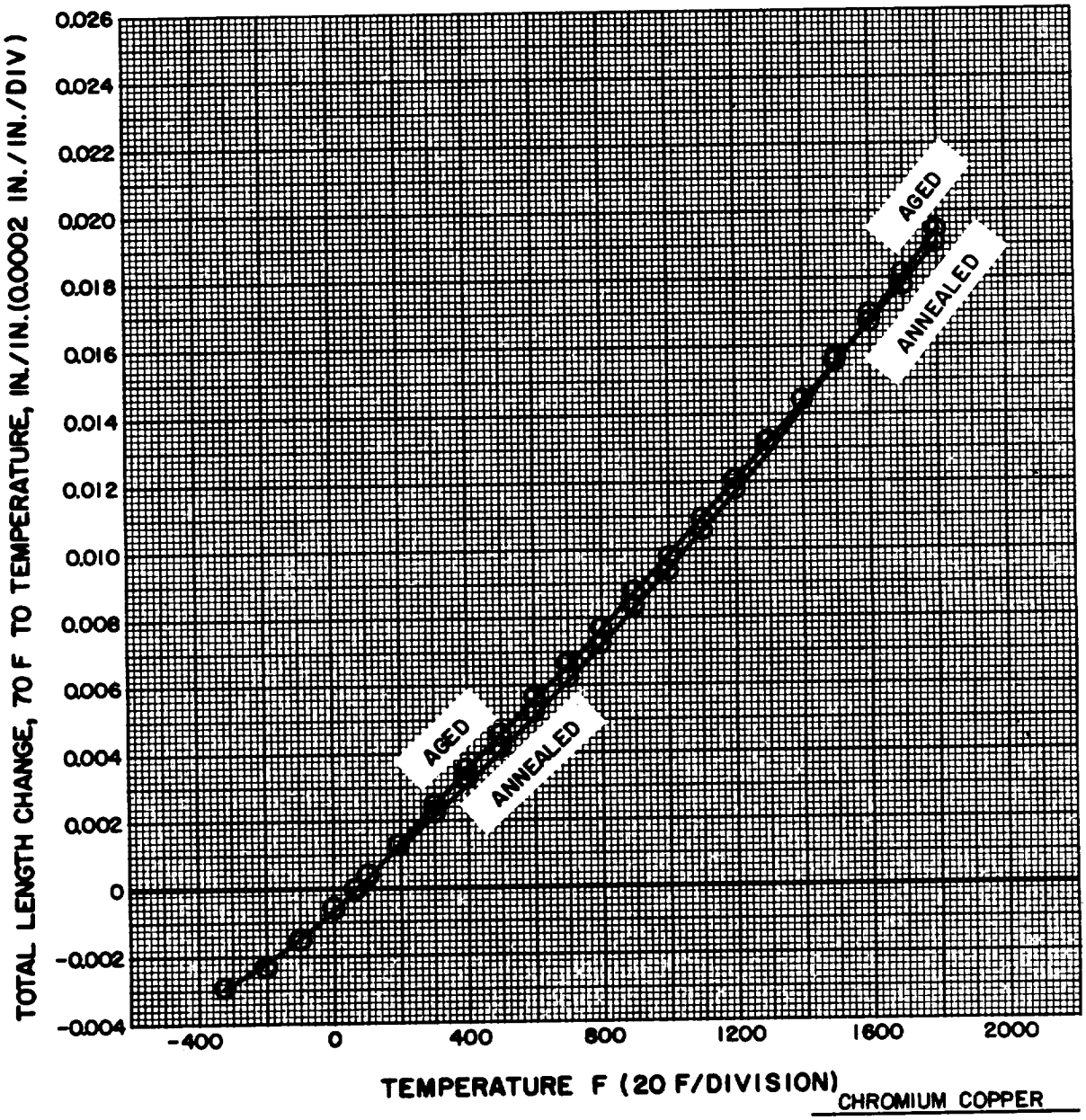
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 5·4·50
MATERIAL CHROMIUM COPPER
FORM WROUGHT
CONDITION ANNEALED/AGED
SPECIFICATION MIL-C-19311
DATE MARCH 1962

NOTES: 1825 °F ± 15°/ WATER QUENCH/AGE 930 °F ± 10°



CHROMIUM COPPER

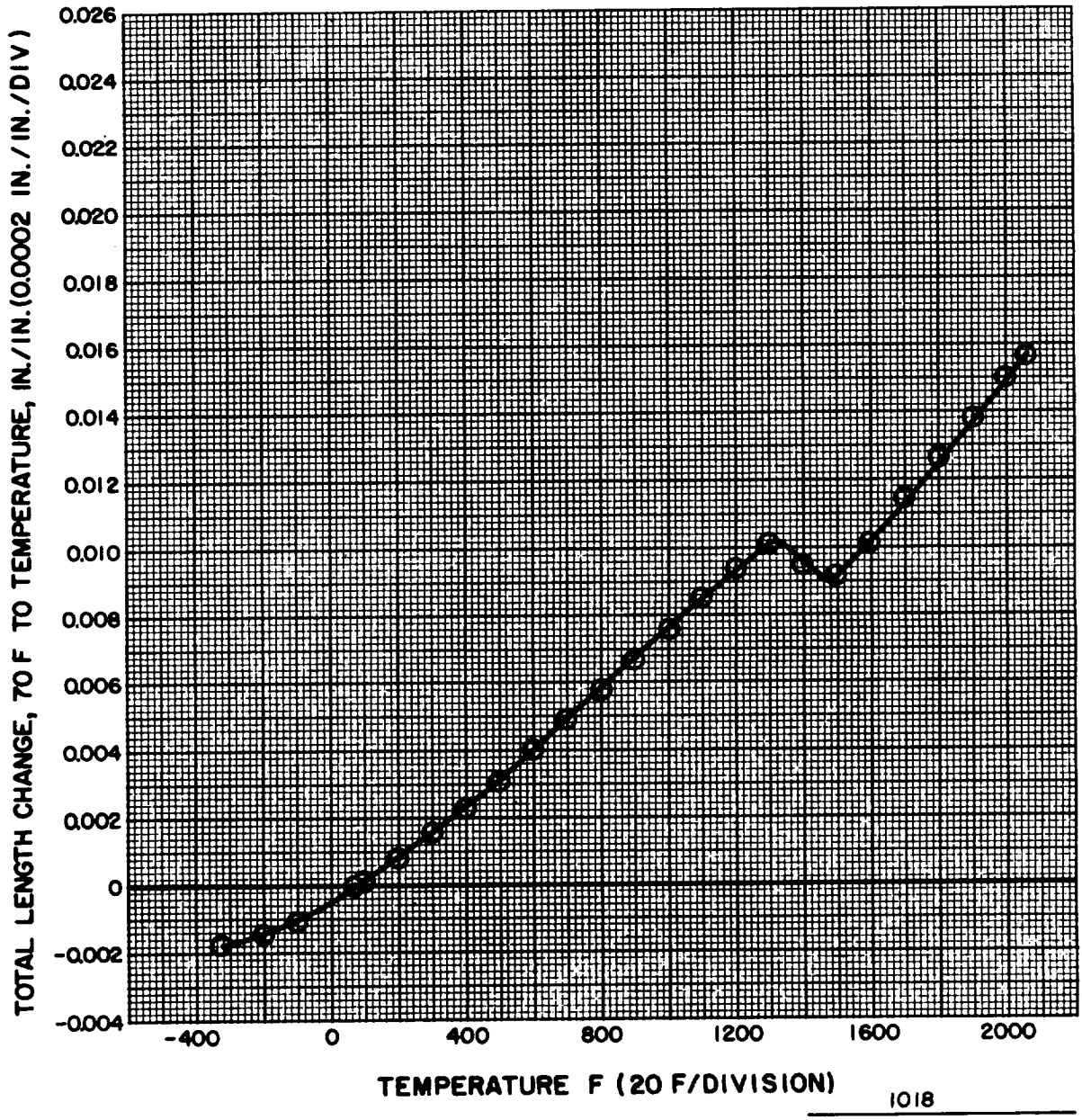
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 6-2-50
MATERIAL 1018
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION QQ-S-633
DATE MARCH 1962

NOTES:



1018

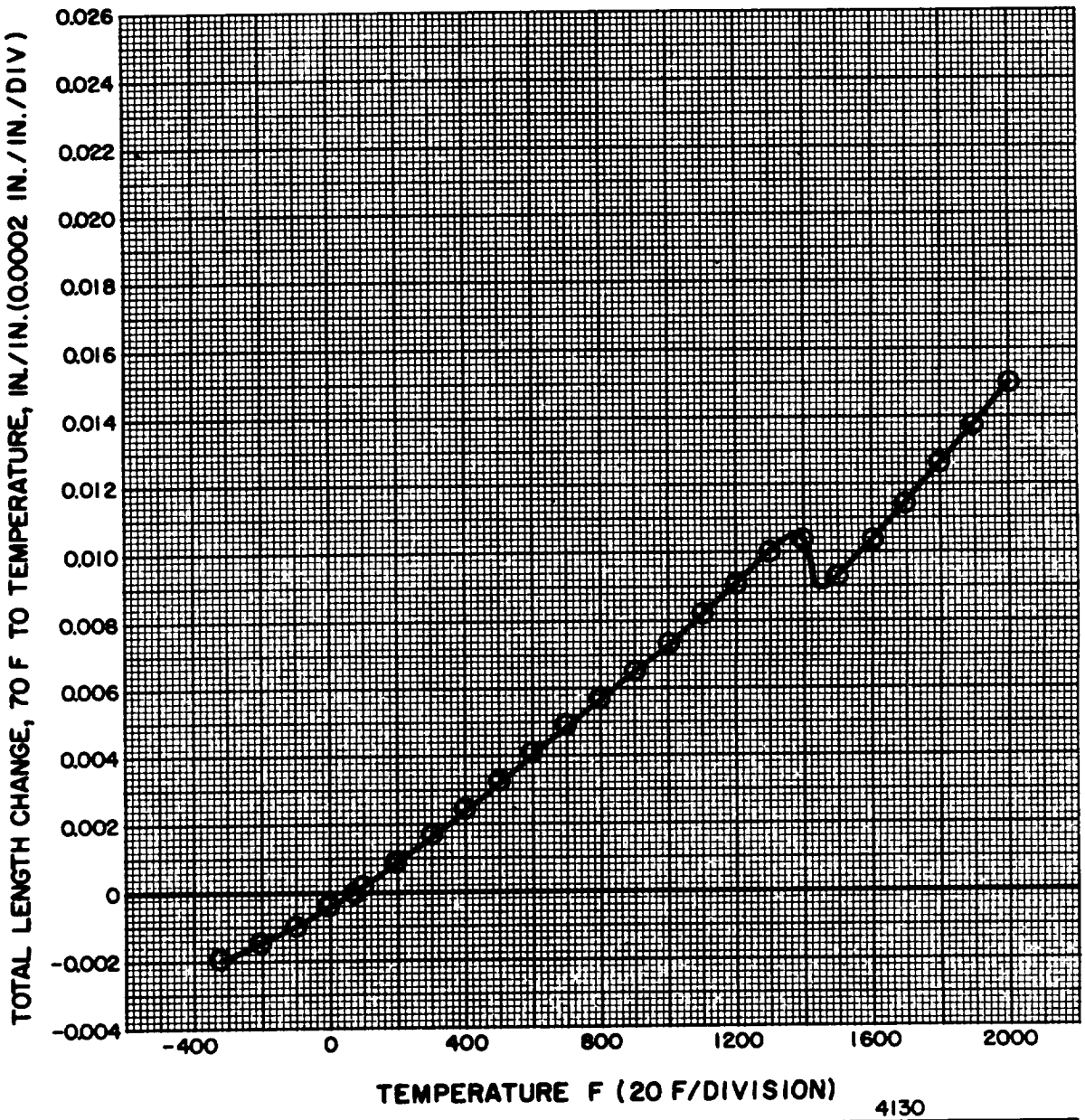
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION
PROPERTIES
AT
ELEVATED TEMPERATURES

CHART NO. 6·3·50
MATERIAL 4130
FORM WROUGHT
CONDITION NORMALIZED
SPECIFICATION MIL-S-6758
DATE MARCH 1962

NOTES:



4130

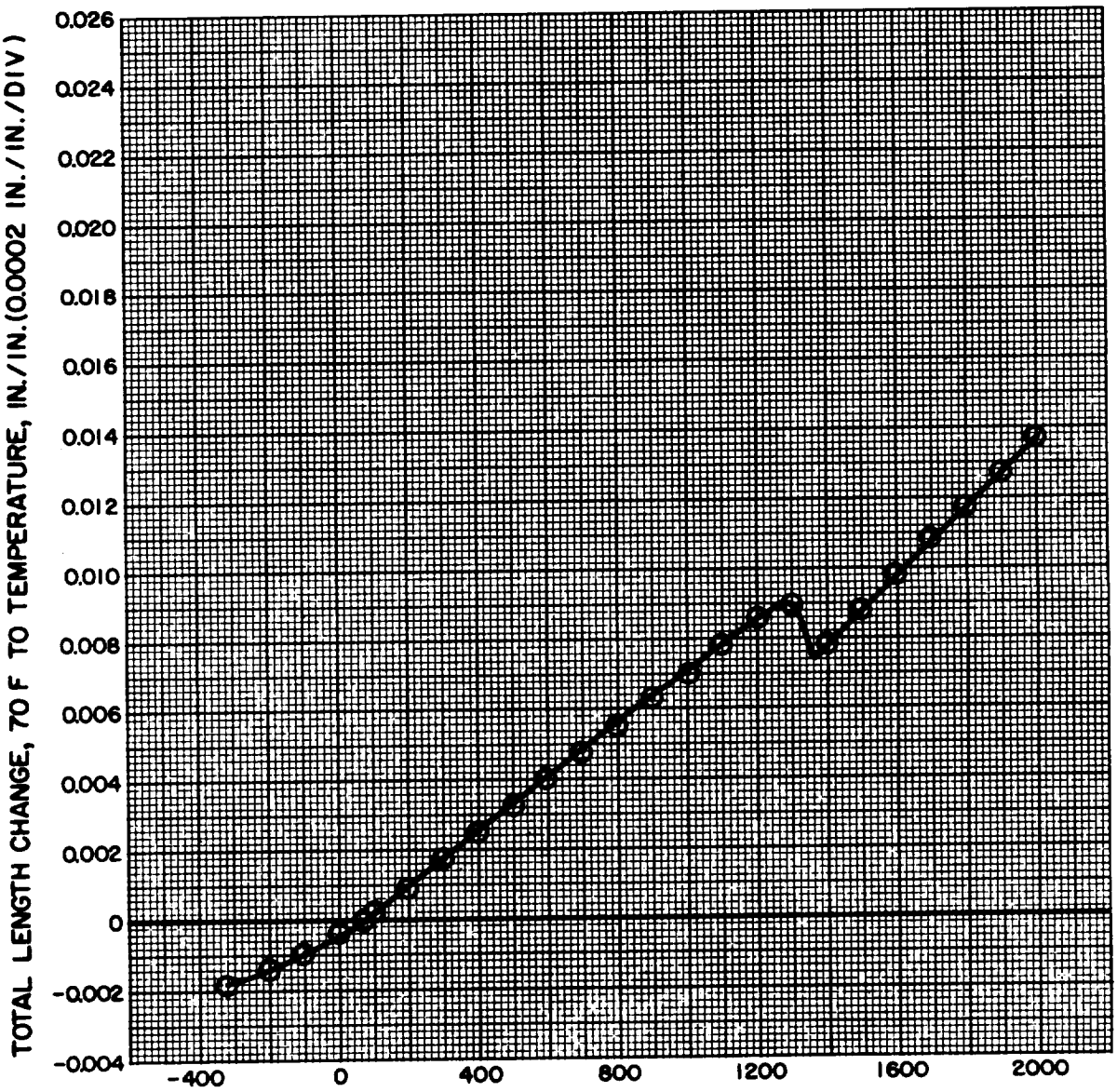
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 6·4·50
MATERIAL 4340
FORM BAR
CONDITION SEE NOTES
SPECIFICATION RBO 160-030
DATE MARCH 1962

NOTES: QUENCHED AND TEMPERED AT 850°F



4340

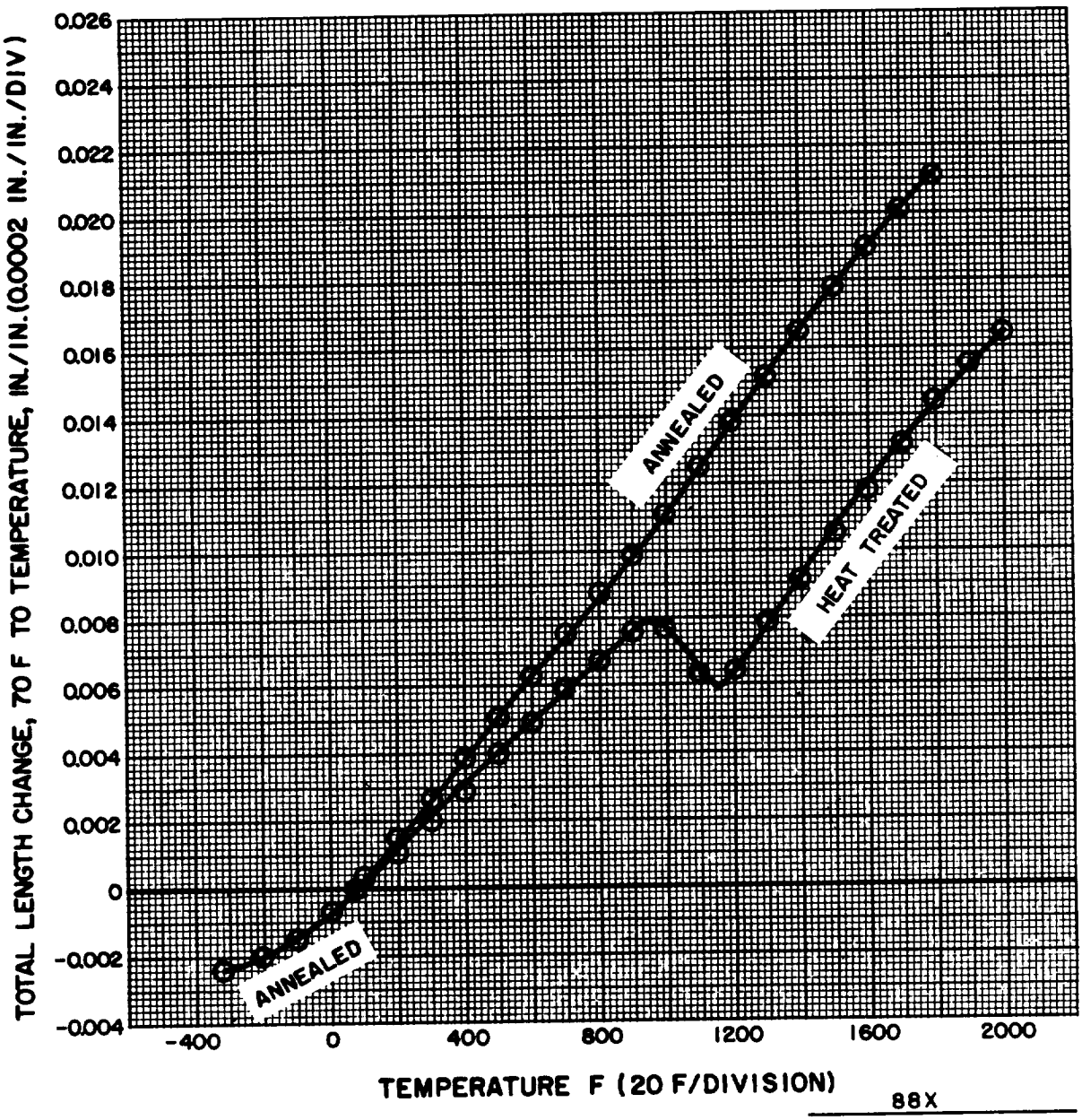
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 6·5·50
MATERIAL 88X
FORM WROUGHT
CONDITION SEE NOTES
SPECIFICATION AMS-5624
DATE MARCH 1962

NOTES: ANNEALED/HEAT TREATED



88X

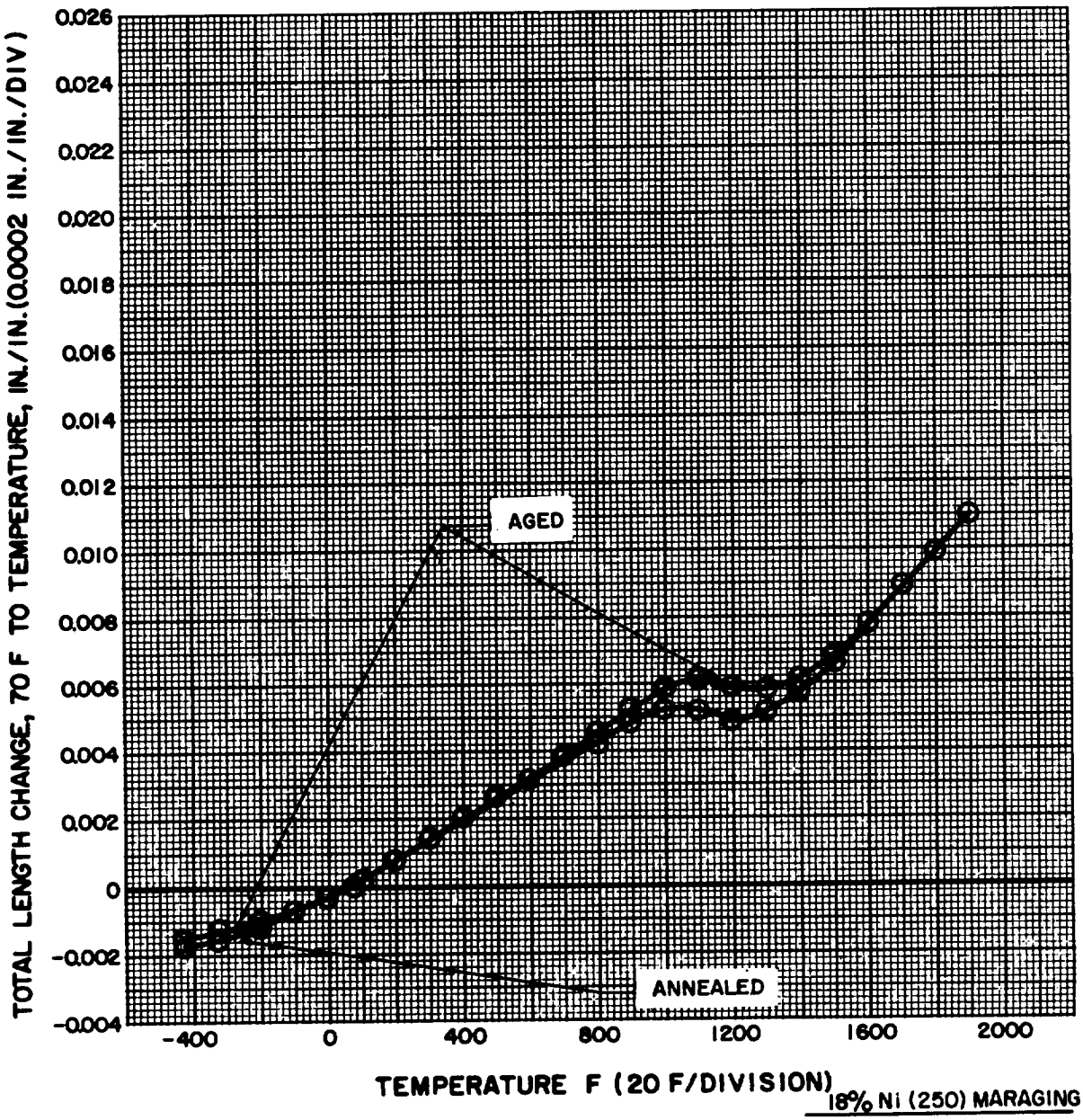
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 6-8-50
MATERIAL 18% Ni (250) MARAGING
FORM FORGING
CONDITION SEE NOTES
SPECIFICATION RB0170-067
DATE JULY 1965

NOTES: ANNEALED 1500°F/1 HR / AGED 900°F/1 HR



18% Ni (250) MARAGING

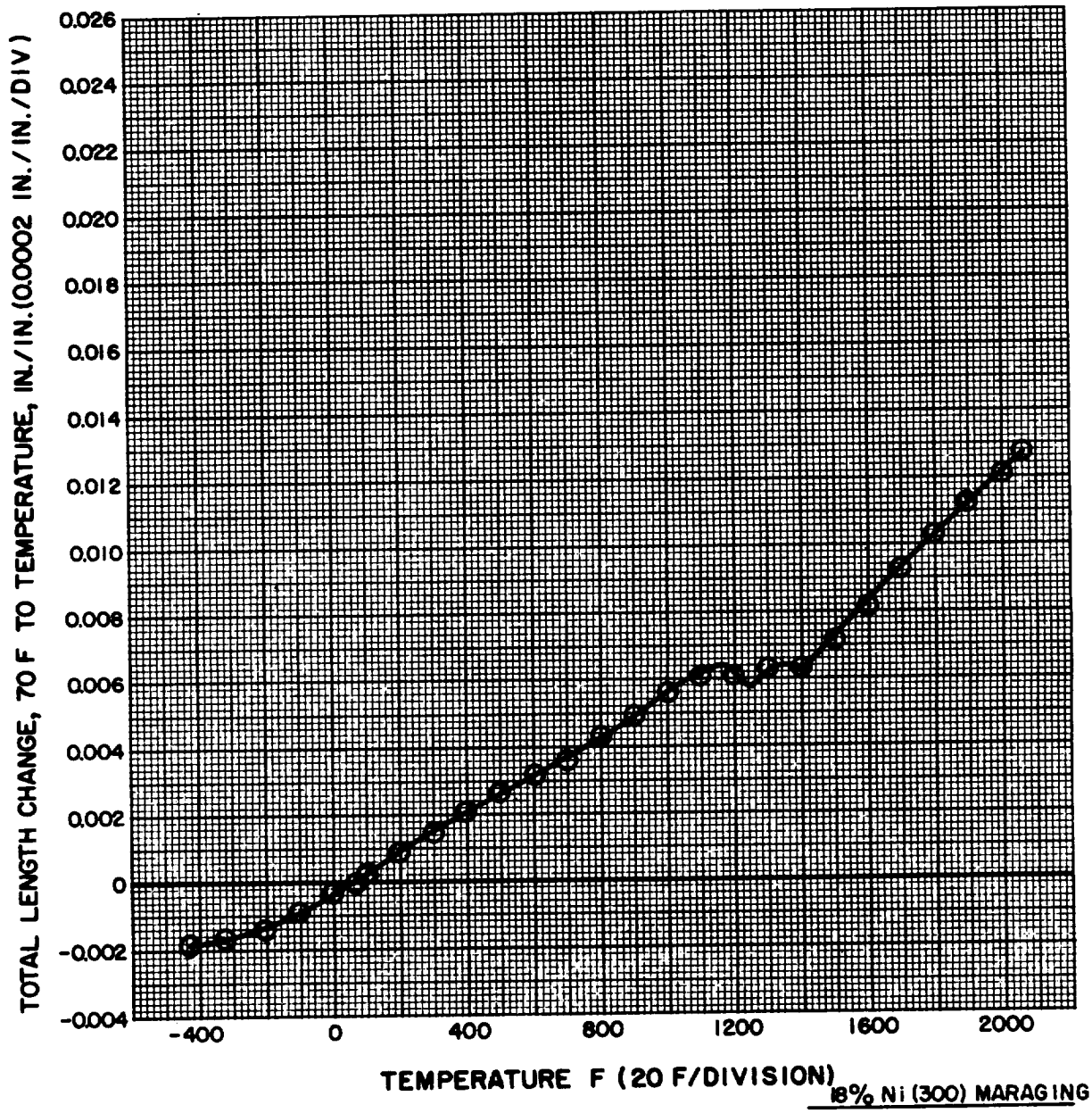
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION
PROPERTIES
AT
ELEVATED TEMPERATURES

CHART NO. 6·9·50
MATERIAL 18% Ni (300) MARAGING
FORM FORGING
CONDITION AGED AT 900°F/1 HR
SPECIFICATION RBO 170-067
DATE JULY 1965

NOTES:



18% Ni (300) MARAGING

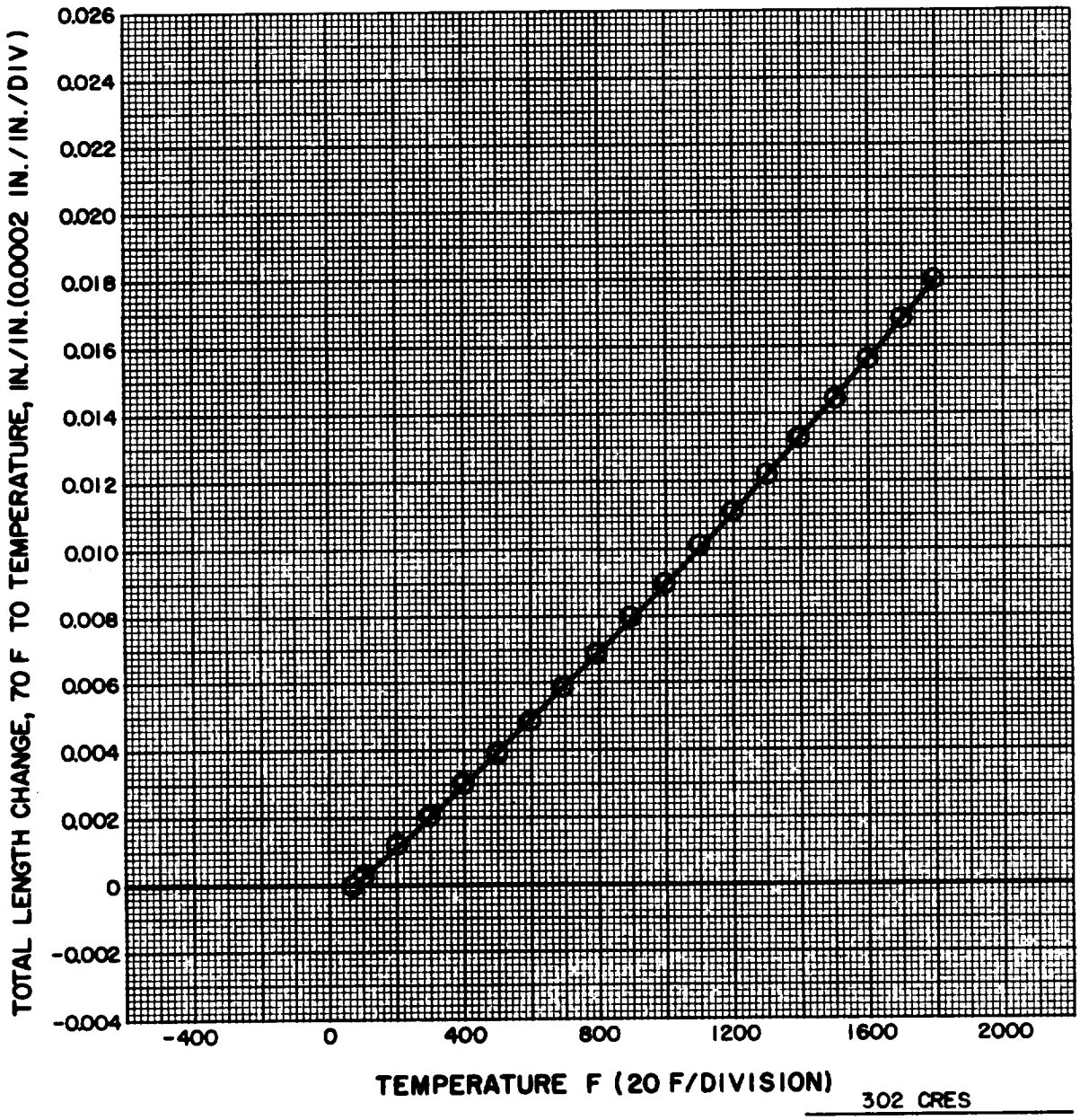
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE NORTHROP DATA

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7·1·50
MATERIAL 302 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION MIL-S-7720
DATE JULY 1965

NOTES:



302 CRES

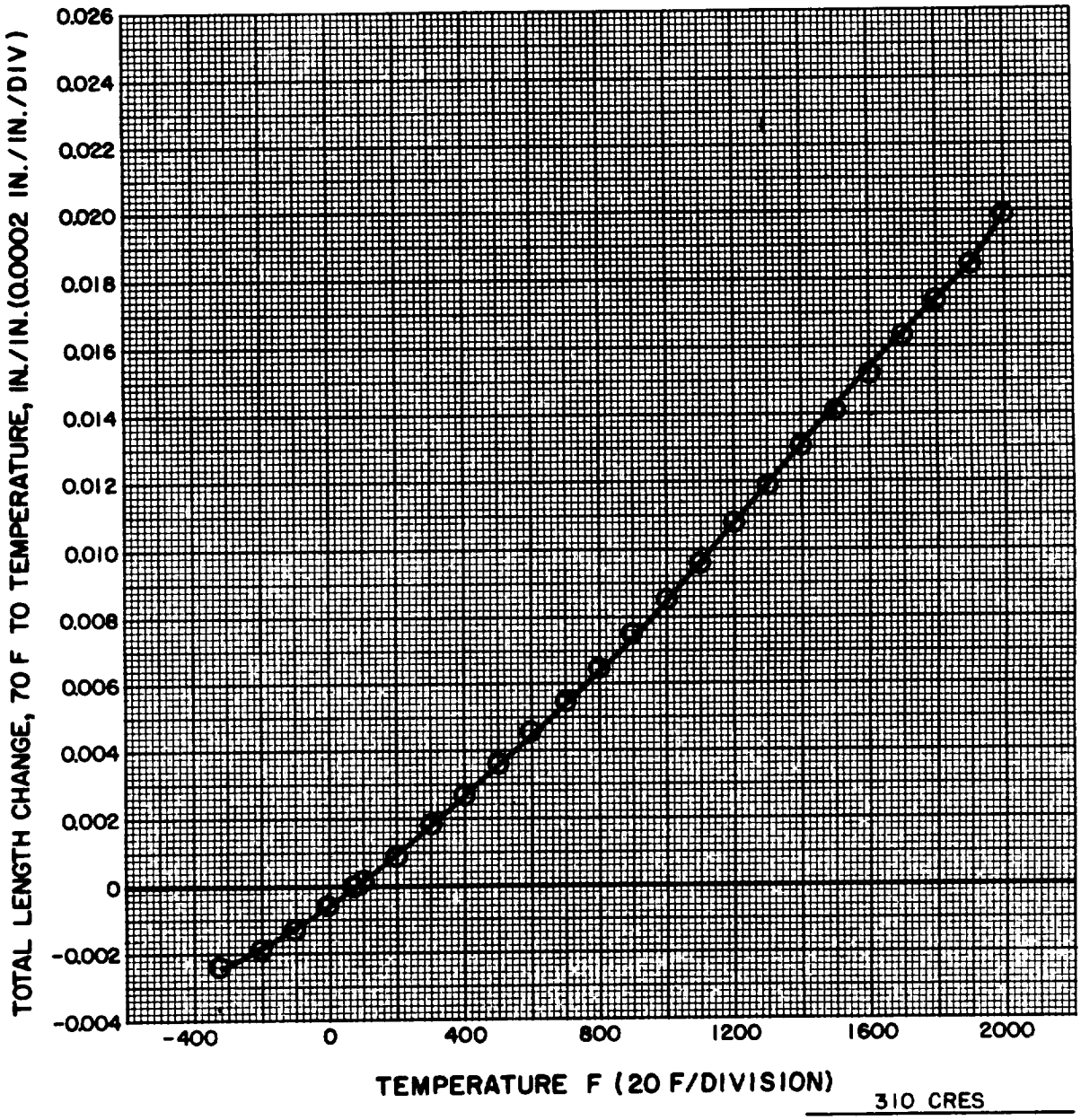
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7·3·50
MATERIAL 310 CRES
FORM CASTING
CONDITION AS CAST
SPECIFICATION ASTM-A-296
DATE MARCH 1962

NOTES:



310 CRES

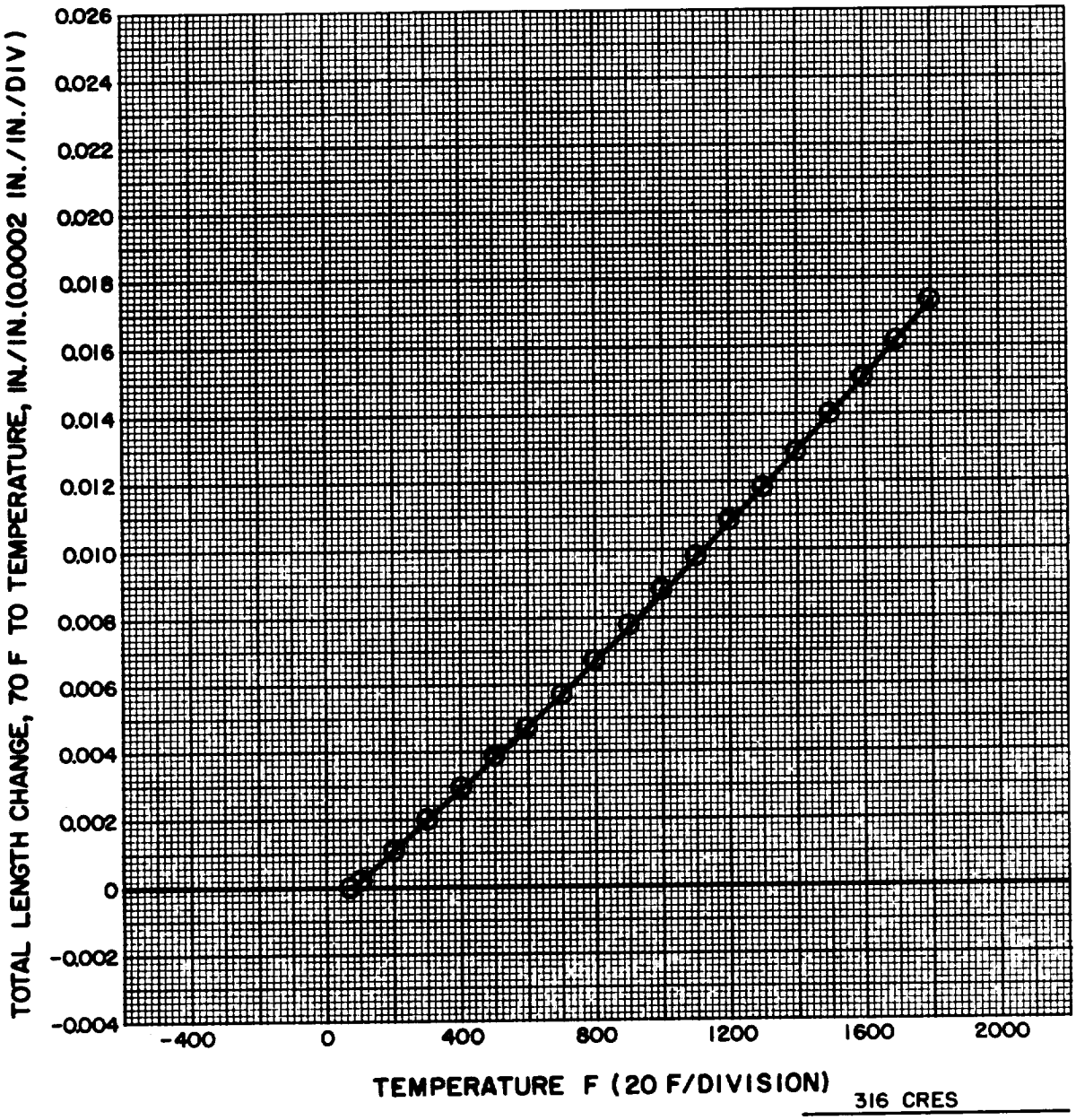
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE NORTHROP DATA

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7·4·50
MATERIAL 316 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-S-763
DATE JULY 1965

NOTES:



316 CRES

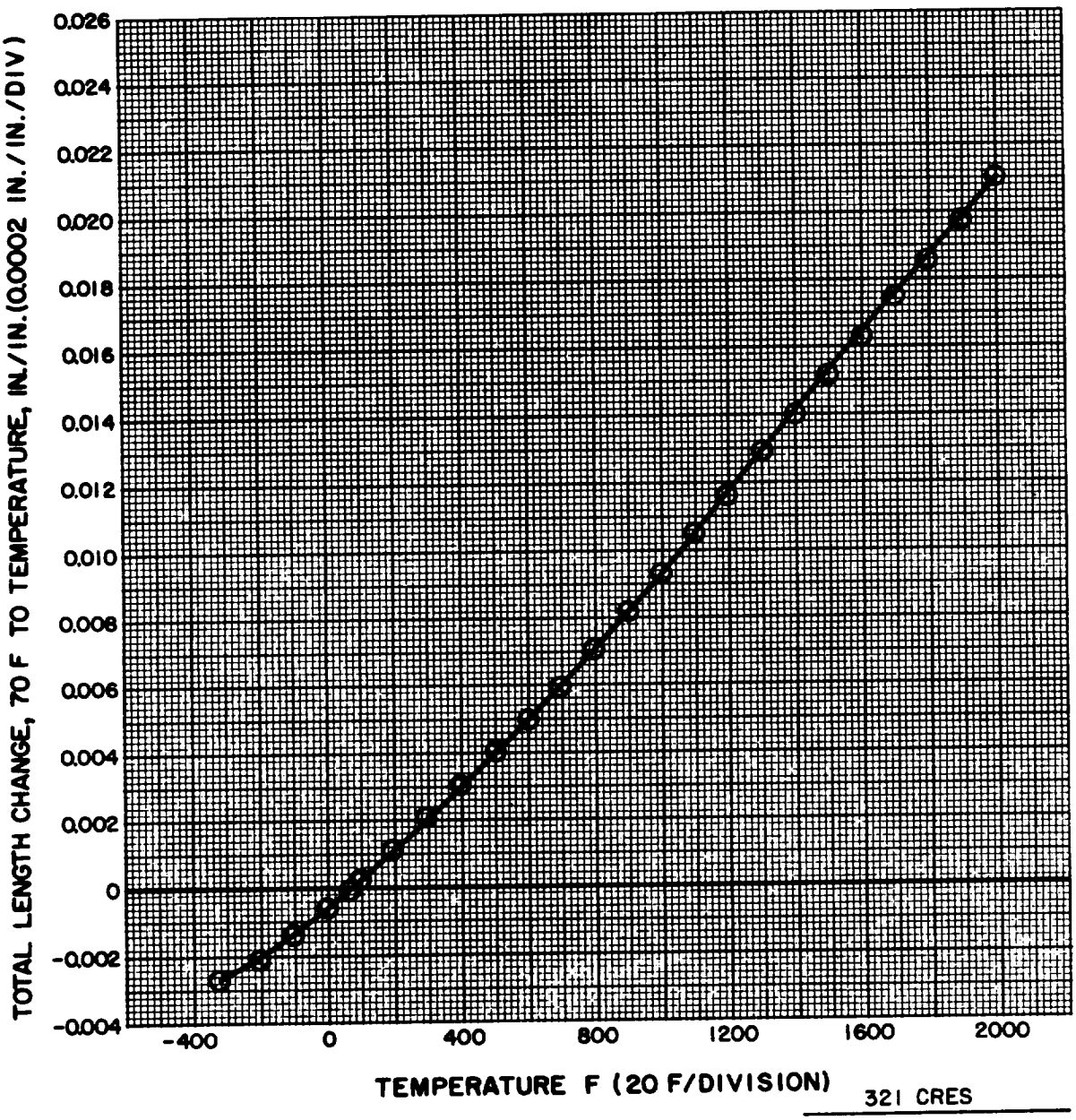
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE NORTHROP DATA

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7-5-50
MATERIAL 321 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-S-763
DATE JULY 1960

NOTES:



321 CRES

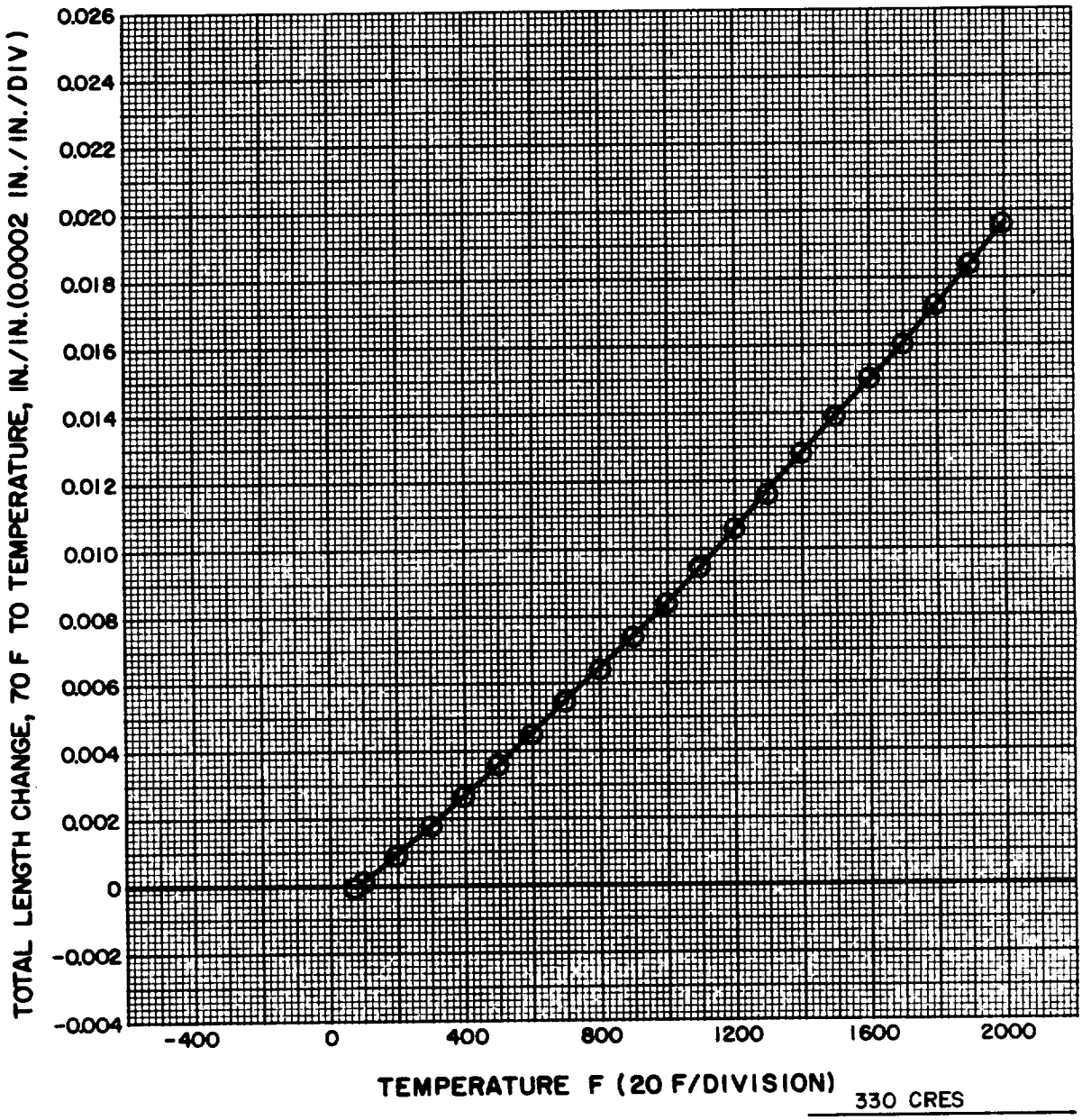
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7·6·50
MATERIAL 330 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION AMS-5592
DATE MARCH 1962

NOTES:



330 CRES

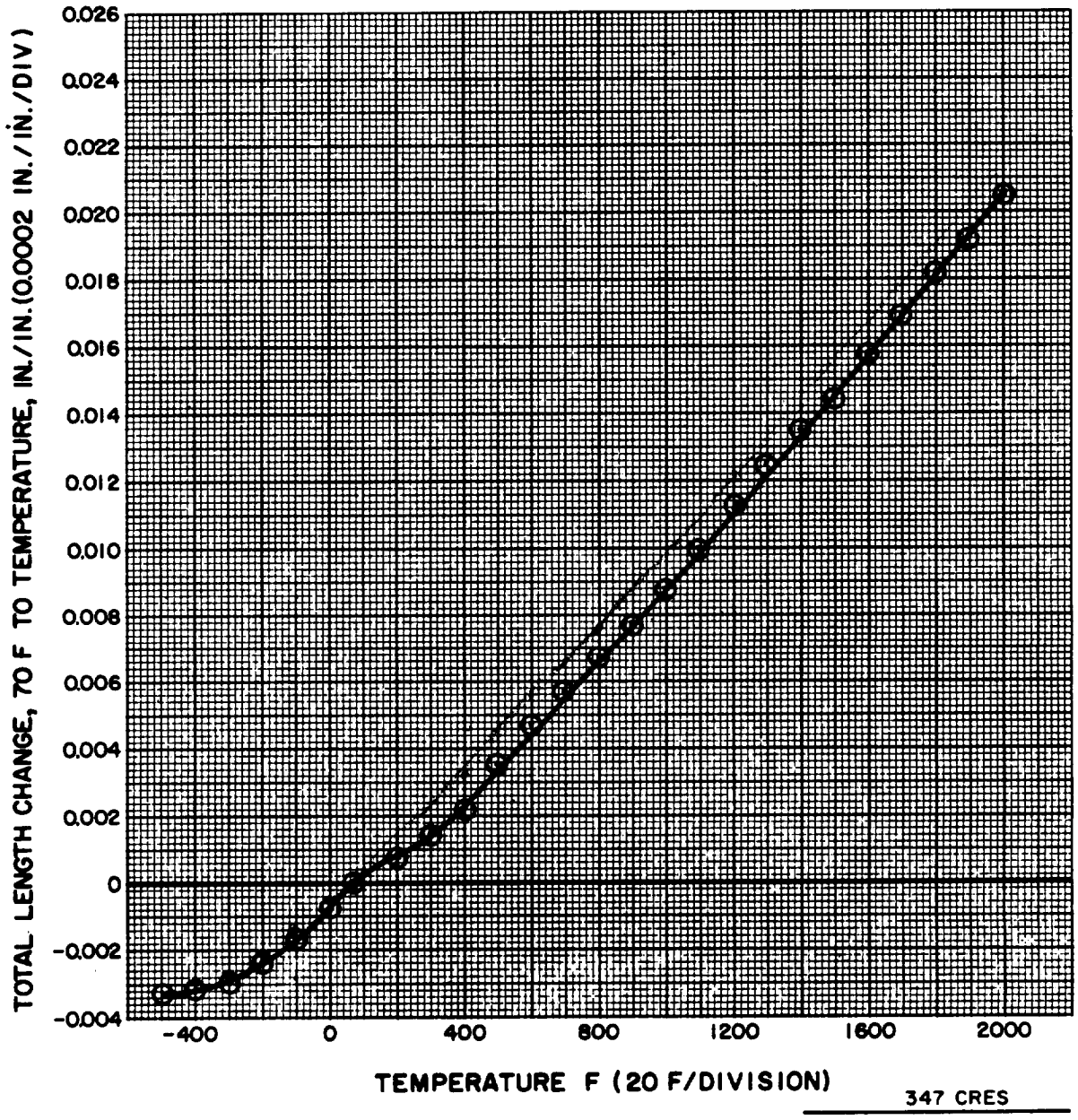
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7-7-50
MATERIAL 347 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-S-763
DATE 6-1-66

NOTES:



347 CRES

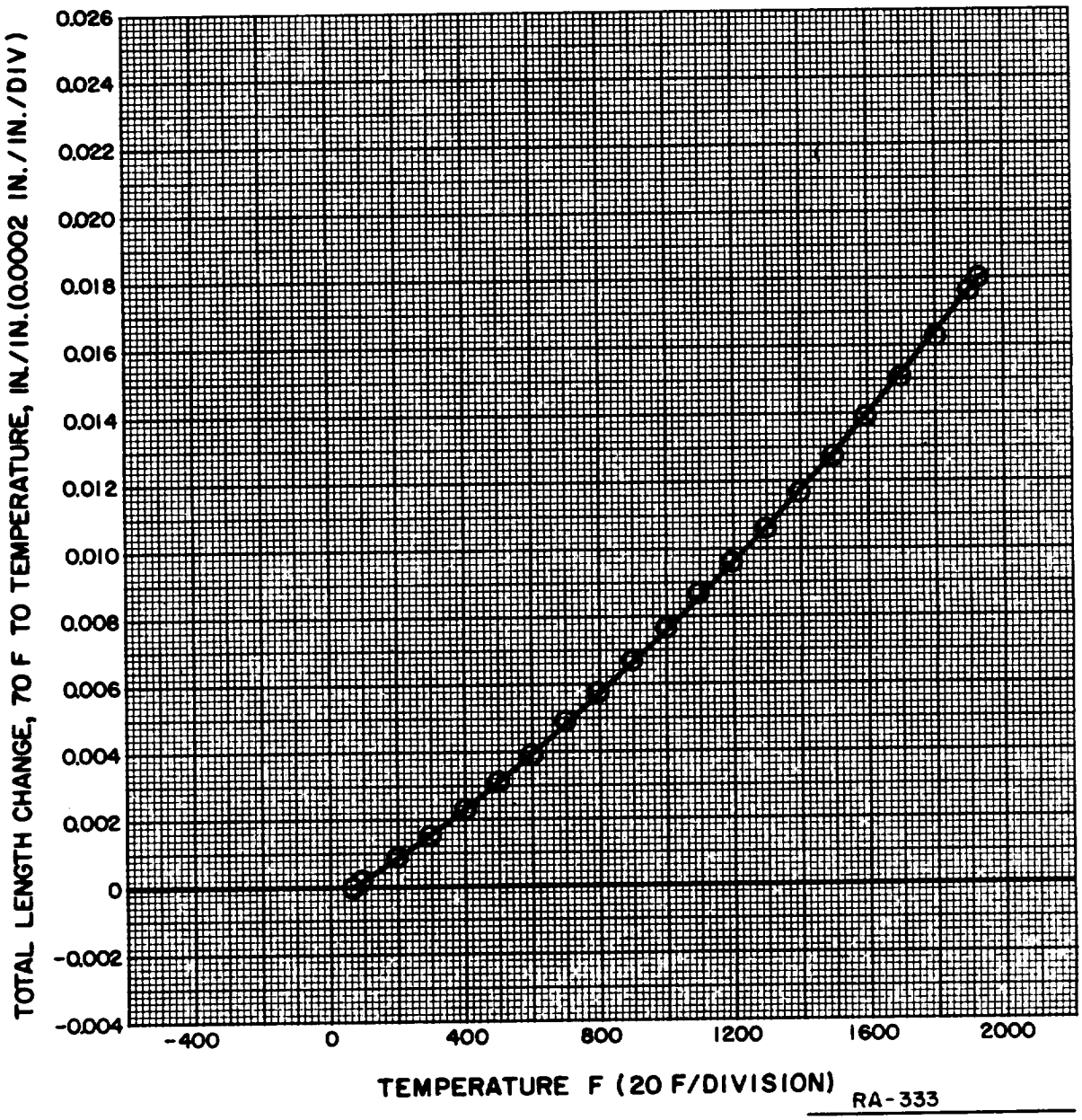
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION
PROPERTIES
AT
ELEVATED TEMPERATURES

CHART NO. 7·8·50
MATERIAL RA-333
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 170-041
DATE JULY 1965

NOTES:



RA-333

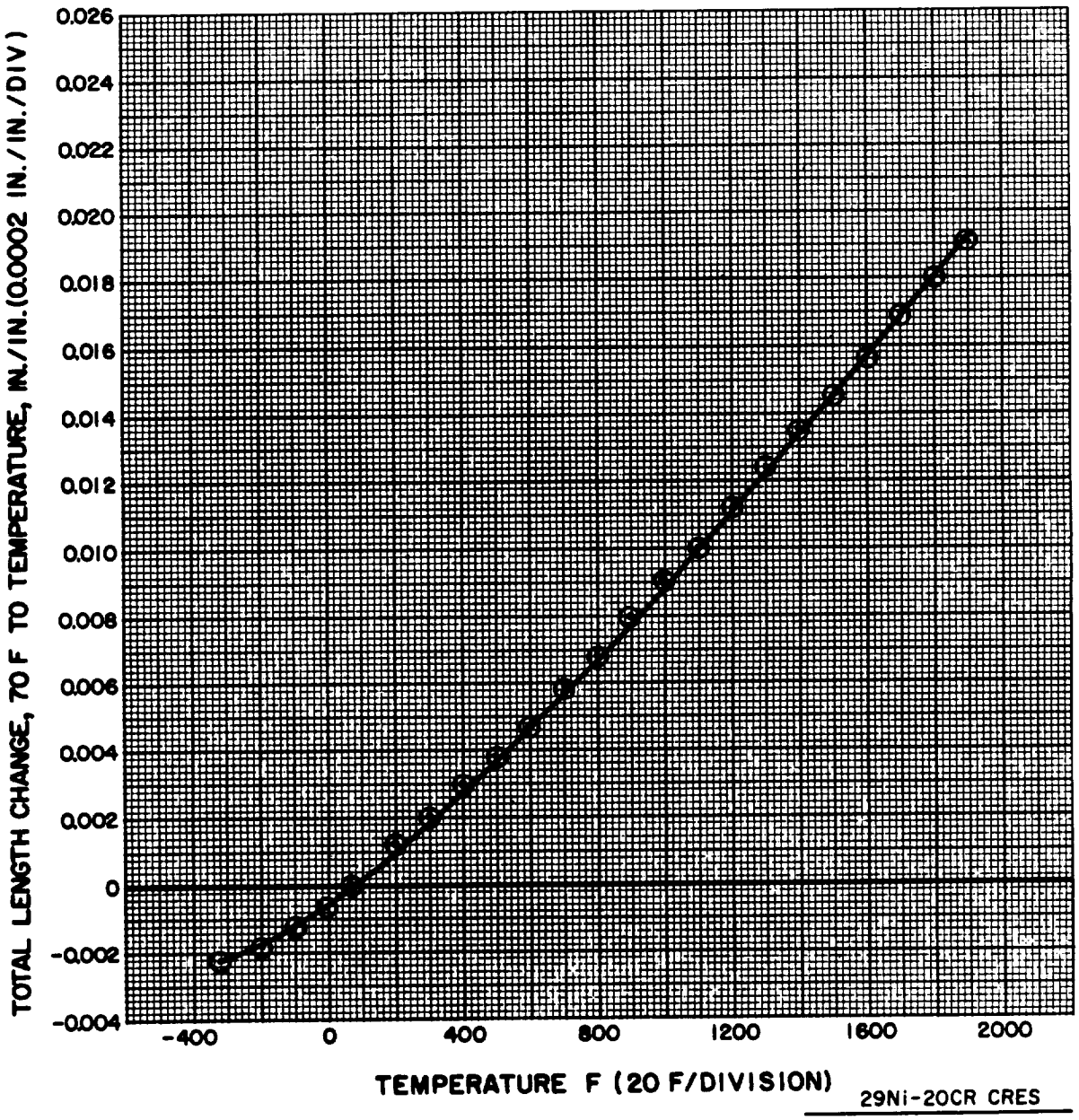
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7-9-50
MATERIAL 29Ni-20CR CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 160-009
DATE MARCH 1962

NOTES:



29Ni-20CR CRES

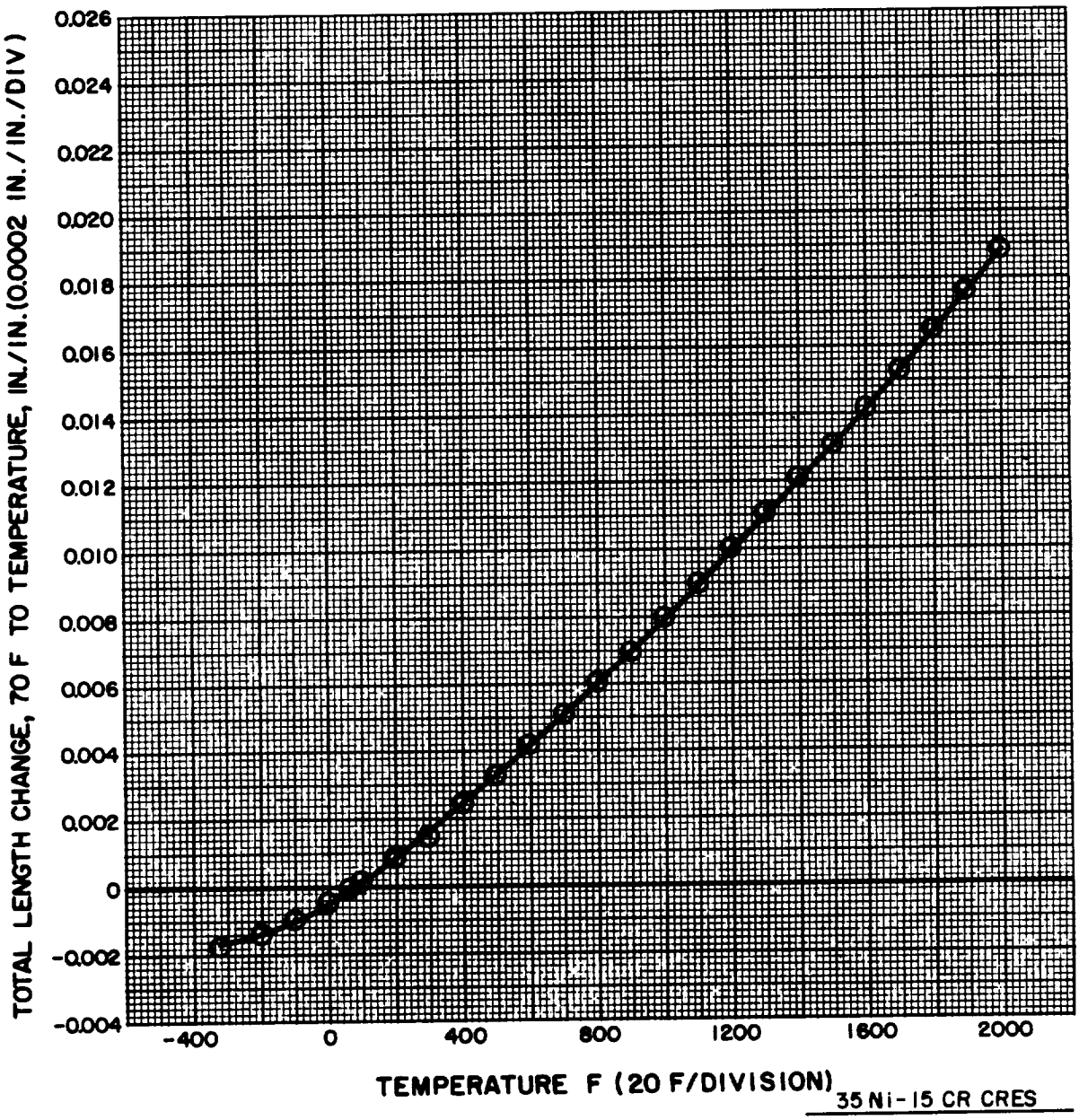
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 7-10-50
MATERIAL 35 Ni - 15 CR CRES
FORM CAST
CONDITION ANNEALED
SPECIFICATION —
DATE MARCH 1962

NOTES:



35 Ni - 15 CR CRES

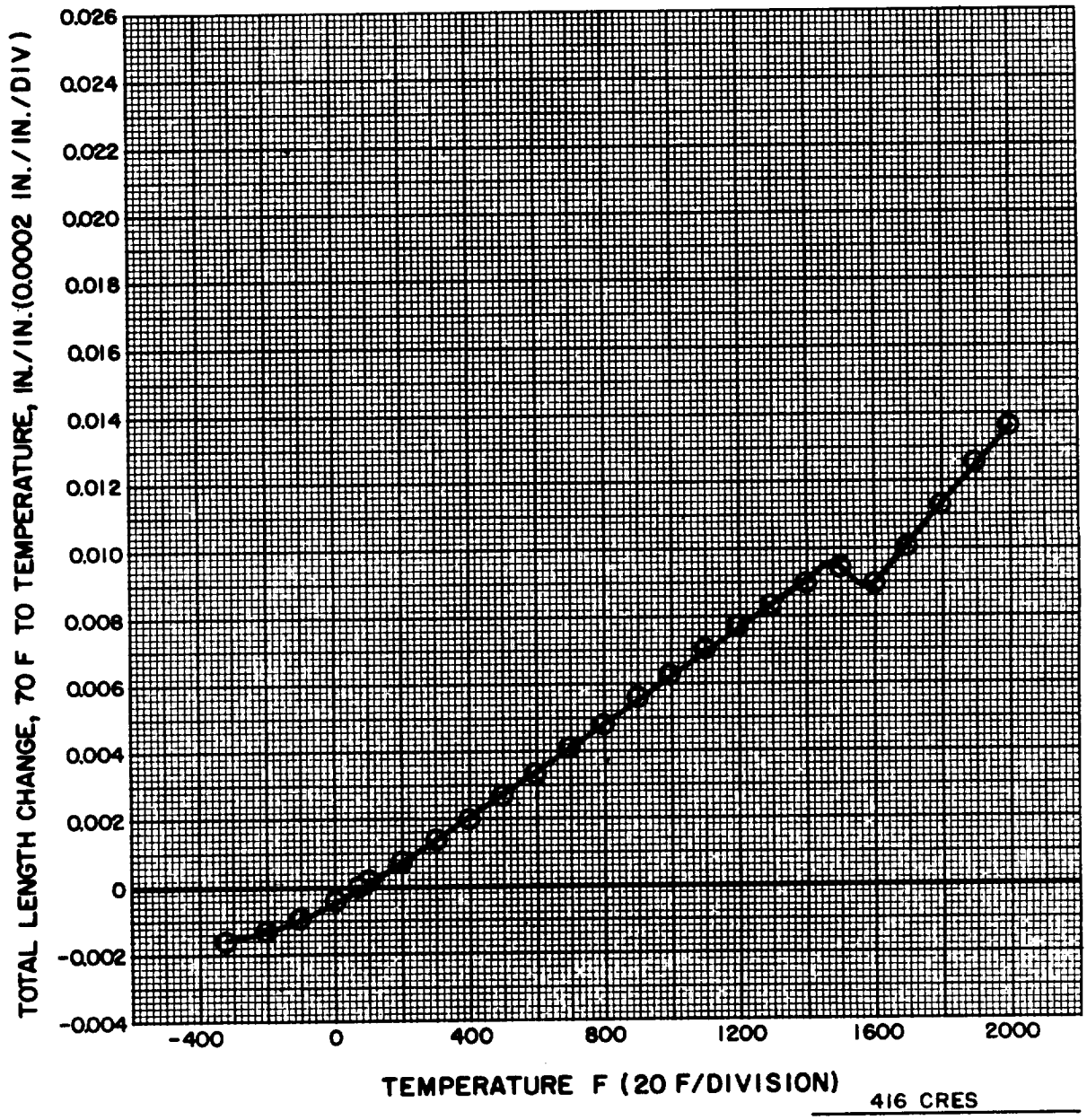
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 8·1·50
MATERIAL 416 CRES
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION AMS 5610
DATE MARCH 1962

NOTES:



416 CRES

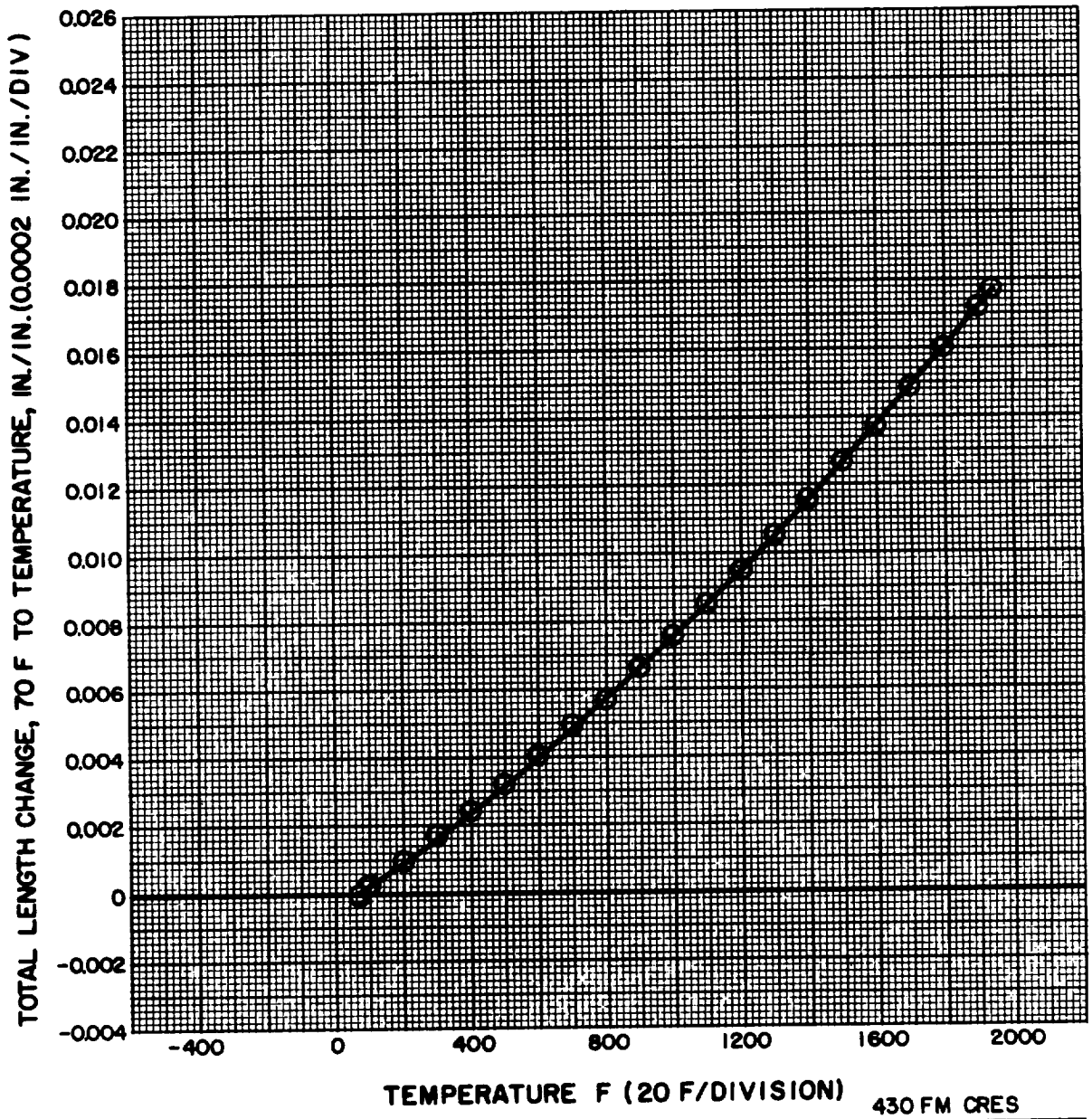
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 8·2·50
MATERIAL 430 FM CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION -
DATE JULY 1965

NOTES:



430 FM CRES

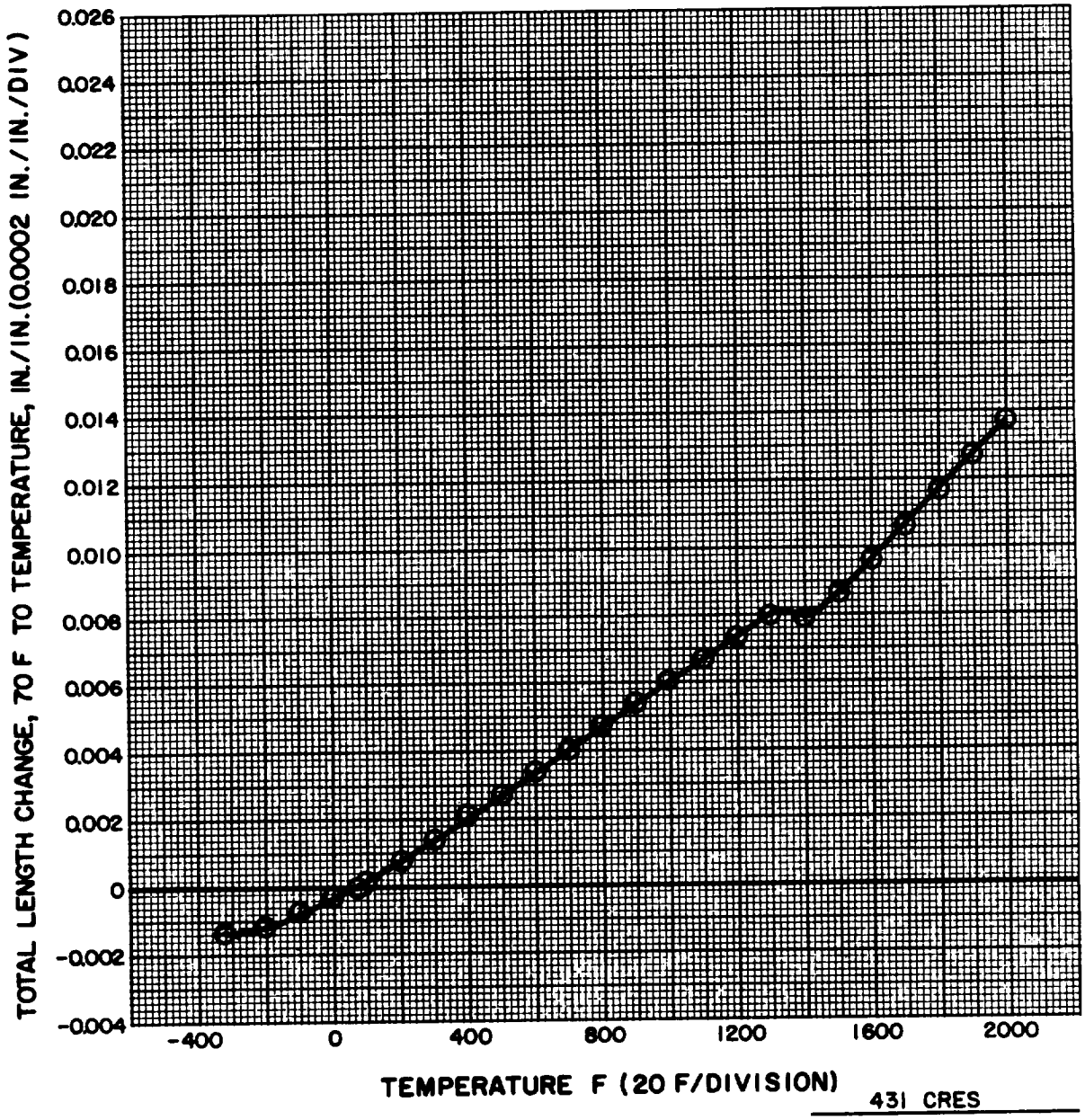
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 8·3·50
MATERIAL 431 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION MIL-S-18732
DATE MARCH 1962

NOTES:



431 CRES

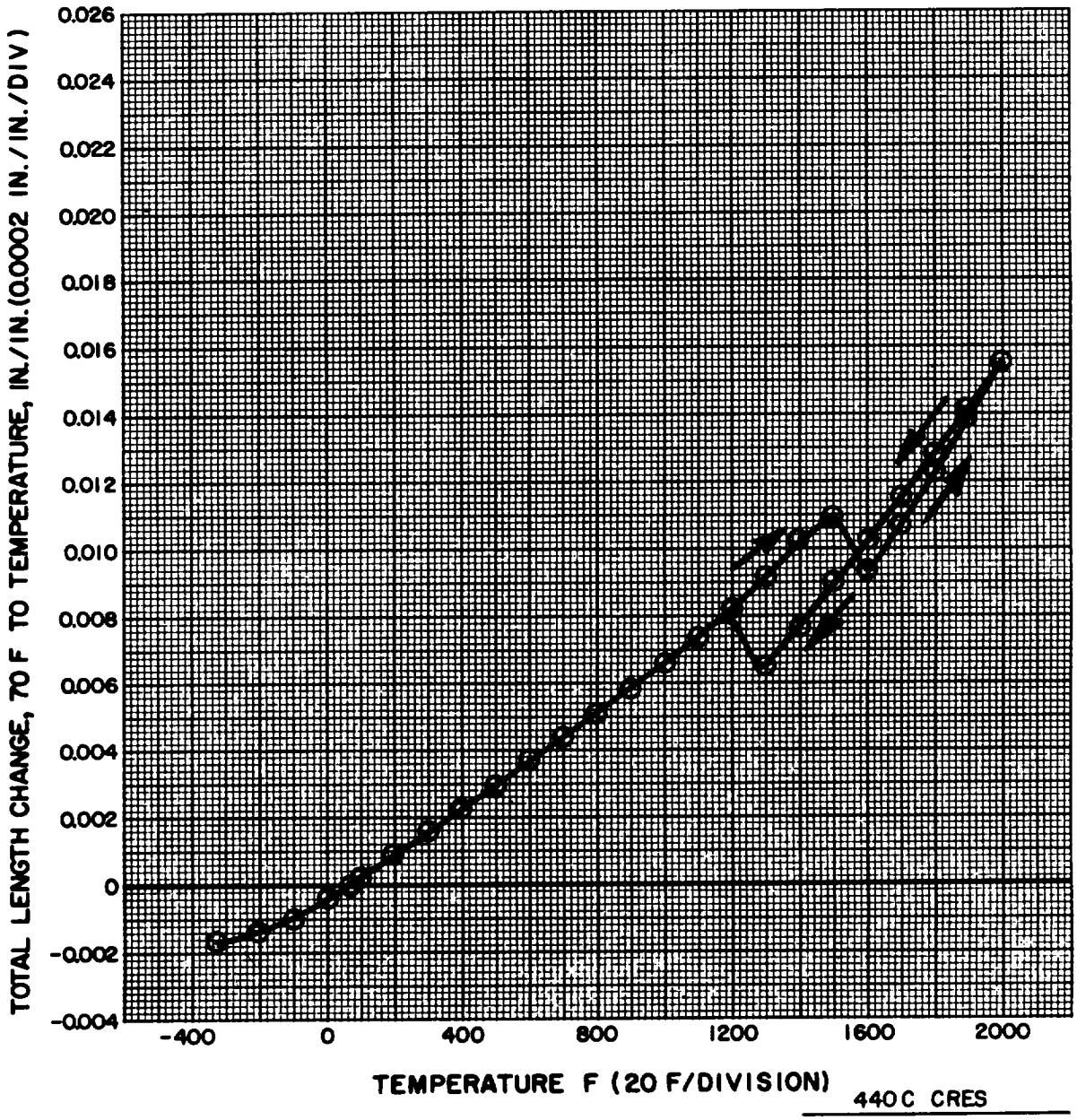
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 8-4-50
MATERIAL 440C CRES
FORM BAR
CONDITION SEE NOTES
SPECIFICATION LBO 160-151
DATE MARCH 1962

NOTES: QUENCHED AND TEMPERED AT 350° F



440C CRES

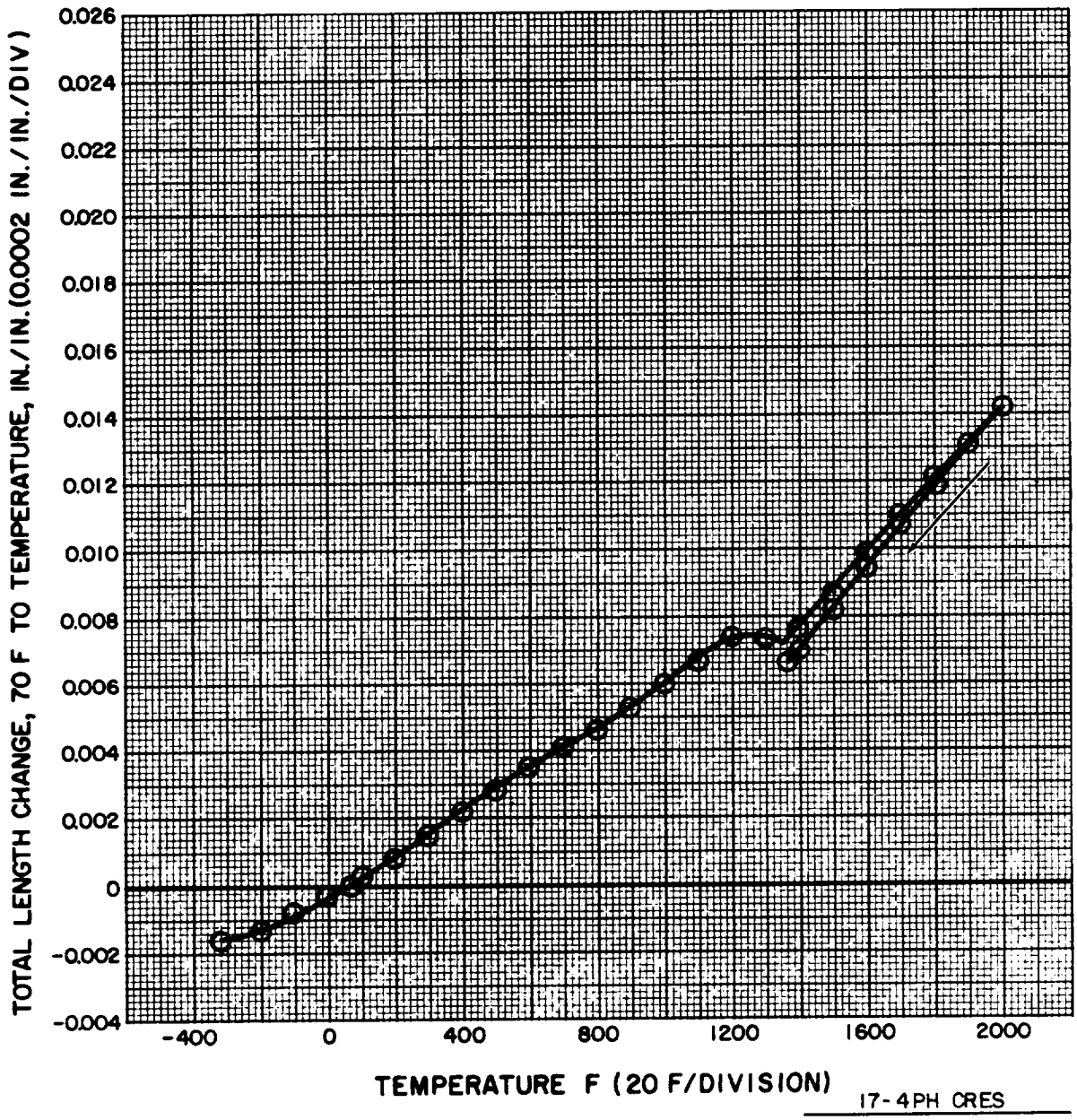
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 8·5·50
MATERIAL 17-4PH CRES
FORM BAR
CONDITION AGED AT 850°F
SPECIFICATION AMS 5643
DATE MARCH 1962

NOTES:



17-4PH CRES

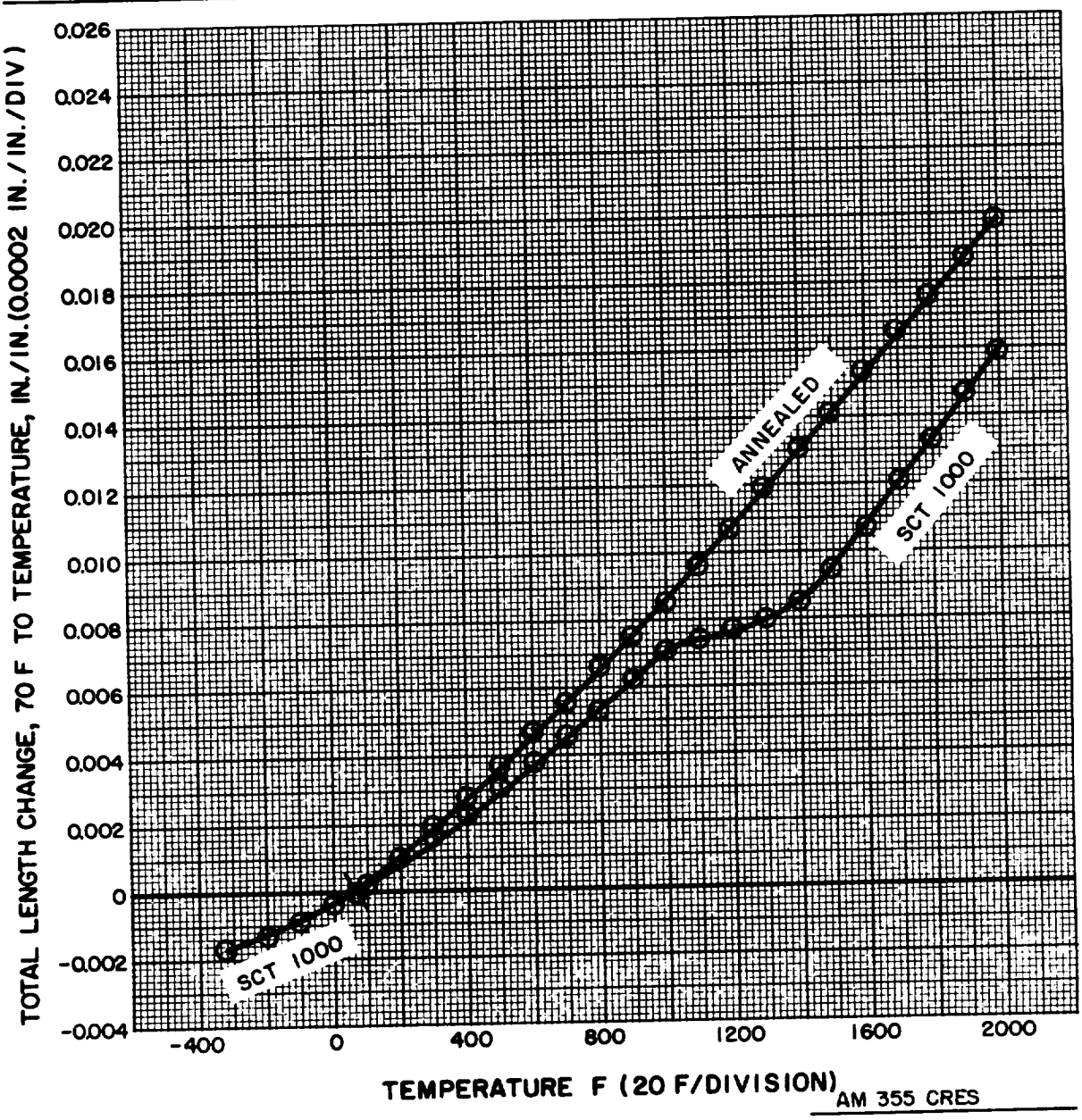
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 8·7·50
MATERIAL AM 355 CRES
FORM BAR
CONDITION ANNEALED/SCT 1000
SPECIFICATION
DATE MARCH 1962

NOTES: 15 Cr - 4 Ni - 3 Mo



AM 355 CRES

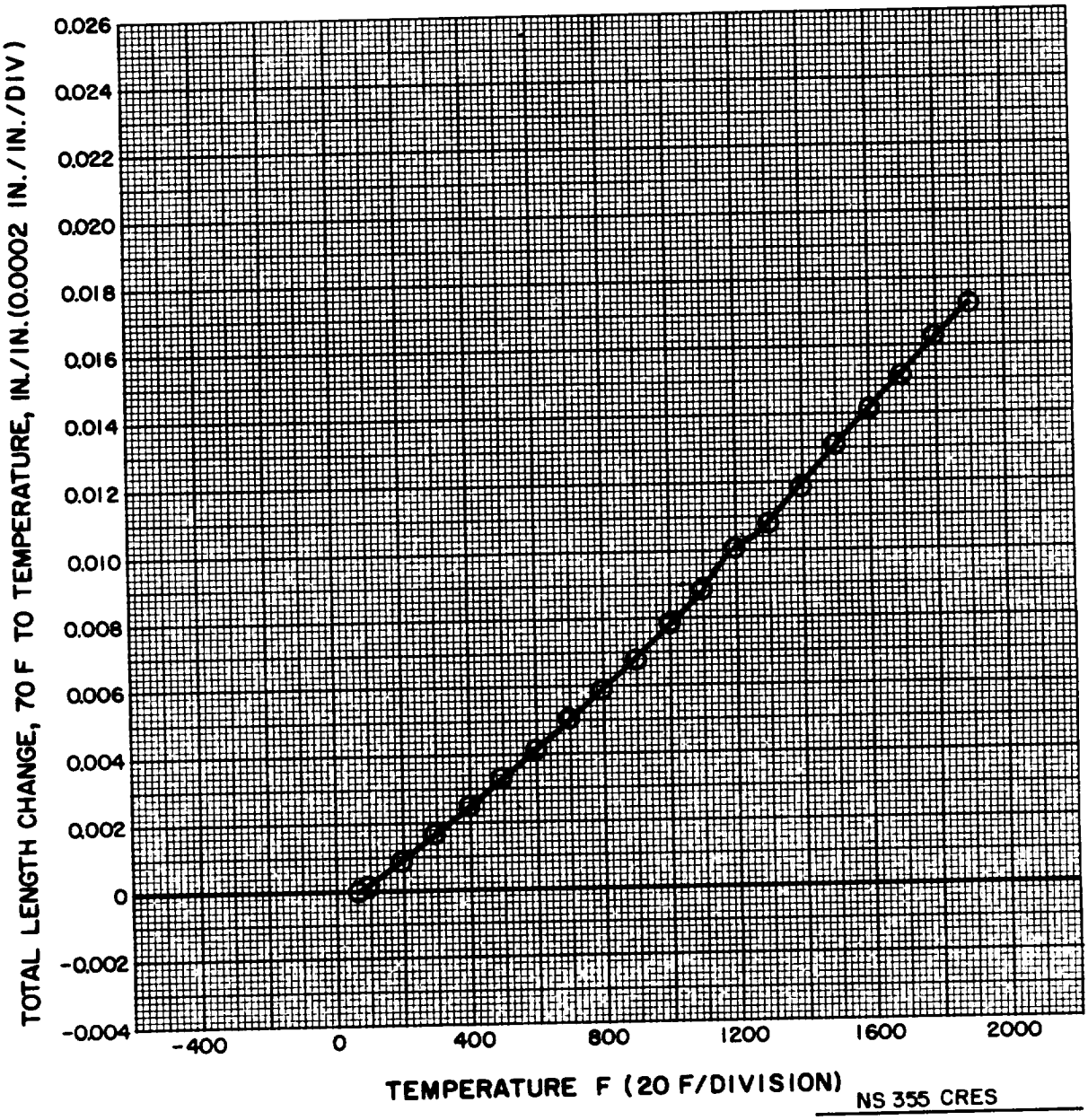
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 8-8-50
MATERIAL NS 355 CRES
FORM BAR
CONDITION HARD DRAWN
SPECIFICATION
DATE JULY 1965

NOTES:



NS 355 CRES

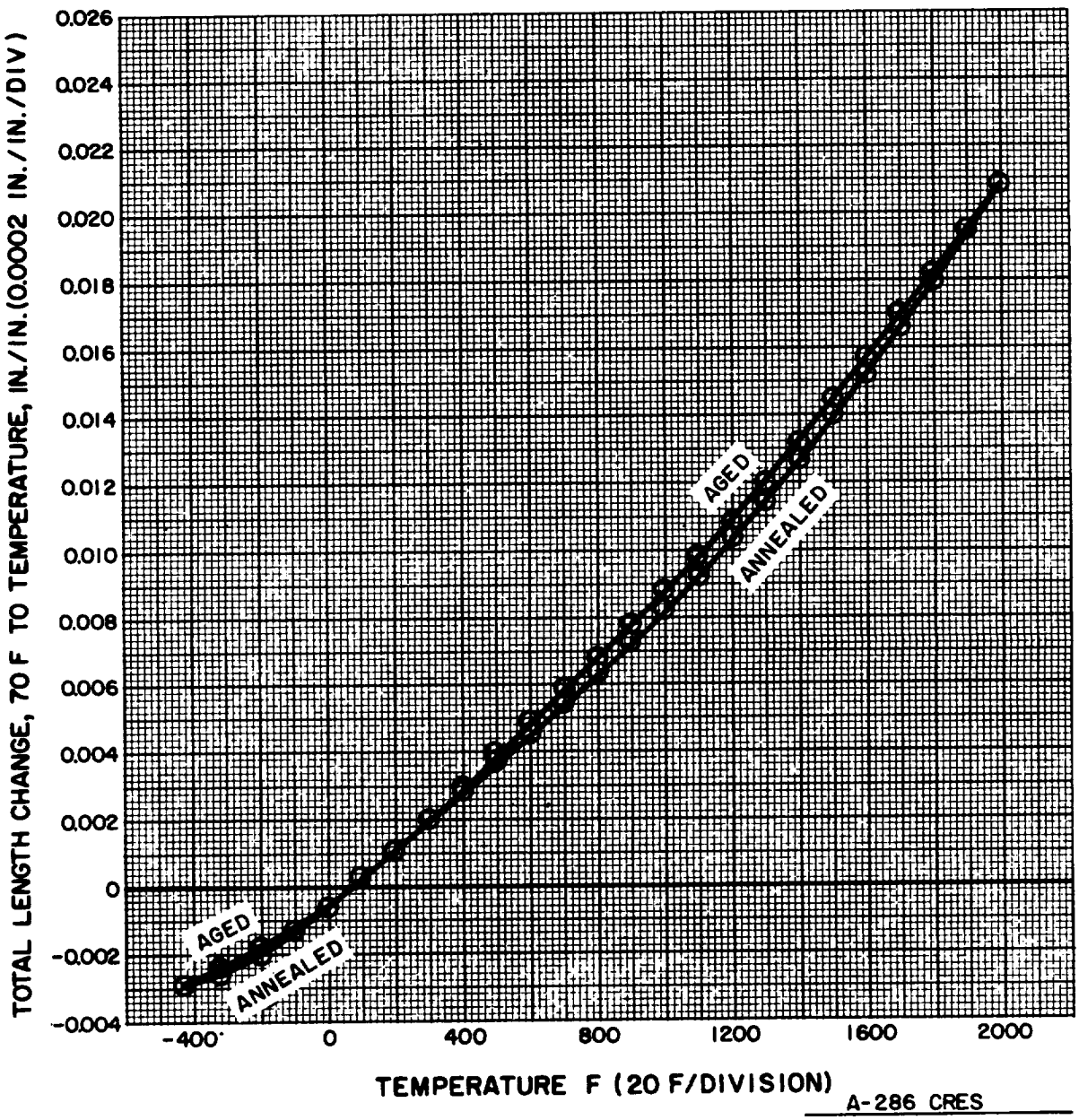
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·1·50
MATERIAL A-286 CRES
FORM BAR
CONDITION ANNEALED/AGED
SPECIFICATION AMS 5734, 5737
DATE JULY 1965

NOTES:



A-286 CRES

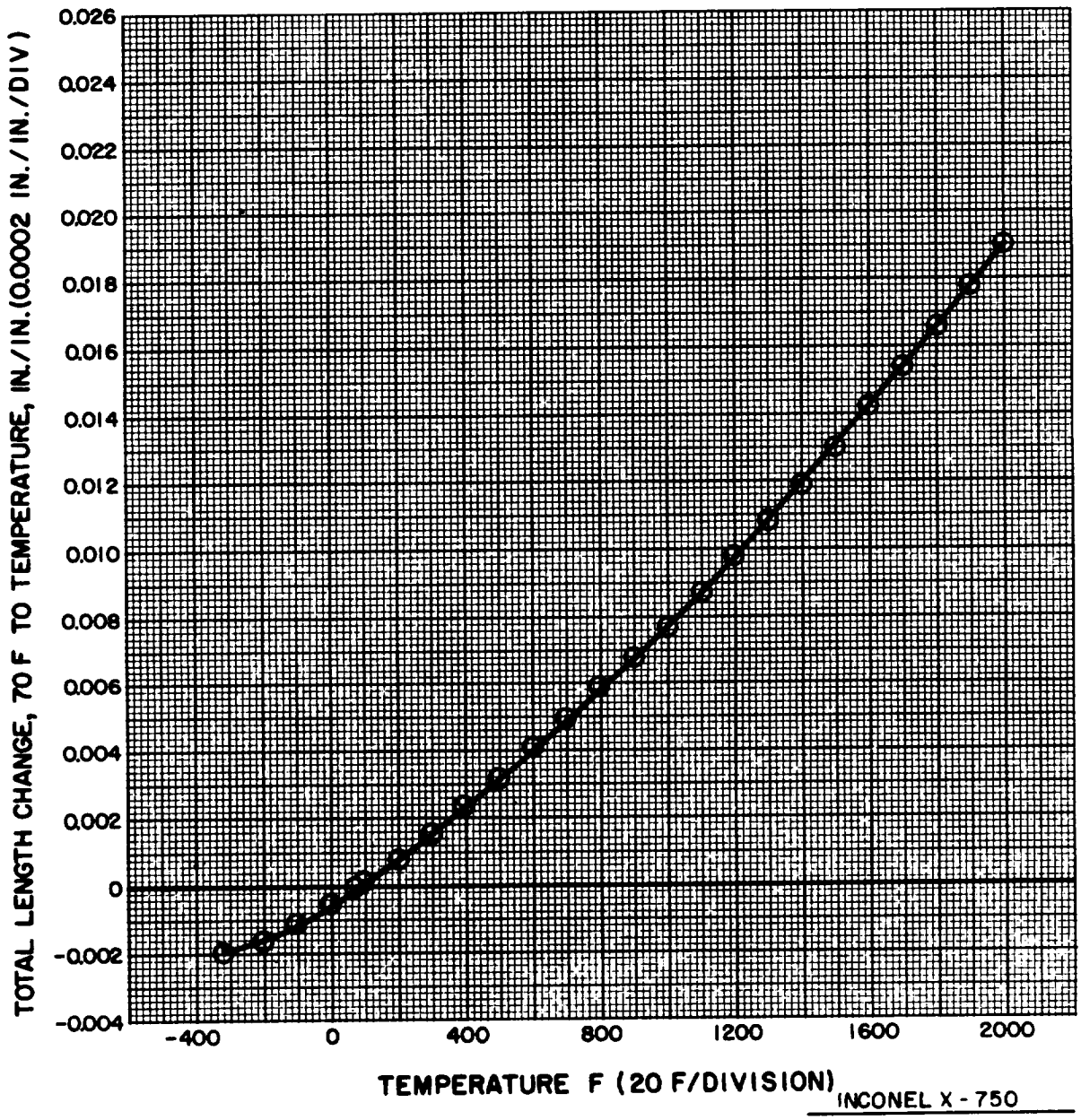
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·3·50
MATERIAL INCONEL X-750
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION RBO 170-043
DATE MARCH 1962

NOTES:



INCONEL X-750

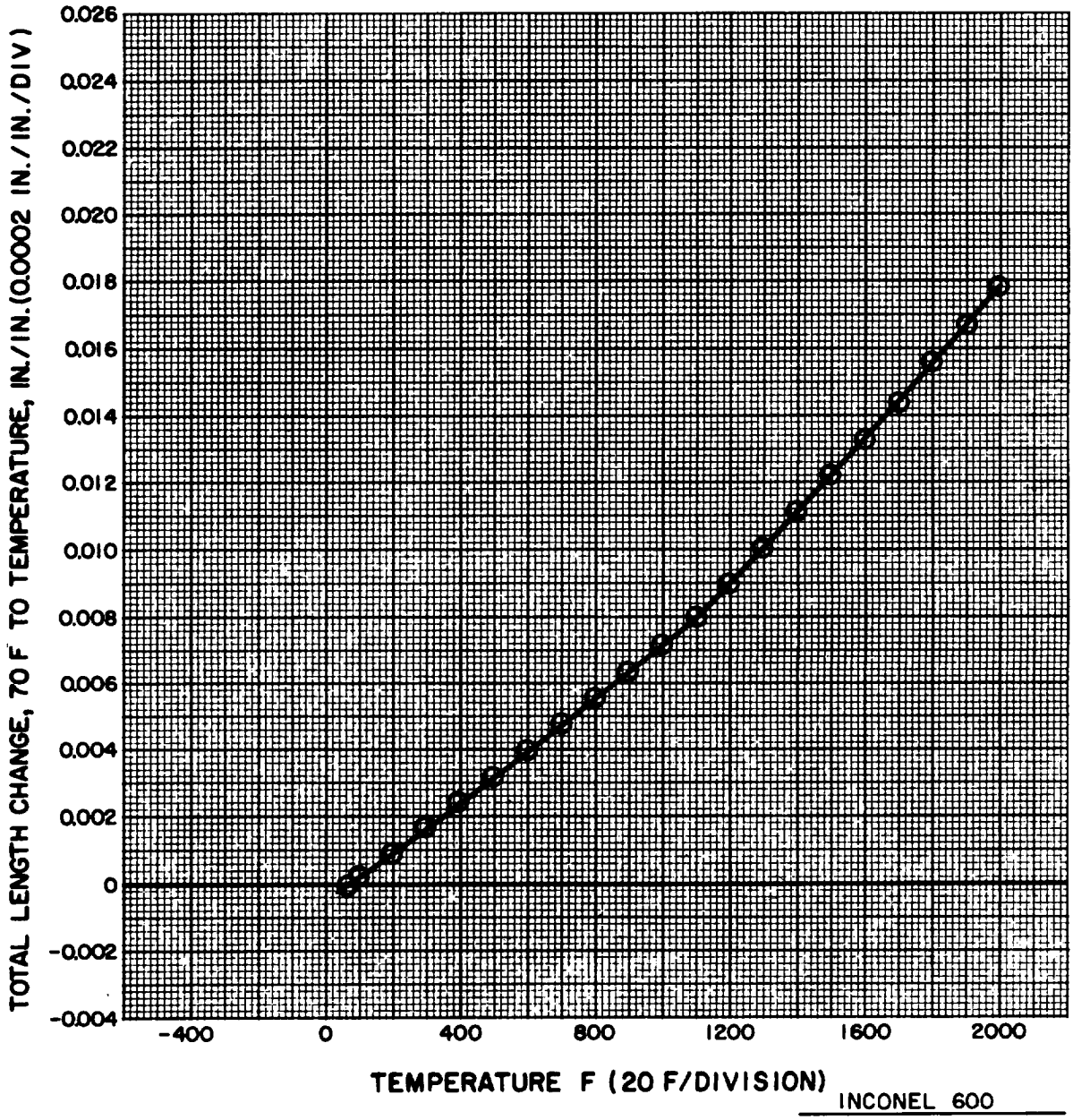
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·4·50
MATERIAL INCONEL 600
FORM BAR
CONDITION ANNEALED
SPECIFICATION MIL-N-6710
DATE MARCH 1962

NOTES: 16 Cr - 7 Fe - 76 Ni



INCONEL 600

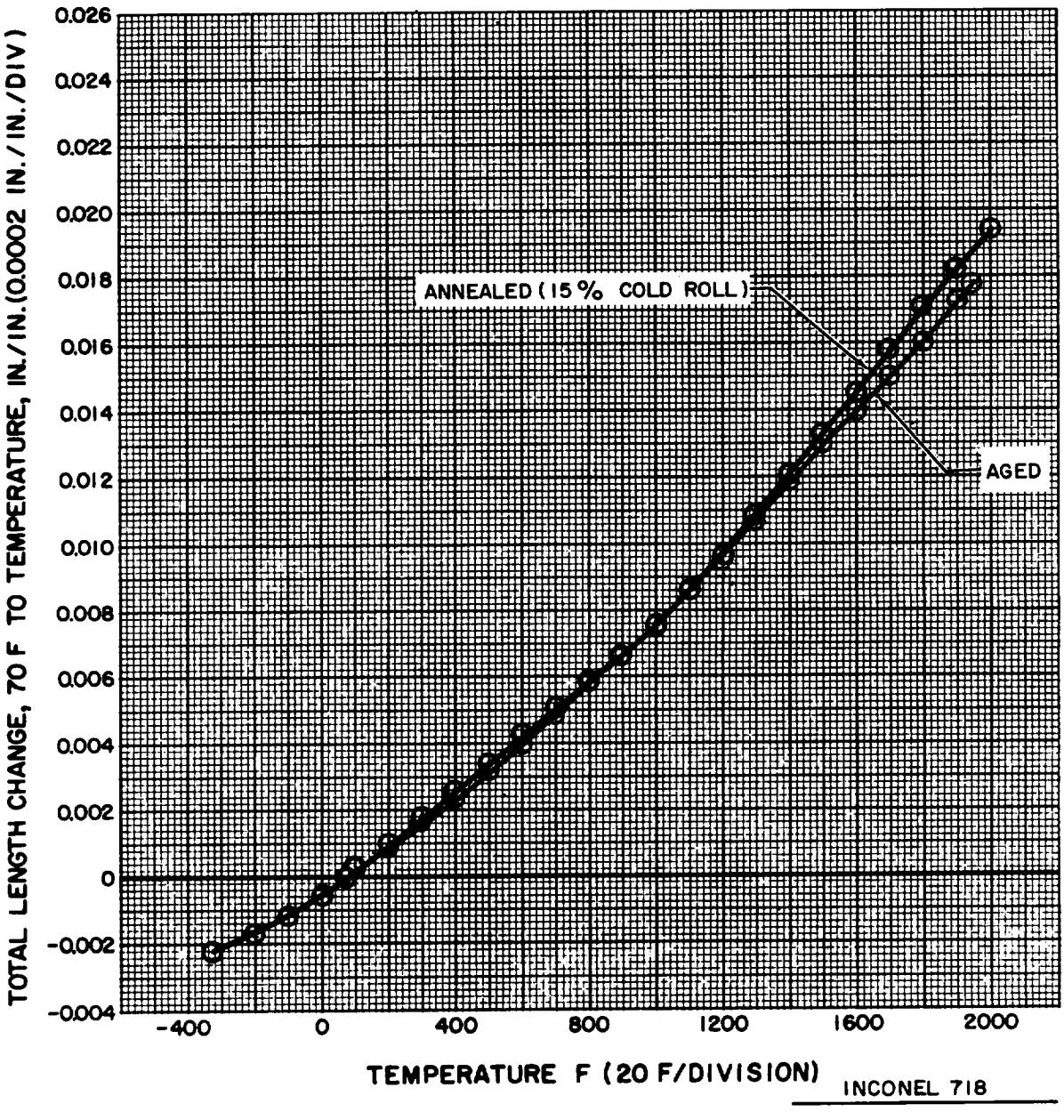
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9-5-50
MATERIAL INCONEL 718
FORM BAR
CONDITION ANNEALED (15% COLD ROLL)/AGED
SPECIFICATION RBO 170-038
DATE MARCH 1962

NOTES: BOTH ANNEALED AND 15% C.R. HAVE THE SAME CURVE



INCONEL 718

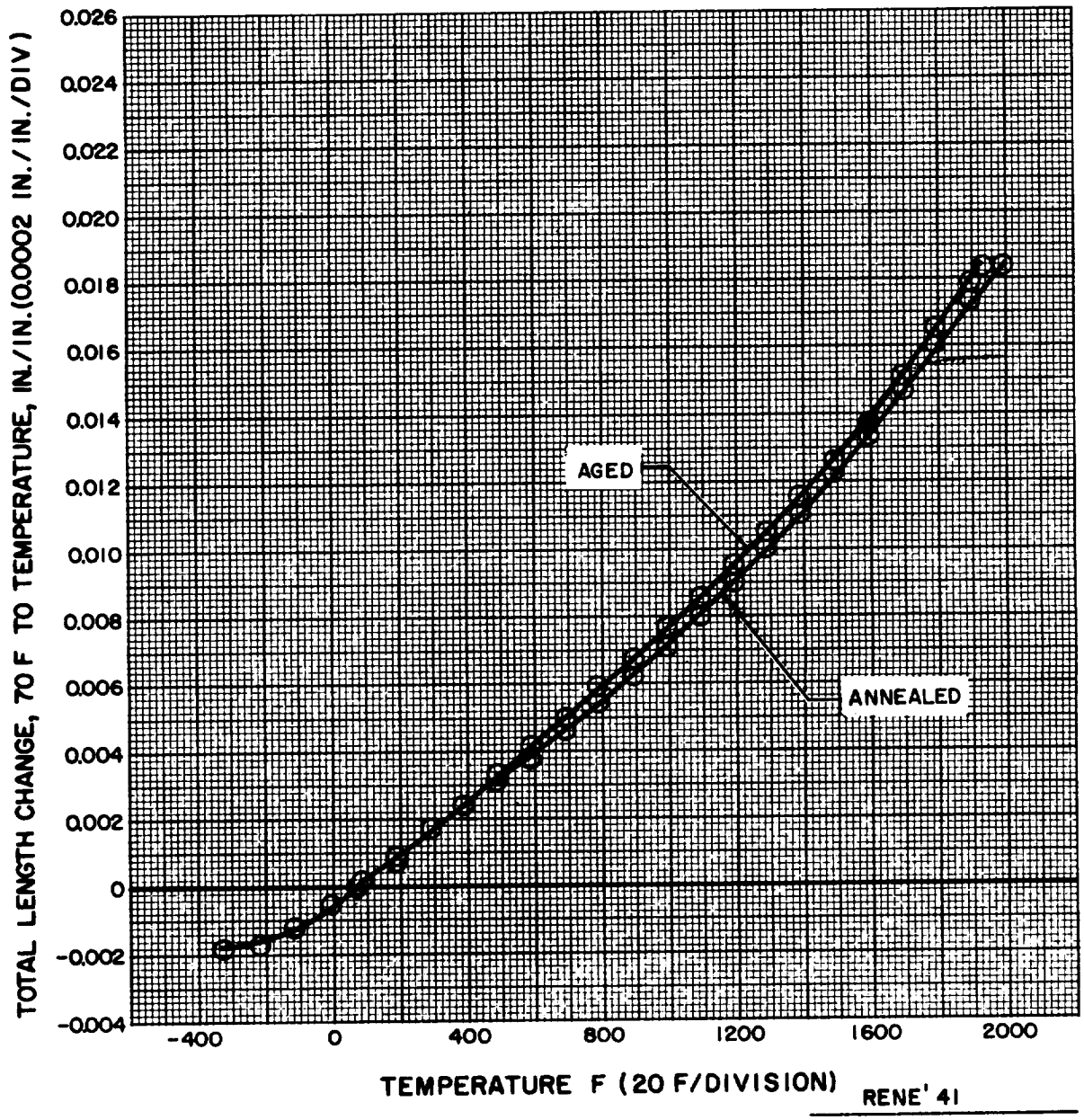
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·6·50
MATERIAL RENE' 41
FORM WROUGHT
CONDITION ANNEALED/AGED
SPECIFICATION RBO 170-049
DATE MARCH 1962

NOTES:



RENE' 41

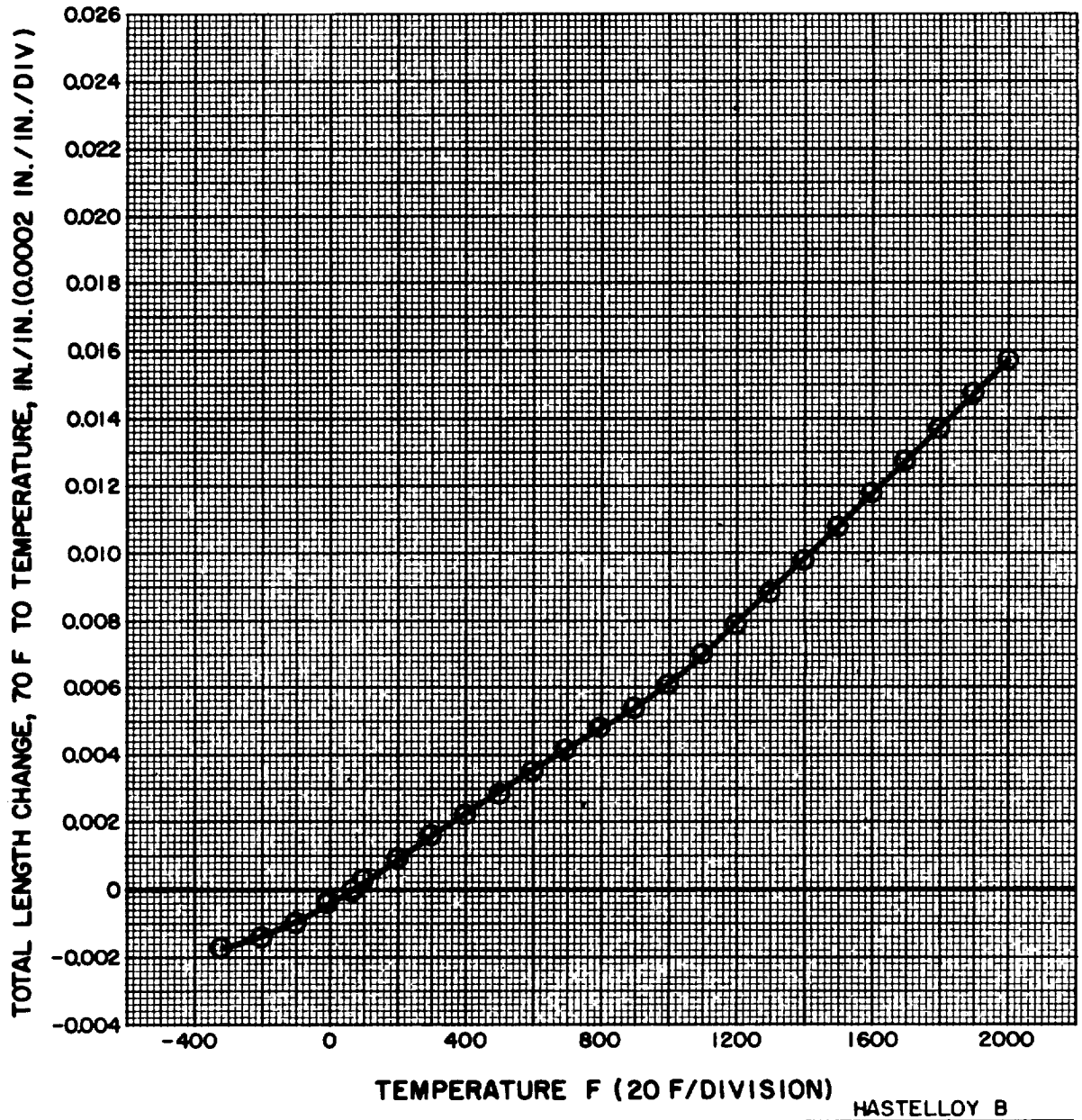
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·7·50
MATERIAL HASTELLOY B
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION RBO 170-002
DATE MARCH 1962

NOTES: 28 Mo - 2.5 Co - 5 Fe - BALANCE Ni



HASTELLOY B

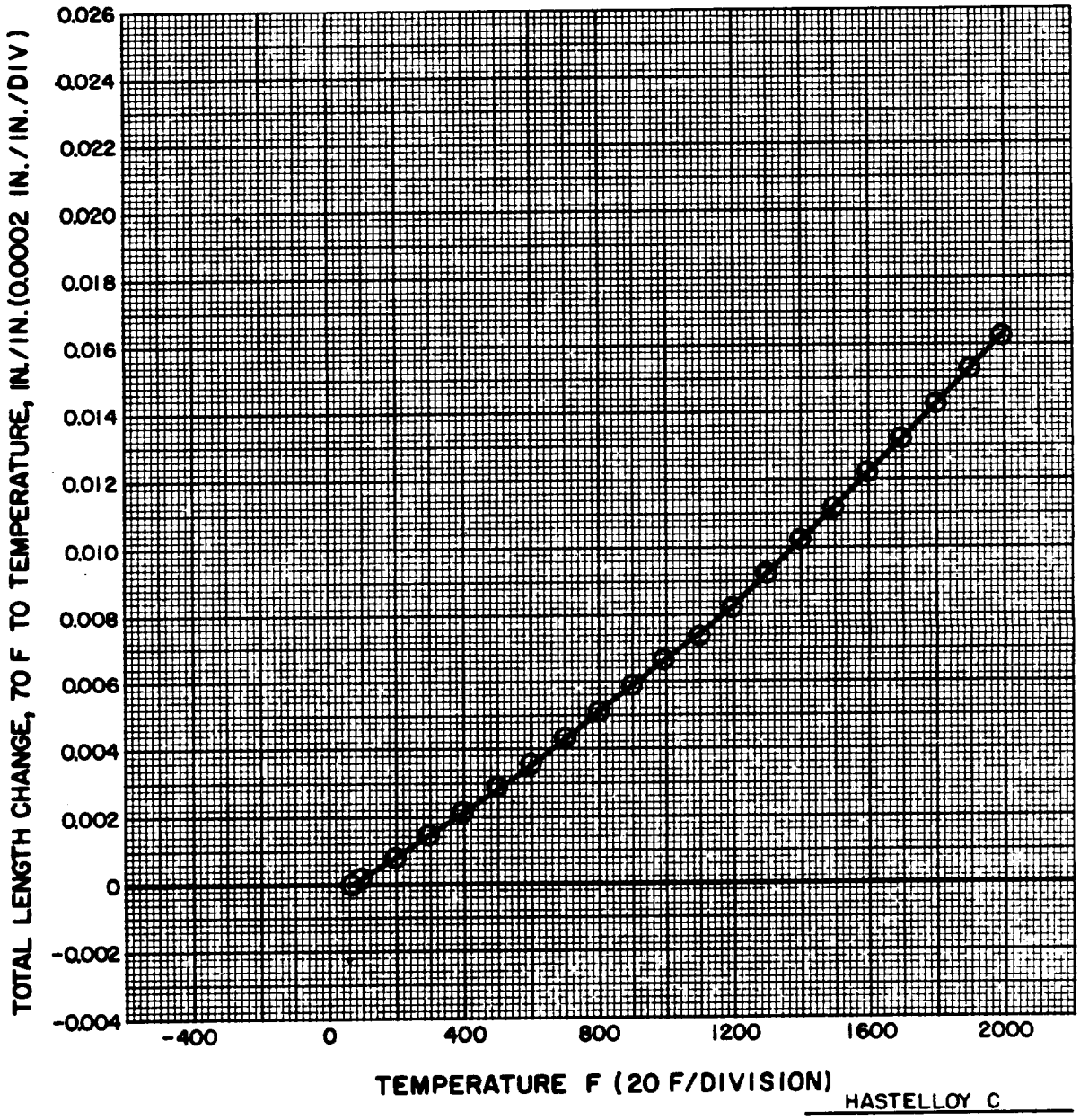
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·8·50
MATERIAL HASTELLOY C
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION RBO170-046
DATE MARCH 1962

NOTES: 16 Mo - 15 Cr - 4 W - 5 Fe - 2.5 Co - BALANCE Ni



HASTELLOY C

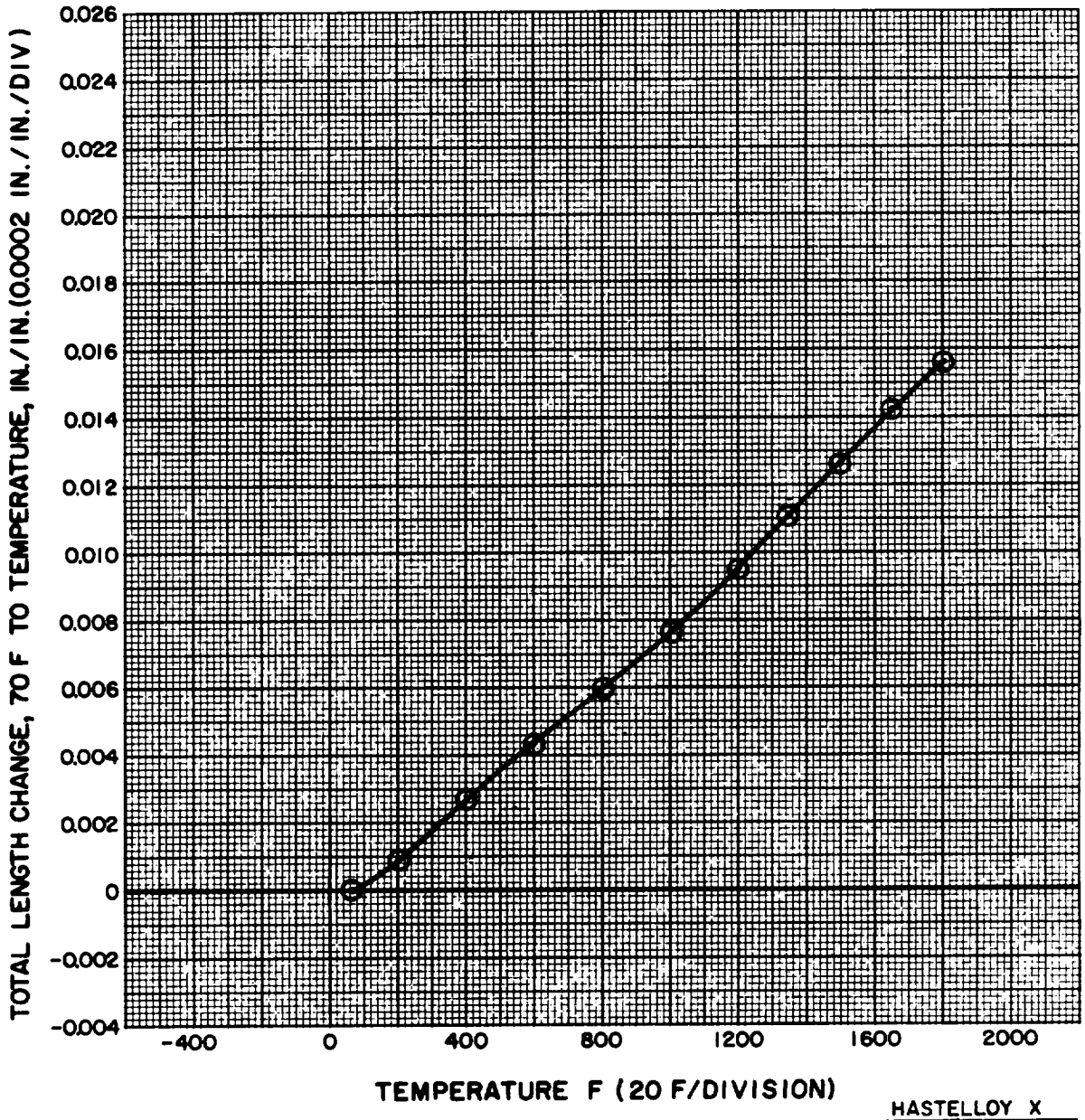
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE UNION CARBIDE-10-64

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·9·50
MATERIAL HASTELLOY X
FORM BAR
CONDITION ANNEALED
SPECIFICATION AMS-5754D
DATE DECEMBER 1966

NOTES: 22 Cr - 19 Fe - 9 Mo - 2 Co - BALANCE Ni



HASTELLOY X

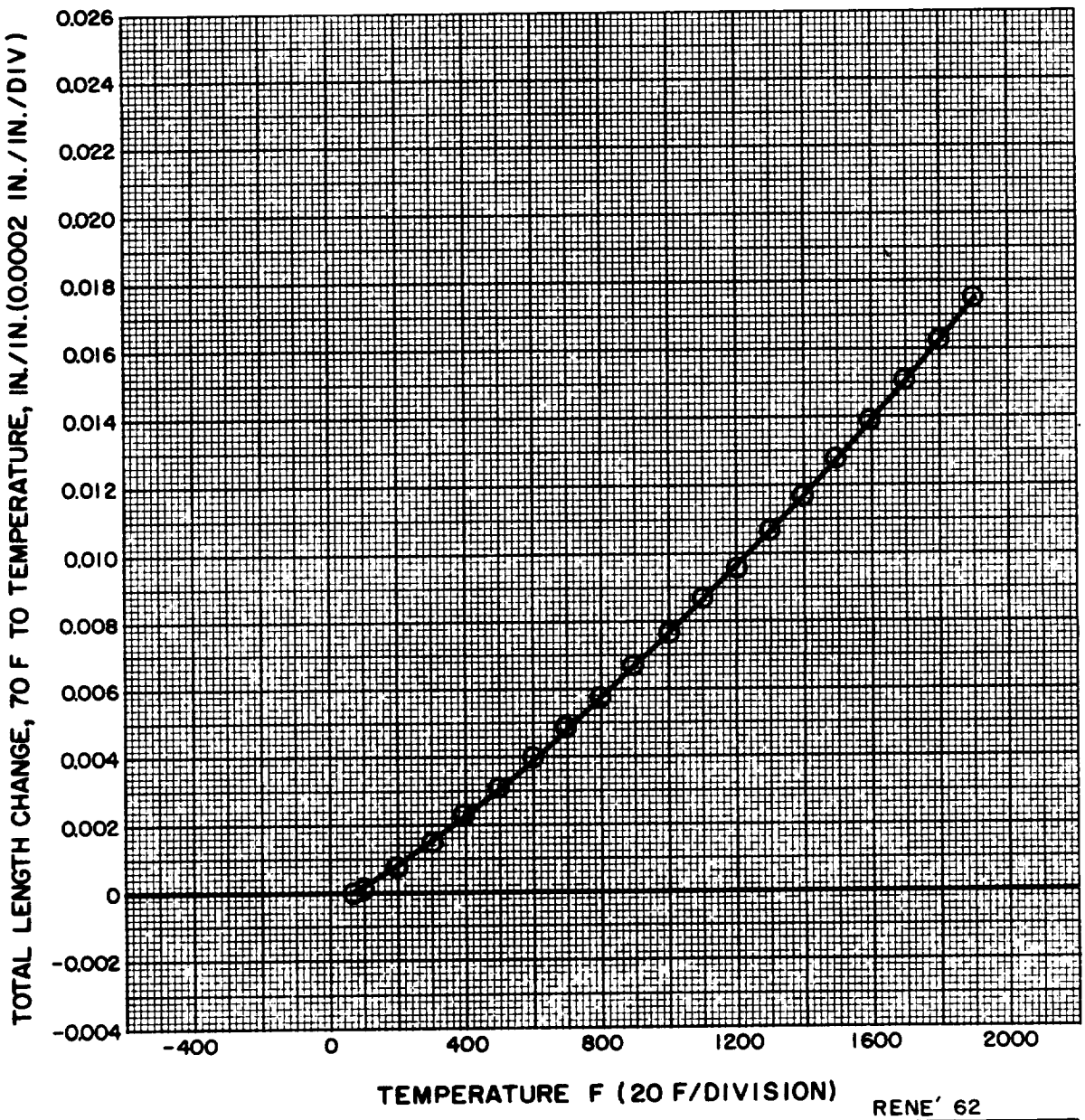
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 9·10·50
MATERIAL RENE' 62
FORM BAR
CONDITION AGED
SPECIFICATION –
DATE JULY 1965

NOTES: 15 Cr - 9 Mo - 2.25 Cb - 2.5 Ti - 1.25 Al - 22 Fe - BALANCE Ni



RENE' 62

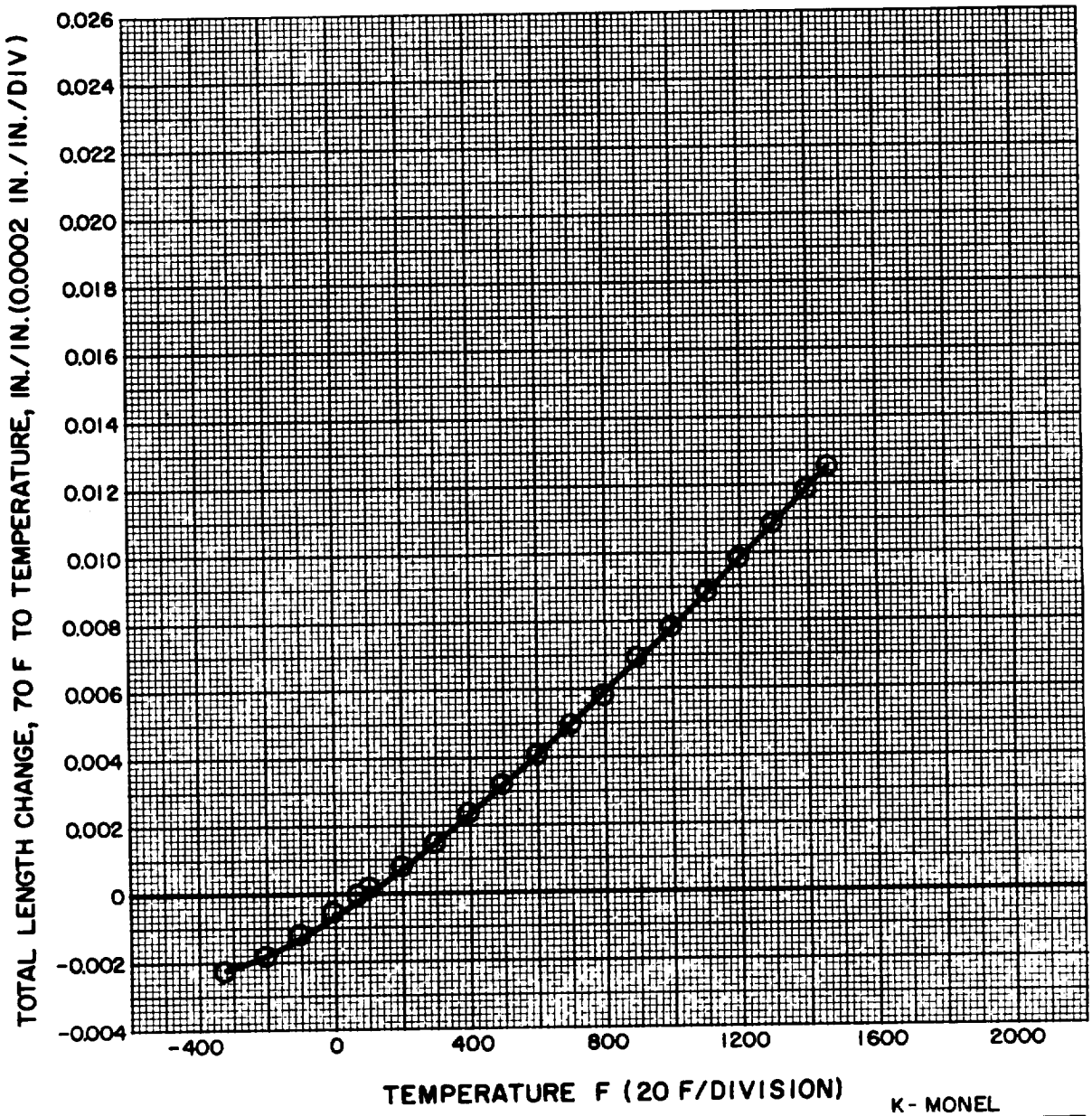
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 10·1·50
MATERIAL K-MONEL
FORM BAR
CONDITION AGED
SPECIFICATION RBO 170-051
DATE MARCH 1962

NOTES:



K-MONEL

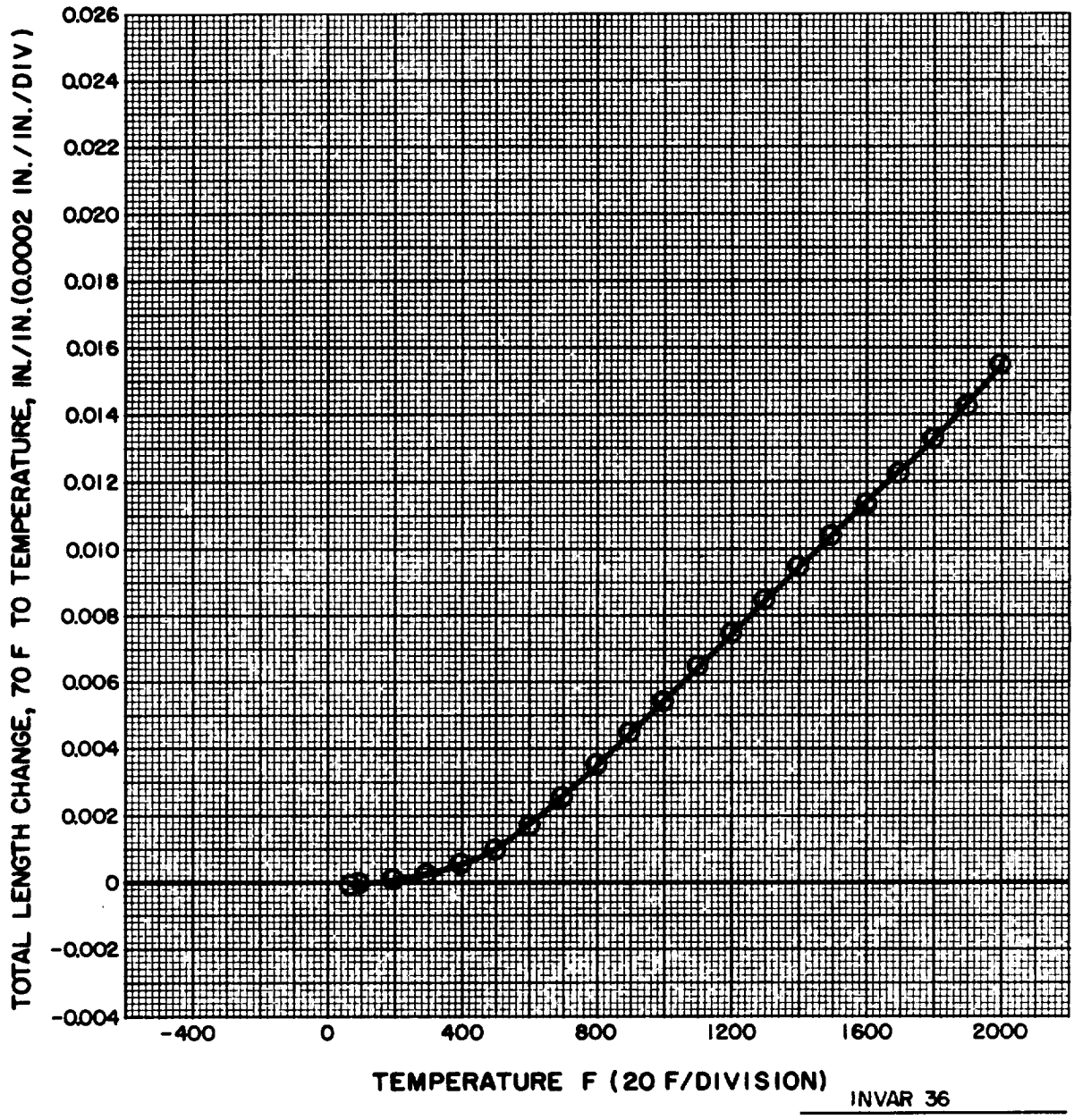
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 10·2·50
MATERIAL INVAR 36
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 160-028
DATE JULY 1965

NOTES:



INVAR 36

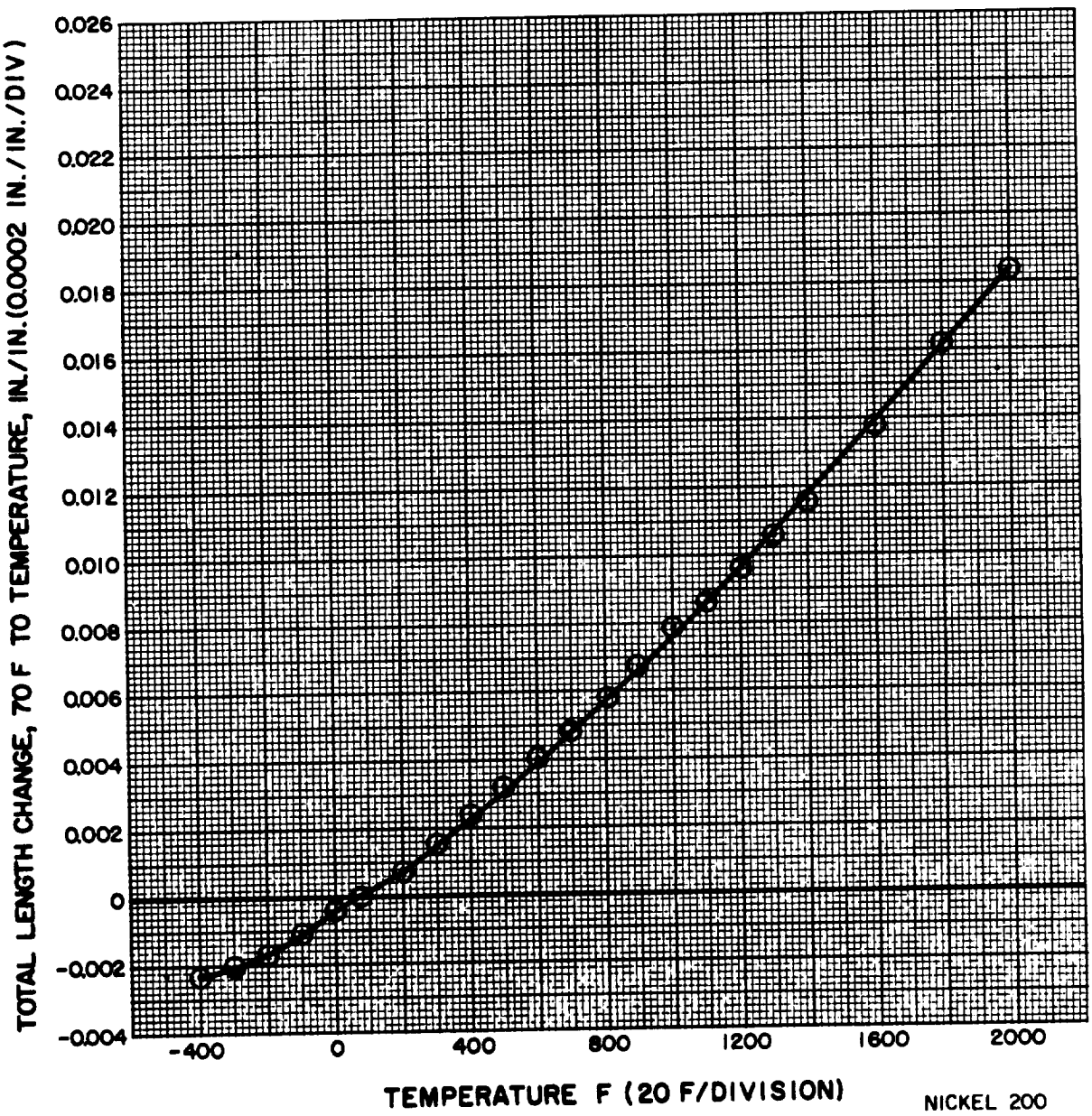
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE INCO DATA

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 10·3·50
MATERIAL NICKEL 200
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 170-014
DATE MARCH 1962

NOTES: 99.5 Ni



NICKEL 200

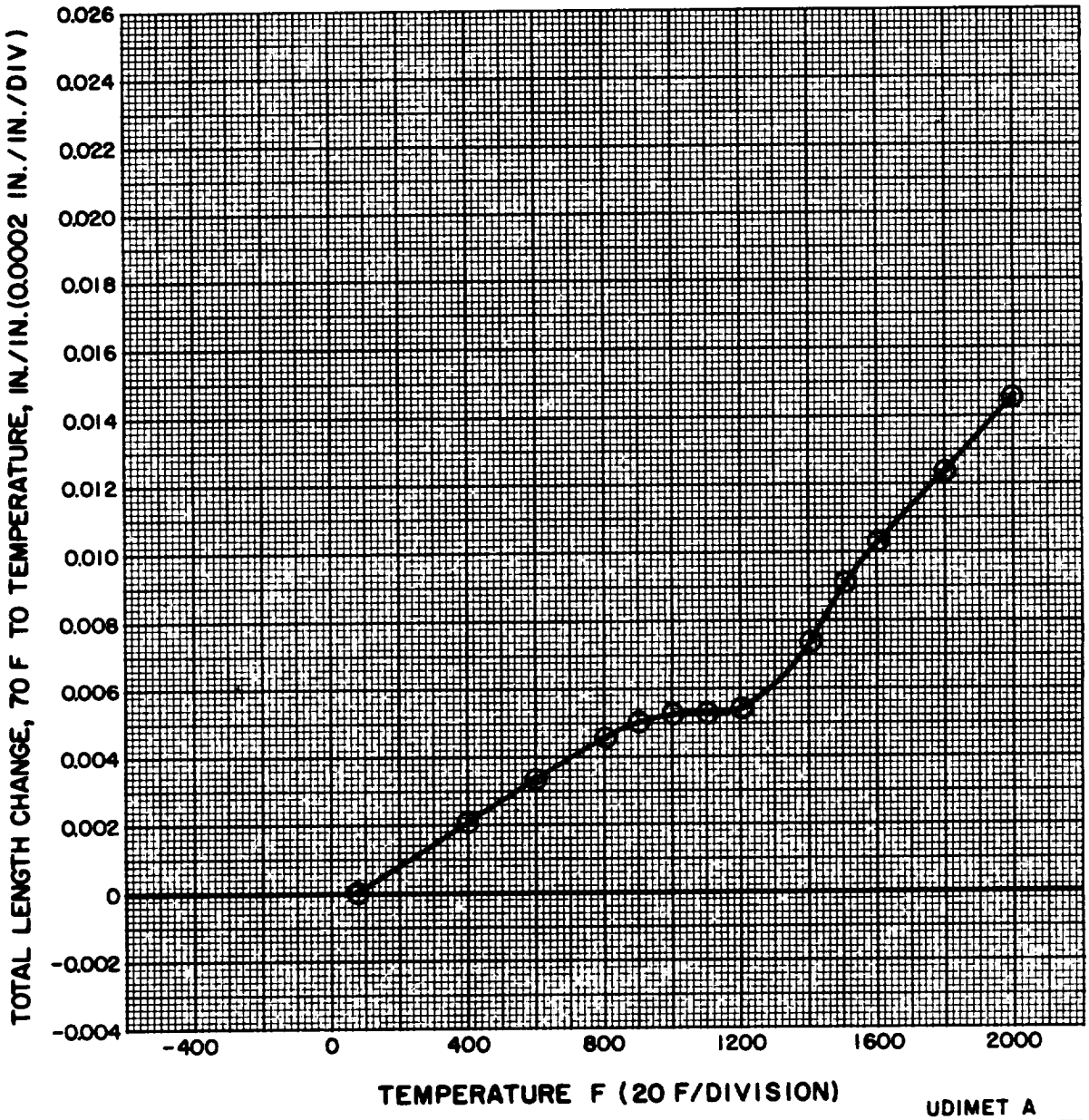
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 10·4·50
MATERIAL UDIMET A
FORM BAR
CONDITION SEE NOTES
SPECIFICATION
DATE DECEMBER 1966

NOTES: 1500 F/1 HR, A.C.; 1300 F/1 HR, A.C.; -100 F/16 HR, A.W.; 900 F/1 HR, A.C.
23 Ni - 1.7 Ti - .3 Al - BALANCE Fe



UDIMET A

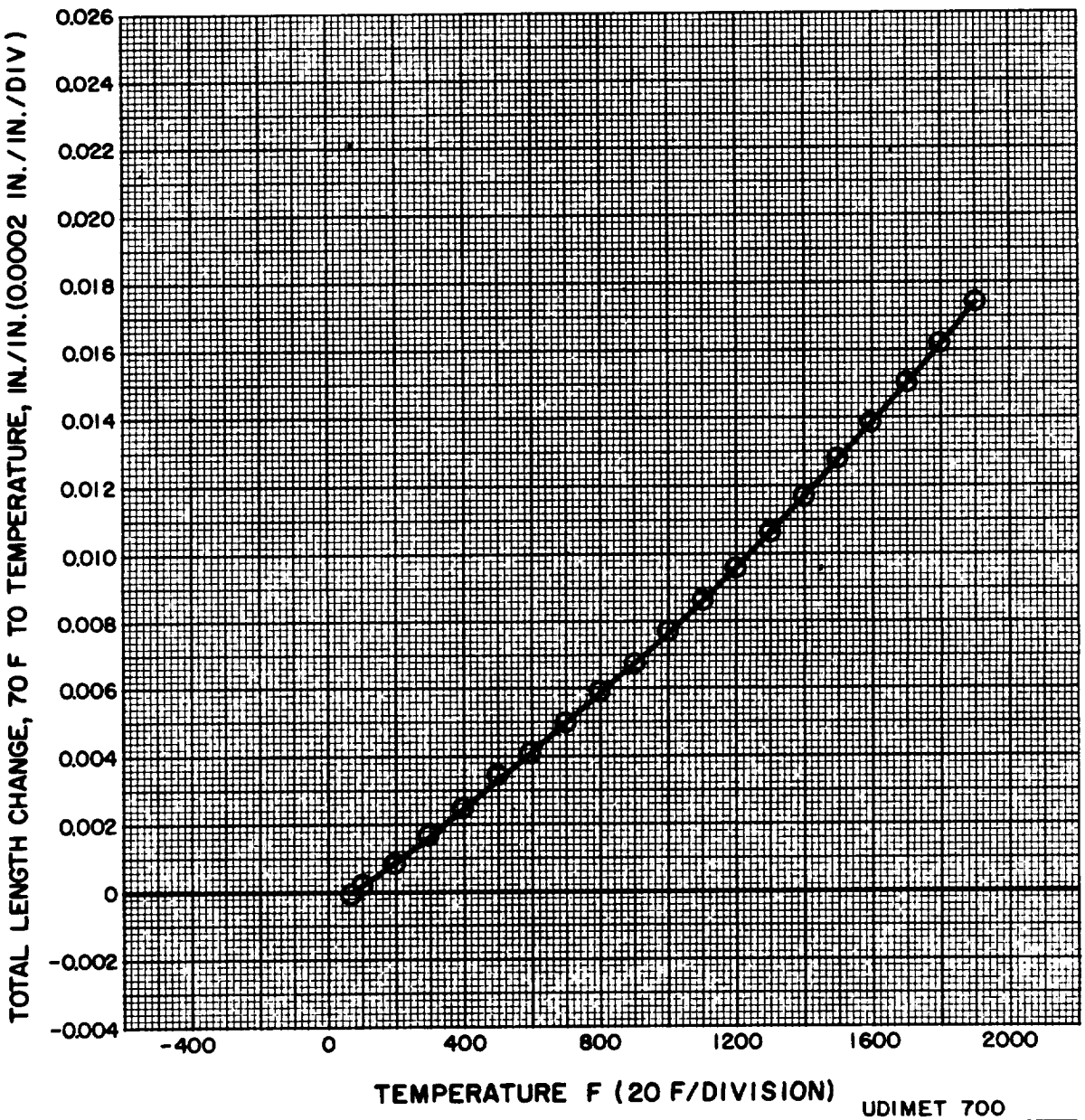
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 10·5·50
MATERIAL UDIMET 700
FORM BAR
CONDITION AGED
SPECIFICATION –
DATE 1964

NOTES: 15Cr-18Co-5Mo-3Ti-4Al BALANCE Ni



UDIMET 700

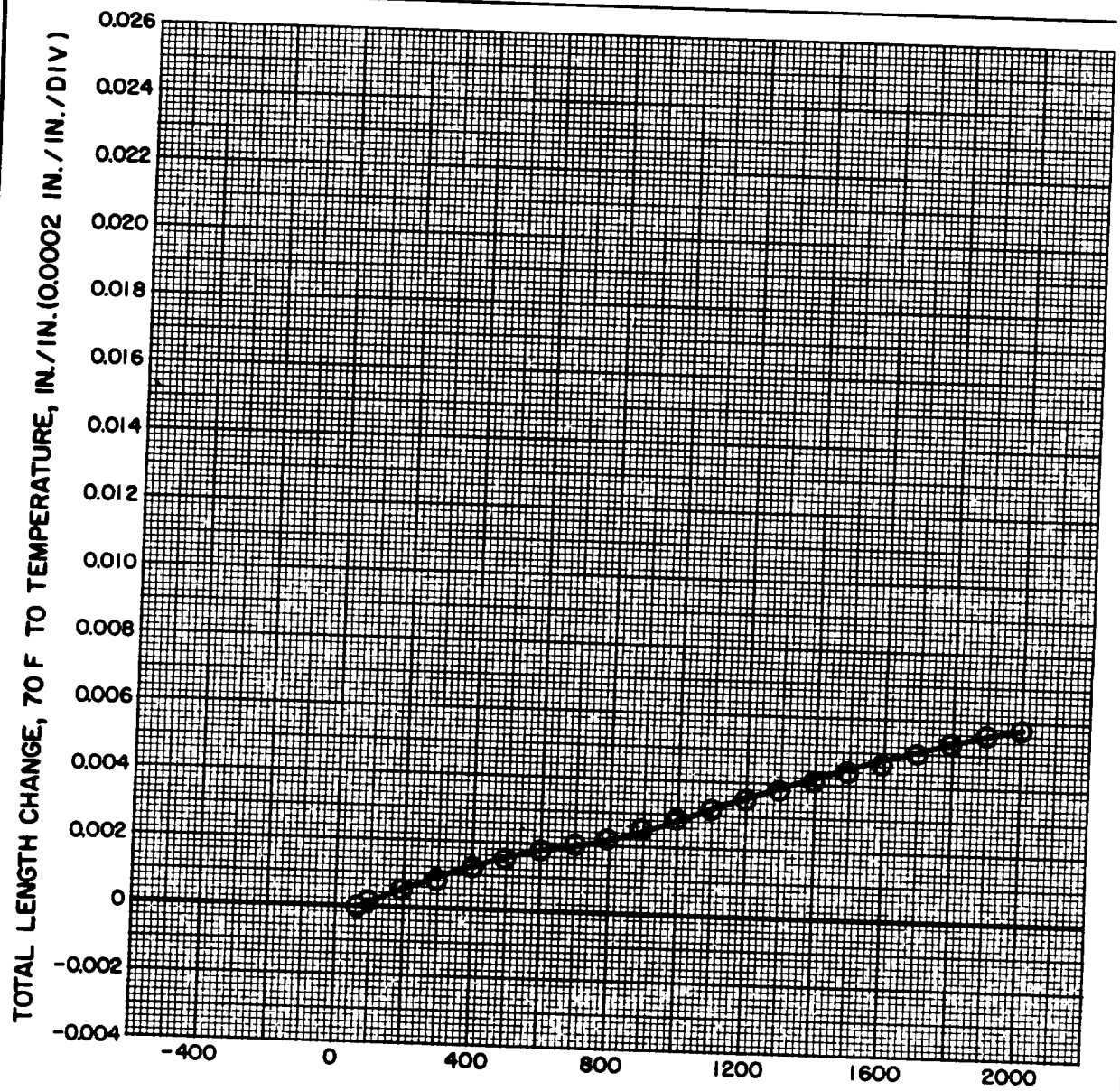
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 11·2·50
MATERIAL Cb-10Ti-10Mo
FORM PLATE
CONDITION AS RECIEVED
SPECIFICATION -
DATE MARCH 1962

NOTES:



Cb-10Ti-10Mo

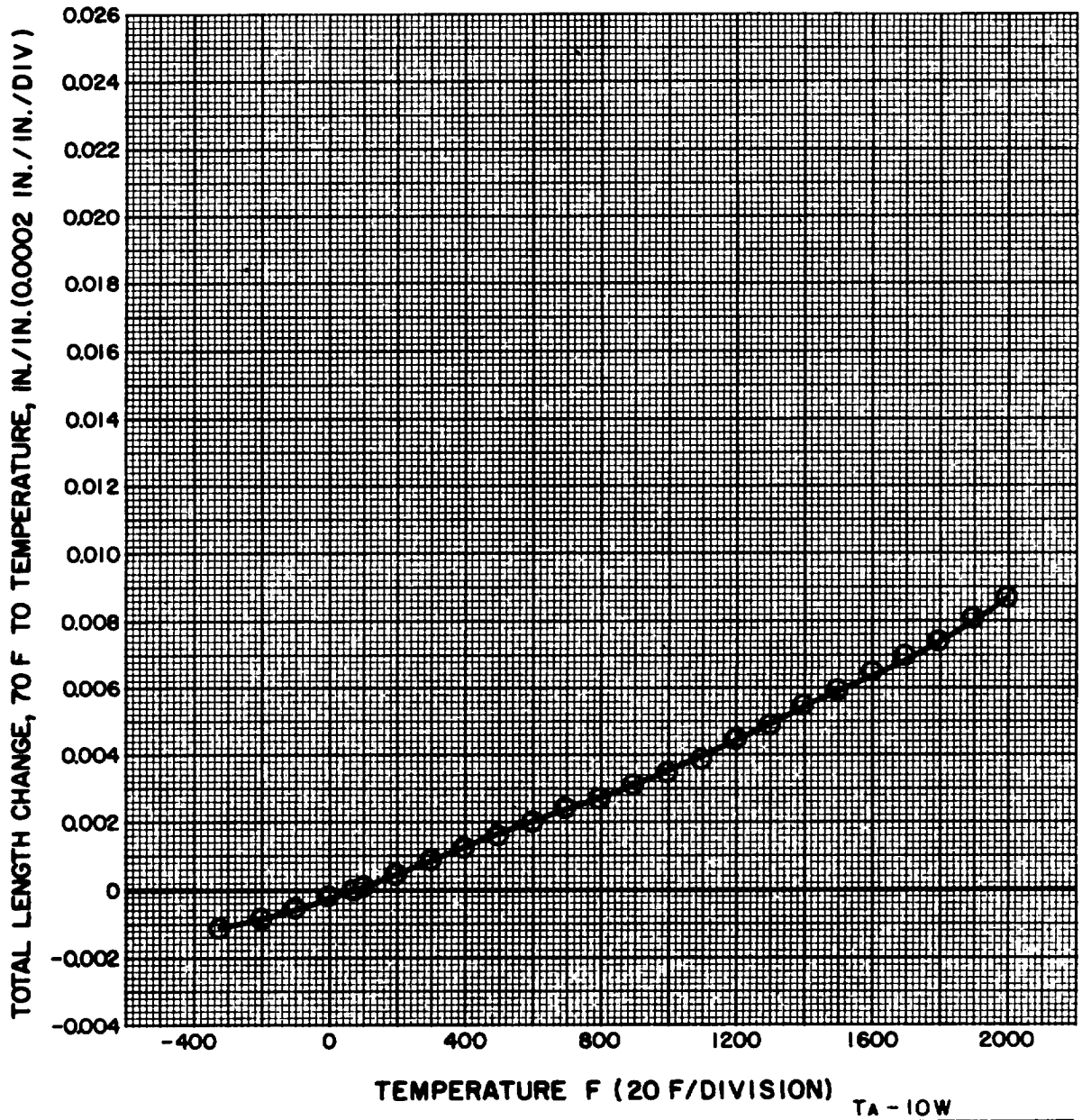
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 11-6-50
MATERIAL TA-10W
FORM BAR
CONDITION AS RECEIVED
SPECIFICATION AMS 7848
DATE MARCH 1962

NOTES:



TA-10W

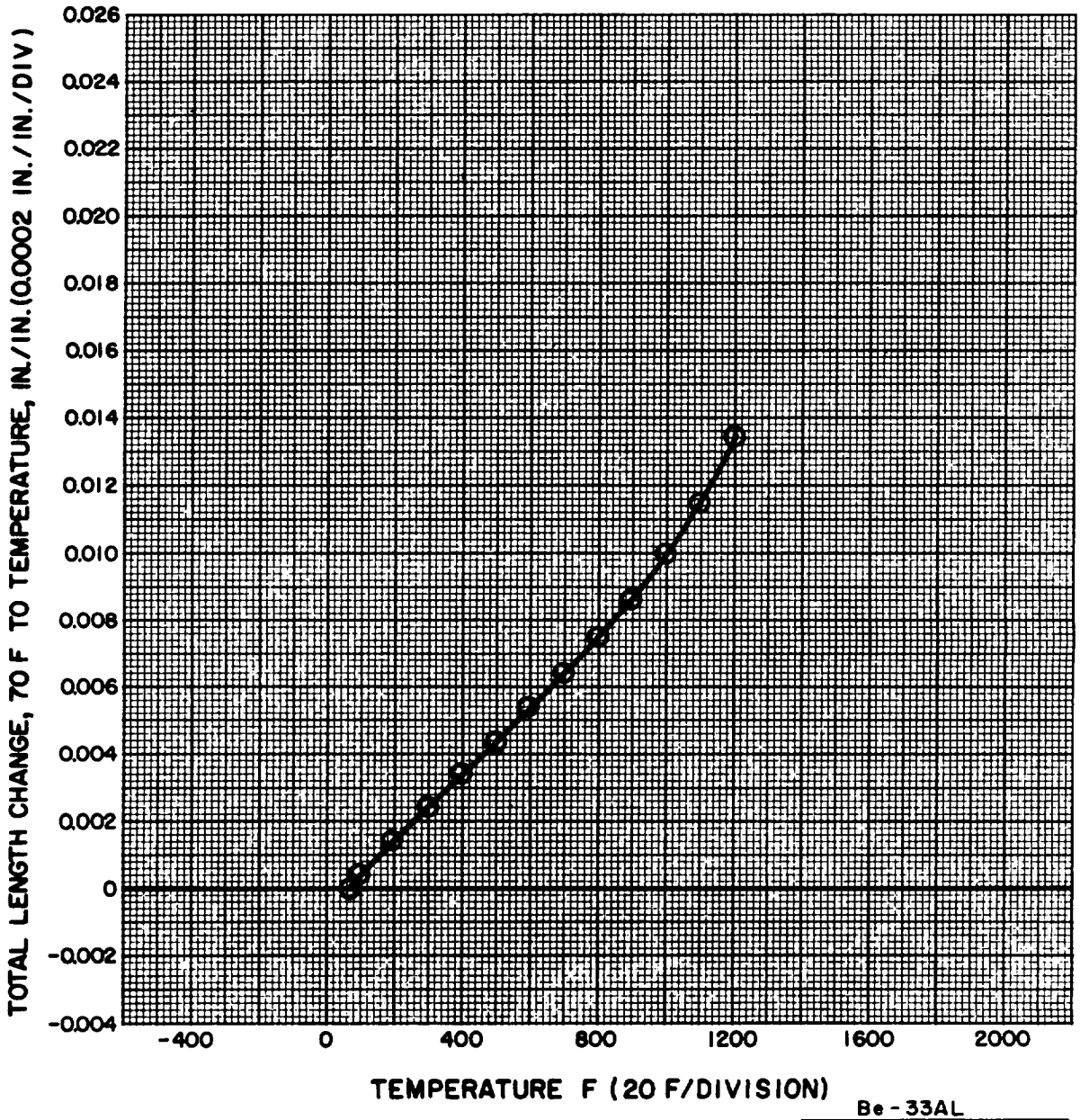
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE LOCKHEED DATA

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 11·7·50
MATERIAL Be - 33AL
FORM BAR
CONDITION AS EXTRUDED
SPECIFICATION -
DATE JULY 1965

NOTES:



Be - 33AL

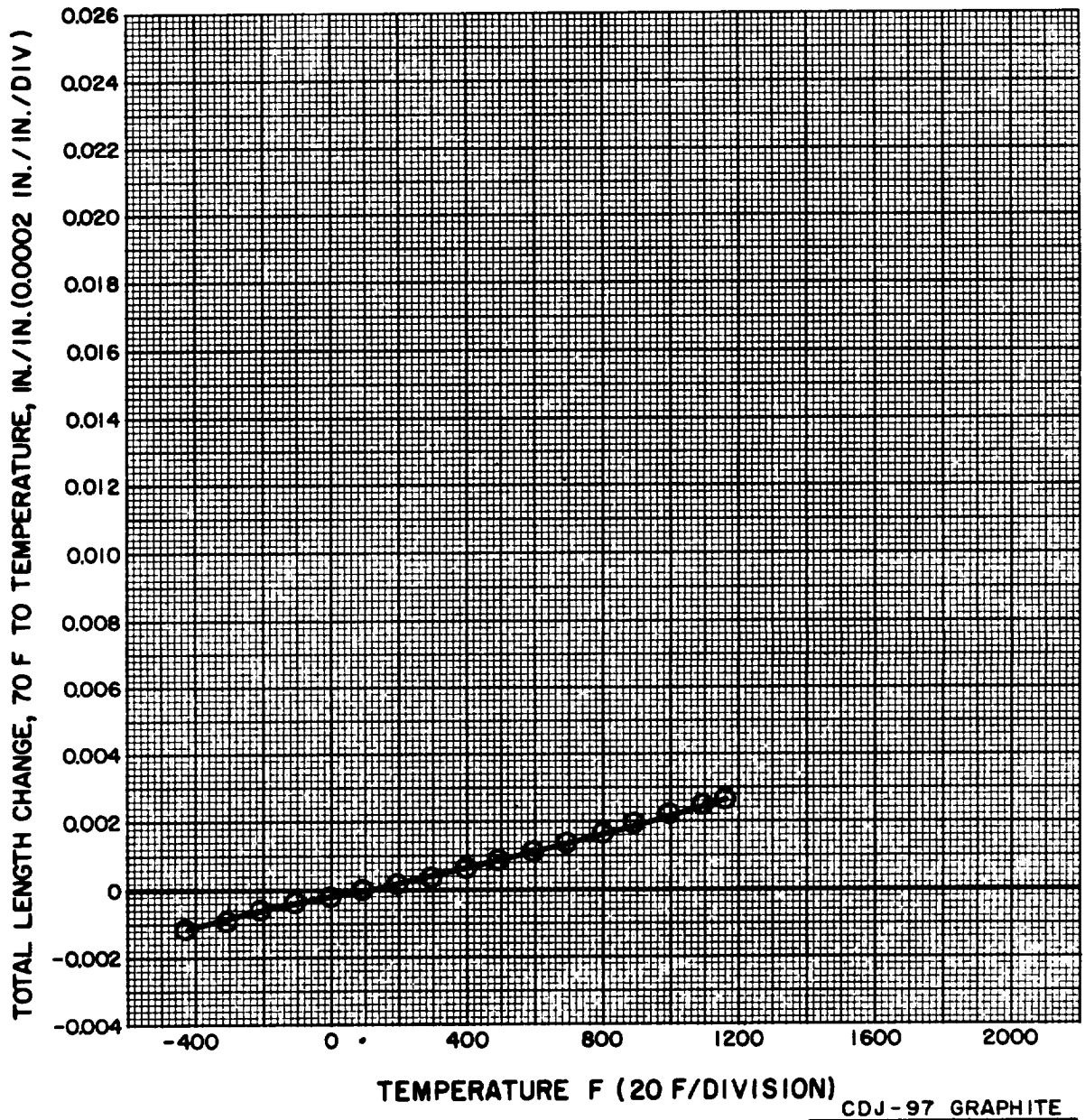
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION
PROPERTIES
AT
ELEVATED TEMPERATURES

CHART NO. 12-1-50
MATERIAL CDJ-97 GRAPHITE
FORM
CONDITION
SPECIFICATION -
DATE JULY 1965

NOTES:



CDJ-97 GRAPHITE

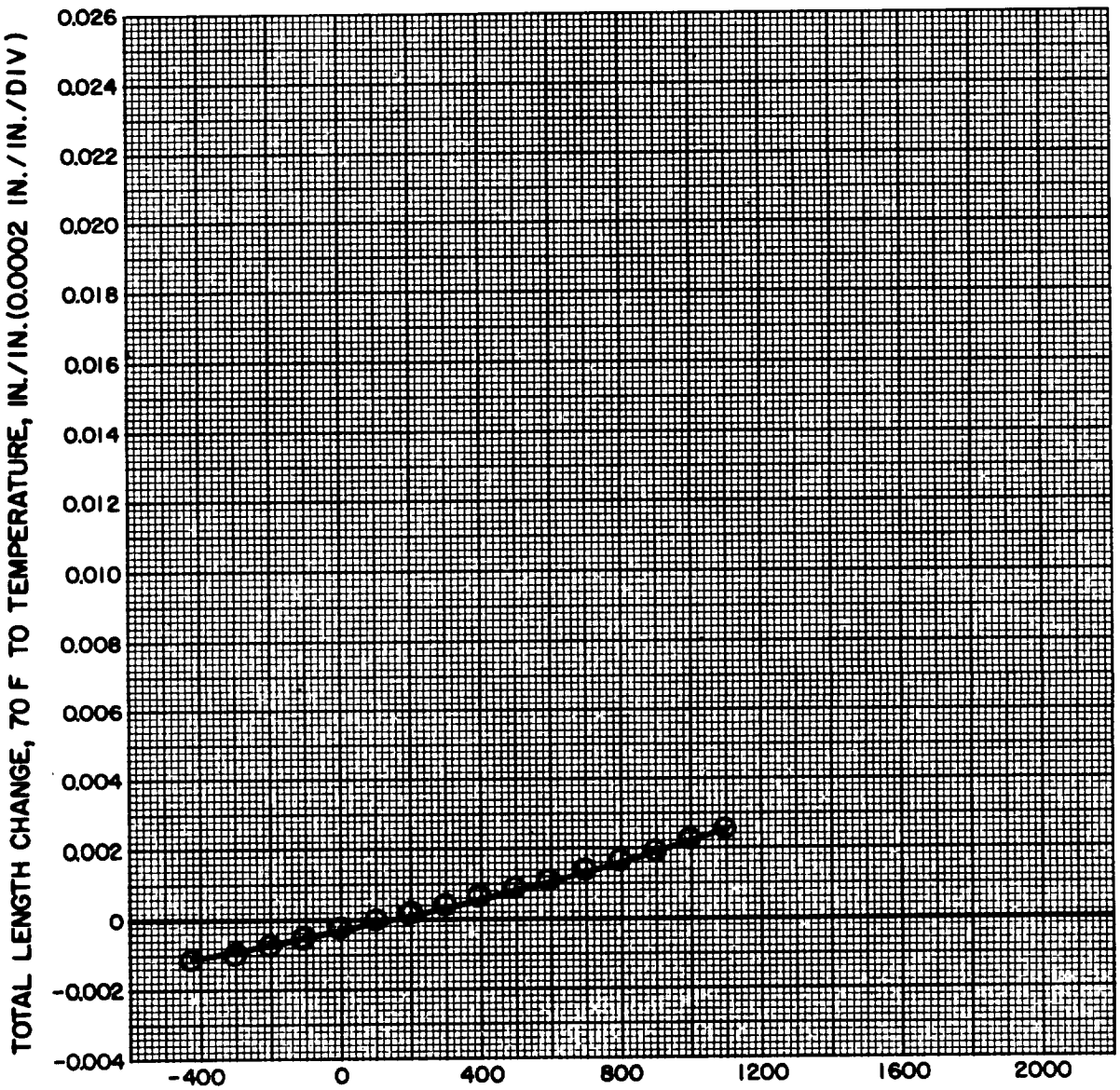
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 12·2·50
MATERIAL P-03-XHT-GRAPHITE
FORM
CONDITION
SPECIFICATION
DATE JULY 1965

NOTES:



P-03-XHT-GRAPHITE

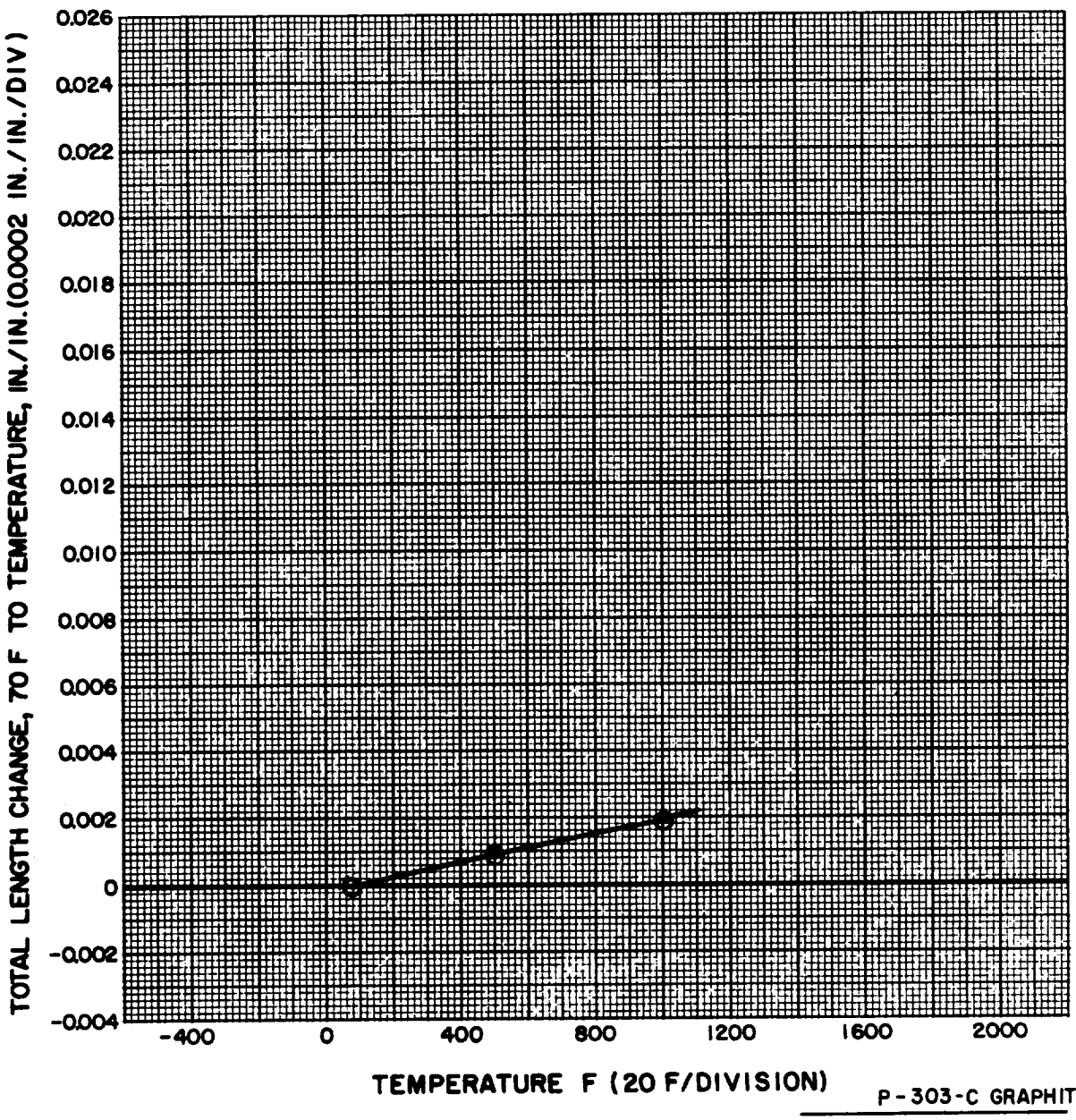
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION
PROPERTIES
AT
ELEVATED TEMPERATURES

CHART NO. 12-3-50
MATERIAL P-303-C GRAPHITE
FORM
CONDITION
SPECIFICATION
DATE

NOTES:



P-303-C GRAPHITE

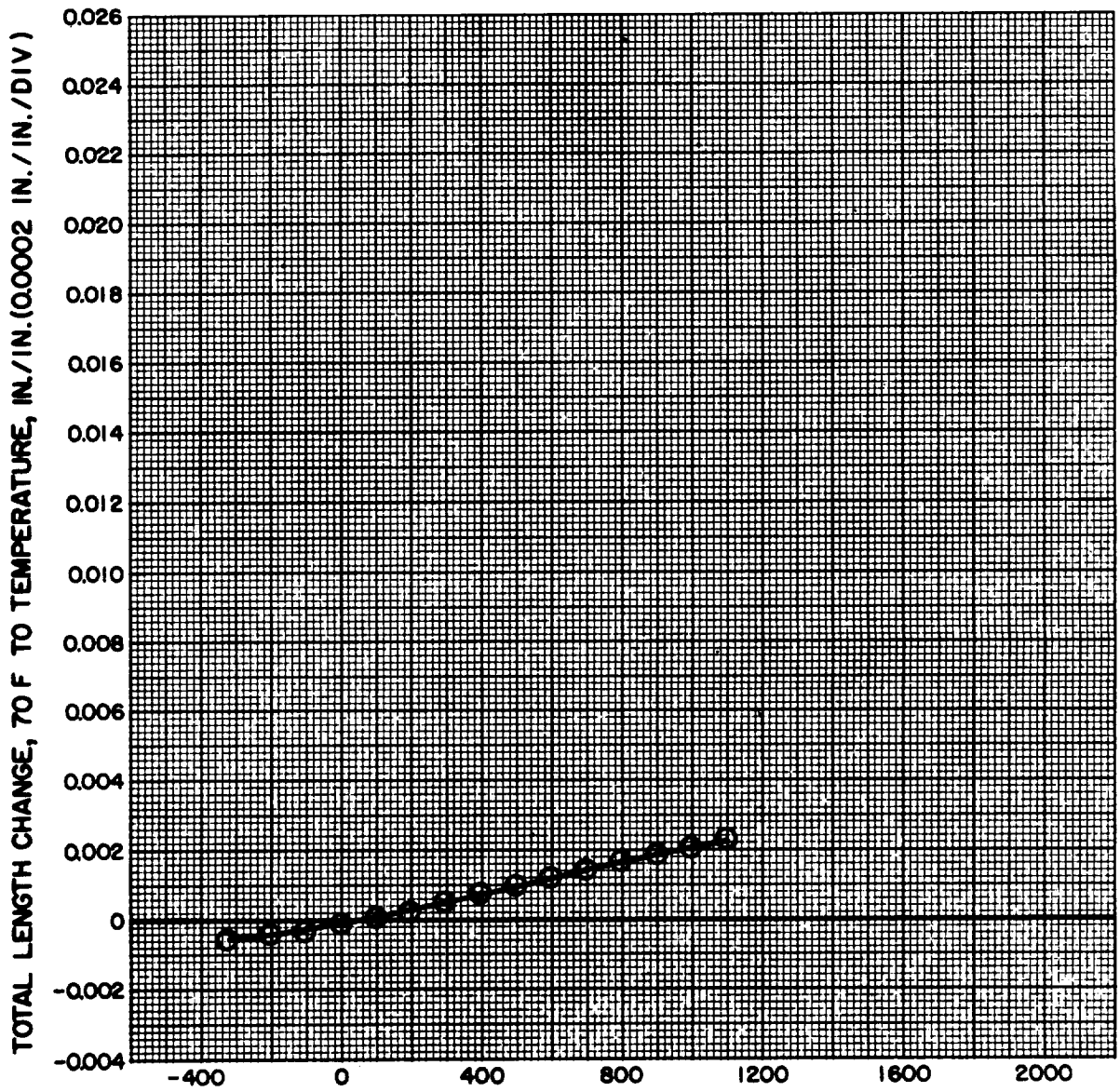
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 12·4·50
MATERIAL #692 GRAPHITE
FORM
CONDITION AS RECIEVED
SPECIFICATION -
DATE MARCH 1962

NOTES:



#692 GRAPHITE

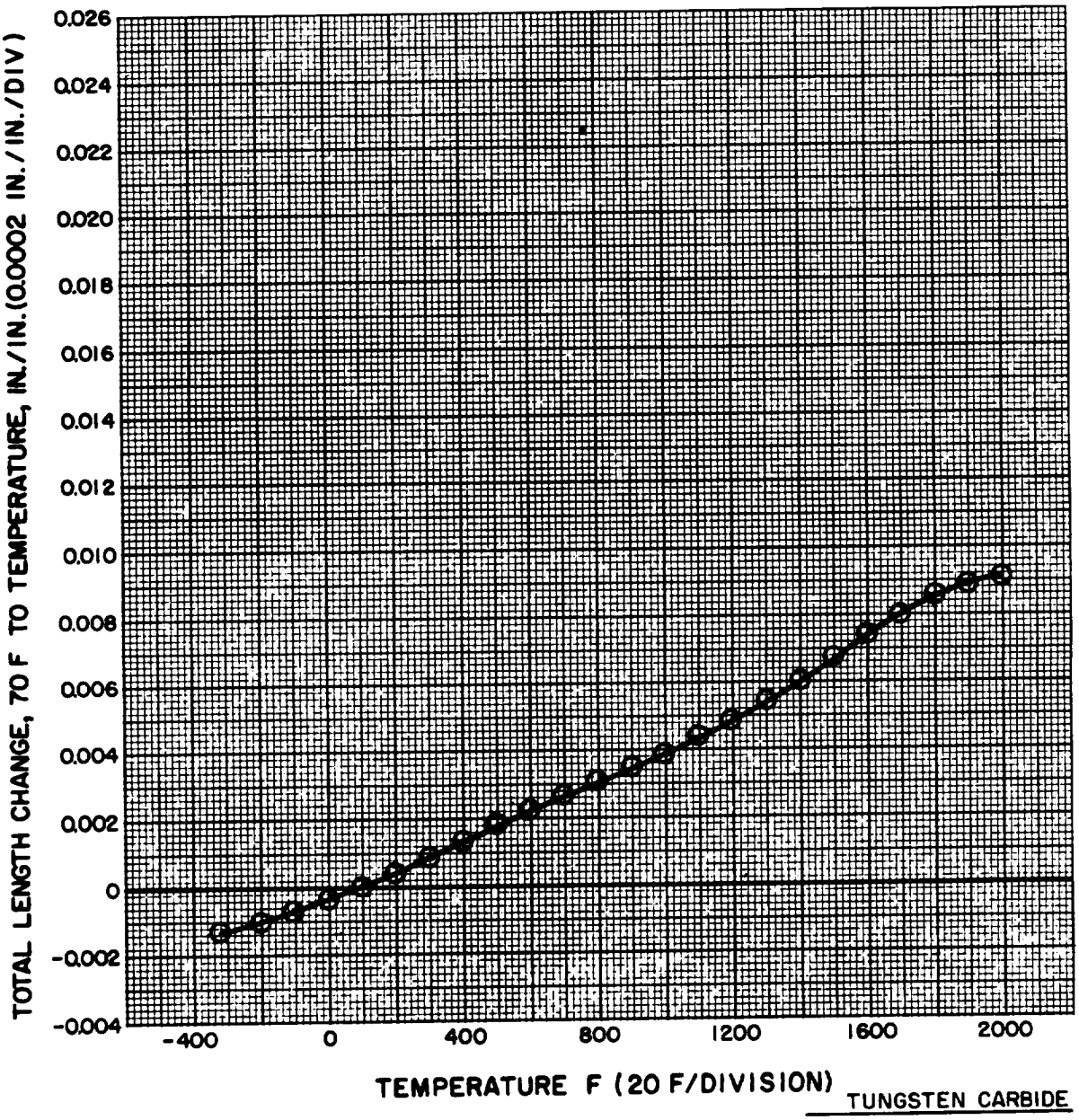
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT ELEVATED TEMPERATURES

CHART NO. 12·9·50
MATERIAL TUNGSTEN CARBIDE
FORM
CONDITION
SPECIFICATION -
DATE JULY 1965

NOTES: LINDE FLAME SPRAYED



TUNGSTEN CARBIDE

SECTION II

THERMAL EXPANSION PROPERTIES OF AEROSPACE MATERIALS AT CRYOGENIC TEMPERATURES

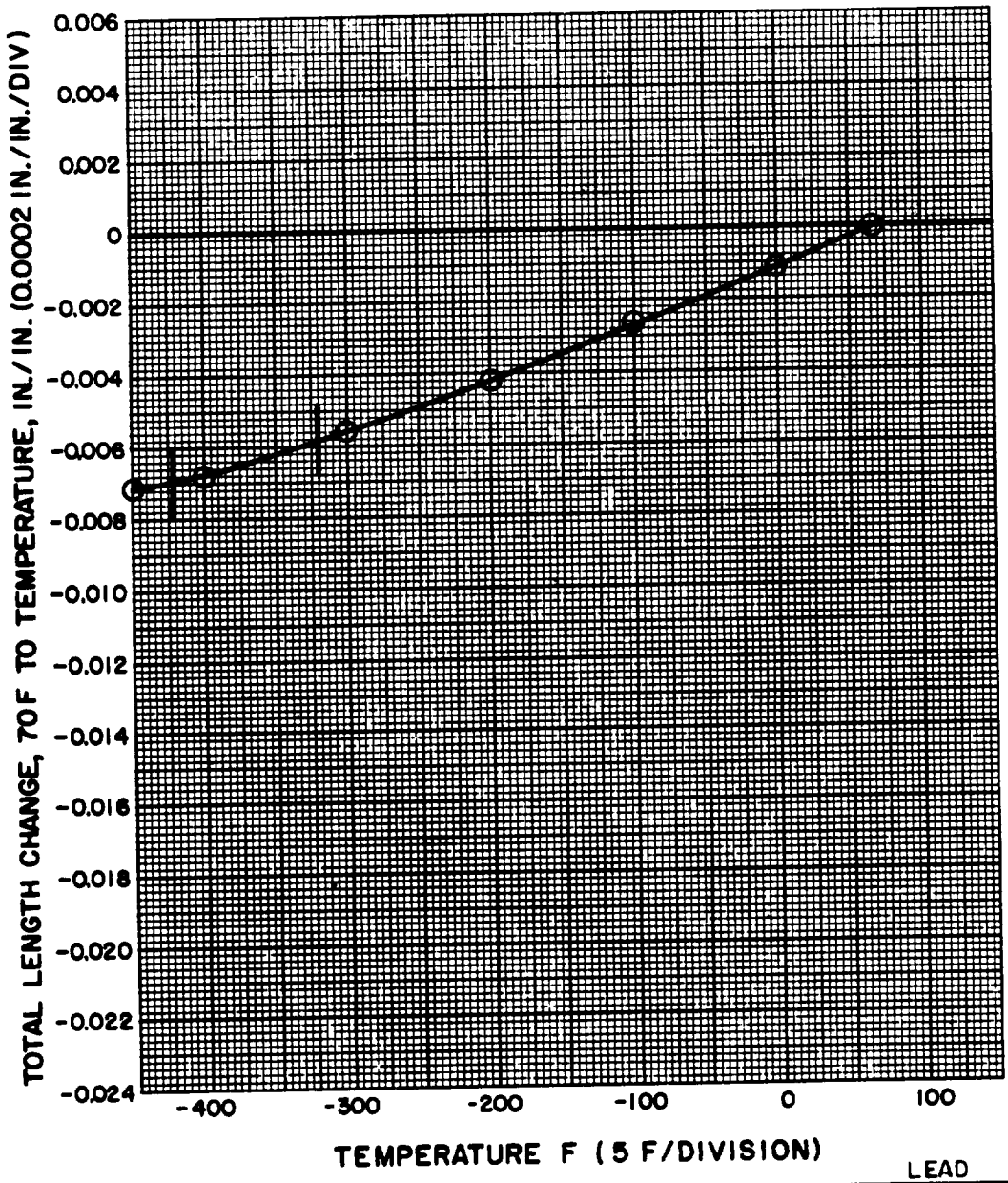
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD TR 60-56, II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 1·2·60
MATERIAL LEAD
FORM WROUGHT
CONDITION
SPECIFICATION
DATE JULY 1965

NOTES:



LEAD

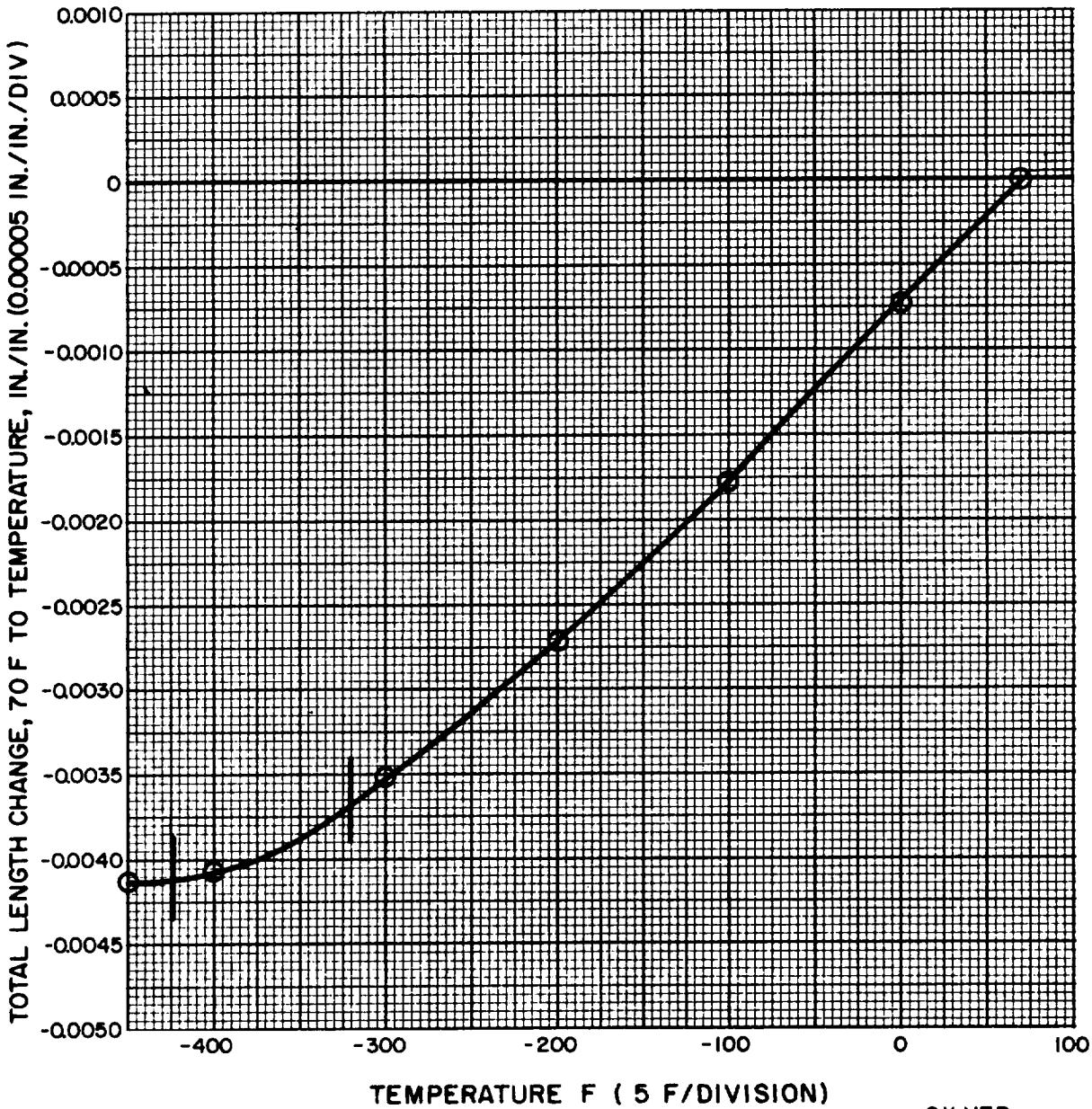
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD TR 60-56, II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 1·3·60
MATERIAL SILVER
FORM WROUGHT
CONDITION
SPECIFICATION
DATE JULY 1965

NOTES:



SILVER

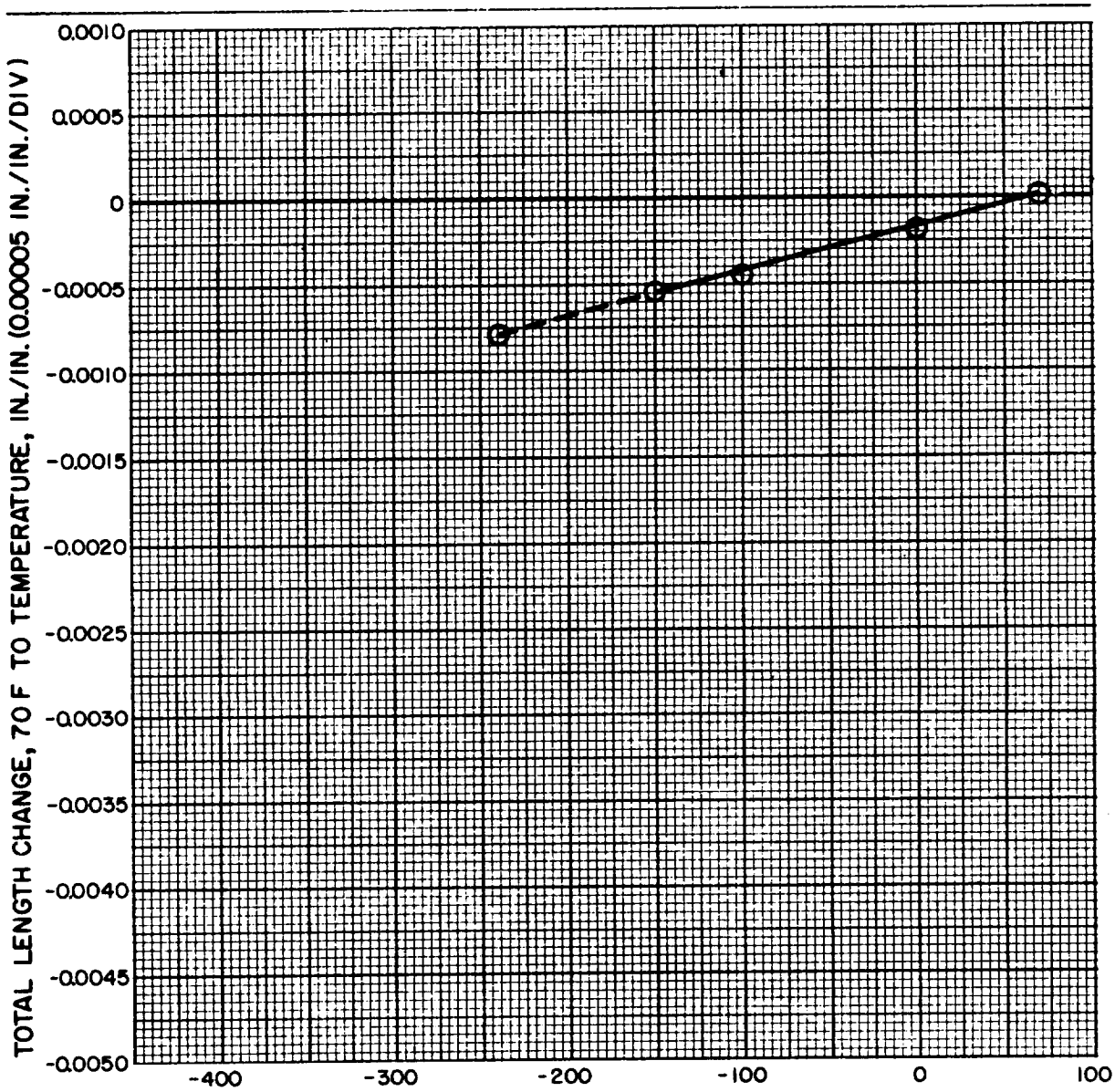
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD TR 60-56, II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 1·4·60
MATERIAL TIN
FORM WROUGHT
CONDITION
SPECIFICATION
DATE JULY 1965

NOTES:



TIN

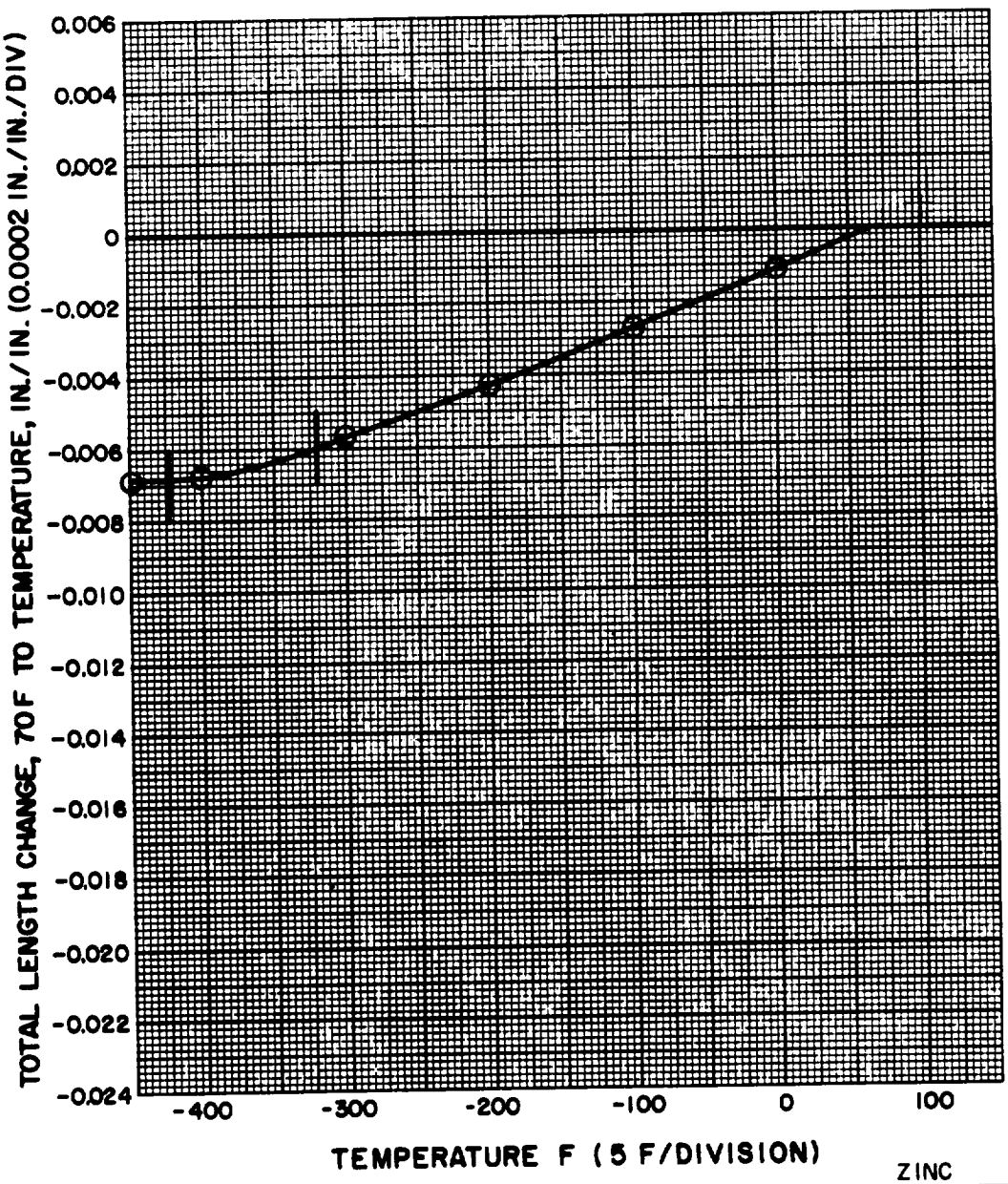
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD, TR 60-56, II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 1·5·60
MATERIAL ZINC
FORM WROUGHT
CONDITION
SPECIFICATION
DATE JULY 1965

NOTES:



ZINC

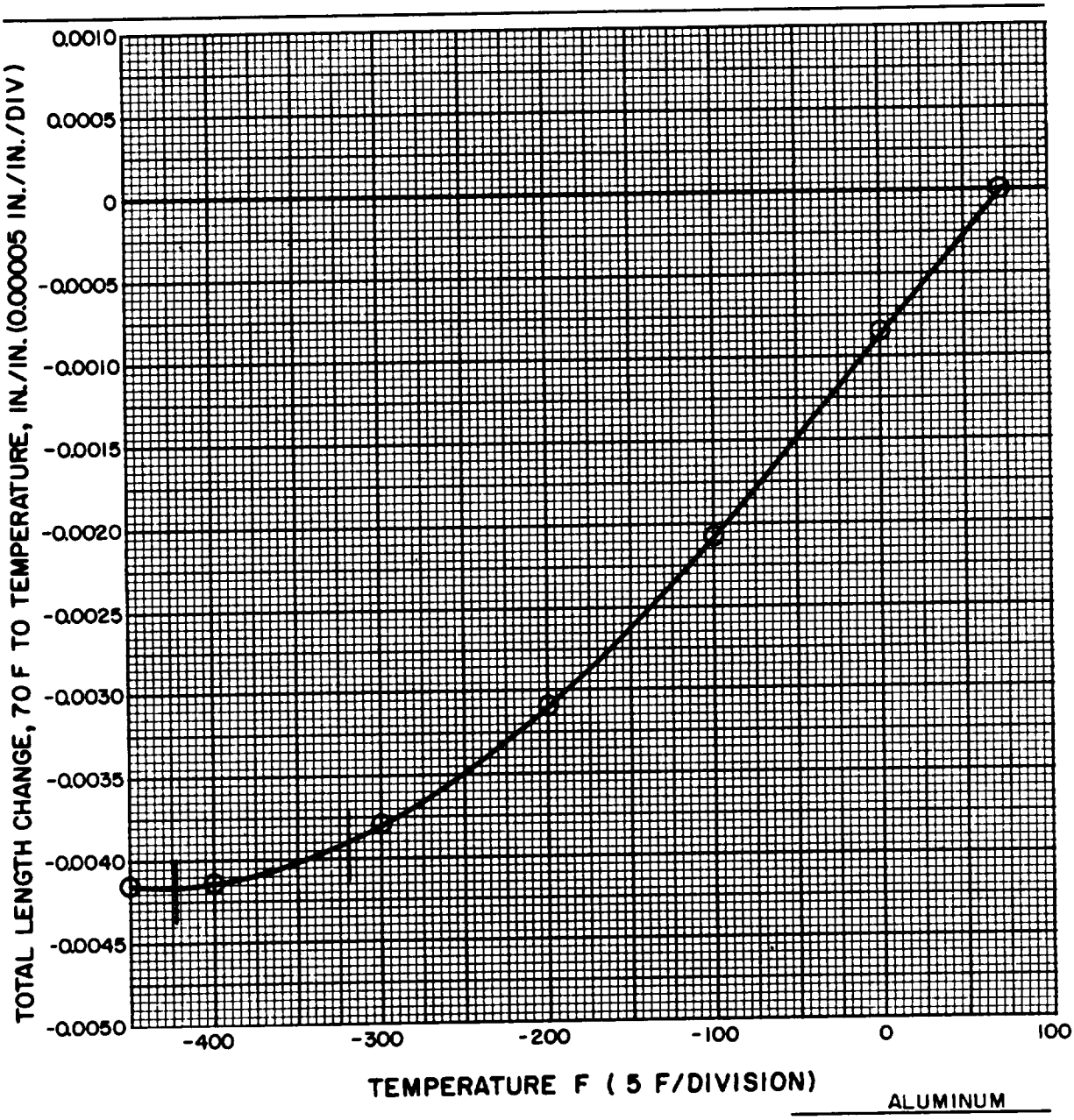
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD TR 60-56 II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·1·60
MATERIAL ALUMINUM
FORM WROUGHT
CONDITION
SPECIFICATION
DATE JULY 1965

NOTES:



ALUMINUM

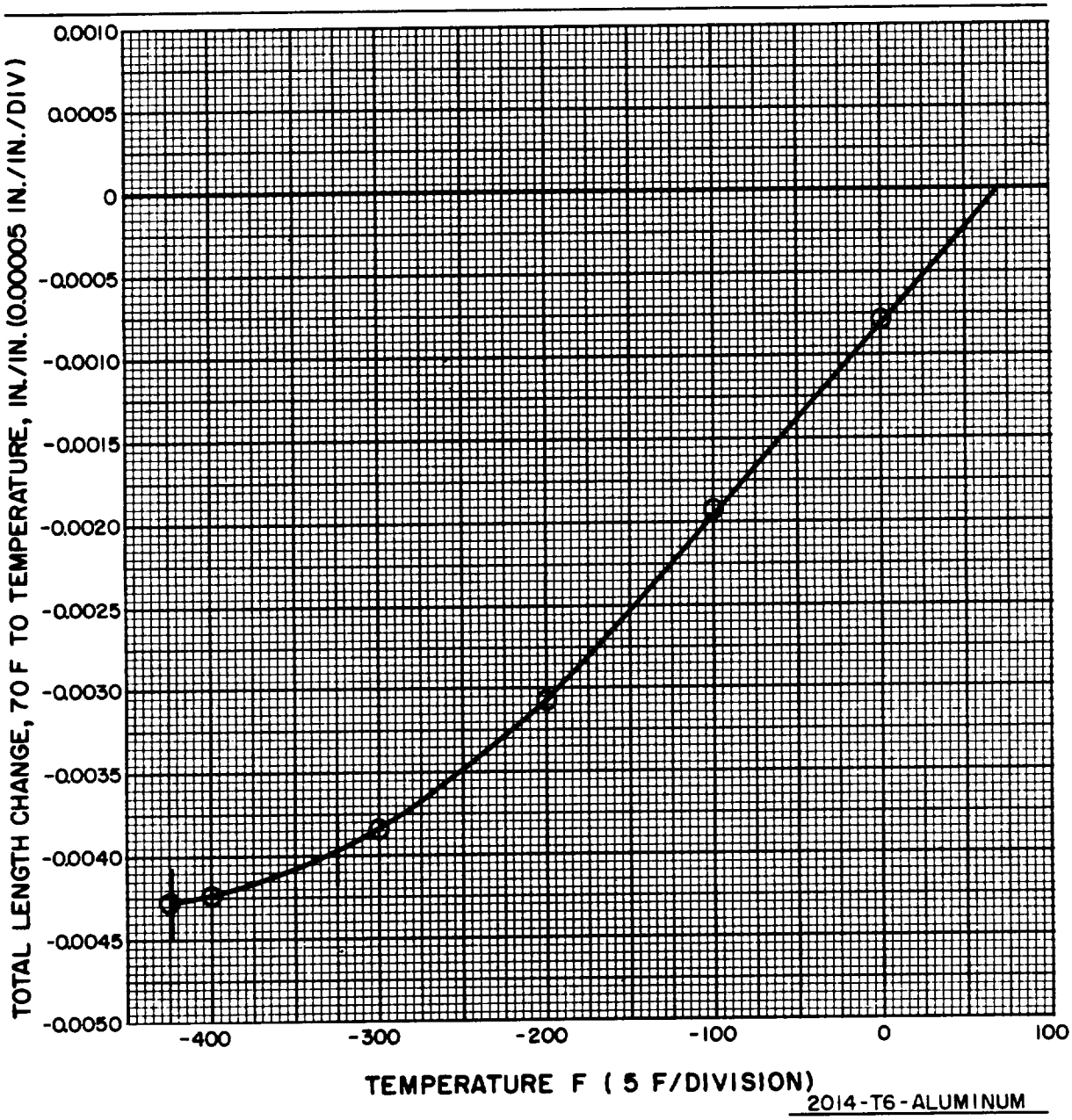
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·3·60
MATERIAL 2014 ALUMINUM
FORM WROUGHT
CONDITION T-6
SPECIFICATION QQ-A-261-266
DATE MARCH 1962

NOTES:



2014-T6-ALUMINUM

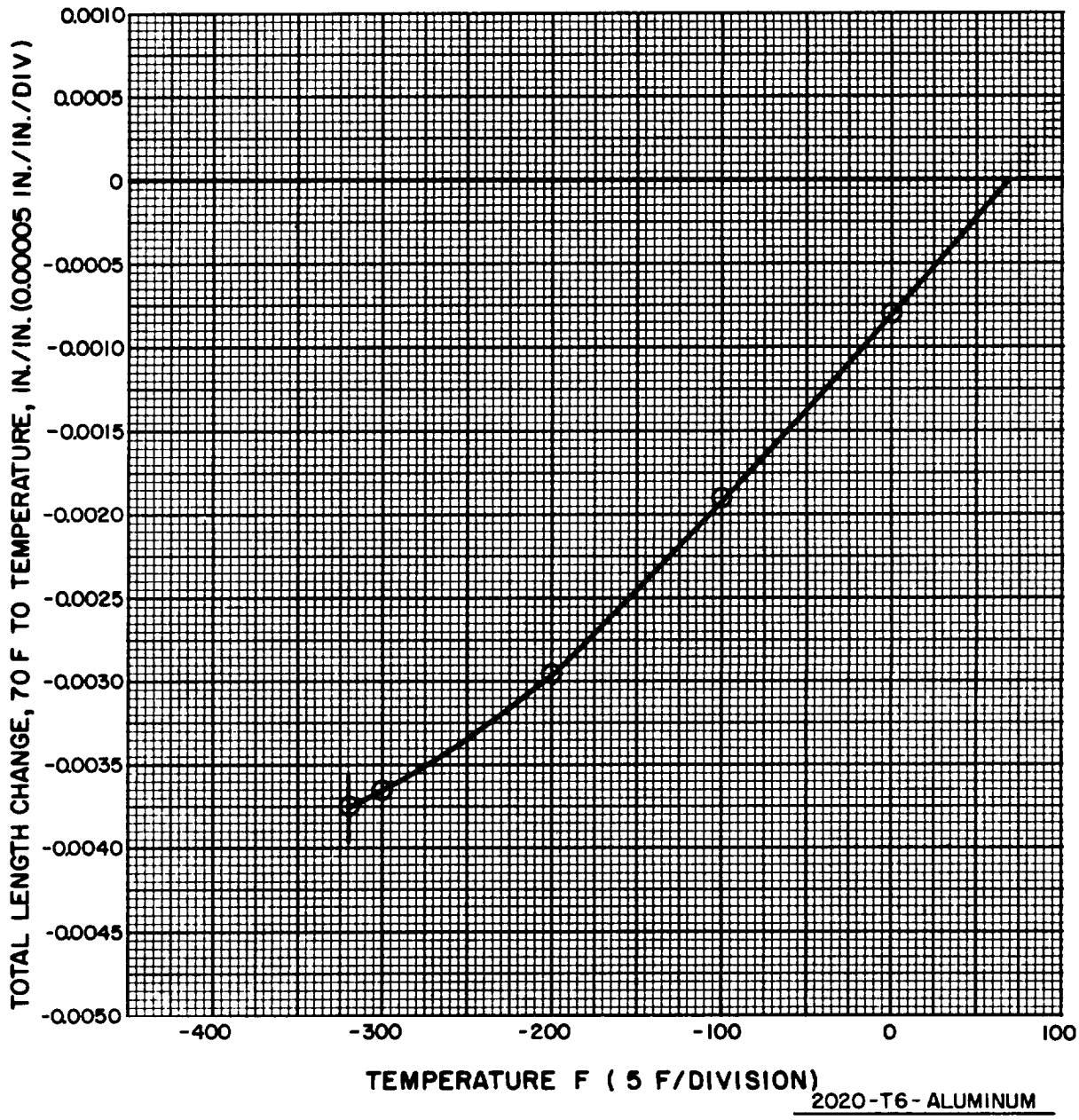
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·4·60
MATERIAL 2020 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION –
DATE MARCH 1962

NOTES: 4 Cu BALANCE Al



2020-T6-ALUMINUM

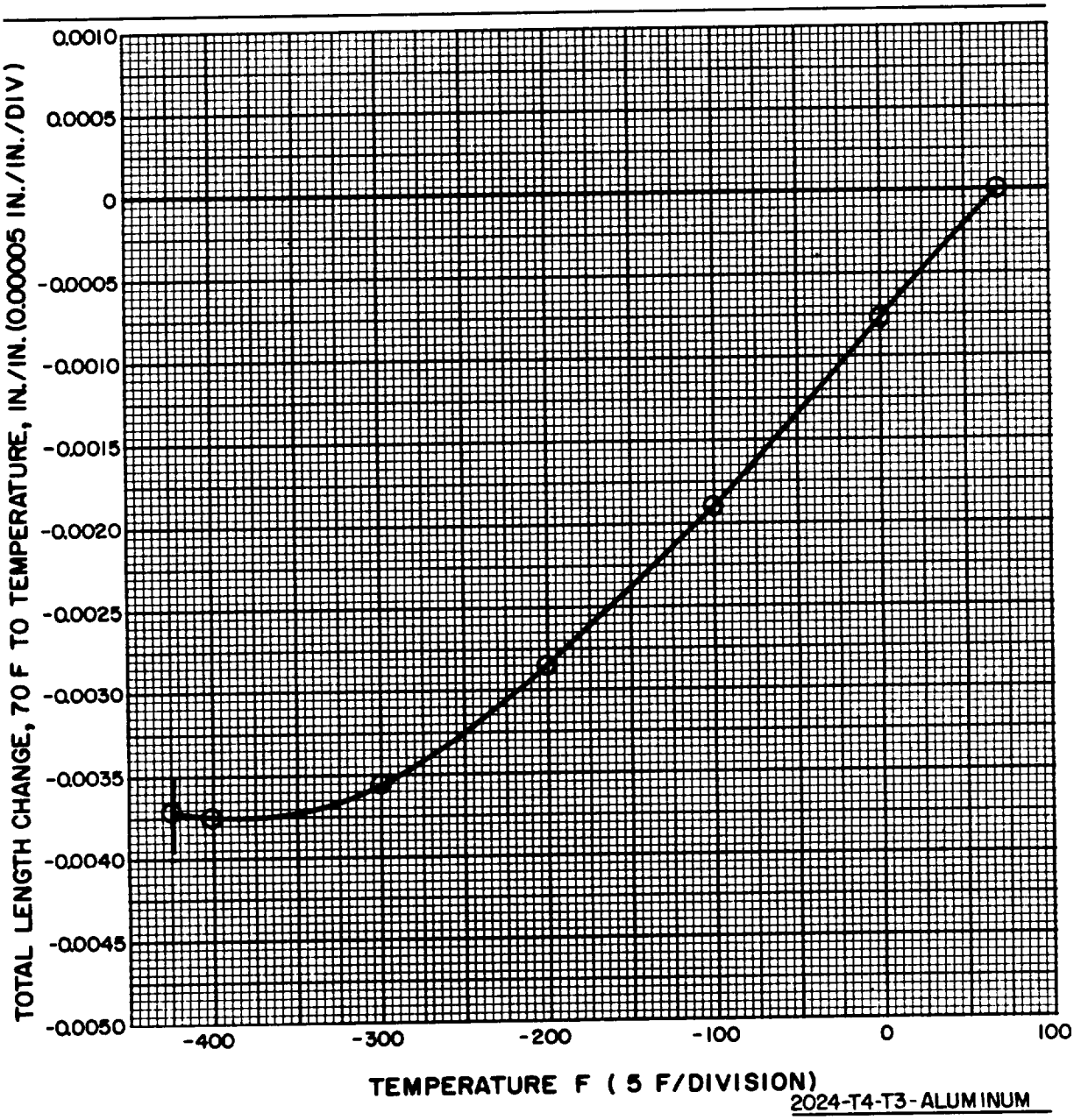
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·5·60
MATERIAL 2024 ALUMINUM
FORM BAR
CONDITION T3
SPECIFICATION QQ-A-268
DATE JULY 1965

NOTES:



2024-T4-T3-ALUMINUM

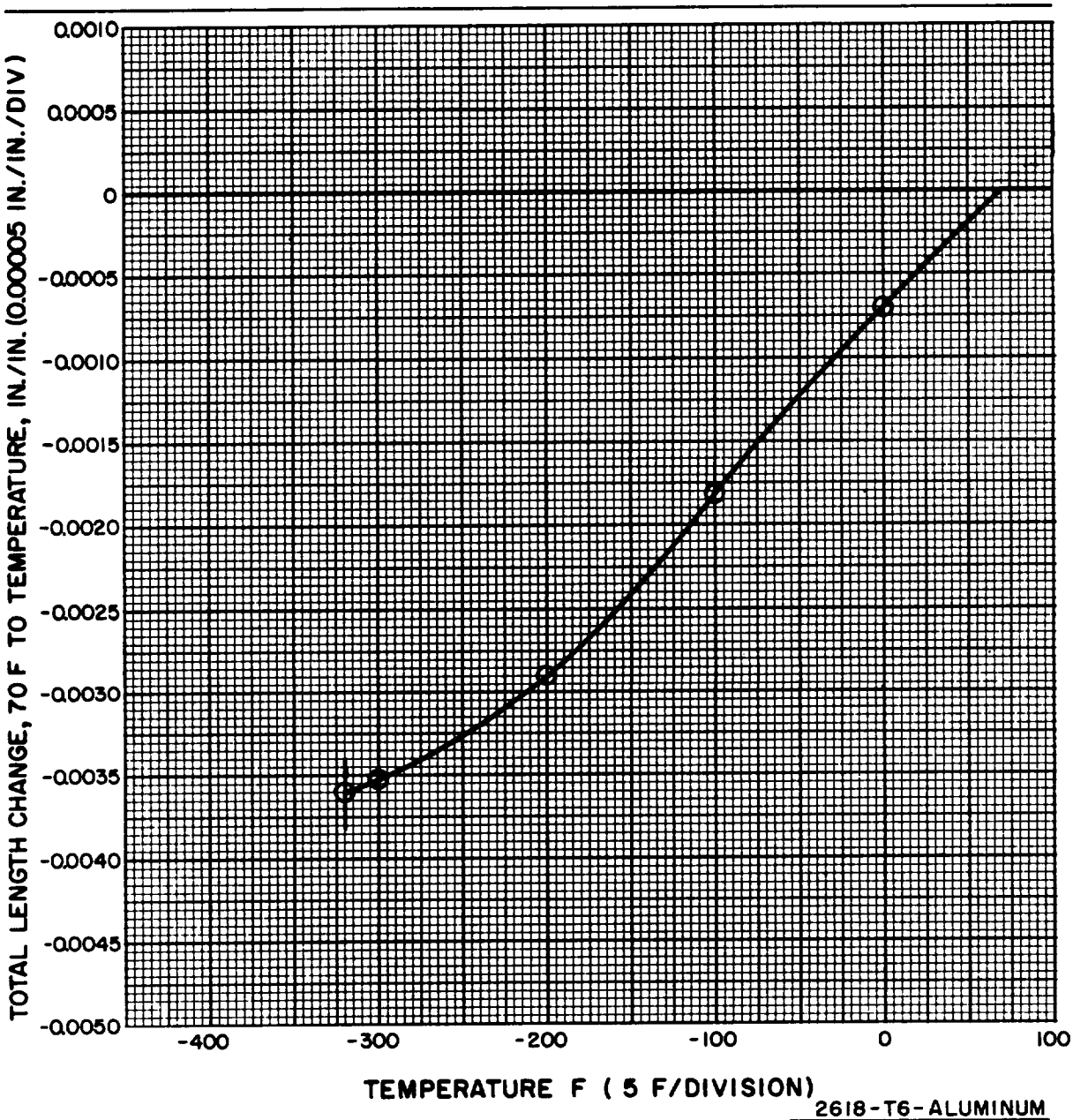
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·6·60
MATERIAL 2618 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION QQ-A-325
DATE MARCH 1962

NOTES:



2618-T6-ALUMINUM

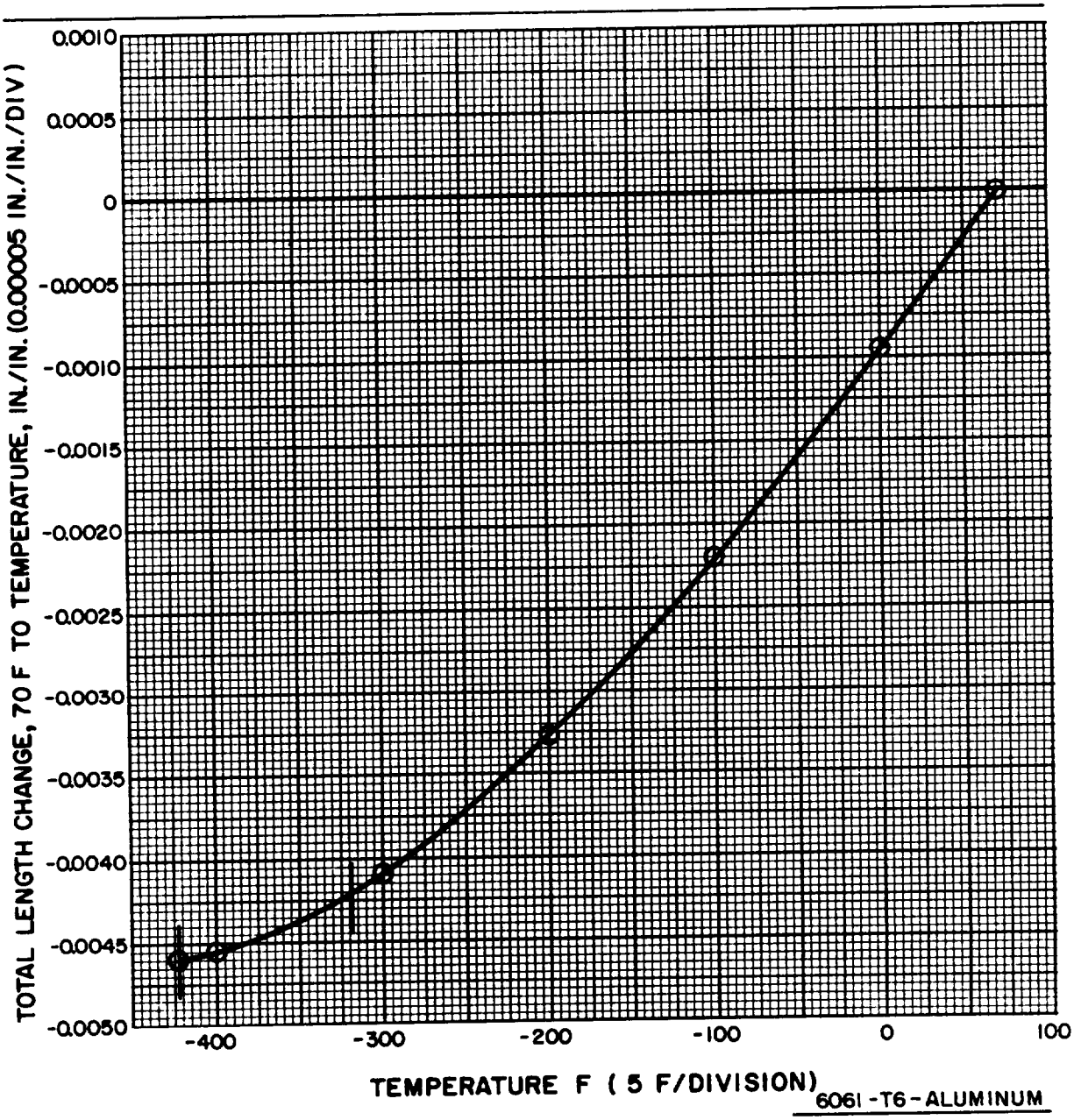
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·7·60
MATERIAL 6061 ALUMINUM
FORM BAR
CONDITION T-6
SPECIFICATION QQ-A-325
DATE JULY 1965

NOTES:



6061-T6-ALUMINUM

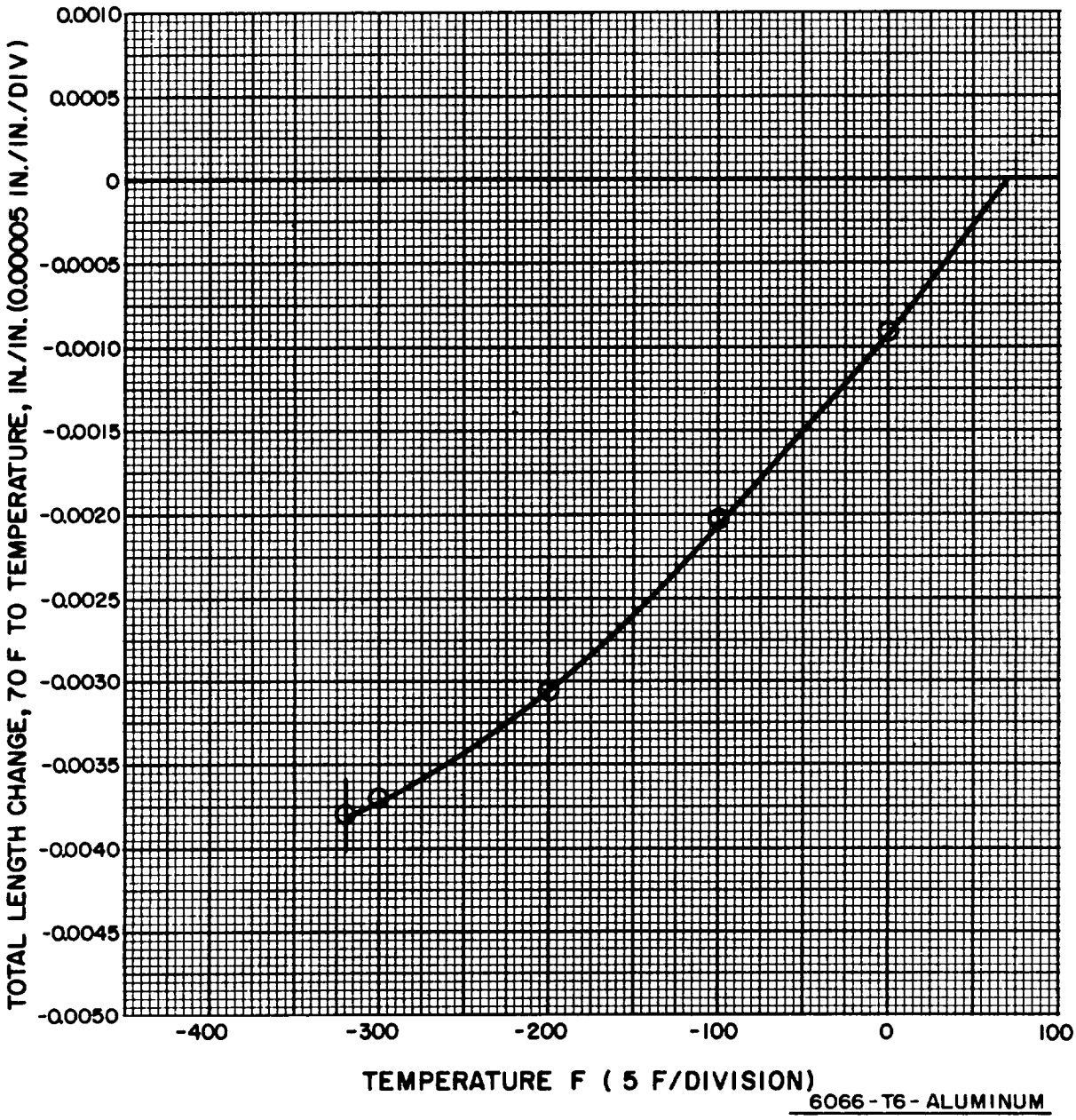
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·8·60
MATERIAL 6066 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION MIL-A-25493
DATE MARCH 1962

NOTES:



6066-T6-ALUMINUM

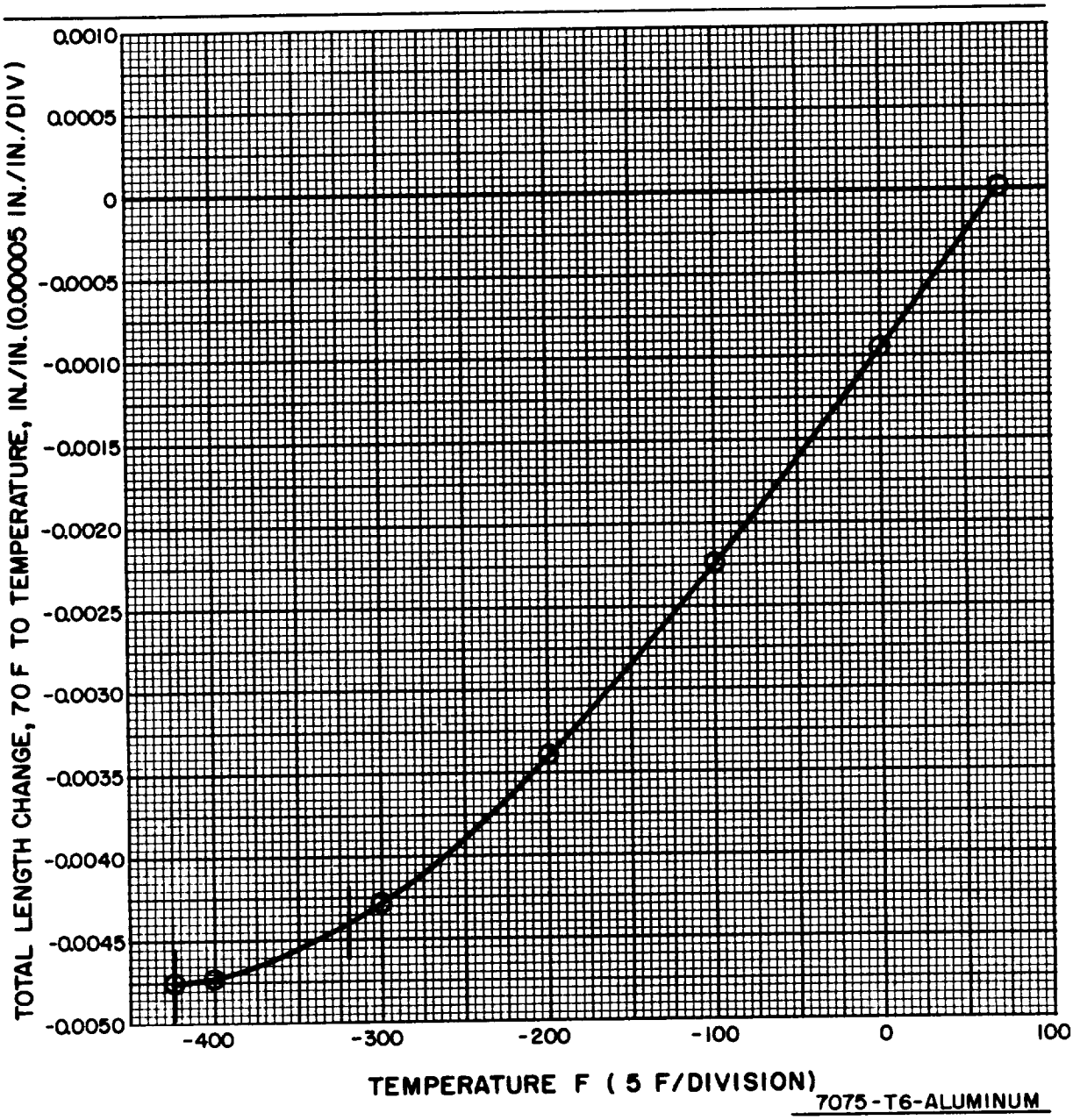
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·9·60
MATERIAL 7075 ALUMINUM
FORM BAR
CONDITION T6
SPECIFICATION QQ-A-282
DATE AUGUST 1965

NOTES:



7075-T6-ALUMINUM

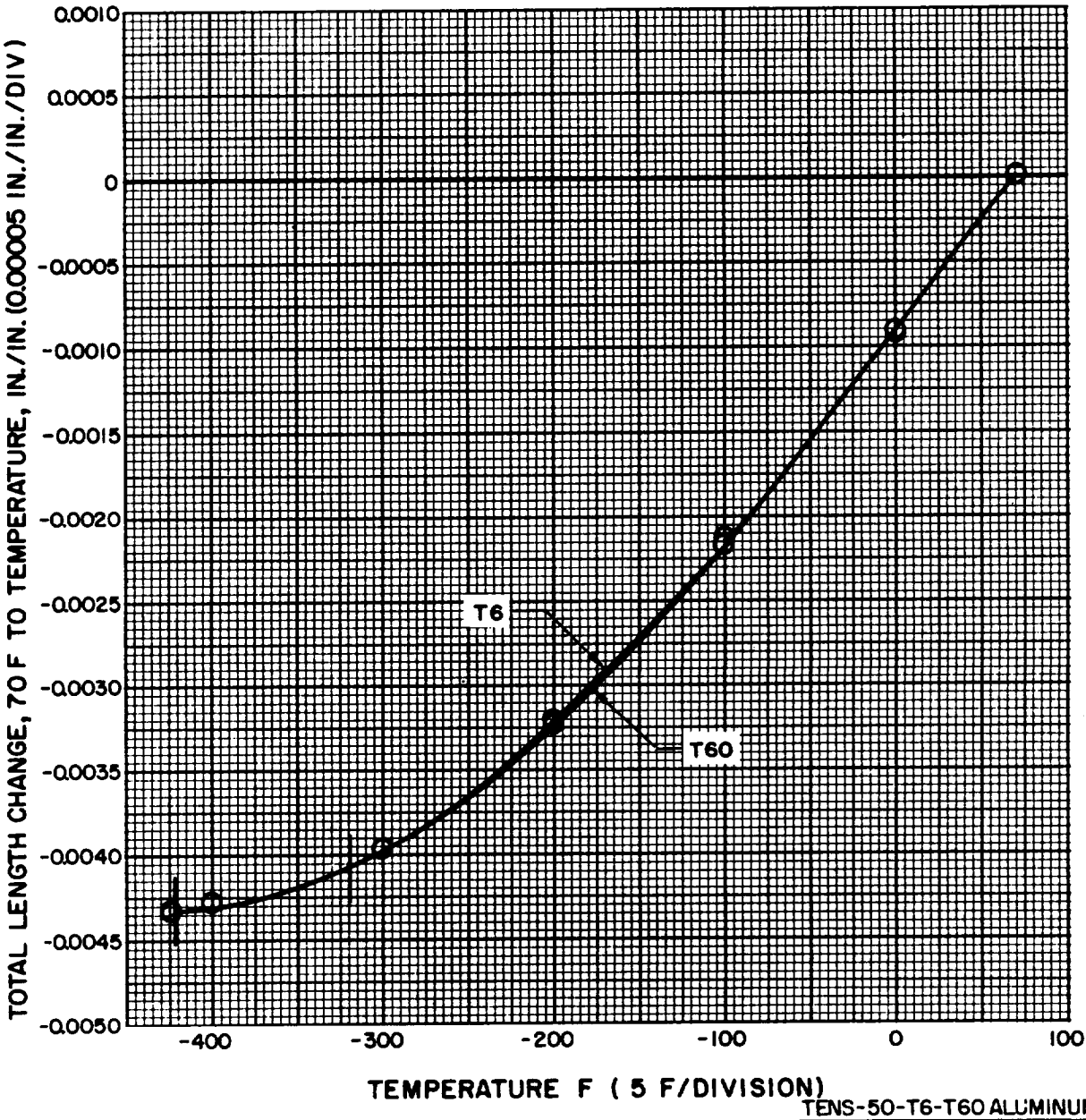
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 2·10·60
MATERIAL TENS-50 ALUMINUM
FORM CAST
CONDITION T-60, T-6
SPECIFICATION RB0170-008
DATE AUGUST 1965

NOTES: 8Si-.5Mg-.2Fe-.15Be-.15Ti-BALANCE Al



TENS-50-T6-T60 ALUMINUM

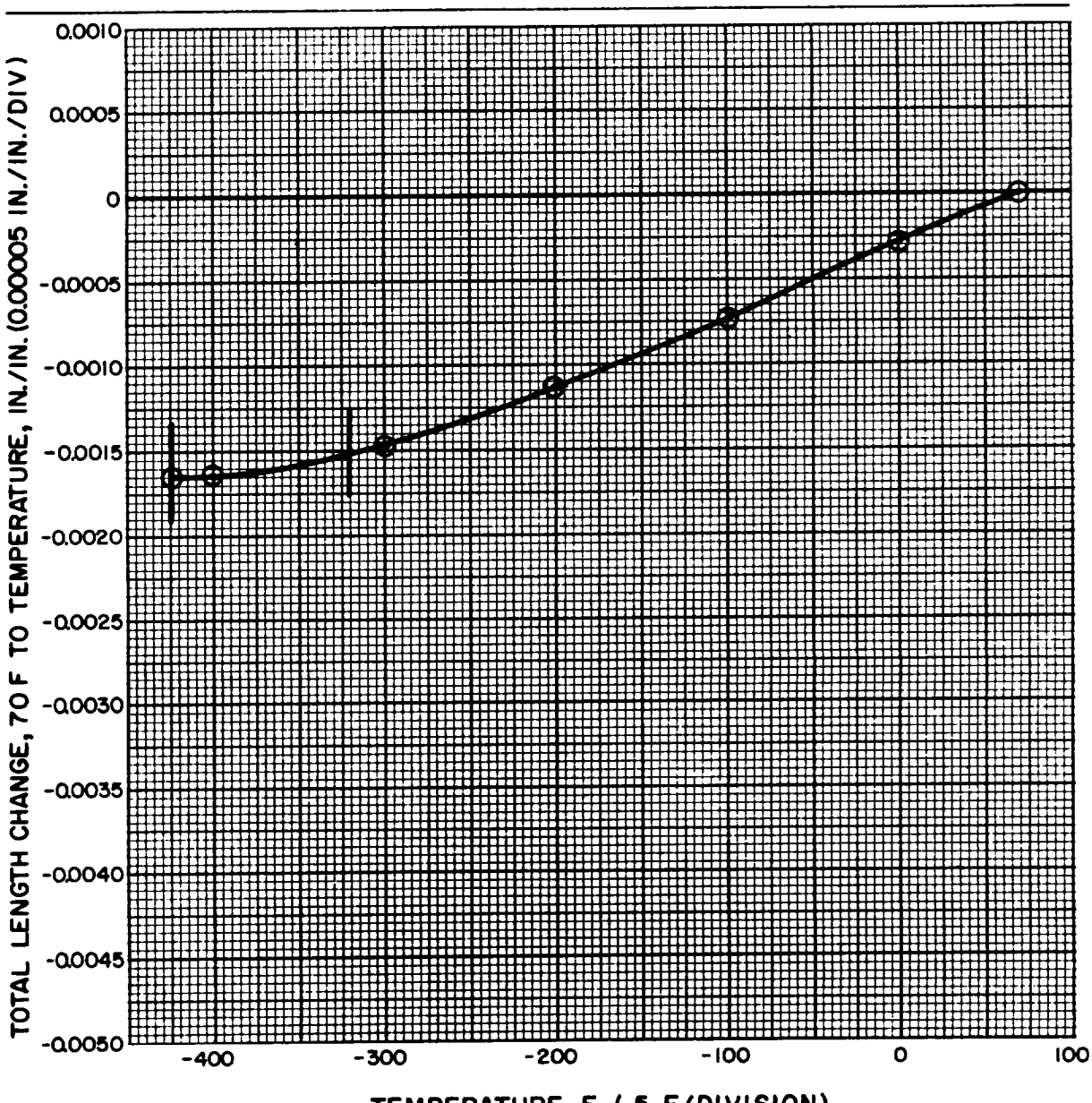
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 4·1·60
MATERIAL Ti-5AL-2.5SN
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 170-079
DATE AUGUST 1965

NOTES:



Ti-5AL-2.5 SN

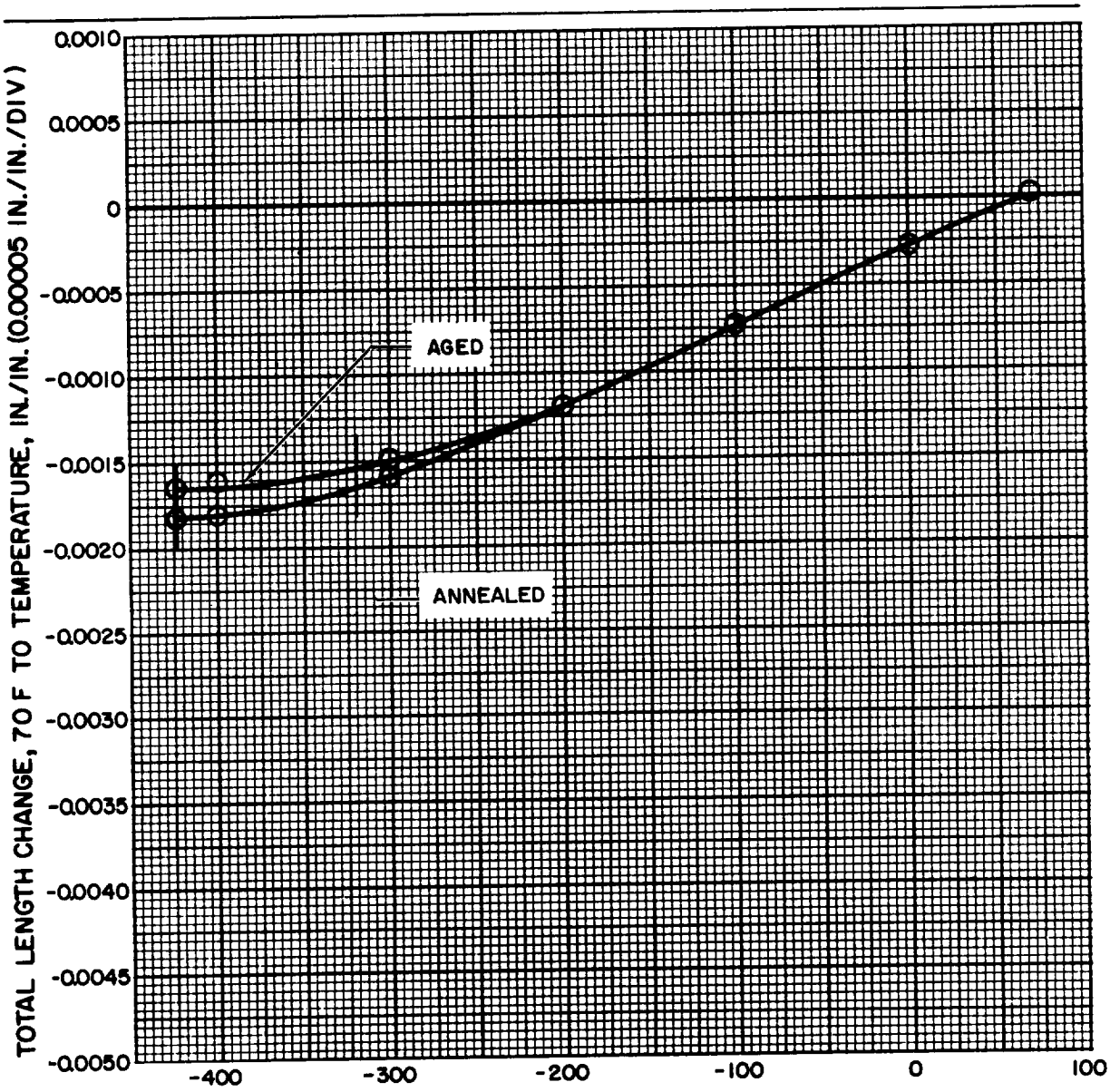
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 4·2·60
MATERIAL Ti-6AL-4V
FORM BAR
CONDITION SEE NOTES
SPECIFICATION RBO 170-054
DATE AUGUST 1965

NOTES: 1400°F ANNEAL/1750°F ANNEAL PLUS 1000°F AGE



Ti-6AL-4V

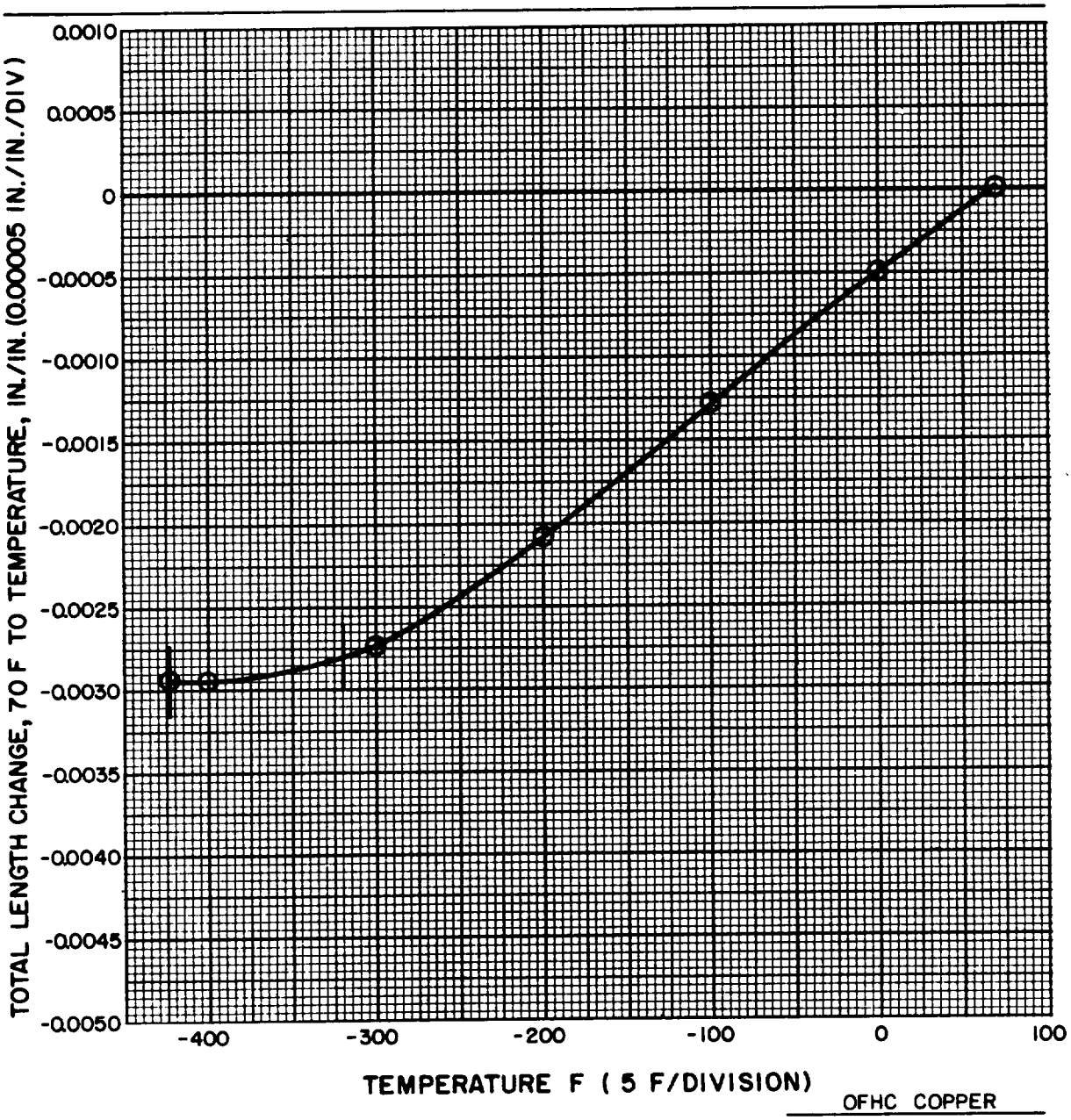
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 5·2·60
MATERIAL OFHC COPPER
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-C-502
DATE AUGUST 1965

NOTES:



OFHC COPPER

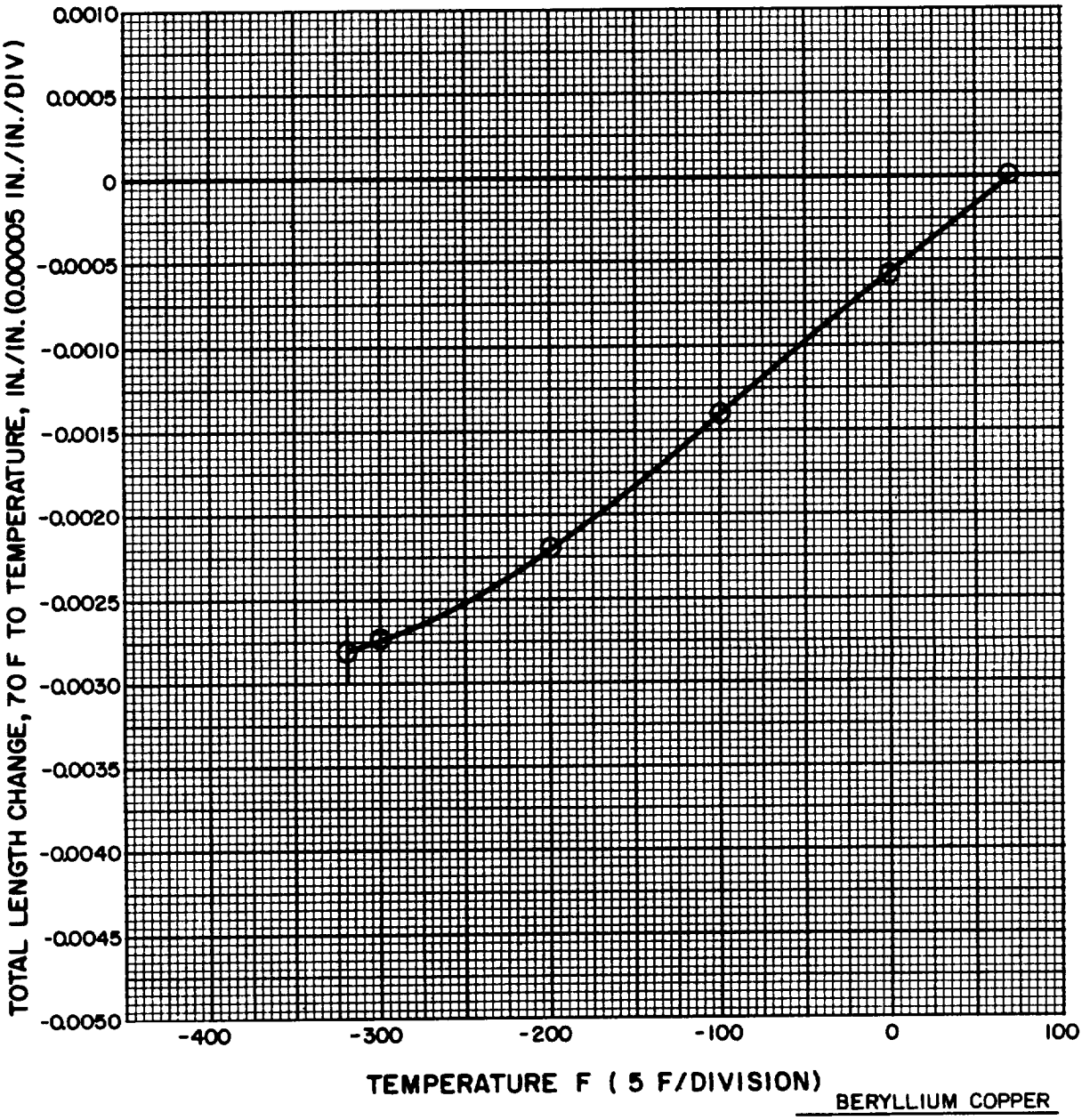
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 5·3·60
MATERIAL BERYLLIUM COPPER
FORM BAR
CONDITION AGED
SPECIFICATION QQ-C-530
DATE MARCH 1962

NOTES: 2 Be-.2 Co-Cu BALANCE (ALLOY NO. 25)



BERYLLIUM COPPER

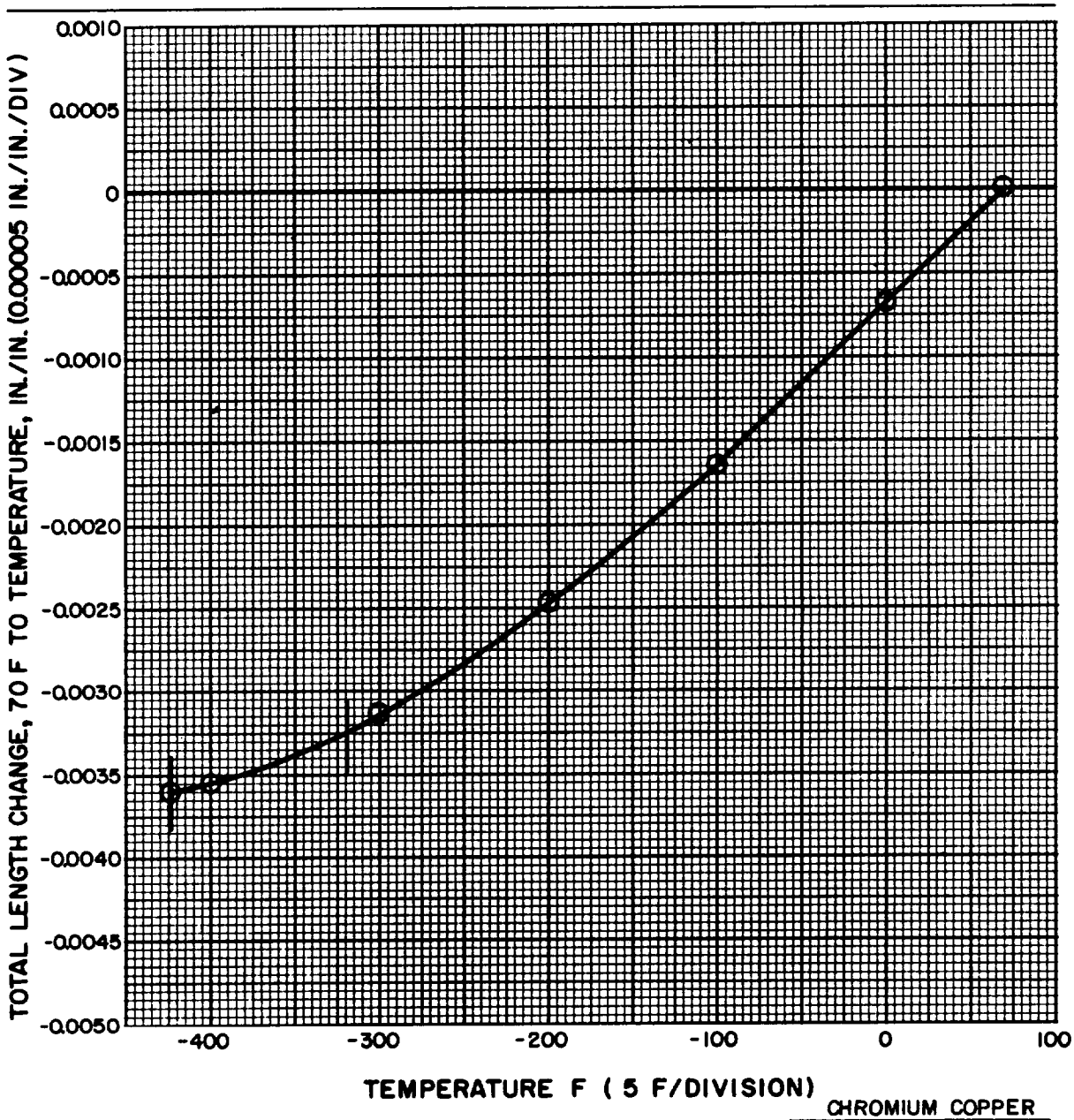
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 5·4·60
MATERIAL CHROMIUM COPPER
FORM BAR
CONDITION SEE NOTES
SPECIFICATION MIL-C-19311
DATE AUGUST 1965

NOTES: 1825°F ± 15°/WATER QUENCH/930°F ± 10°



CHROMIUM COPPER

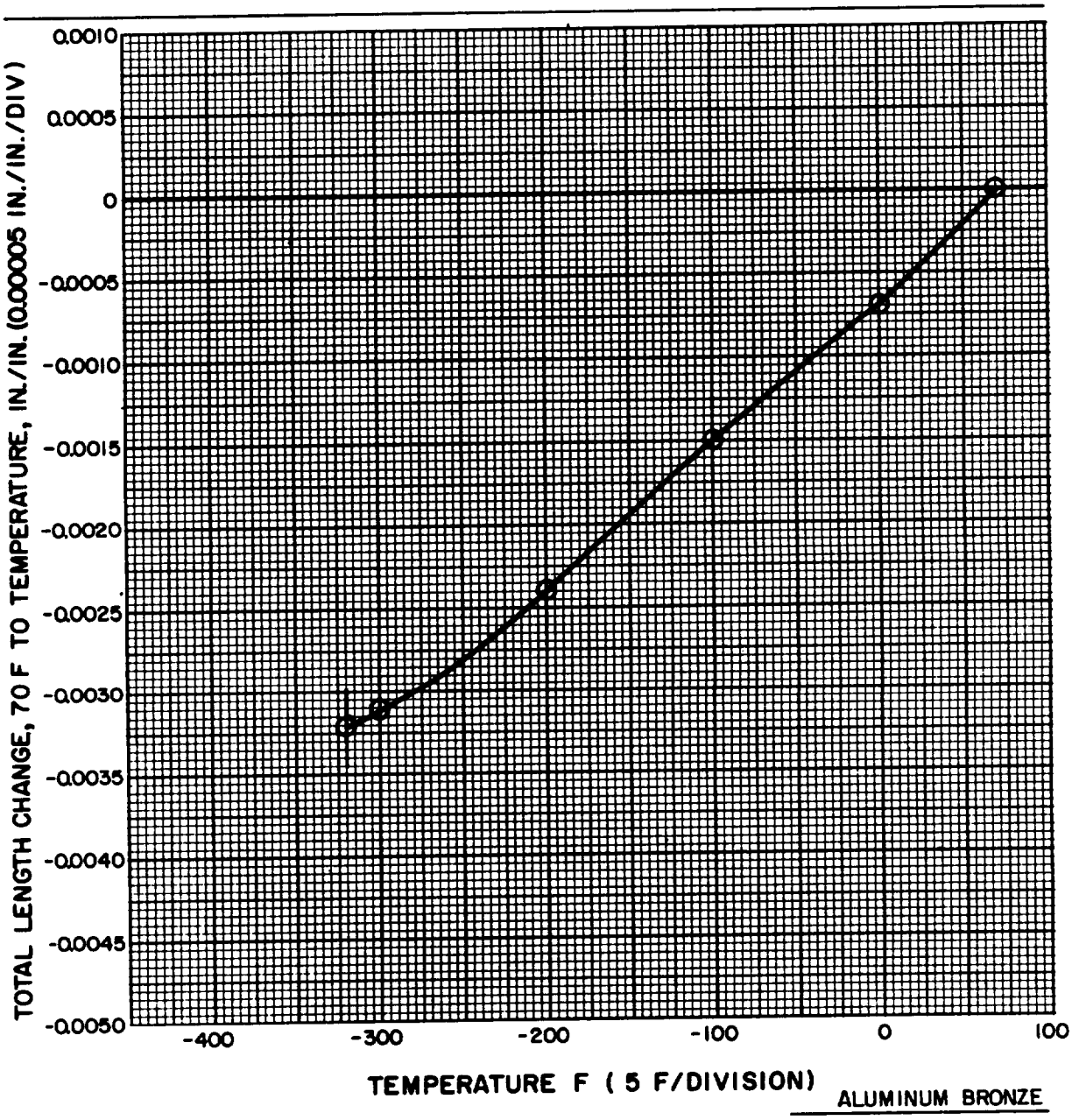
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 5·5·60
MATERIAL ALUMINUM BRONZE
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-A-630
DATE MARCH 1962

NOTES:



ALUMINUM BRONZE

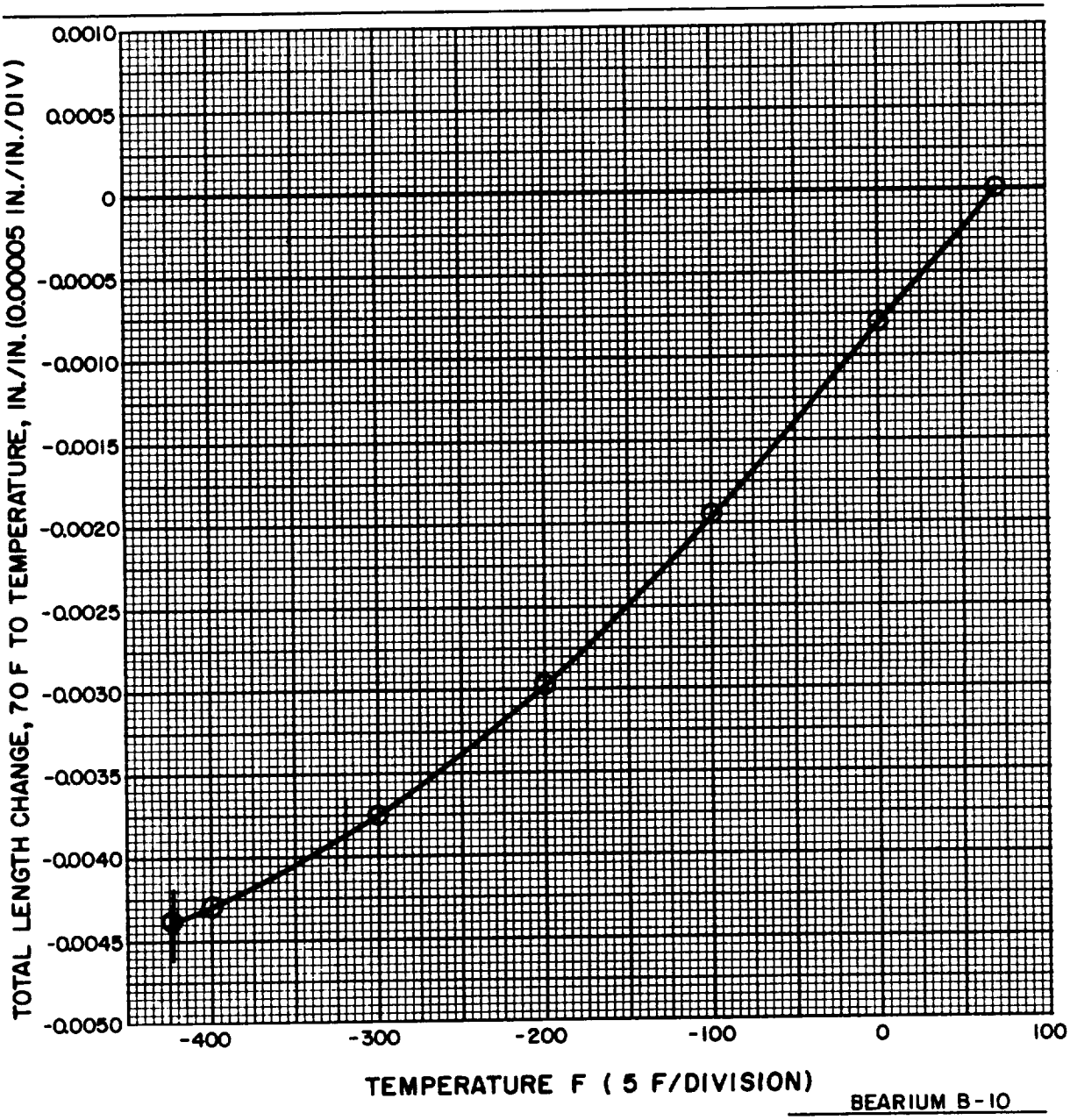
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 5-6-60
MATERIAL BEARIUM B-10
FORM CASTING
CONDITION AS CAST
SPECIFICATION RB0170-094
DATE AUGUST 1965

NOTES: 30Cu-20Pb-10Sn



BEARIUM B-10

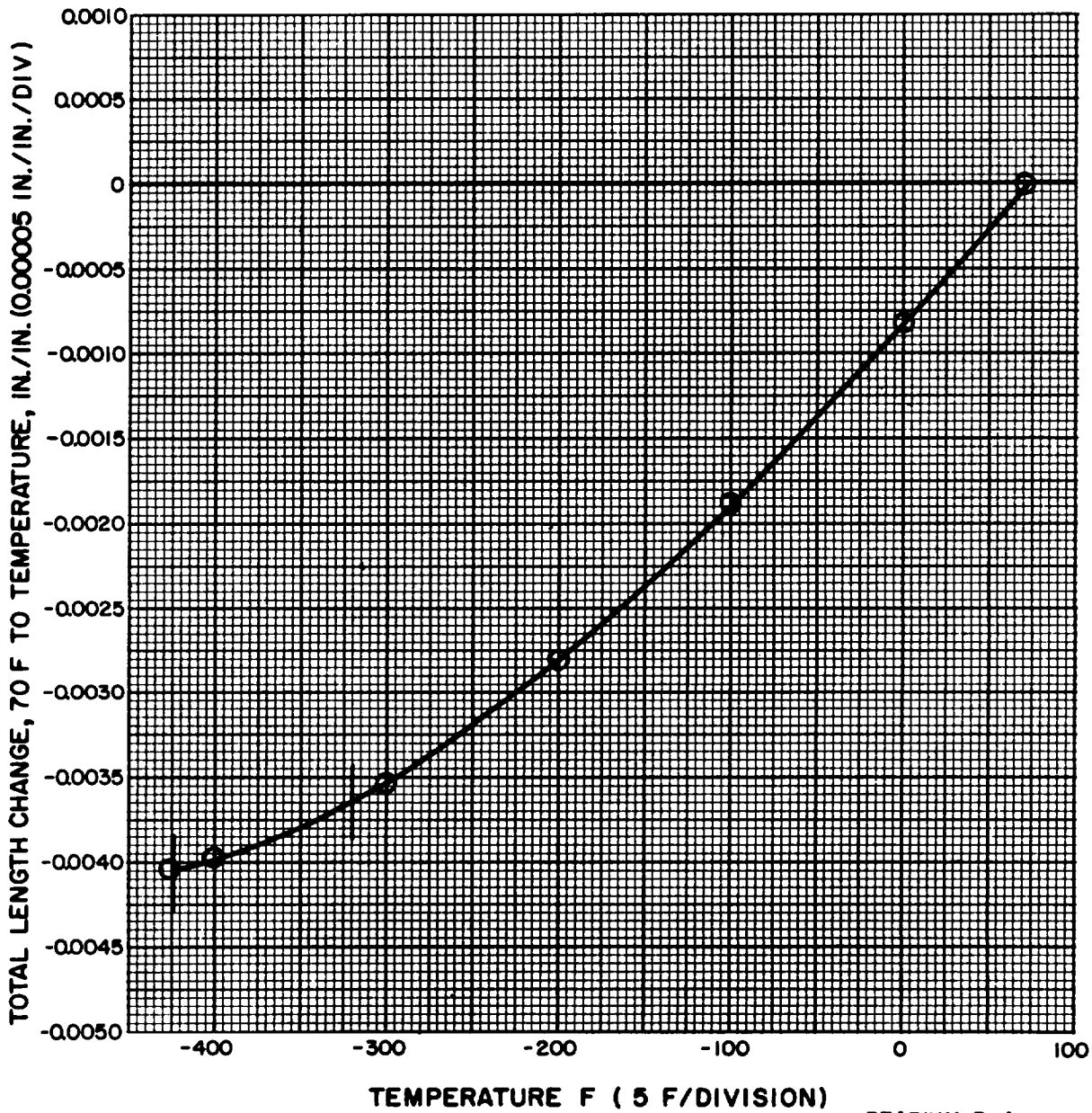
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 5·7·60
MATERIAL BEARIUM B-4
FORM CASTING
CONDITION AS CAST
SPECIFICATION
DATE AUGUST 1965

NOTES: 30 Cu-26 Pb-4 Sn



BEARIUM B-4

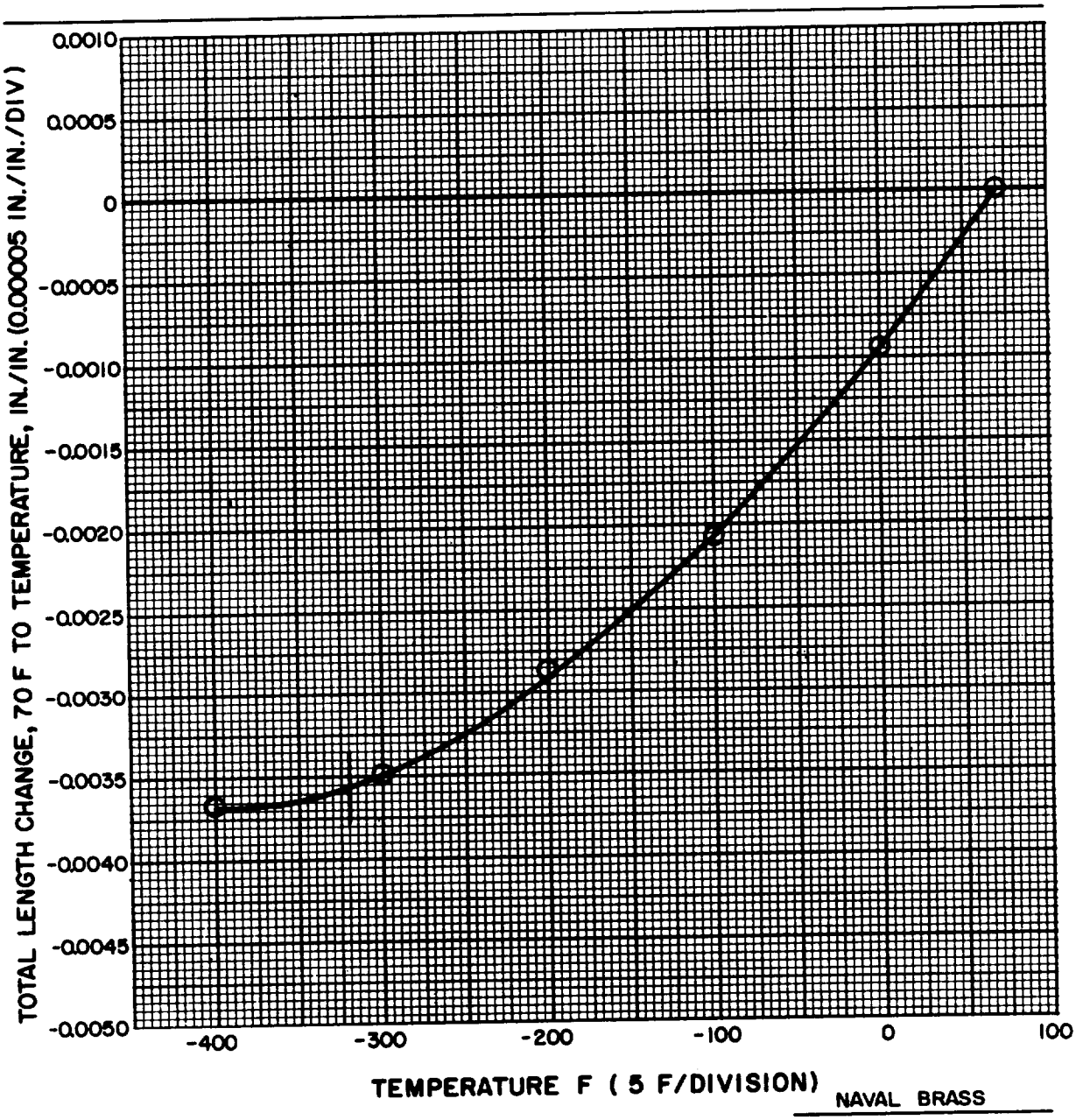
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 5·8·60
MATERIAL NAVAL BRASS
FORM BAR
CONDITION ANNEALED
SPECIFICATION AMS 4611C - 4612 D
DATE AUGUST 1965

NOTES:



NAVAL BRASS

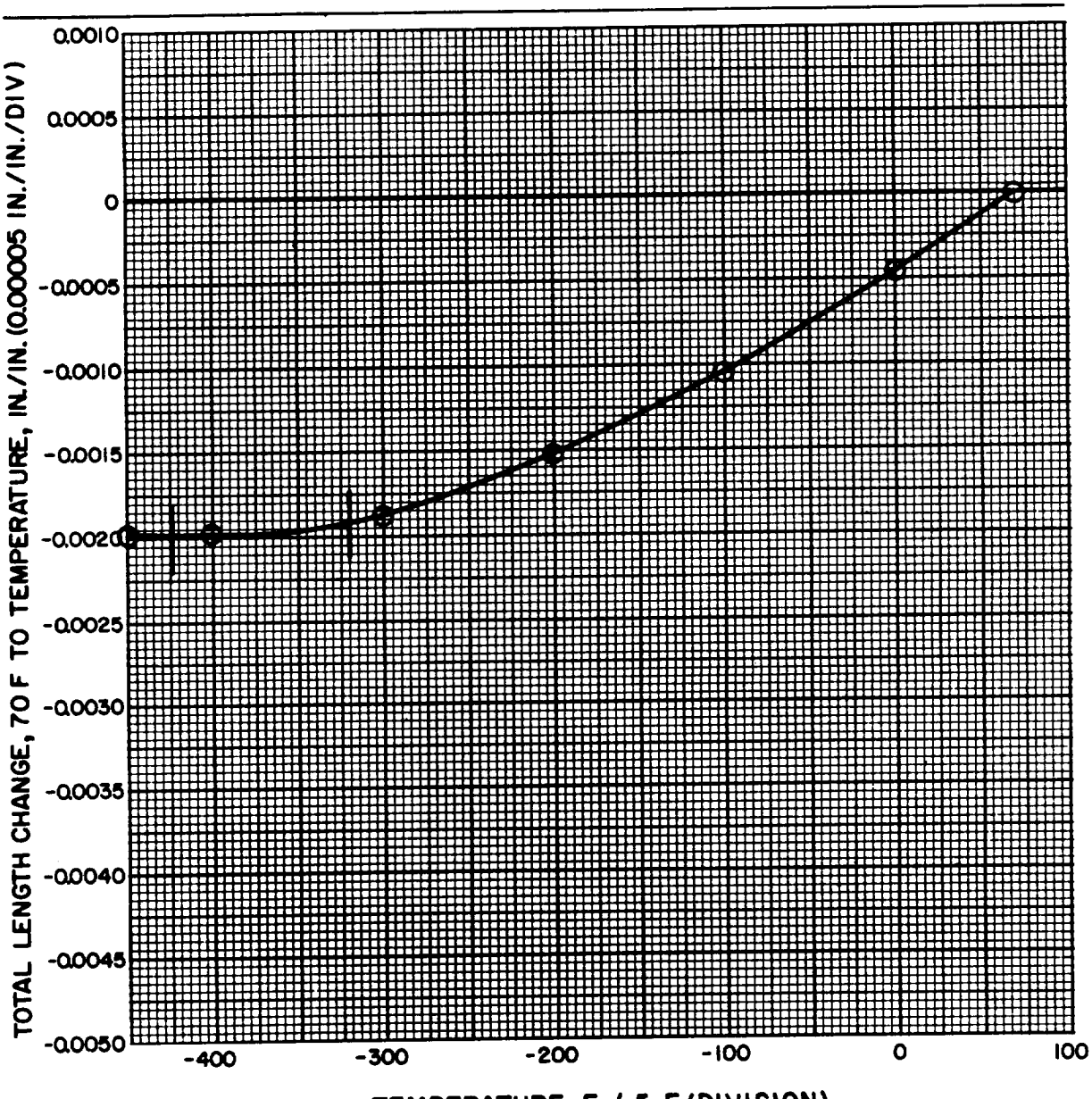
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD TR 60-56, II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6-1-60
MATERIAL IRON
FORM CASTING
CONDITION SEE NOTES
SPECIFICATION -
DATE AUGUST 1965

NOTES: AS GROWN CRYSTALS/ANNEALED



IRON

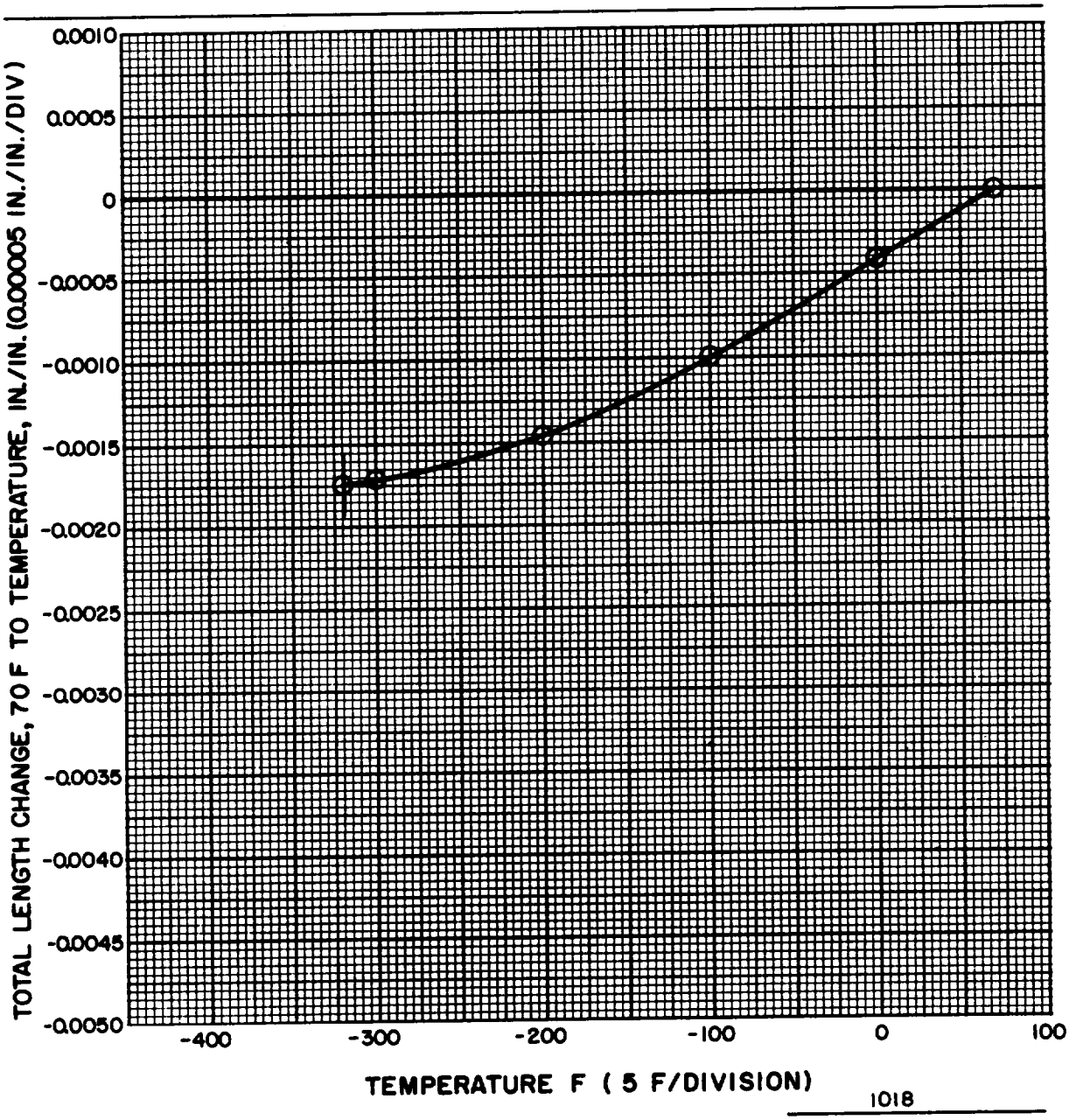
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·2·60
MATERIAL 1018
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION QQ-S-633
DATE MARCH 1962

NOTES:



1018

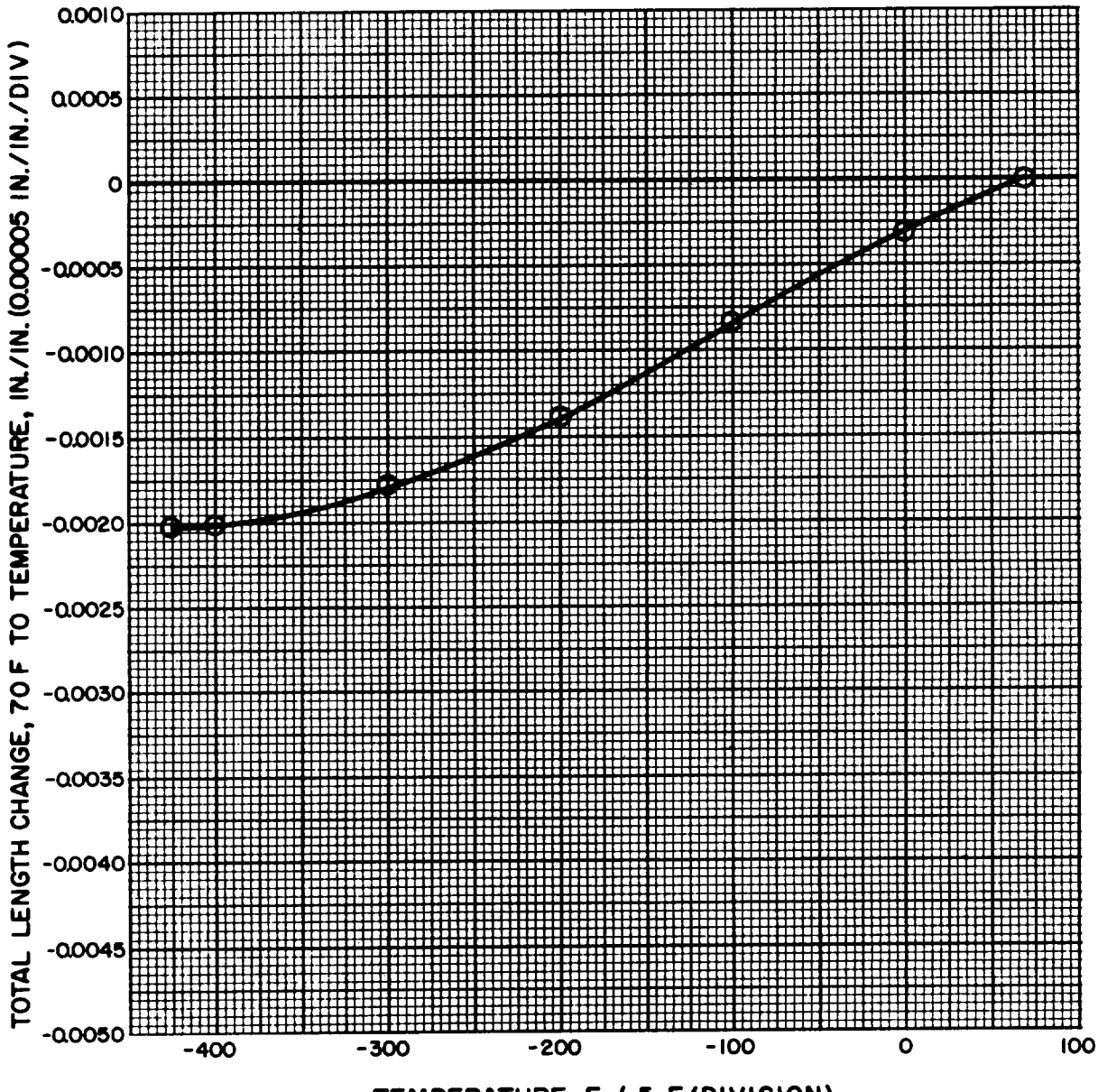
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·3·60
MATERIAL 4130
FORM BAR
CONDITION NORMALIZED AT 1650°F
SPECIFICATION MIL-S-6758
DATE AUGUST 1965

NOTES:



4130

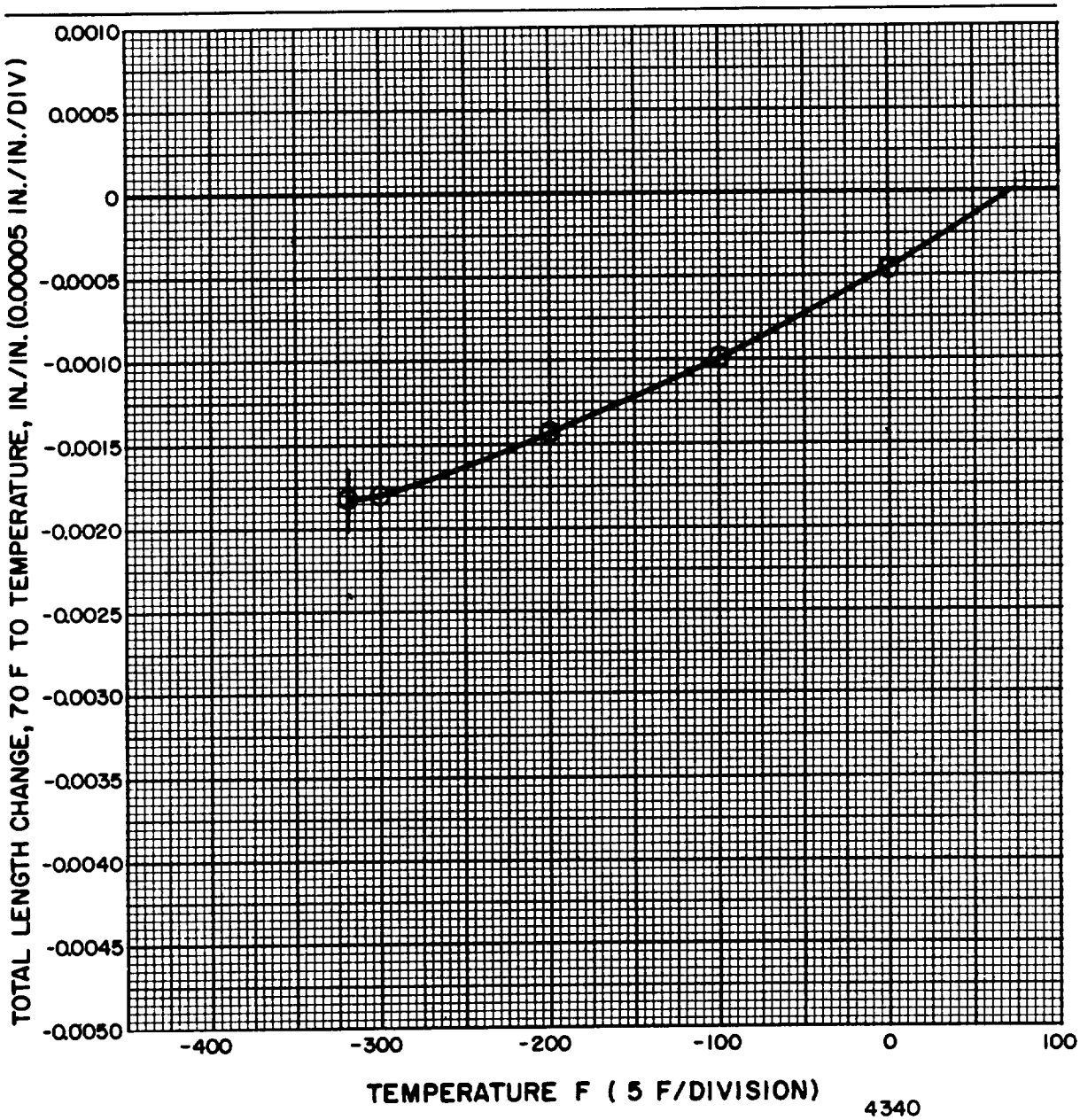
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·4·60
MATERIAL 4340
FORM BAR
CONDITION SEE NOTES
SPECIFICATION RB0160-030
DATE MARCH 1962

NOTES: QUENCHED AND TEMPERED AT 850° F / UTS - 200,000 PSI



4340

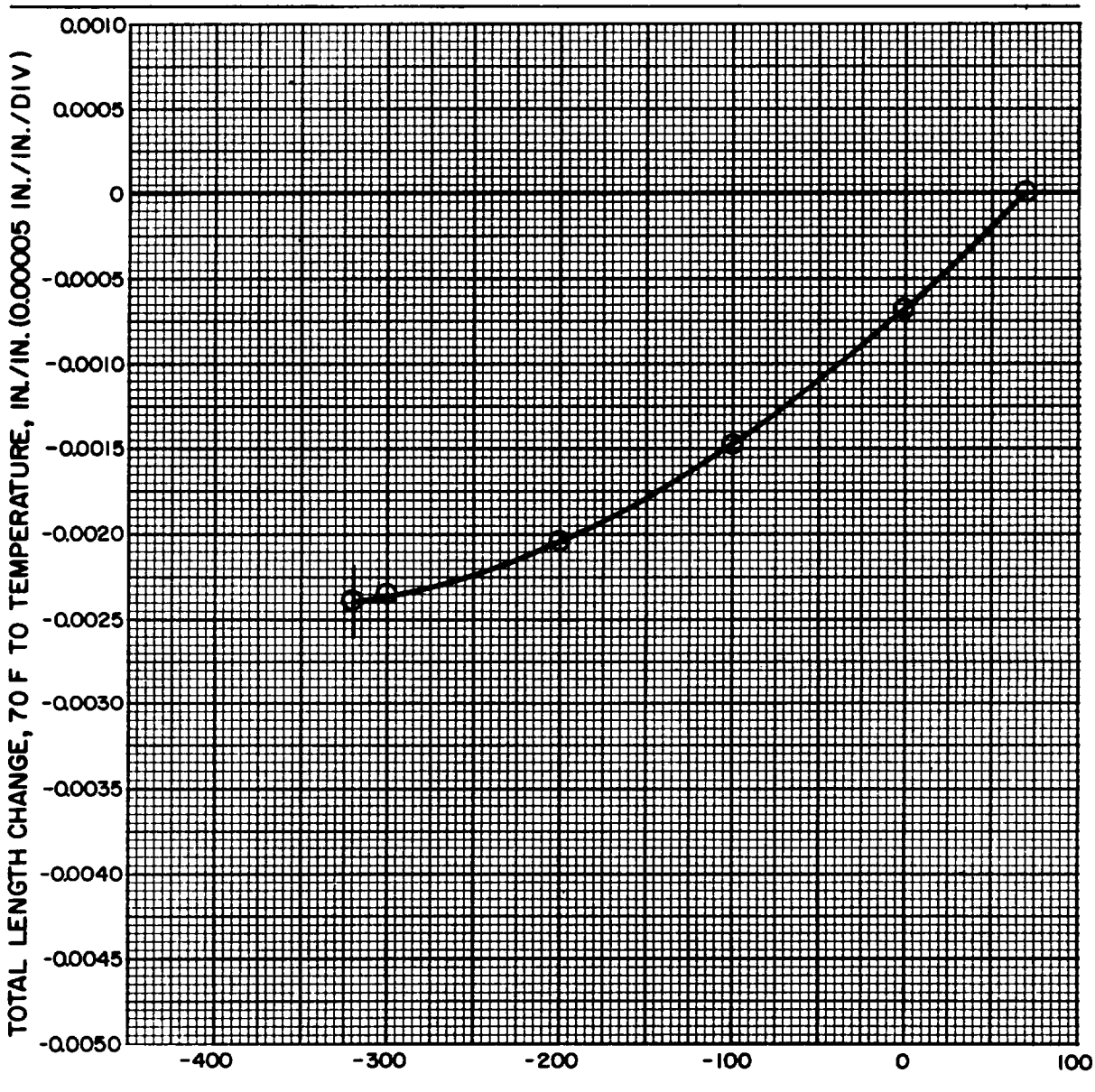
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·5·60
MATERIAL 88 X
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION AMS-5624
DATE MARCH 1962

NOTES:



88 X

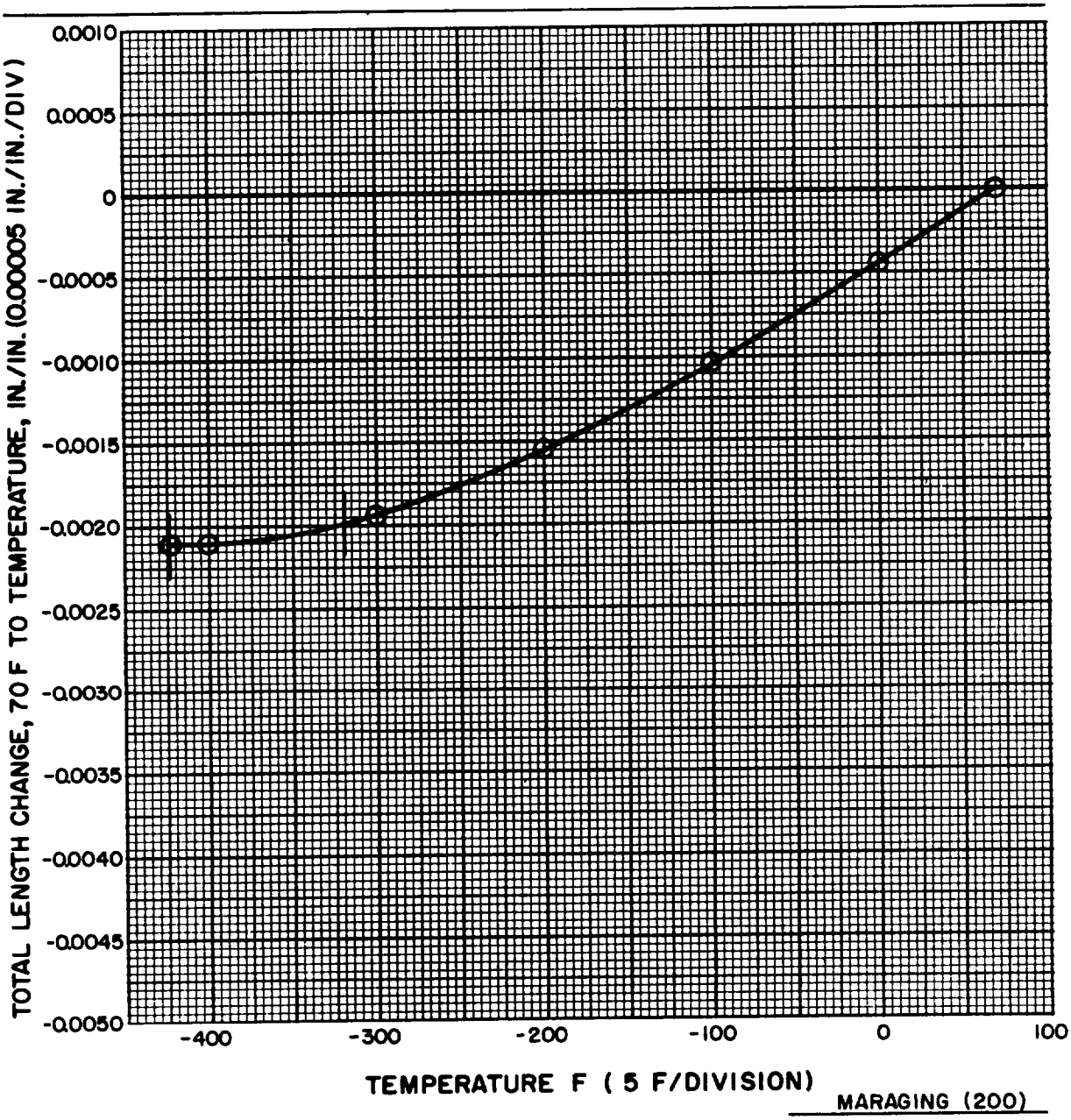
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·6·60
MATERIAL MARAGING (200)
FORM BAR
CONDITION SEE NOTES
SPECIFICATION –
DATE AUGUST 1965

NOTES: SOLUTIONED AT 1500°F AND AGED AT 900°F



MARAGING (200)

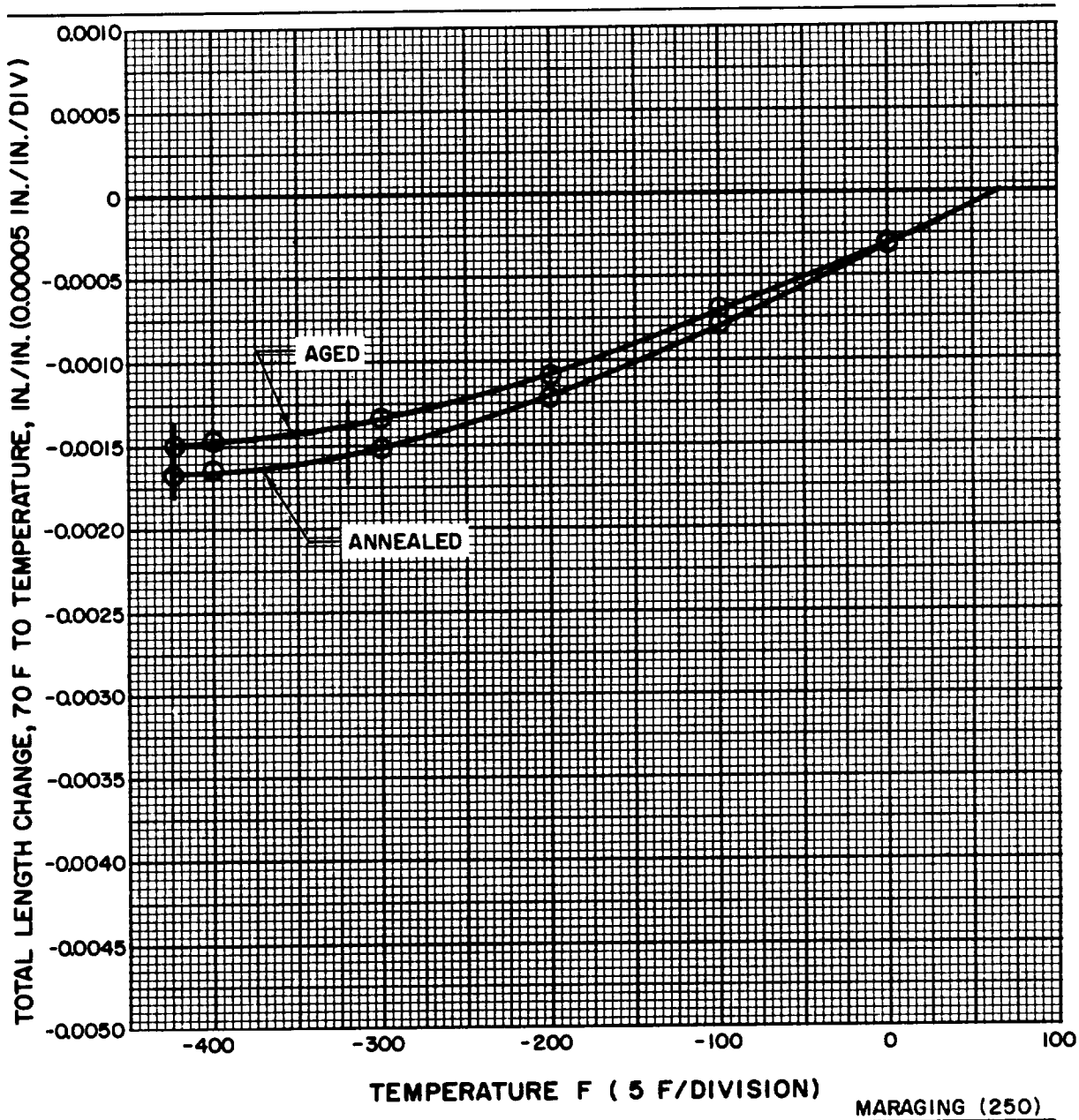
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·8·60
MATERIAL MARAGING (250)
FORM FORGING
CONDITION SEE NOTES
SPECIFICATION RBO 170-067
DATE AUGUST 1965

NOTES: ANNEALED 1500°F/1 HR AND/OR AGED 900°F/1 HR



MARAGING (250)

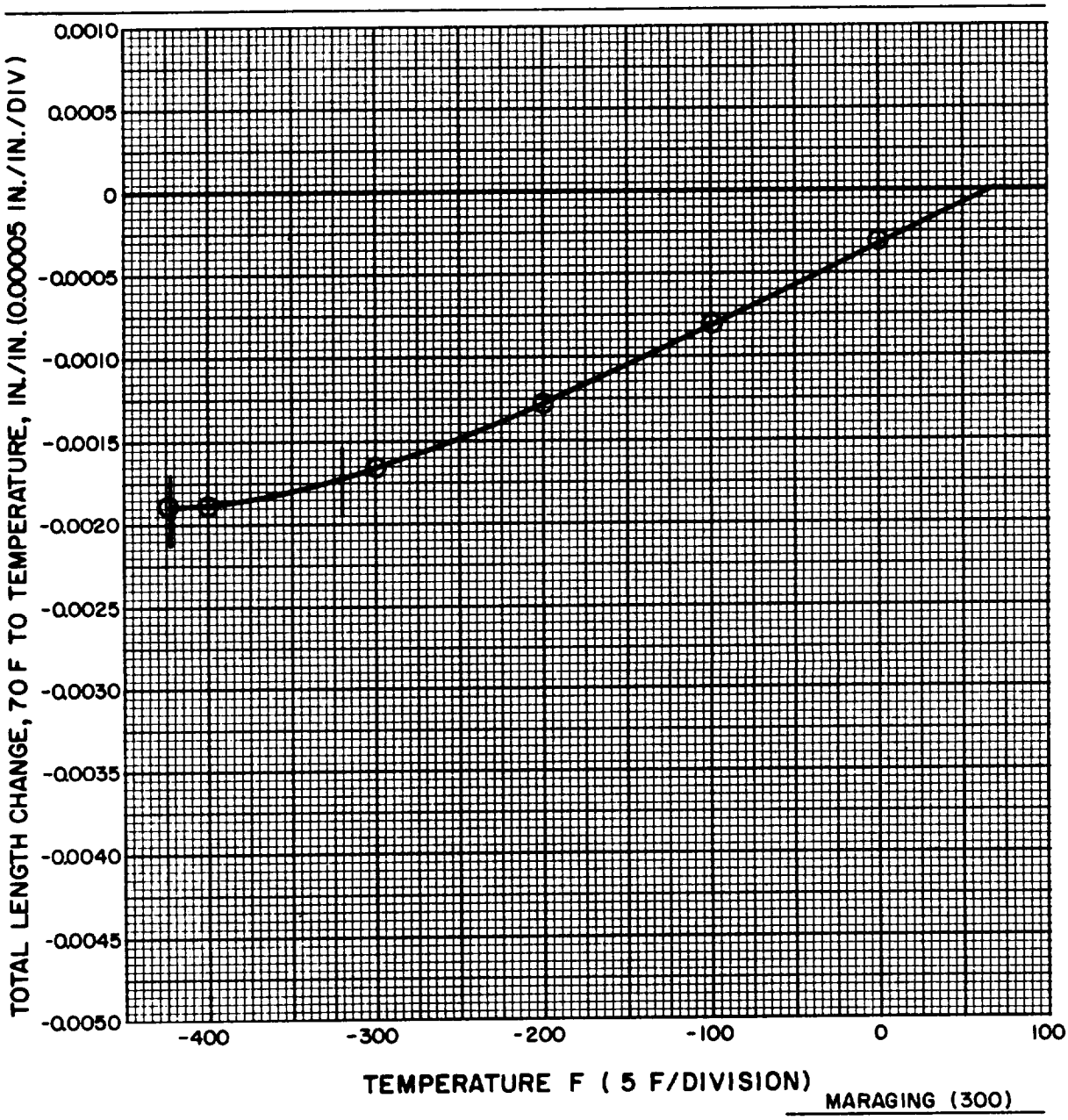
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·9·60
MATERIAL MARAGING (300)
FORM FORGING
CONDITION AGED AT 900°F/1 HR
SPECIFICATION –
DATE AUGUST 1965

NOTES:



MARAGING (300)

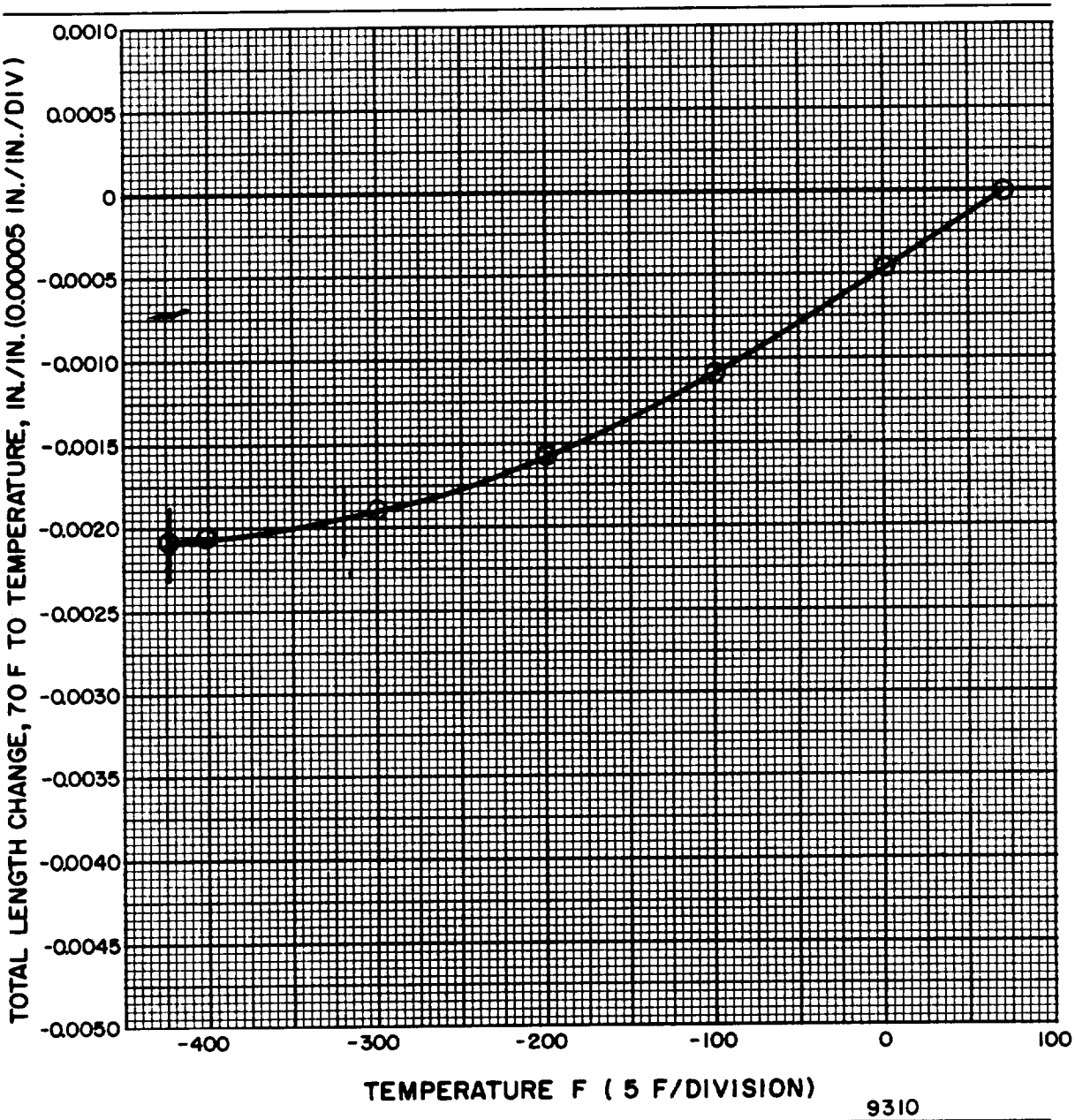
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·10·60
MATERIAL 9310
FORM BAR
CONDITION Q. T. R_c 36-40
SPECIFICATION AMS 6260 - 6265
DATE AUGUST 1965

NOTES:



9310

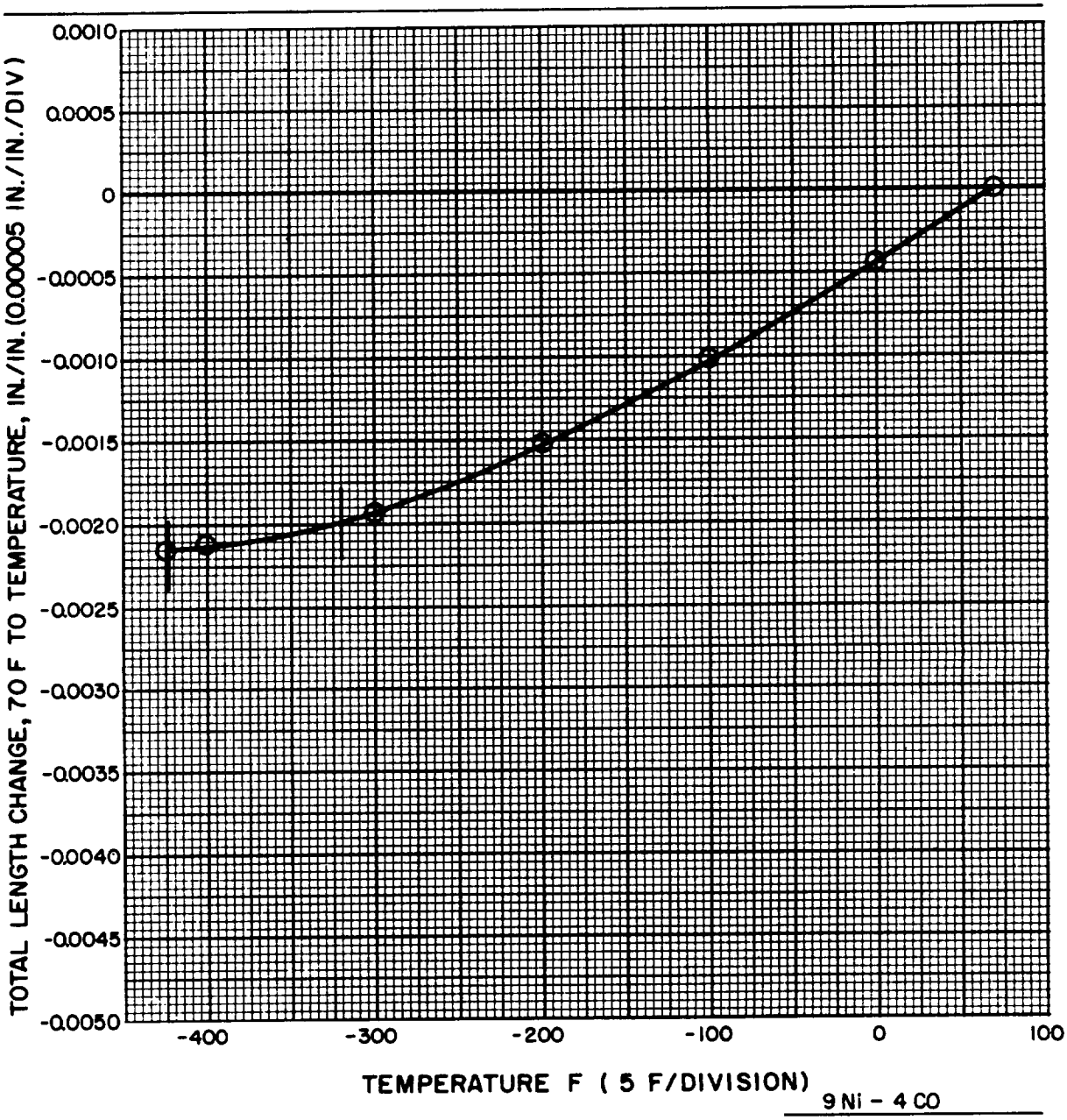
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 6·11·60
MATERIAL 9 Ni - 4 CO
FORM BAR
CONDITION SEE NOTES
SPECIFICATION
DATE AUGUST 1965

NOTES: SOLUTIONED 1550°F PLUS DOUBLE TEMPER 1000 °F



9 Ni - 4 CO

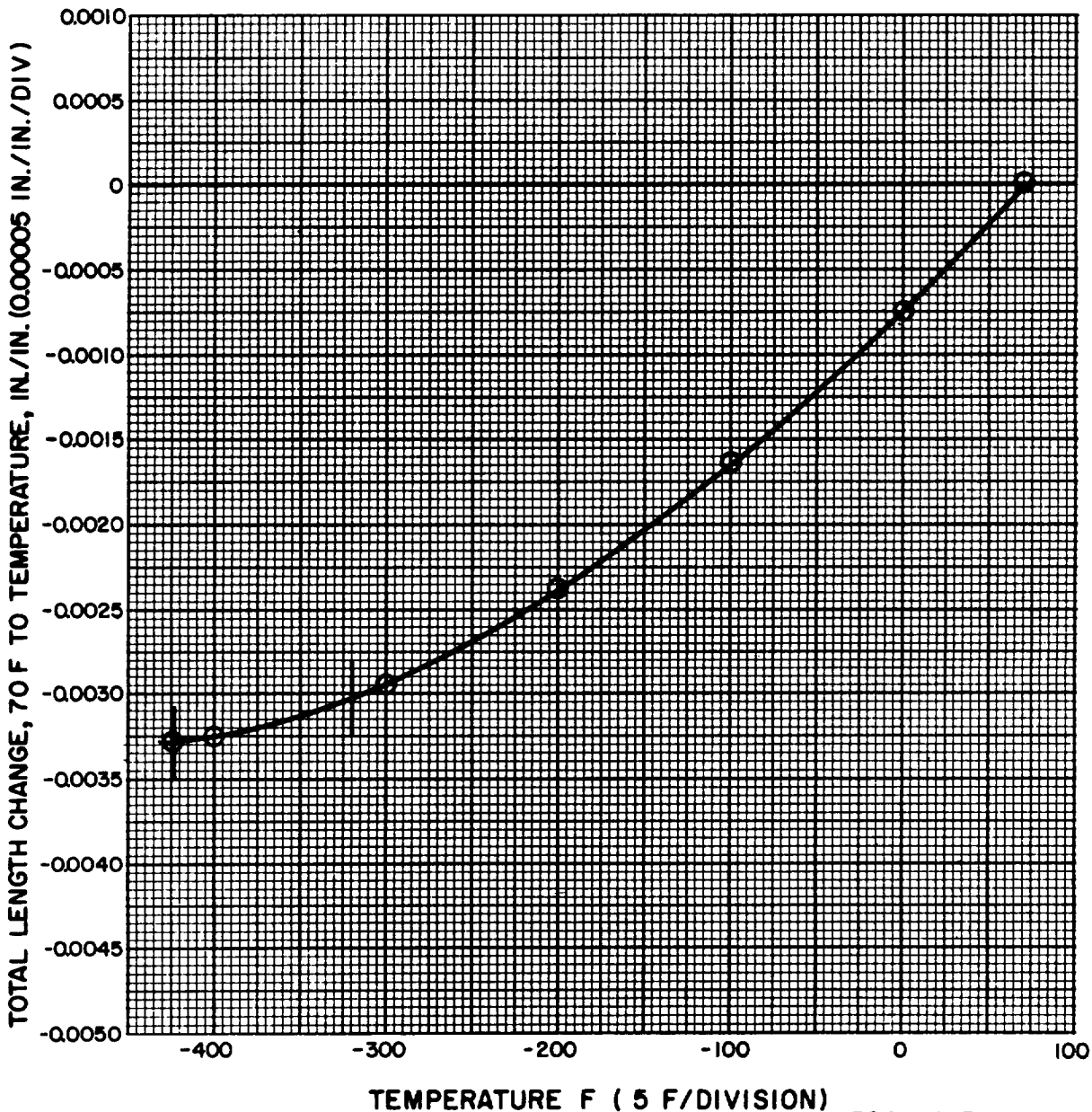
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·2·60
MATERIAL 304 L CRES
FORM BAR
CONDITION SEE NOTES
SPECIFICATION QQ-S-763
DATE AUGUST 1965

NOTES: ANNEALED AT 1950° F, WATER QUENCHED



304 L CRES

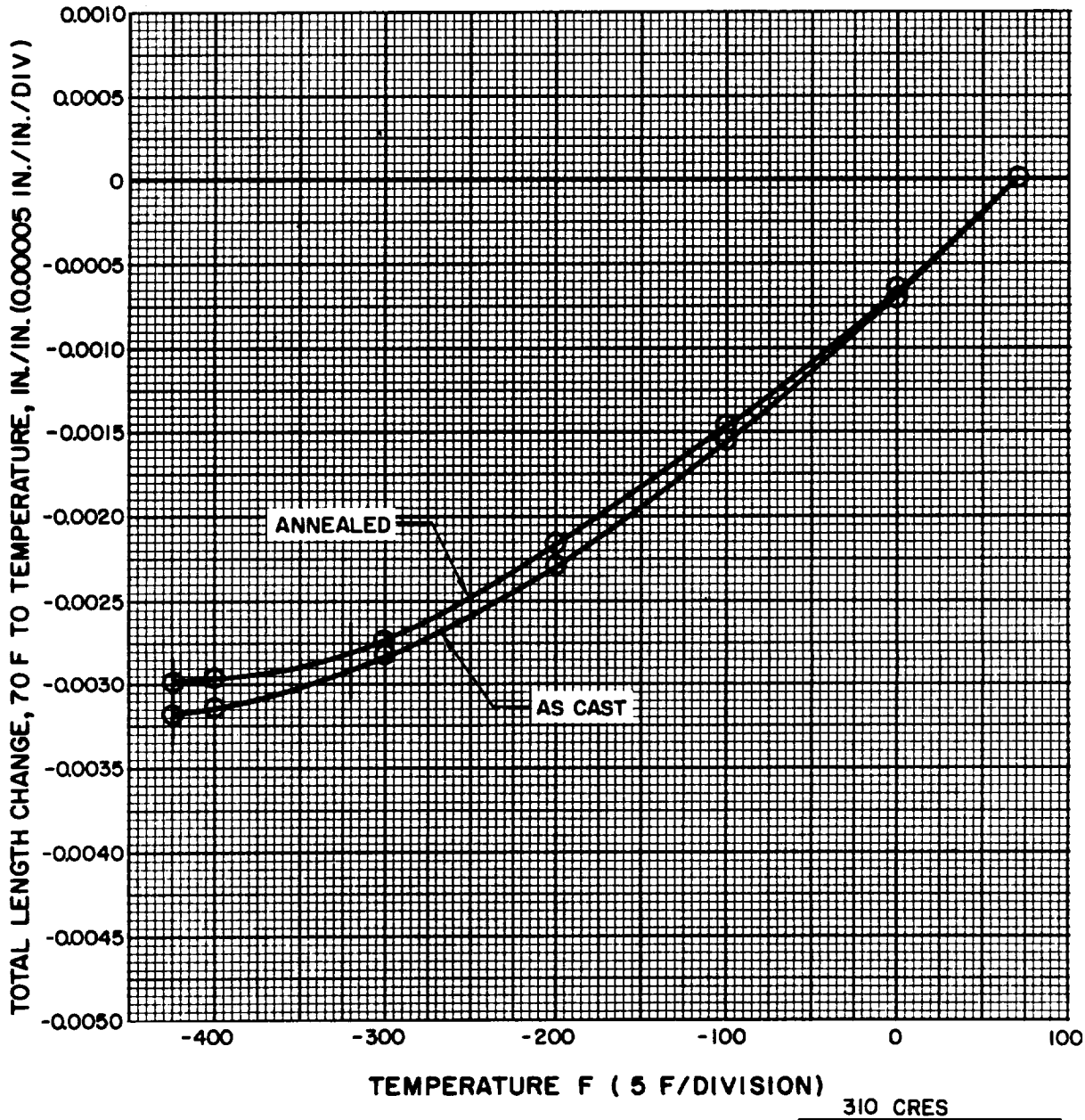
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·3·60
MATERIAL 310 CRES
FORM CASTING
CONDITION SEE NOTES
SPECIFICATION ASTM-A-296
DATE AUGUST 1965

NOTES: AS CAST / ANNEALED



310 CRES

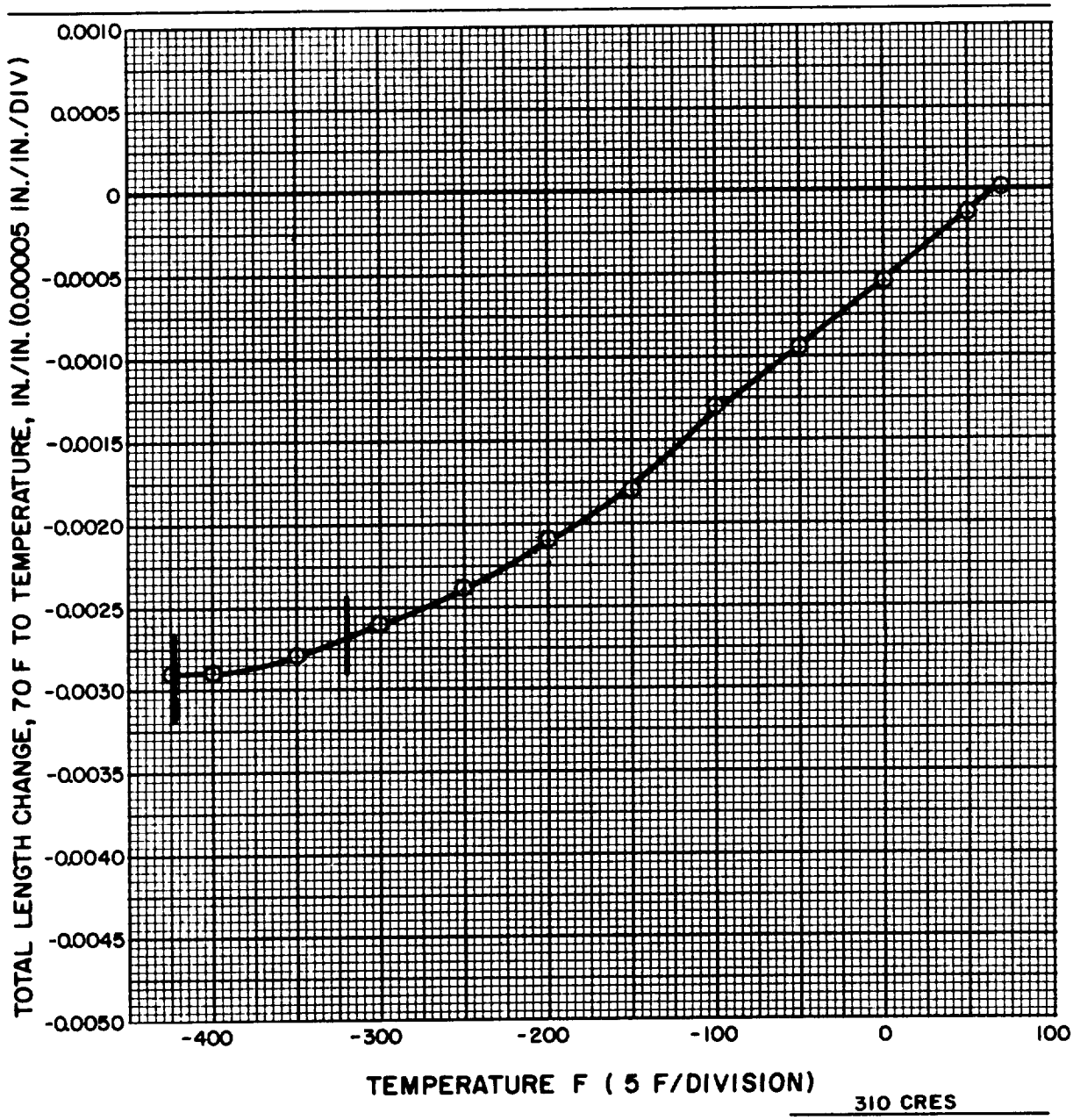
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE NATIONAL BUREAU OF STANDARDS
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·3A·60
MATERIAL 310 CRES
FORM BAR (WROUGHT)
CONDITION ANNEALED
SPECIFICATION
DATE SEPTEMBER 1966

NOTES:



310 CRES

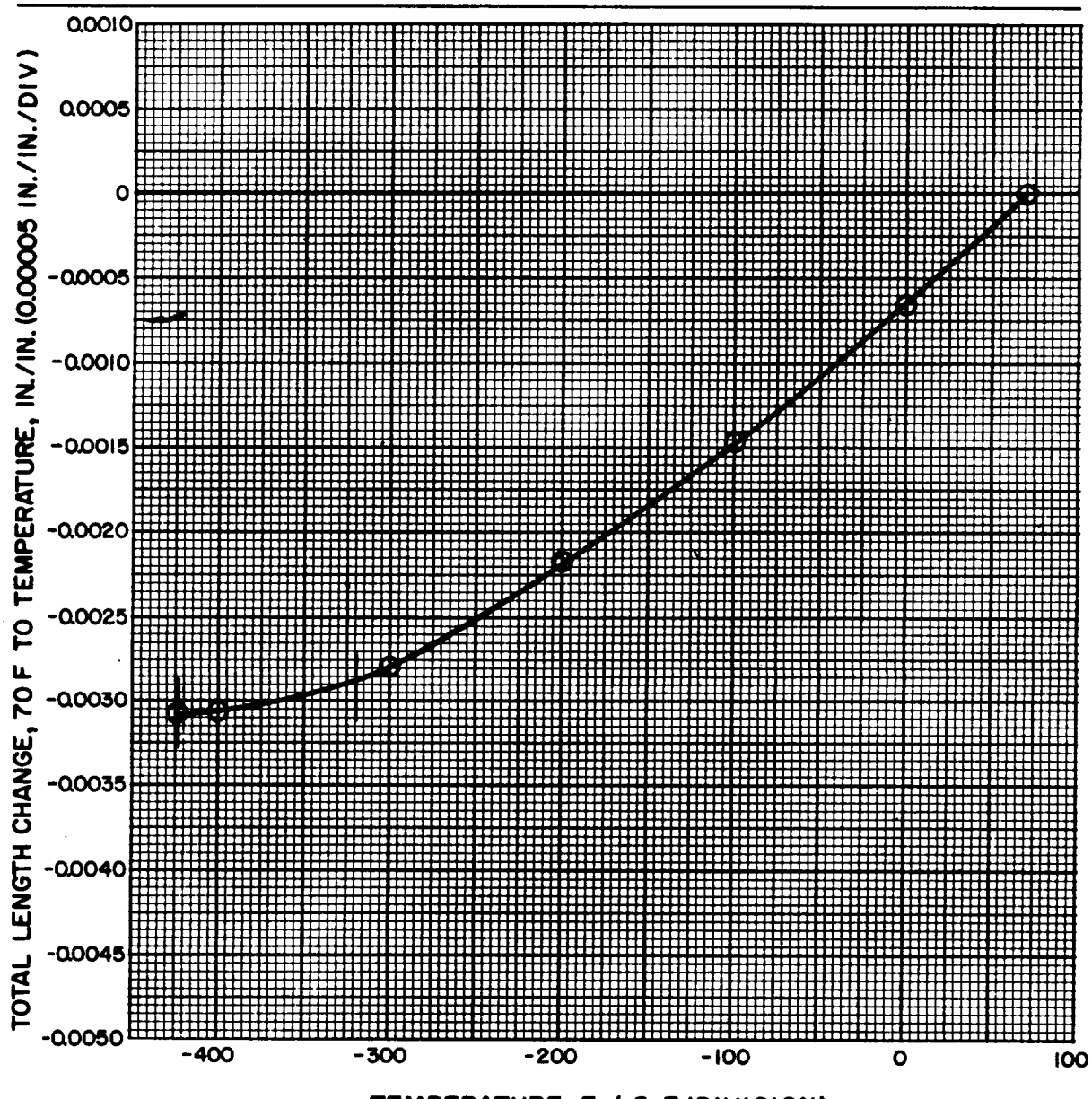
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·4·60
MATERIAL 316 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-S-763
DATE AUGUST 1965

NOTES:



316 CRES

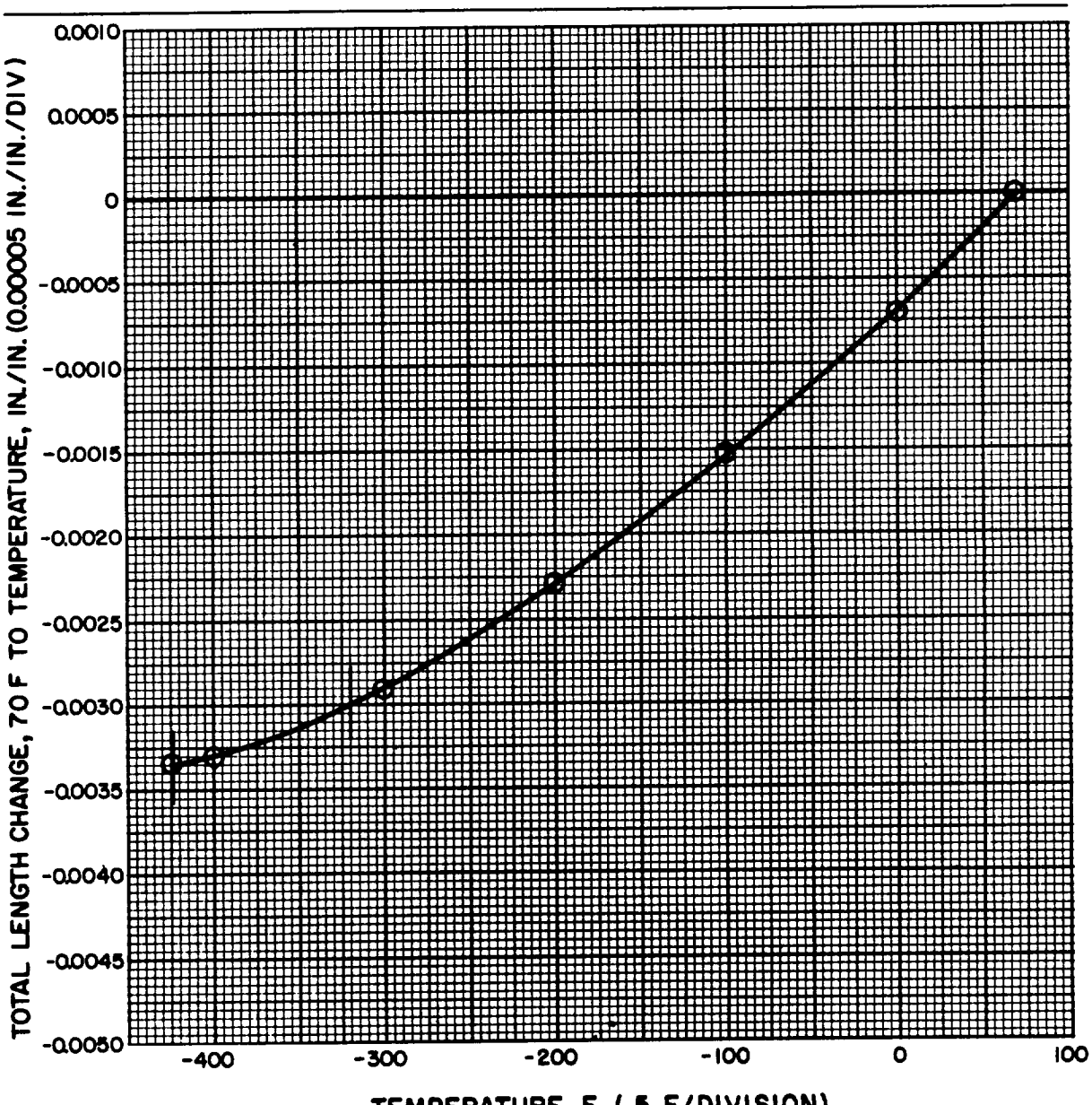
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·5·60
MATERIAL 321 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-S-763
DATE AUGUST 1965

NOTES:



321 CRES

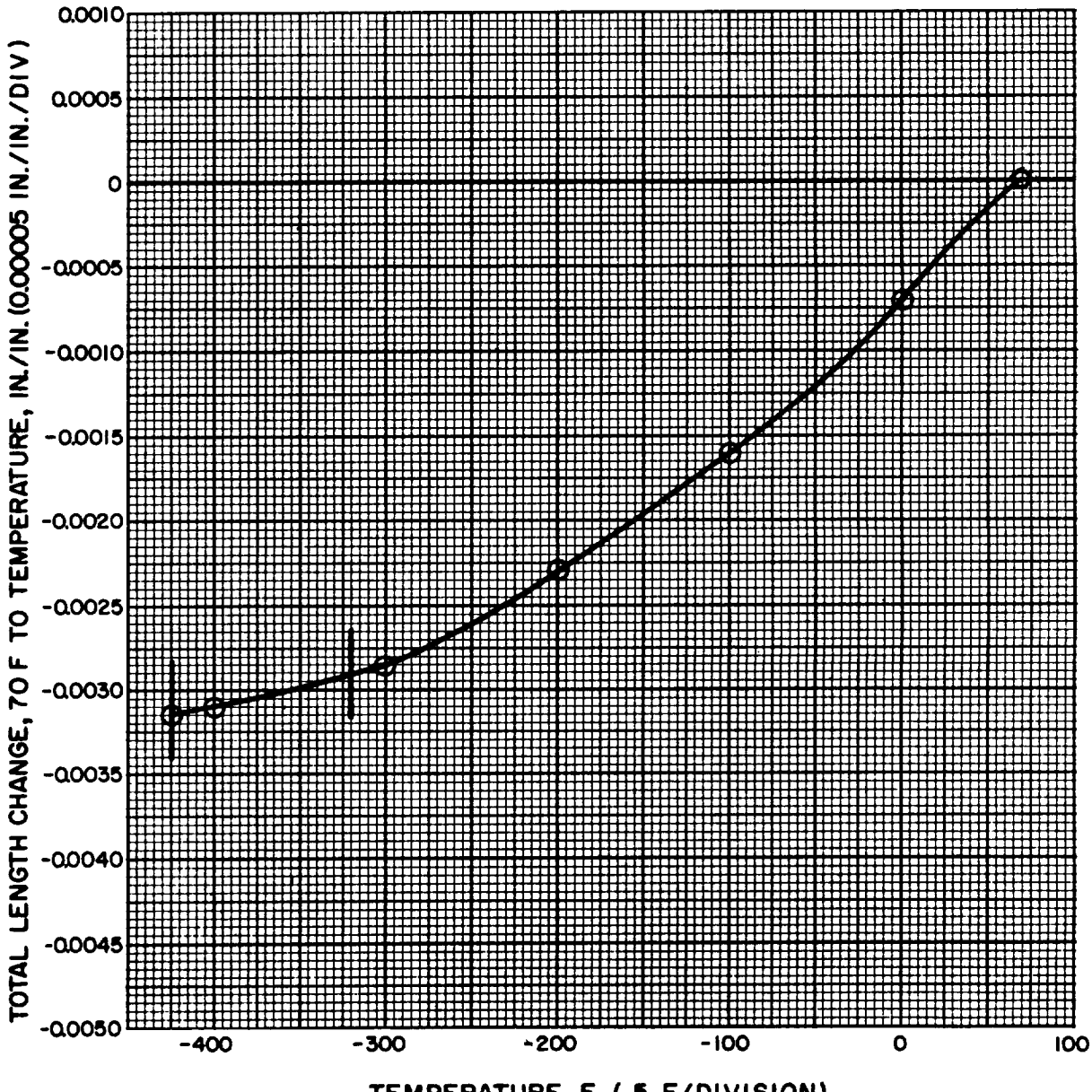
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·7·60
MATERIAL 347 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION QQ-S-763
DATE AUGUST 1965

NOTES:



347 CRES

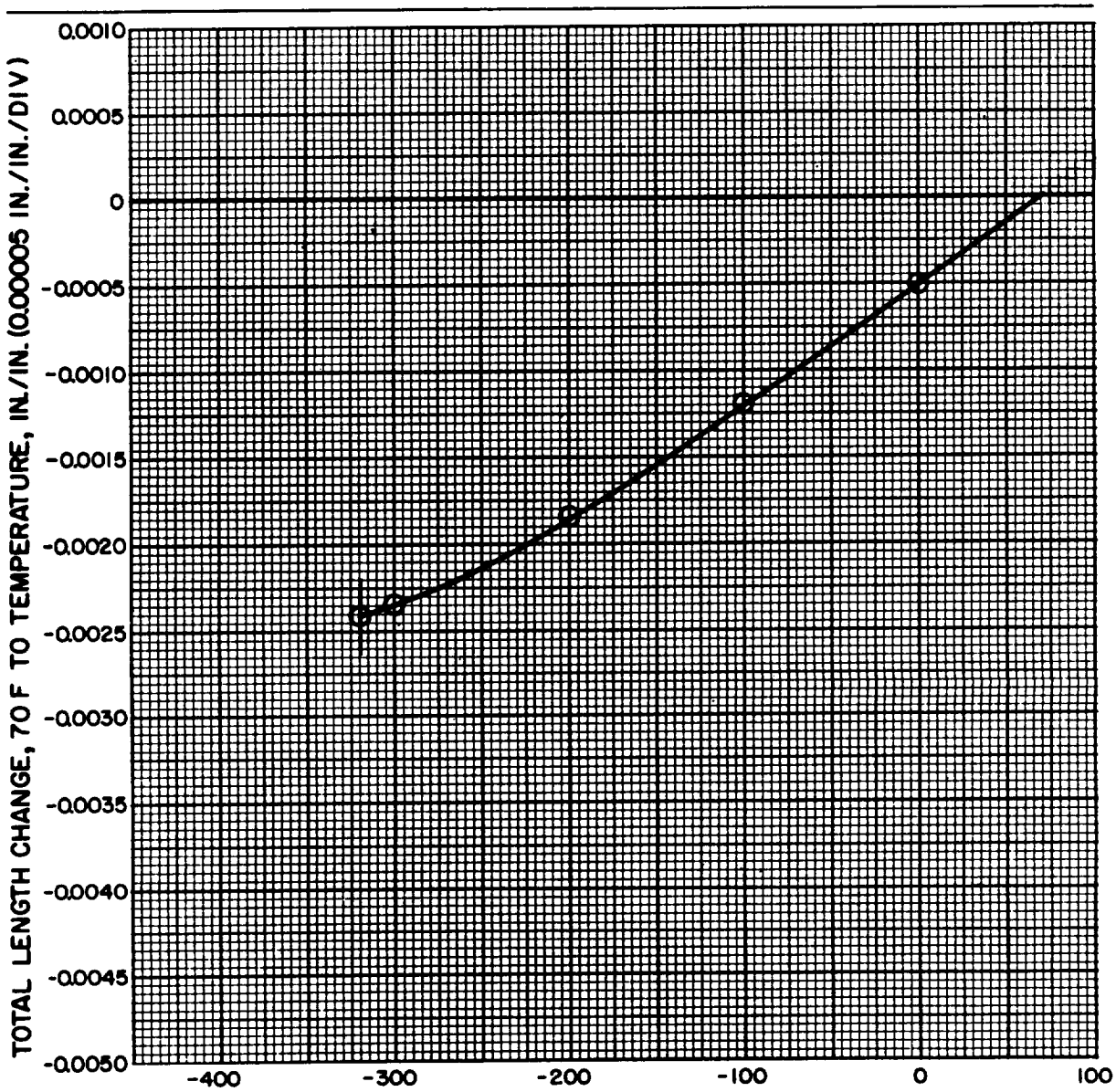
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·9·60
MATERIAL 29 NI-20 CR
FORM BAR
CONDITION ANNEALED
SPECIFICATION RBO 160-009
DATE MARCH 1962

NOTES:



29 NI-20 CR

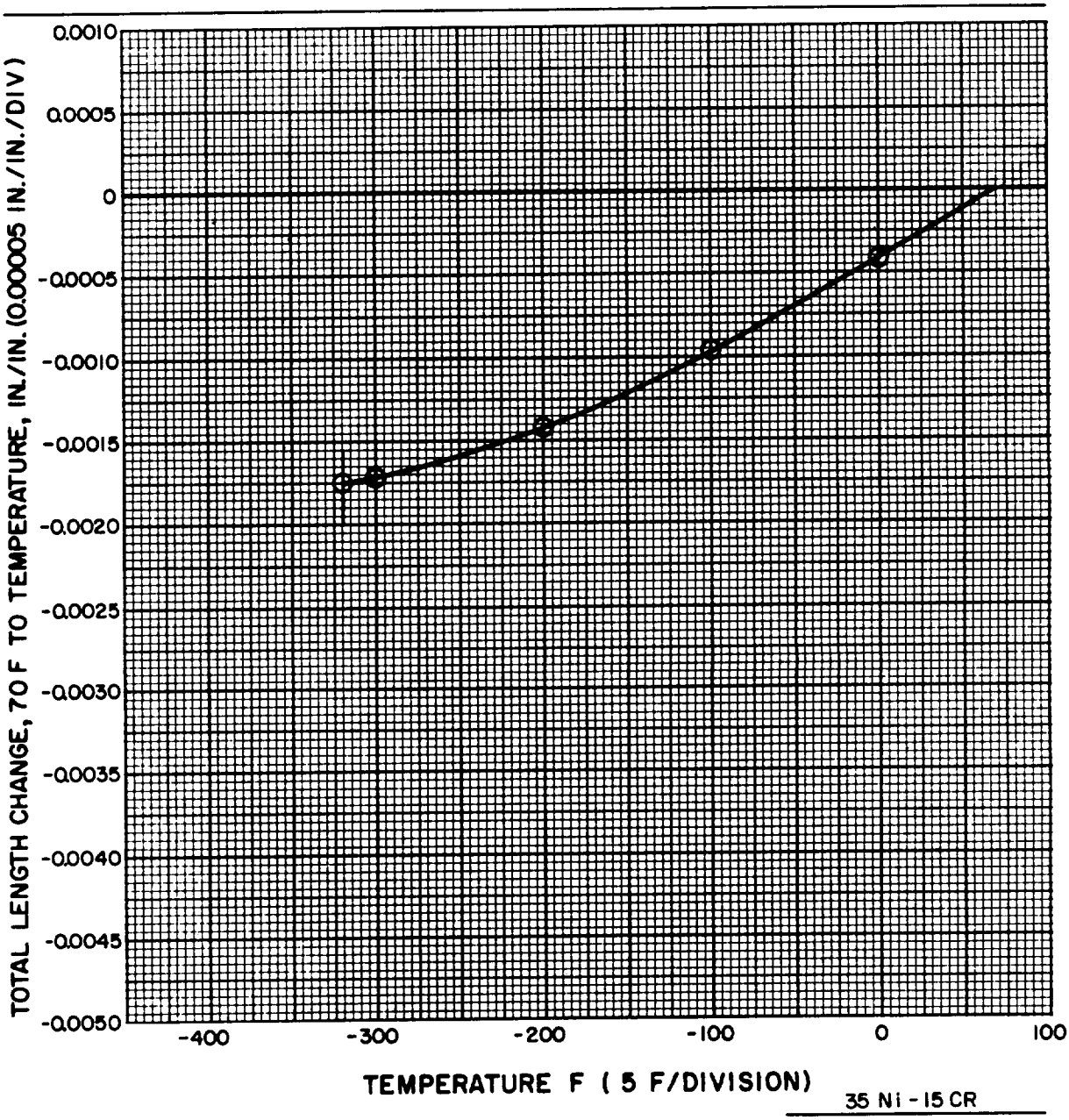
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·10·60
MATERIAL 35 Ni-15 CR
FORM CASTING
CONDITION CAST AND ANNEALED
SPECIFICATION
DATE MARCH 1962

NOTES:



35 Ni-15 CR

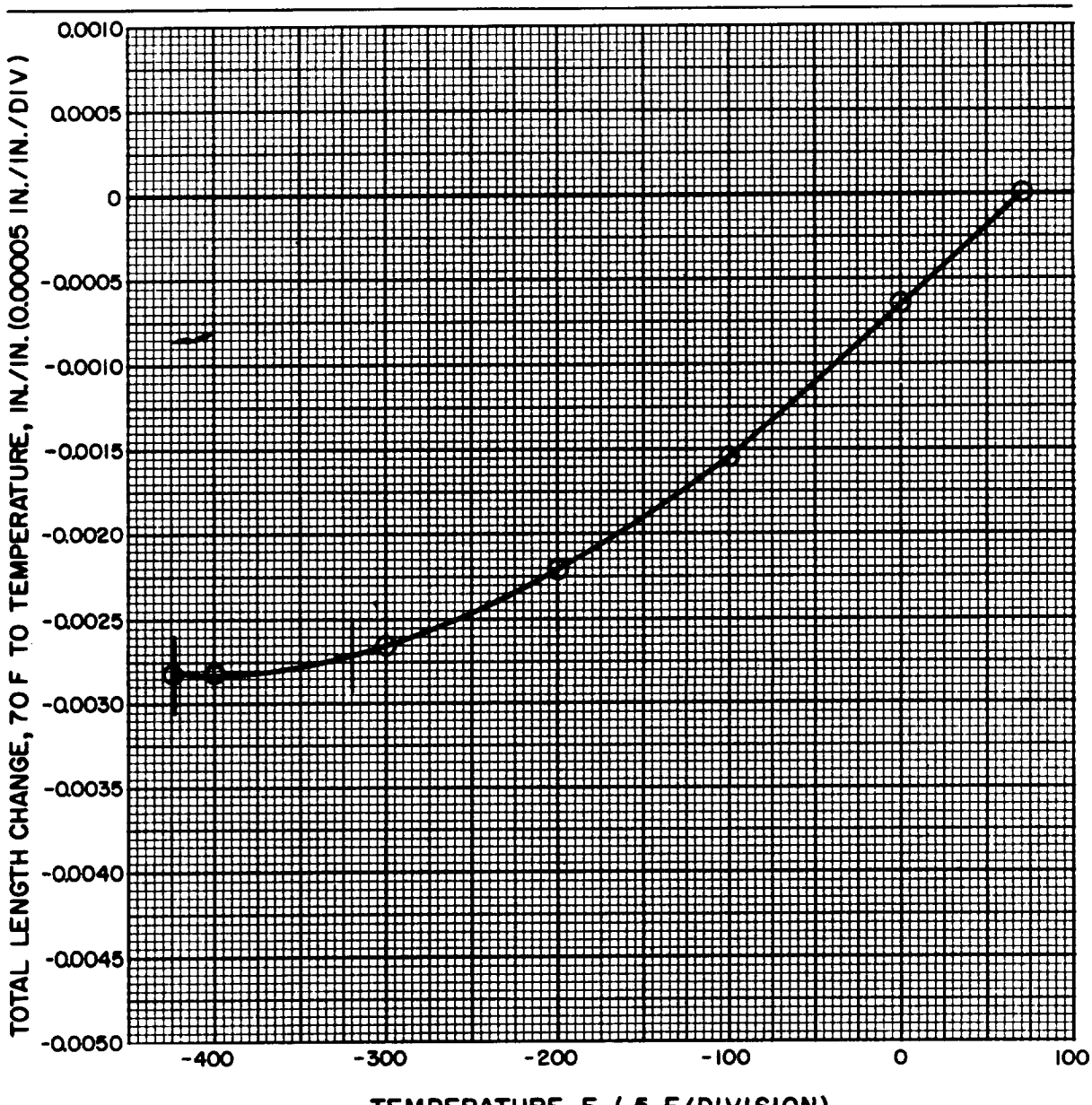
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 7·11·60
MATERIAL ARMCO 21-6-9
FORM BAR
CONDITION SEE NOTES
SPECIFICATION —
DATE AUGUST 1965

NOTES: ANNEALED AT 1950°F / 1 HR., WATER QUENCHED
21 Cr - 6 Ni - 9 Mn BALANCE Fe



ARMCO 21-6-9

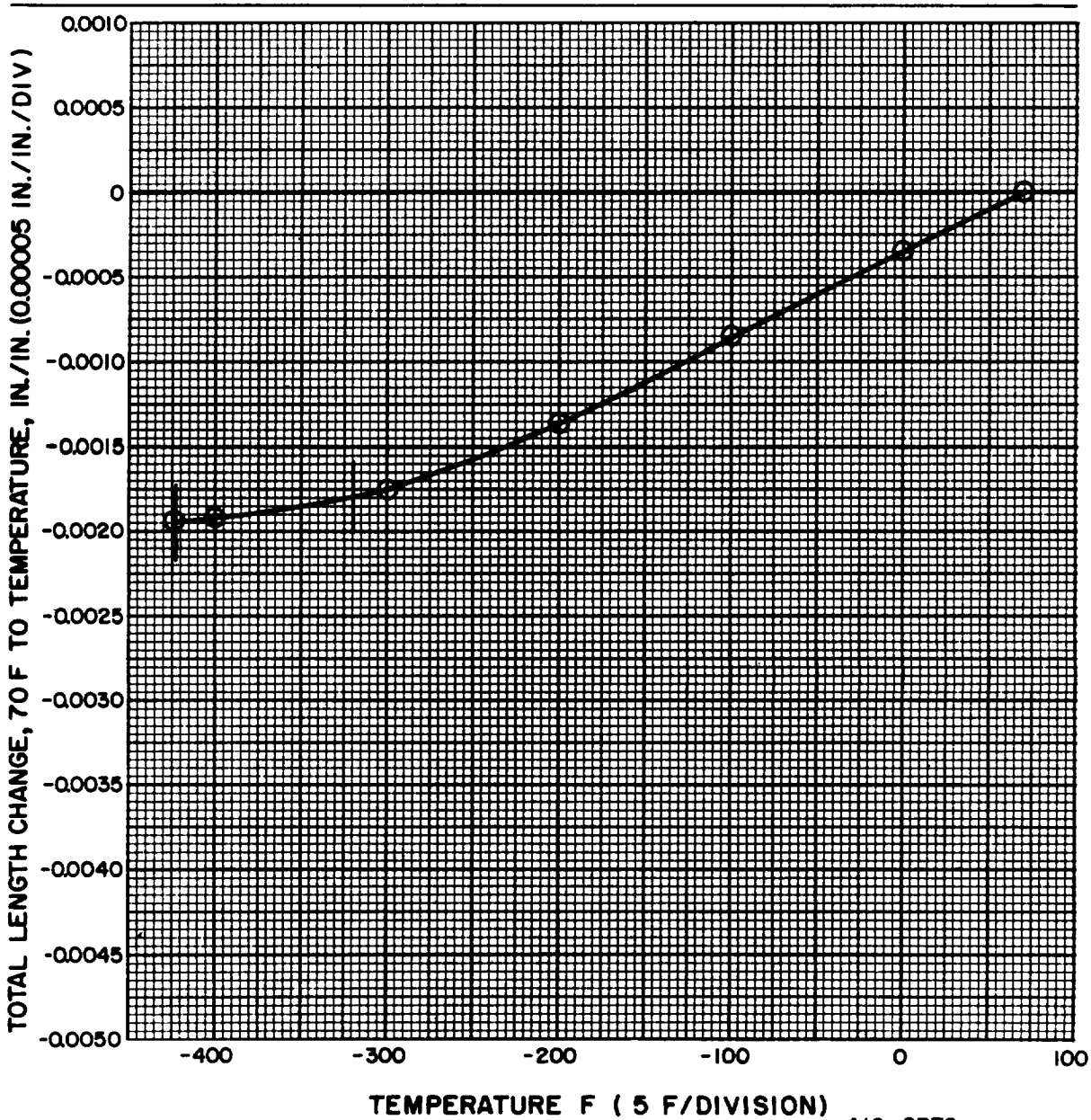
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8·1·60
MATERIAL 416 CRES
FORM BAR
CONDITION SEE NOTES
SPECIFICATION AMS 5610
DATE AUGUST 1965

NOTES: 1825° ± 25°F / 1/2 HR., O.Q., PLUS 525° ± 10°F / 3 HR. R_c 39-45



416 CRES

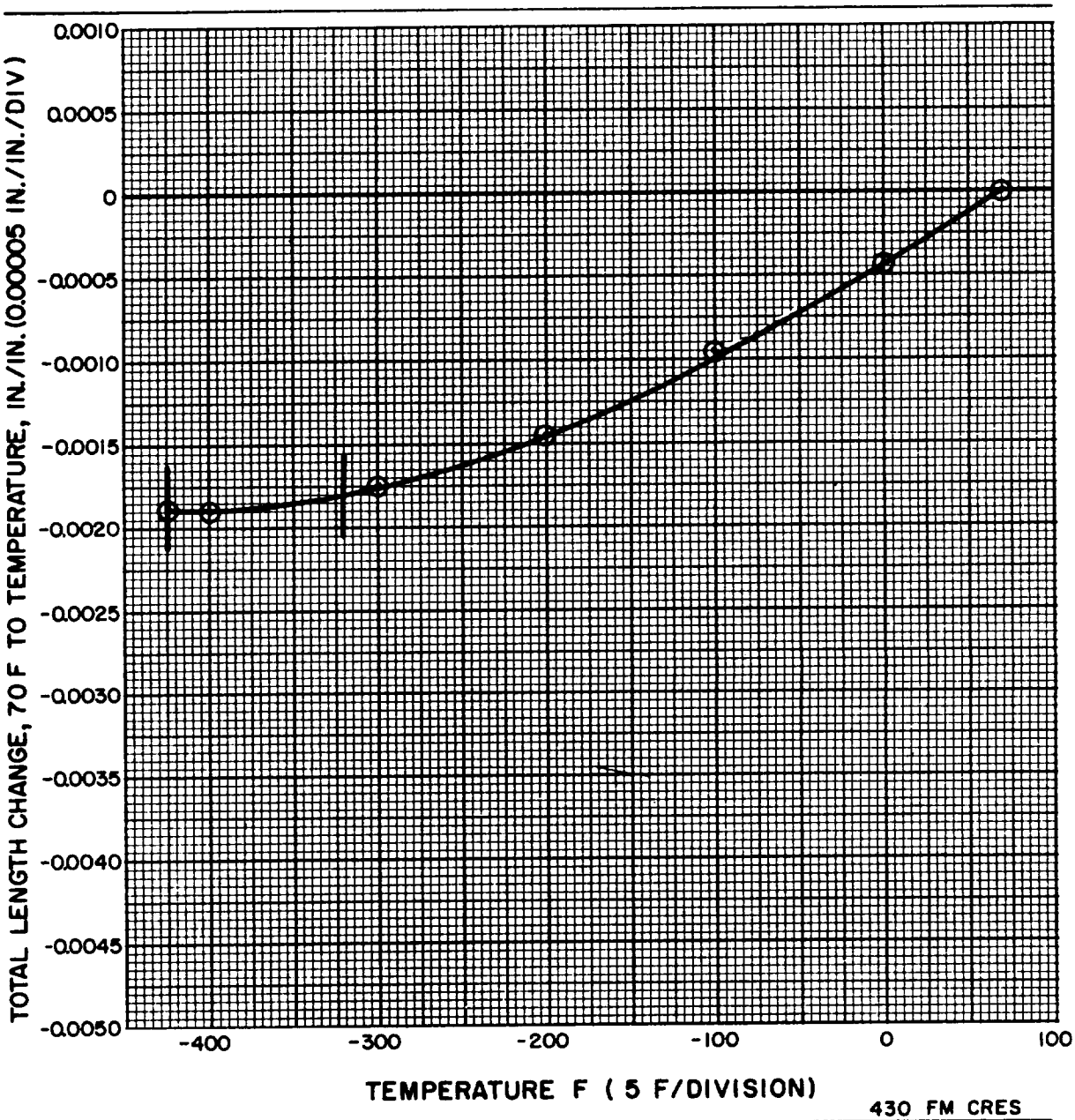
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8·2·60
MATERIAL 430 FM CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION
DATE AUGUST 1965

NOTES:



430 FM CRES

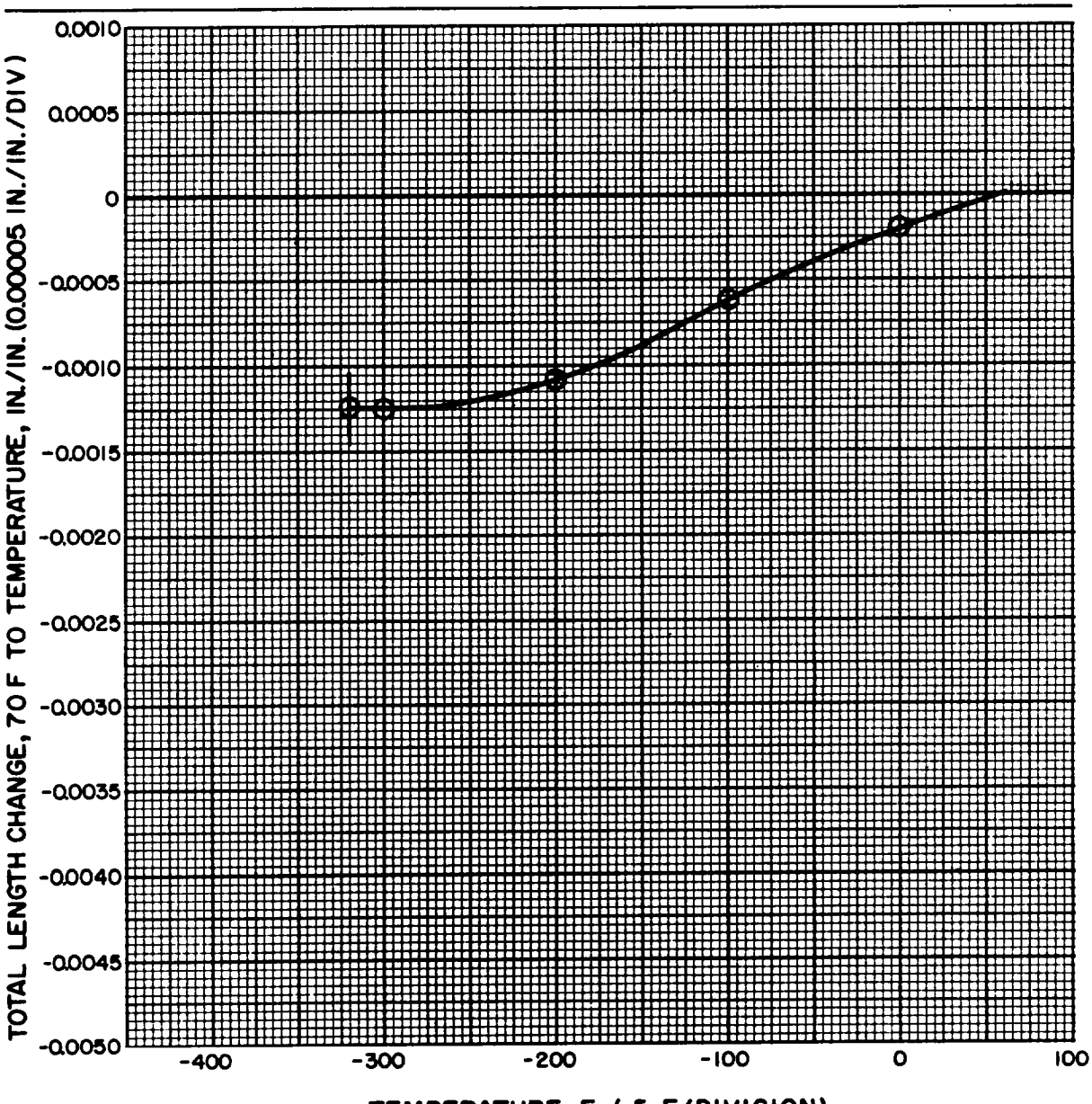
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8-3-60
MATERIAL 431 CRES
FORM BAR
CONDITION ANNEALED
SPECIFICATION MIL-S-18732
DATE MARCH 1962

NOTES:



431 CRES

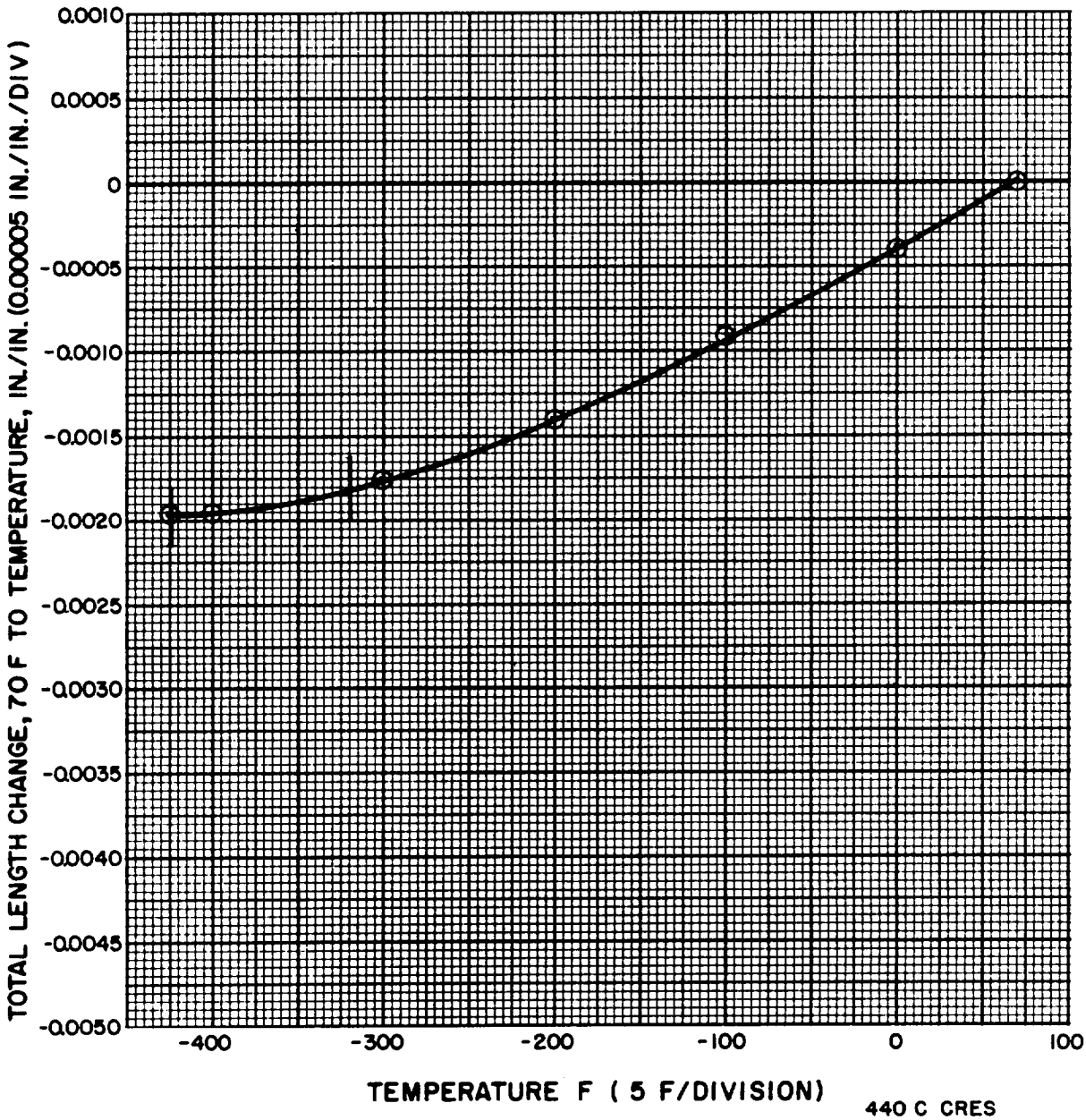
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8-4-60
MATERIAL 440 C CRES
FORM BAR
CONDITION RC 53-58
SPECIFICATION QQ-S-763
DATE AUGUST 1965

NOTES:



440 C CRES

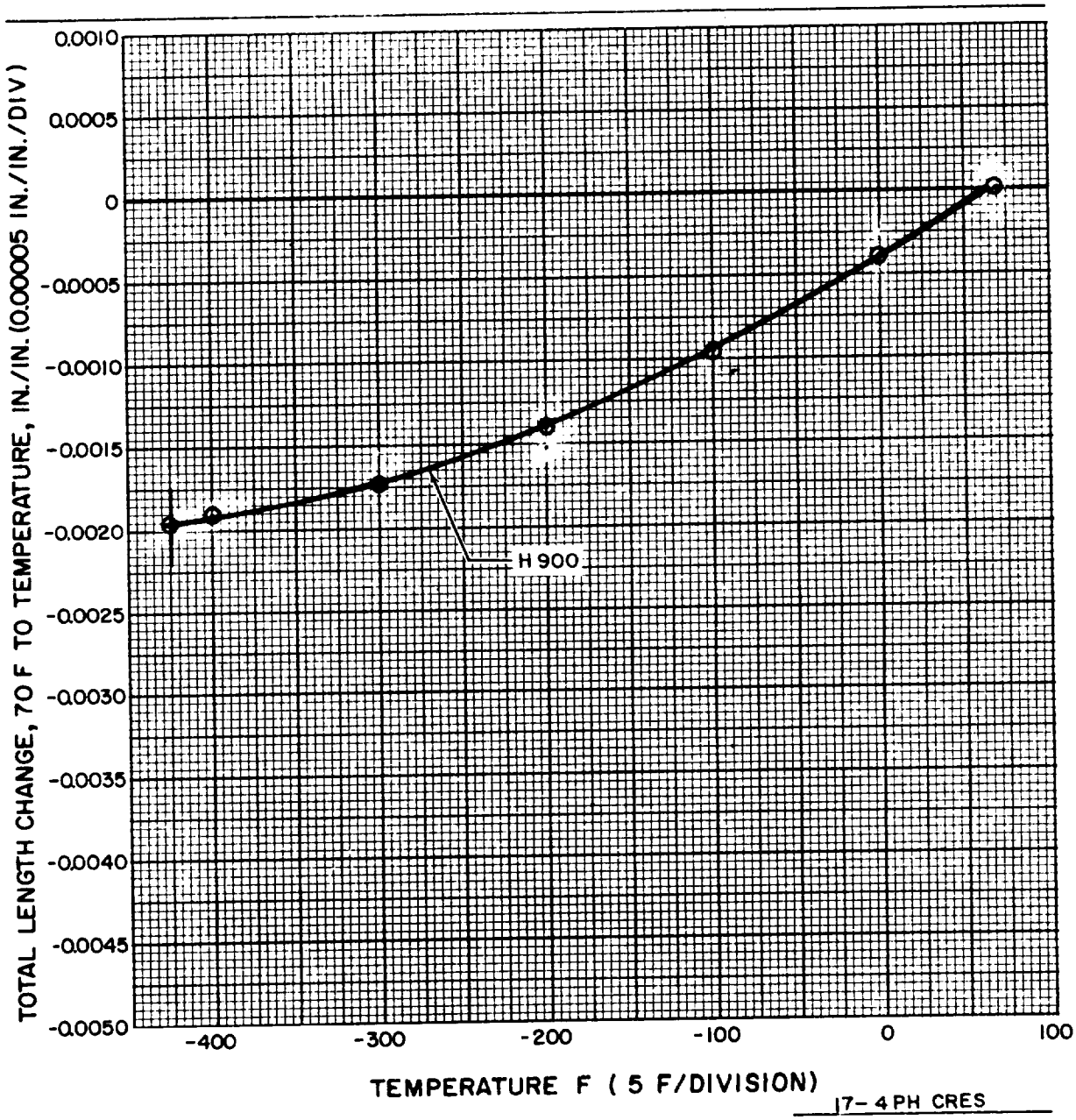
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8-5-60
MATERIAL 17-4PH CRES
FORM BAR
CONDITION H900
SPECIFICATION AMS 5643
DATE AUGUST 1965

NOTES:



17-4 PH CRES

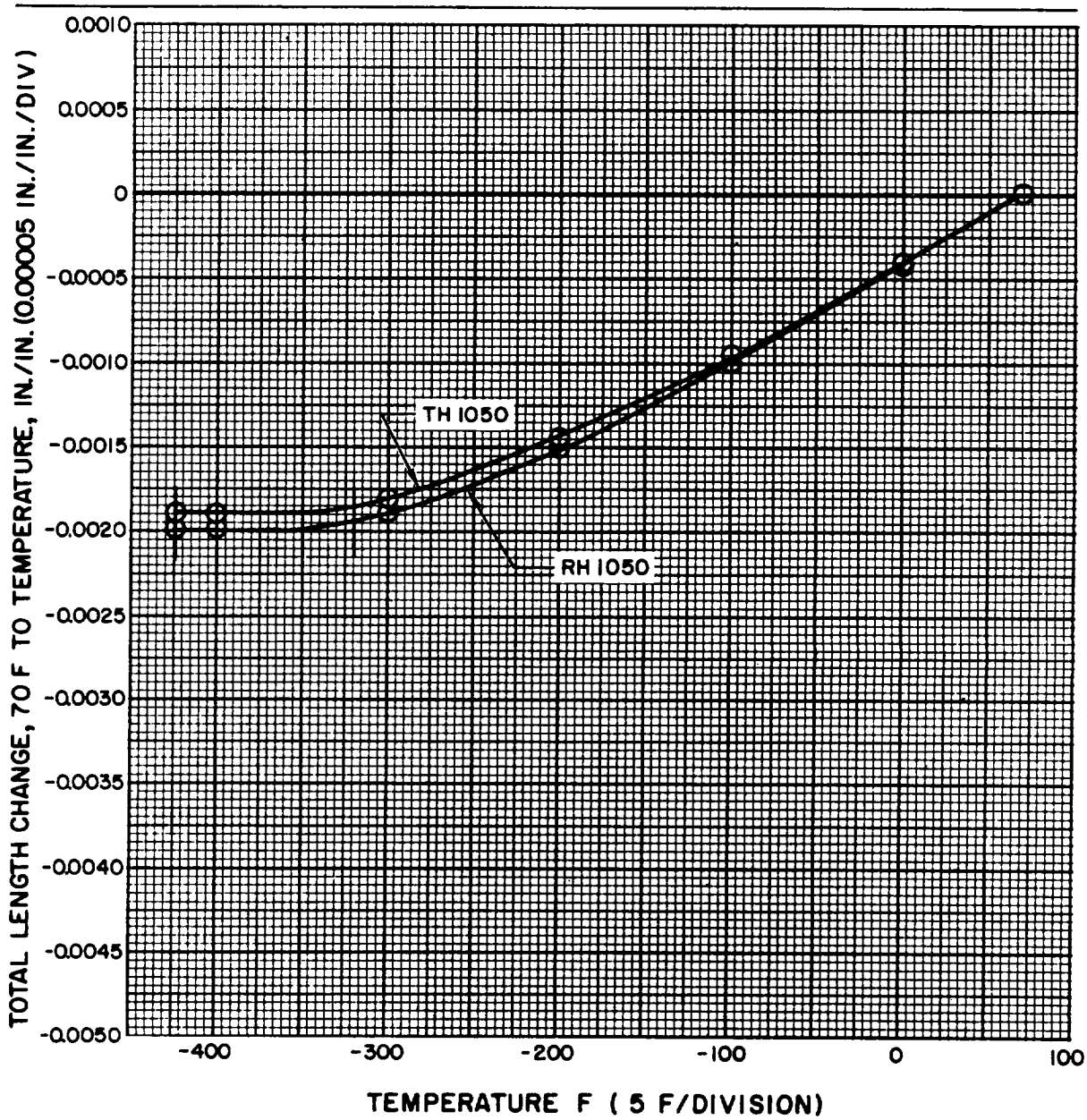
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8-6-60
MATERIAL 17-7PH CRES
FORM BAR
CONDITION TH 1050/RH 1050
SPECIFICATION SEE NOTES
DATE AUGUST 1965

NOTES: AMS 5644 - RB0160-003



17-7PH CRES

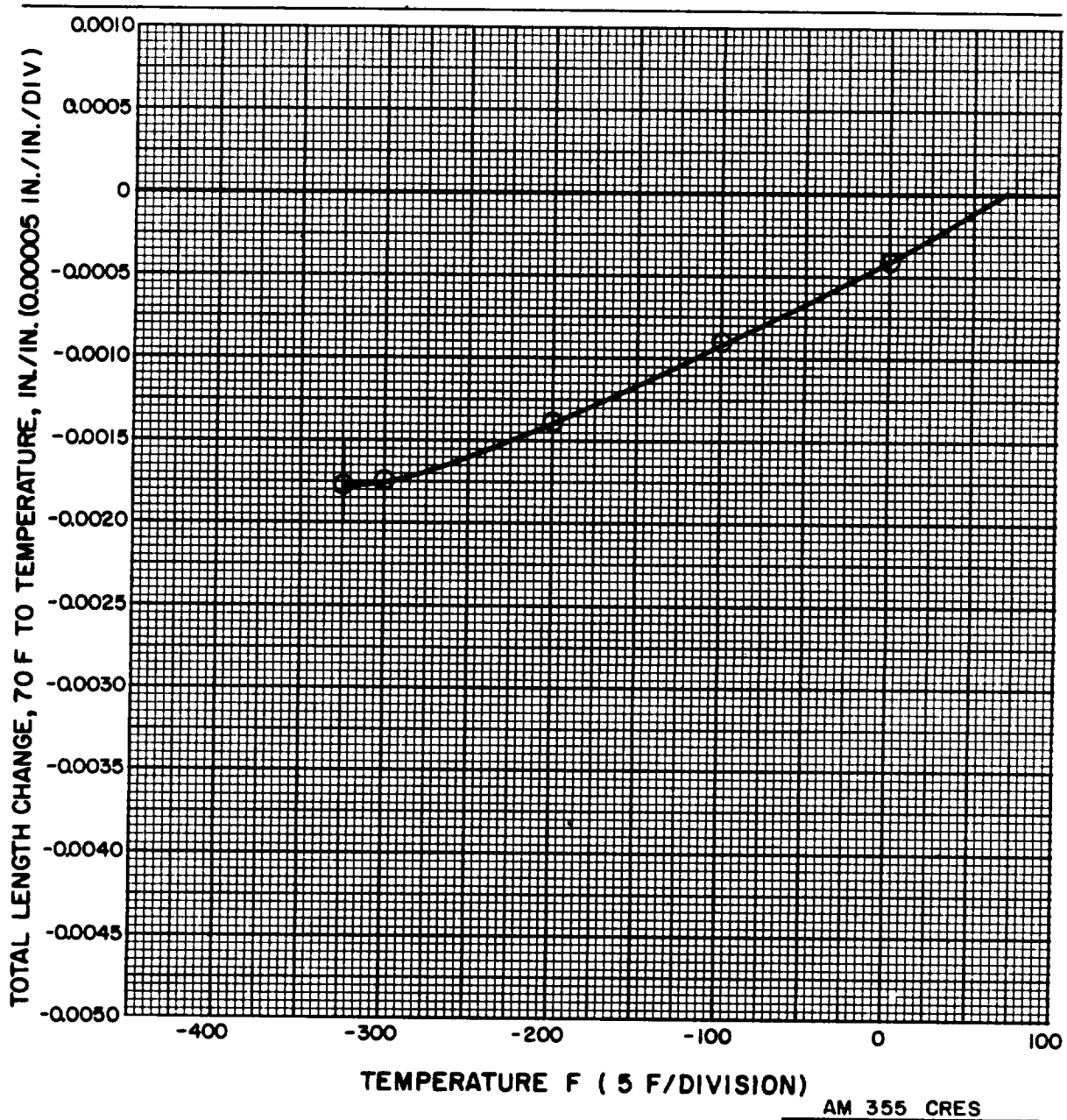
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8-7-60
MATERIAL AM 355 CRES
FORM BAR
CONDITION SCT 1000
SPECIFICATION AMS 5744
DATE MARCH 1962

NOTES: 15 Cr-4 Ni-3 Mo



AM 355 CRES

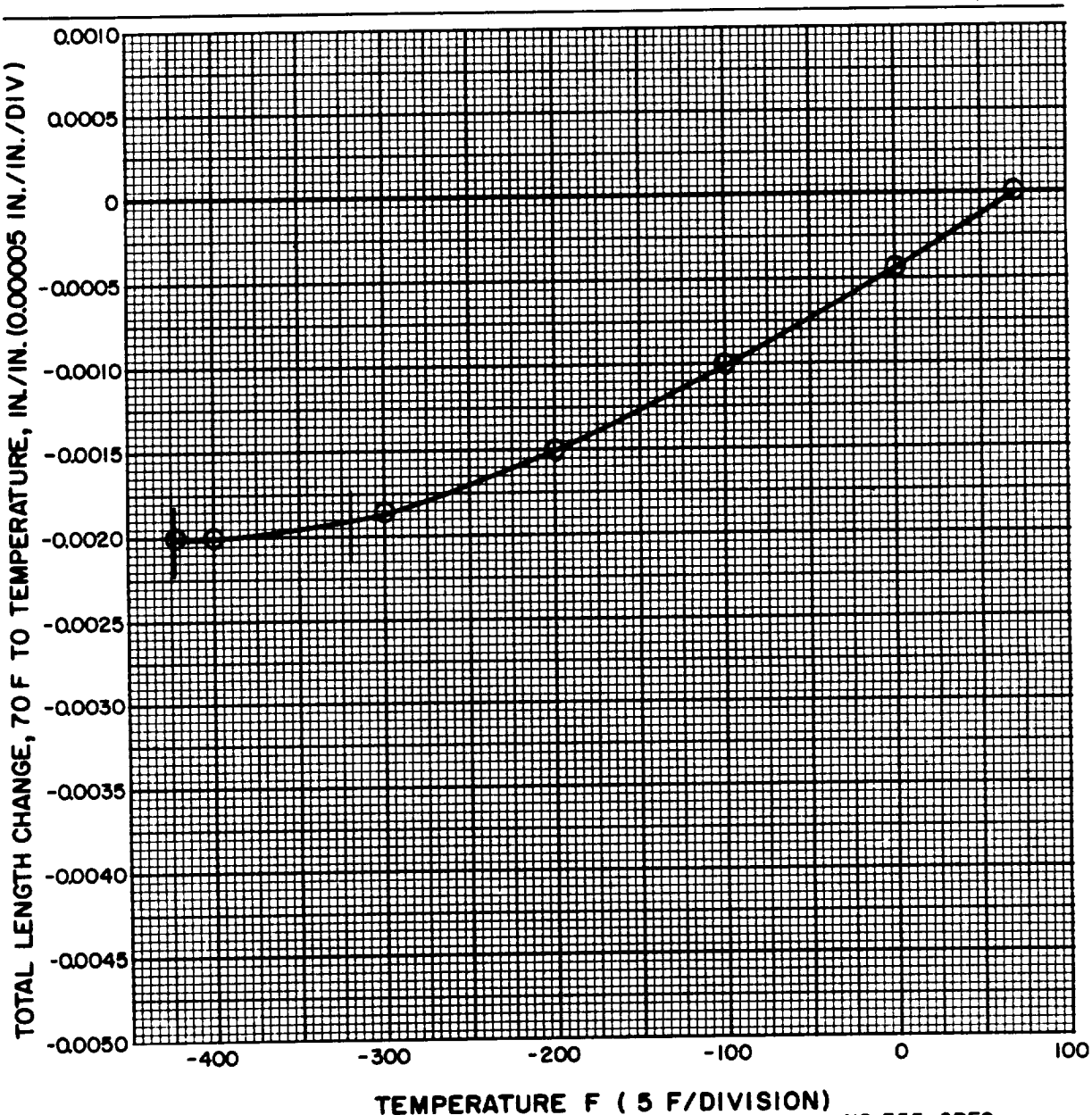
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8·8·60
MATERIAL NS 355 CRES
FORM BAR
CONDITION HARD DRAWN
SPECIFICATION
DATE AUGUST 1965

NOTES:



NS 355 CRES

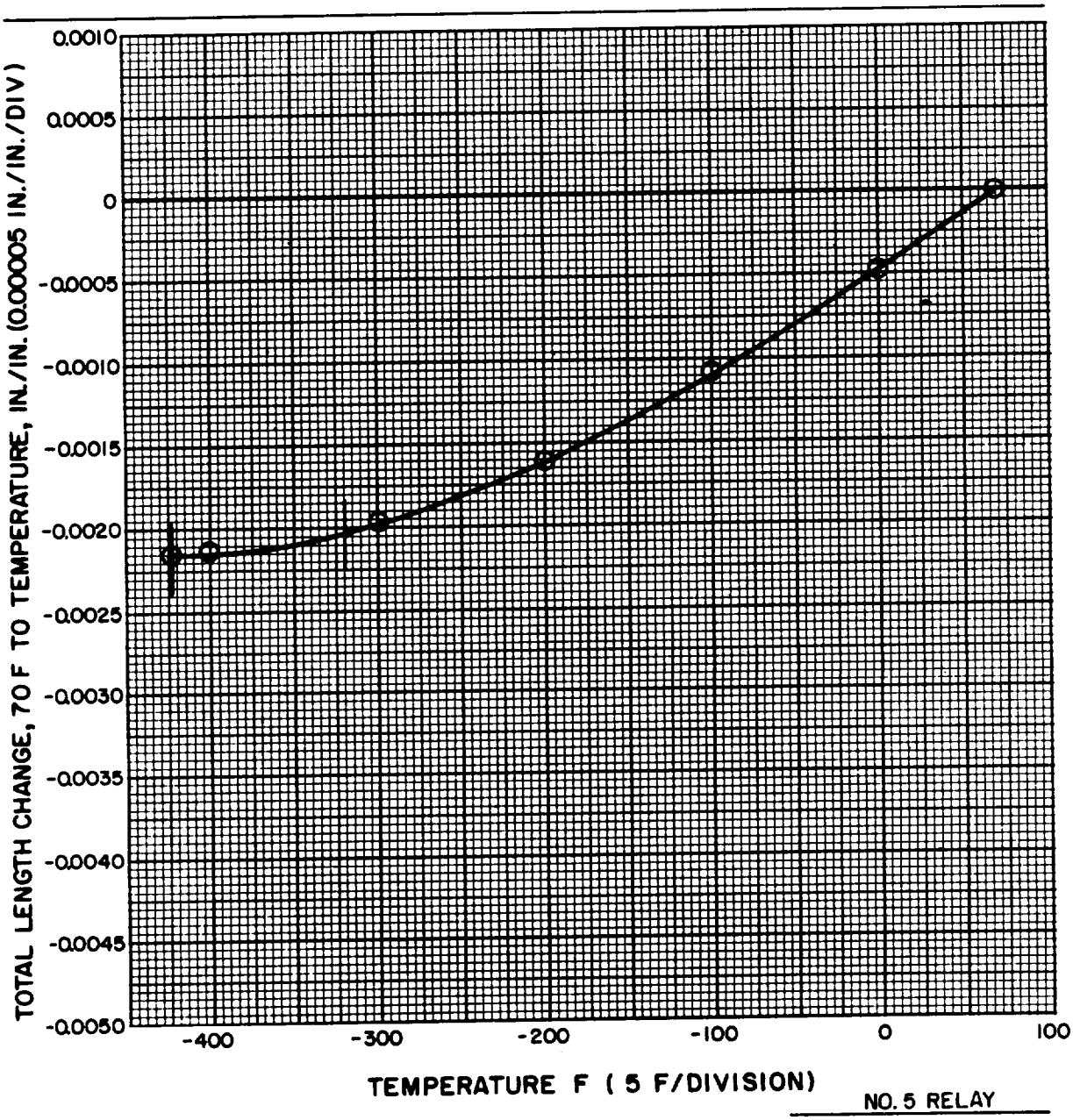
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8·9·60
MATERIAL NO. 5 RELAY*
FORM BAR
CONDITION
SPECIFICATION
DATE AUGUST 1965

NOTES: * TRADE NAME - ALLEGHENY-LUDLUM STEEL CORP
2.5 Si - BALANCE Fe



NO. 5 RELAY

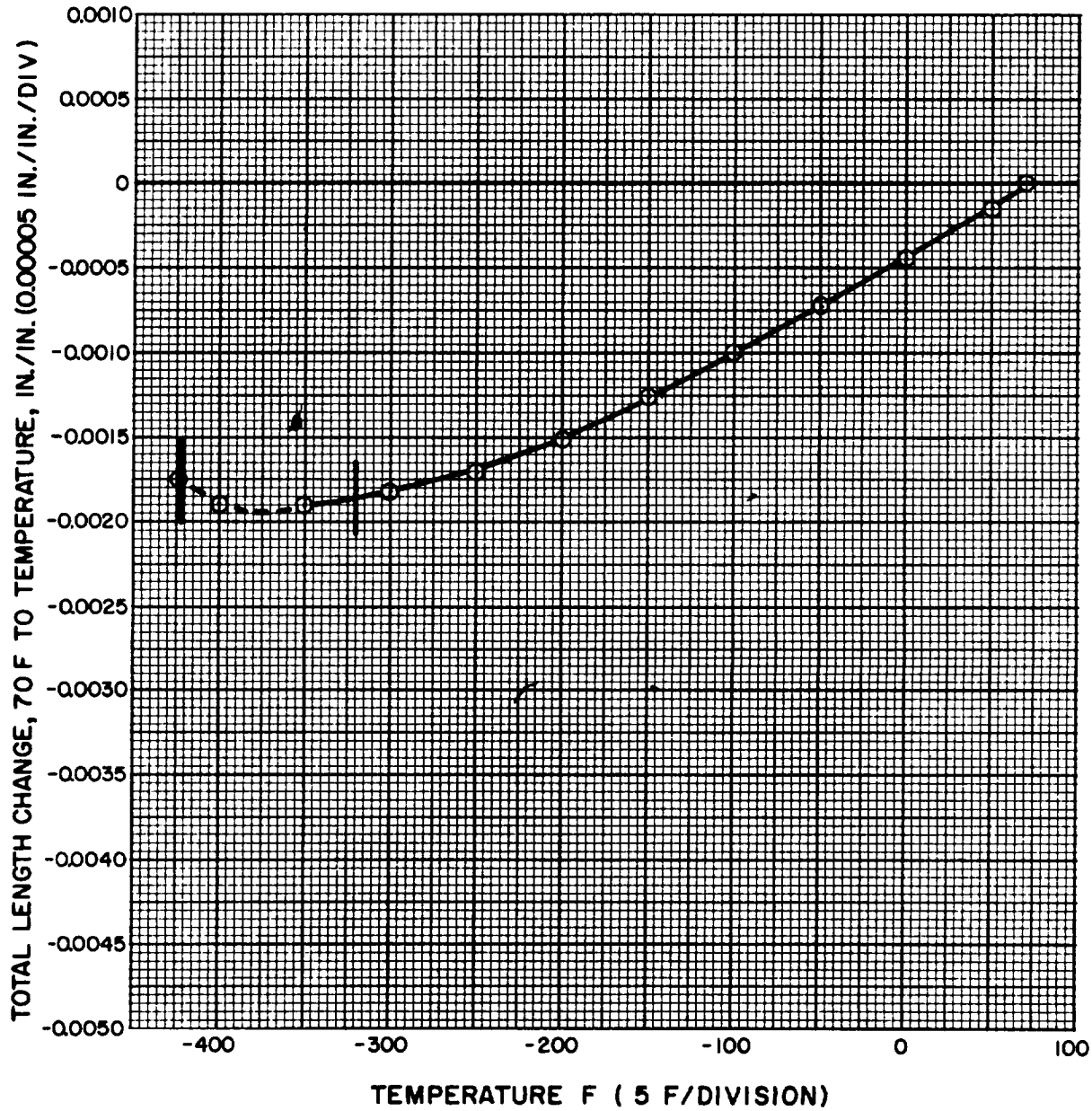
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 8·10·60
MATERIAL VANADIUM PERMENDUR
FORM BAR
CONDITION ANNEALED
SPECIFICATION
DATE APRIL 1965

NOTES: 49 Fe - 49 Co - 2V



VANADIUM PERMENDUR

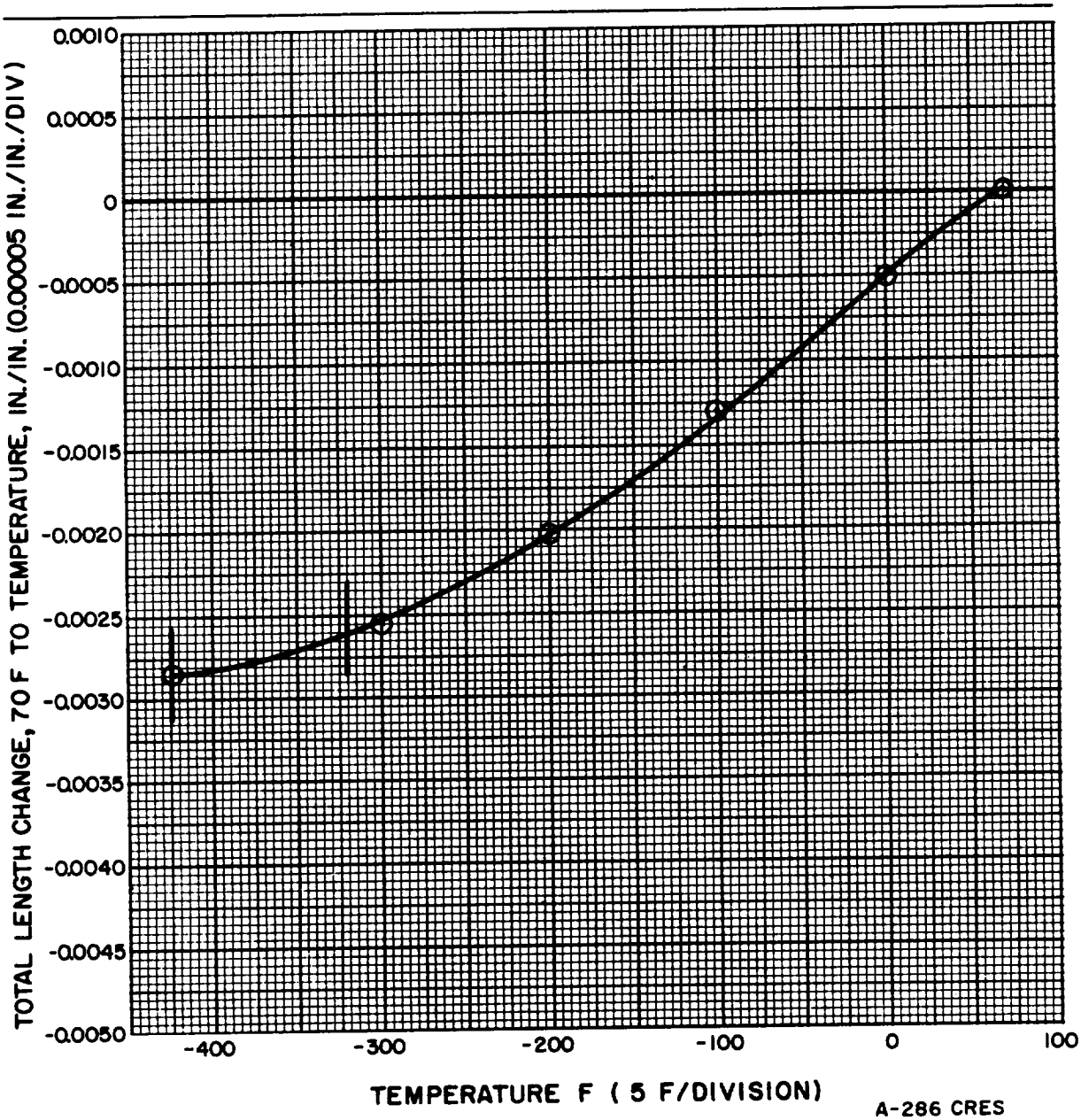
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES
AT
CRYOGENIC TEMPERATURES

CHART NO. 9·1·60
MATERIAL A-286 CRES
FORM BAR
CONDITION AGED
SPECIFICATION AMS 5736
DATE AUGUST 1965

NOTES:



A-286 CRES

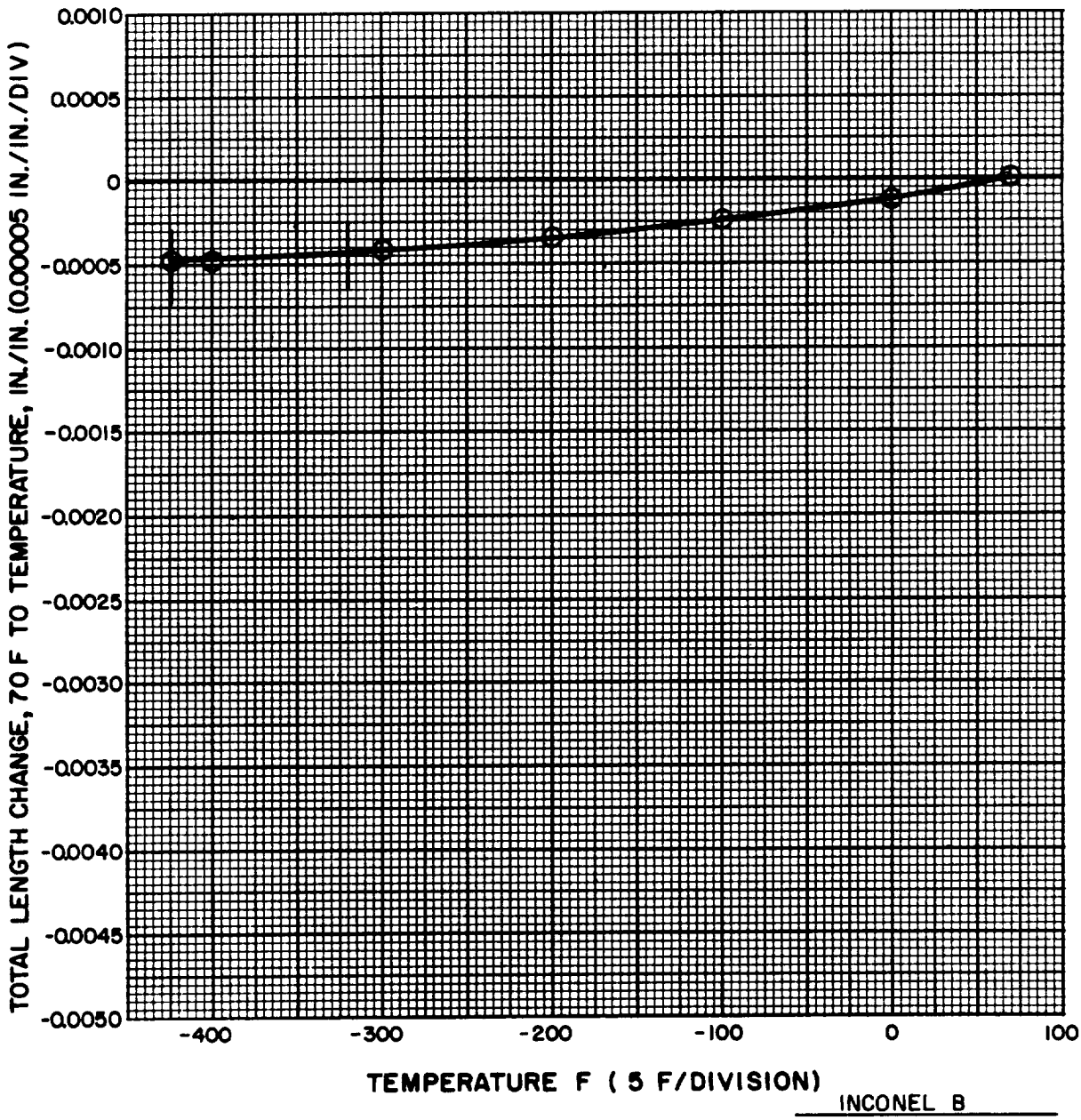
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9·2·60
MATERIAL INCONEL B
FORM WELD METAL
CONDITION AS WELDED
SPECIFICATION
DATE AUGUST 1965

NOTES:



INCONEL B

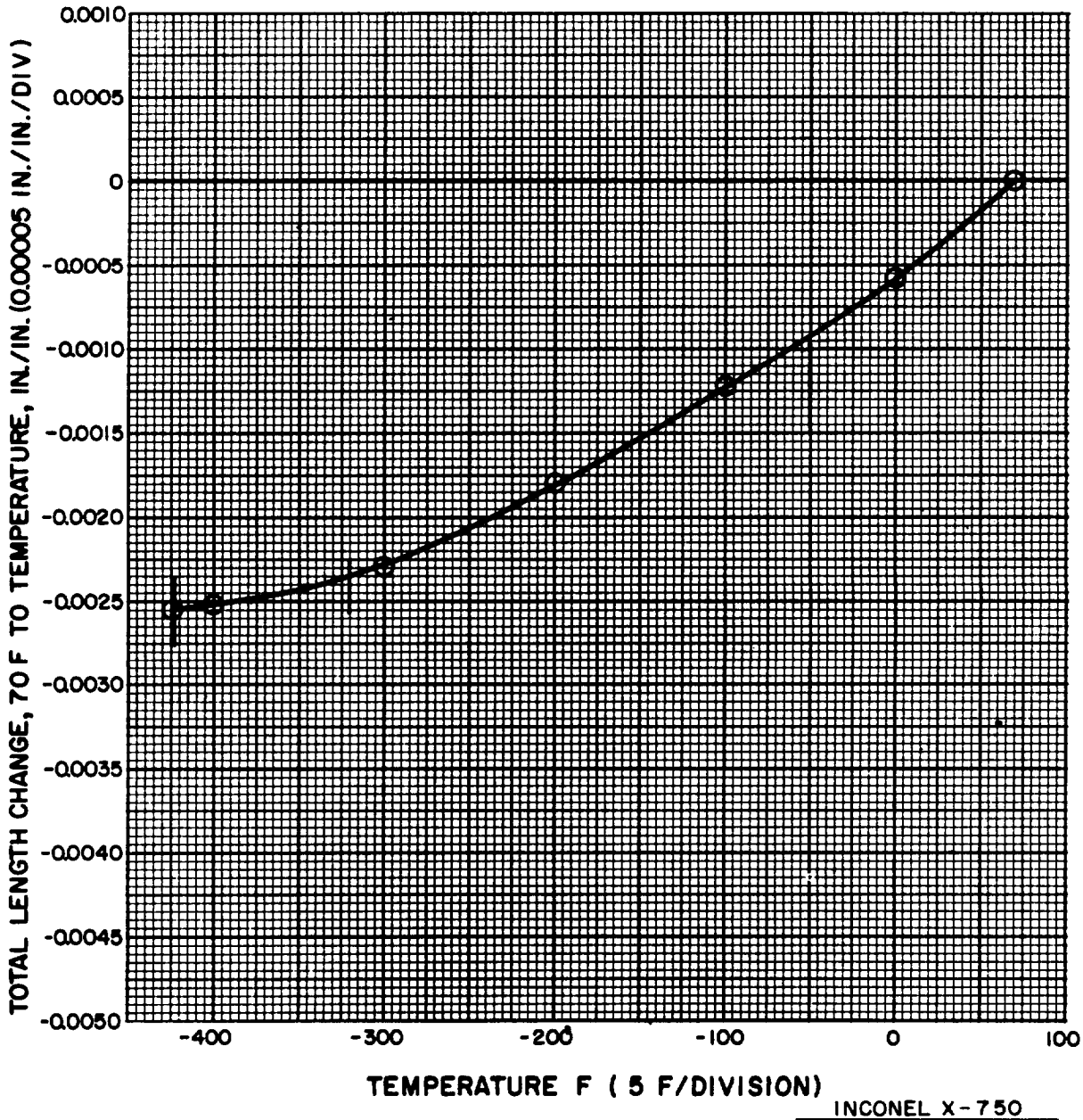
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9·3·60
MATERIAL INCONEL X-750
FORM BAR
CONDITION SEE NOTES
SPECIFICATION AMS 5667
DATE AUGUST 1965

NOTES: AGED AT 1300°F/10 HR, A.C.



INCONEL X-750

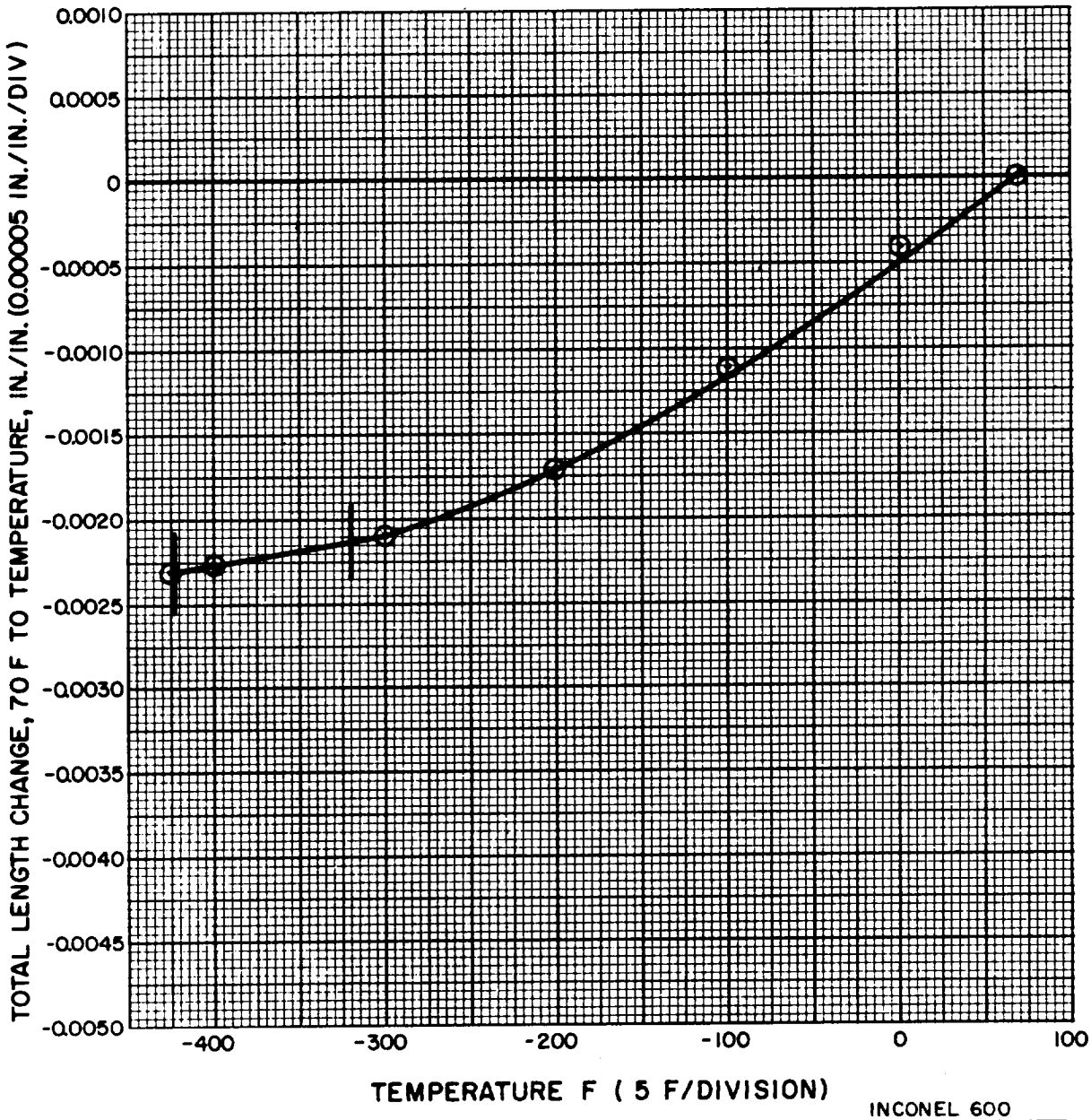
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE AD618-065
CRYOGENIC MAT'LS HANDBOOK (70)

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9·4·60
MATERIAL INCONEL 600
FORM
CONDITION ANNEALED
SPECIFICATION
DATE 11-18-66

NOTES: 16 Cr - 7 Fe - 76 Ni



INCONEL 600

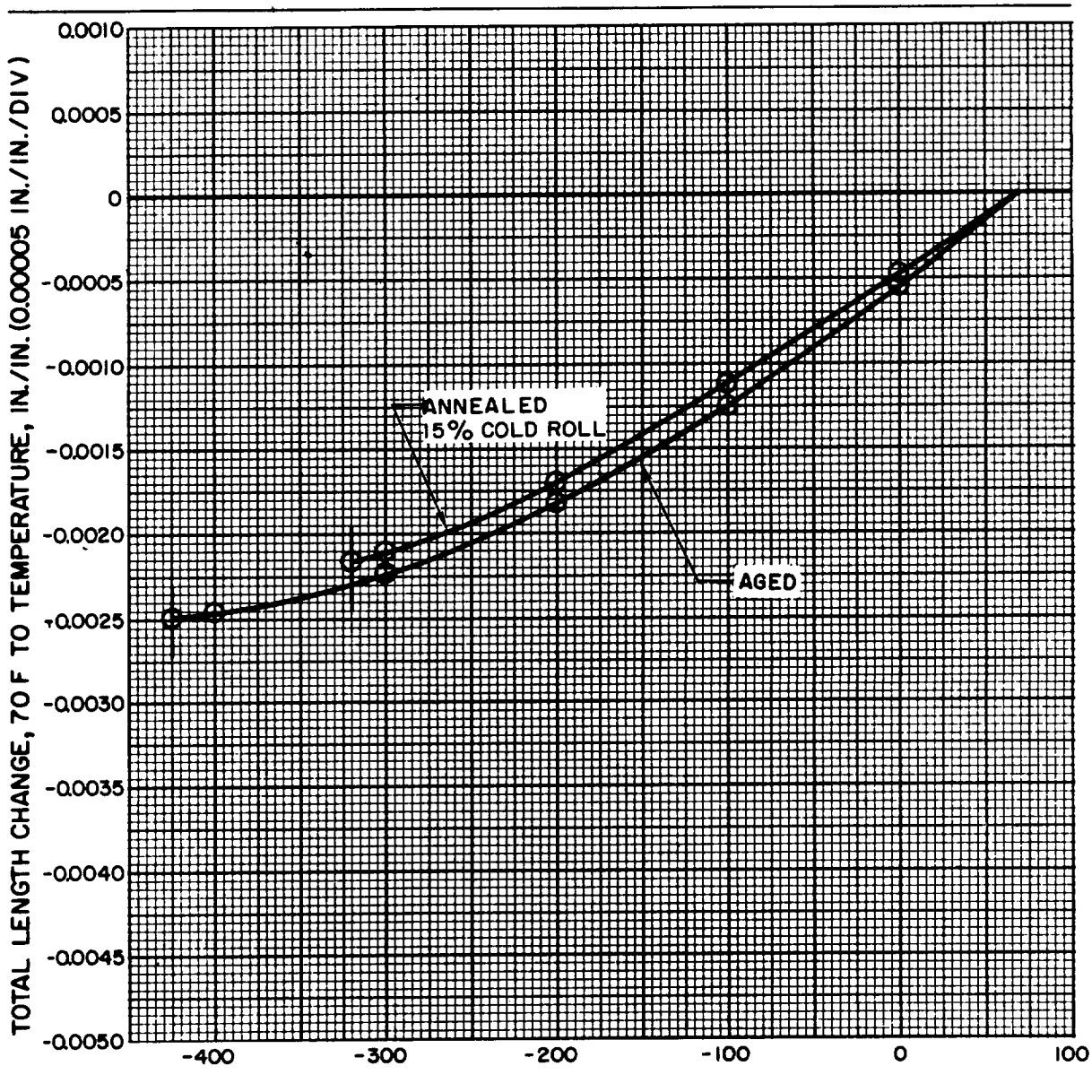
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9·5·60
MATERIAL INCONEL 718
FORM BAR
CONDITION SEE NOTES
SPECIFICATION RB0170-038
DATE JULY 1965

NOTES: BOTH ANNEALED AND 15% C.R. HAVE THE SAME CURVE



INCONEL 718

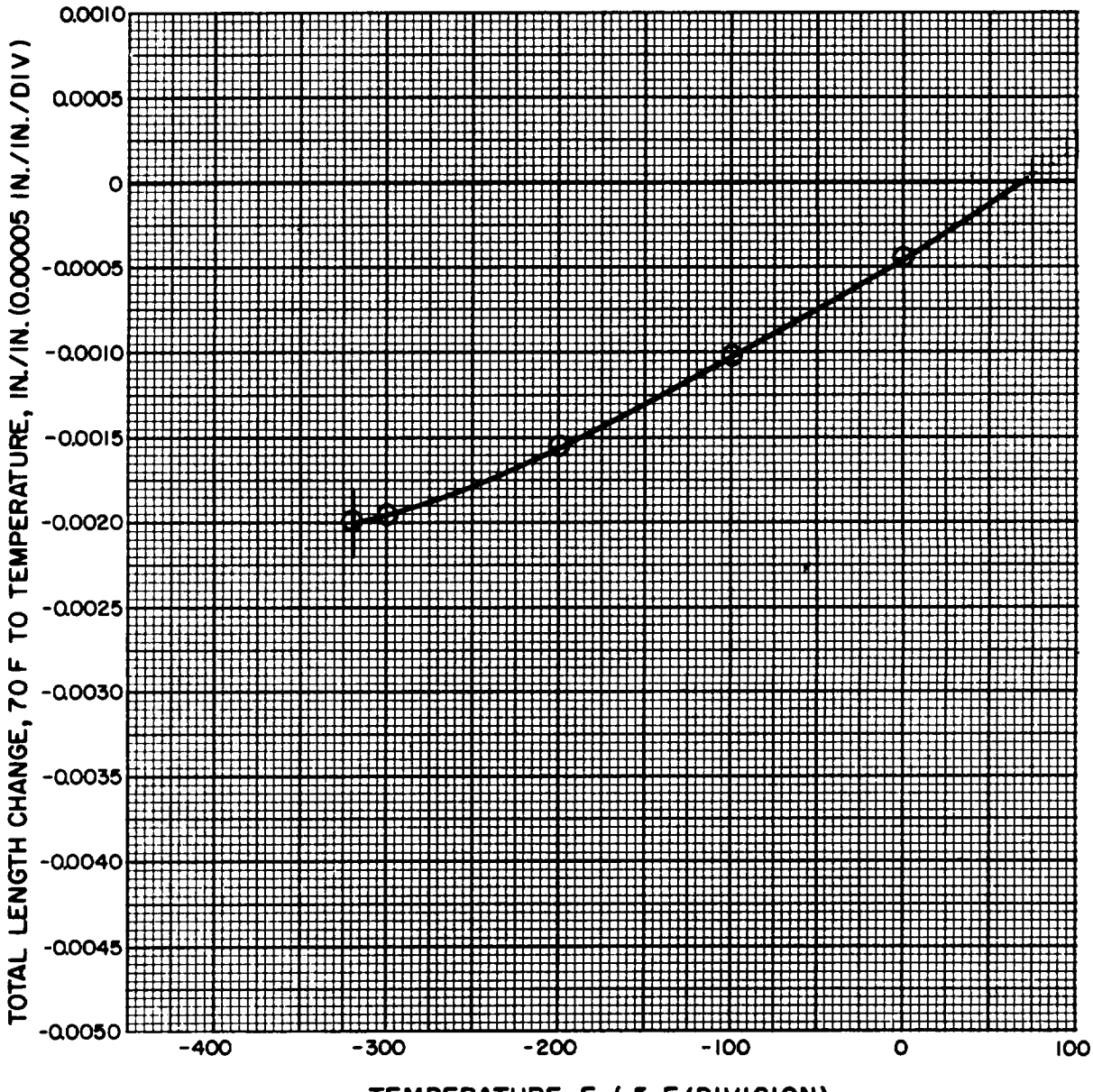
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9-6-60
MATERIAL RENE' 41
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION AMS 5545
DATE MARCH 1962

NOTES:



RENE' 41

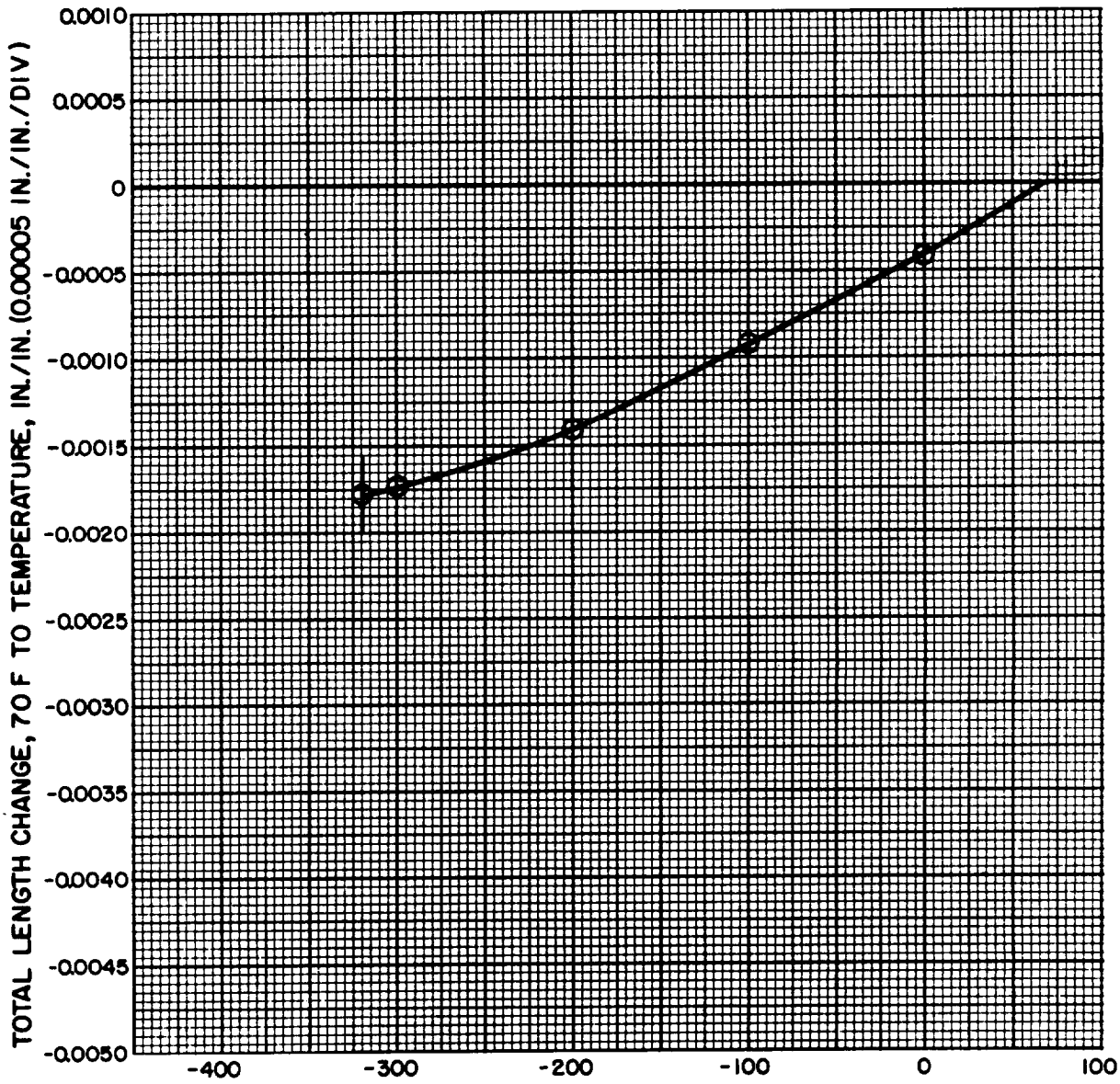
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9-7-60
MATERIAL HASTELLOY B
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION RB0170-002
DATE MARCH 1962

NOTES: 28 Mo - 2.5 Co - 5 Fe - BALANCE Ni



HASTELLOY B

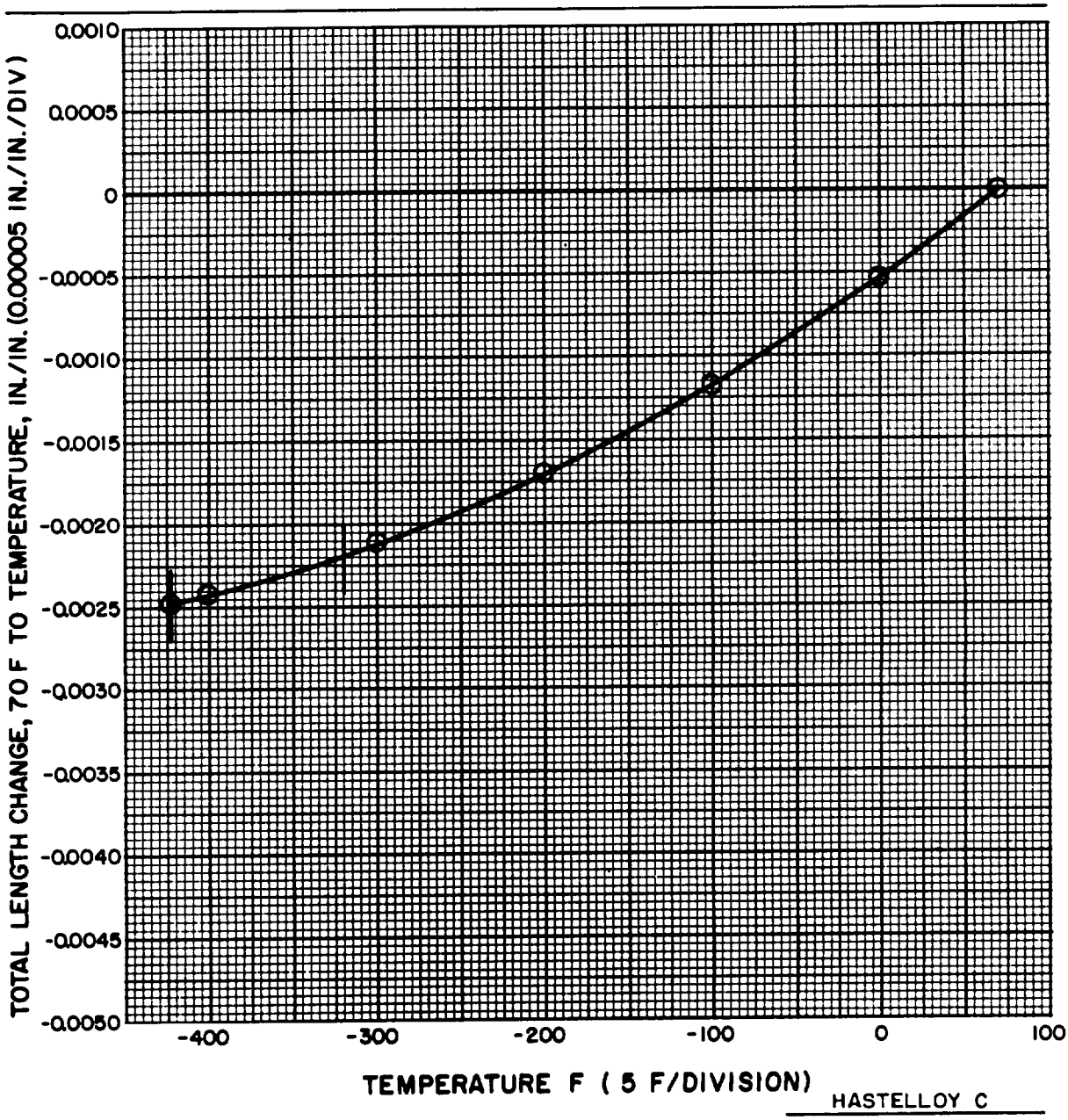
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9·8·60
MATERIAL HASTELLOY C
FORM BAR
CONDITION SEE NOTES
SPECIFICATION RB0170-046
DATE AUGUST 1965

NOTES: ANNEALED AT 2225° F / 1 HR., W.Q.
16 Mo - 15 Cr - 4 W - 5 Fe - 2.5 Co - BALANCE NI



HASTELLOY C

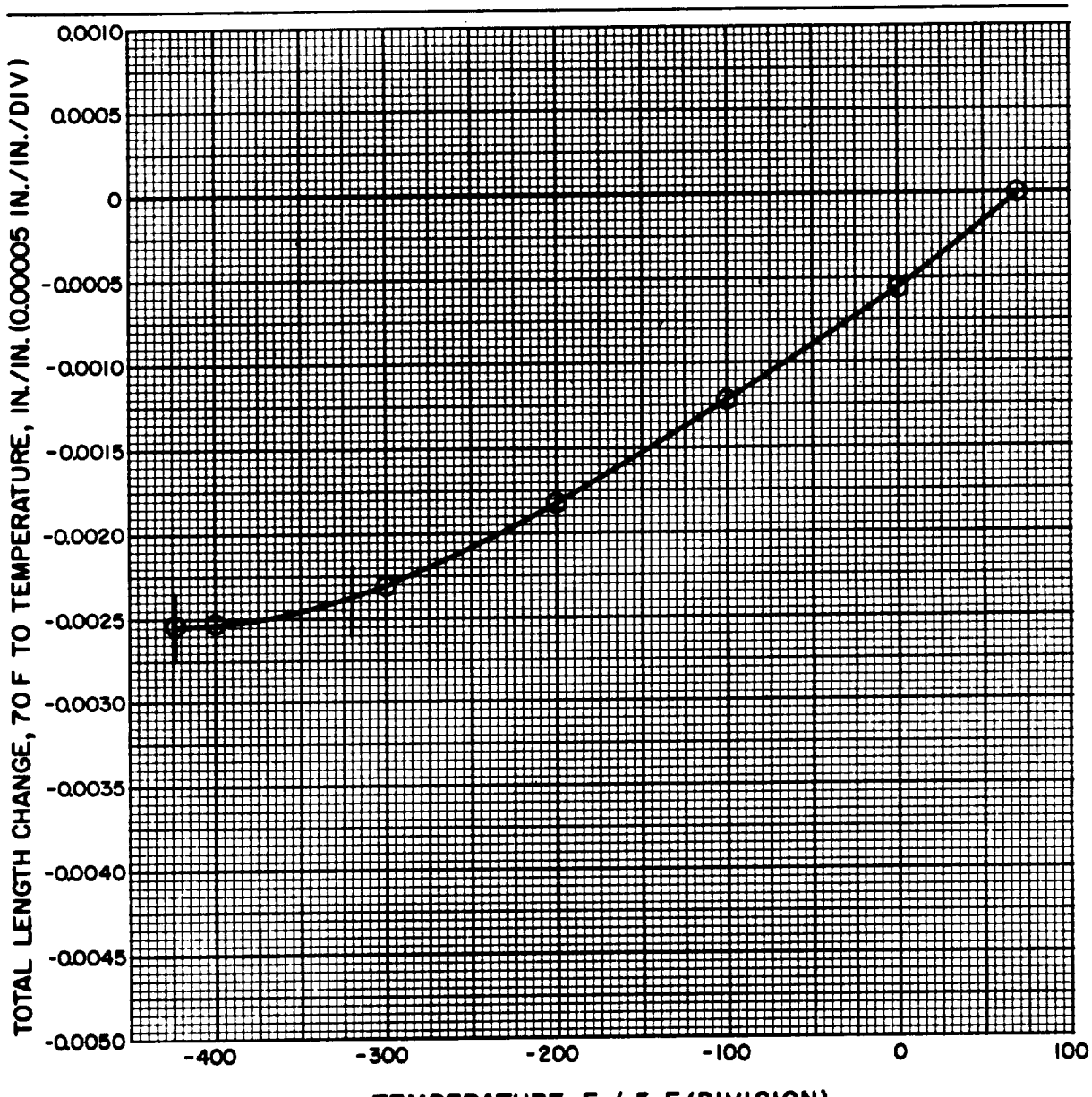
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 9·9·60
MATERIAL HASTELLOY X
FORM BAR
CONDITION ANNEALED
SPECIFICATION AMS 5390
DATE AUGUST 1965

NOTES: 22 Cr - 19 Fe - 9 Mo - 2 Co - BALANCE Ni



HASTELLOY X

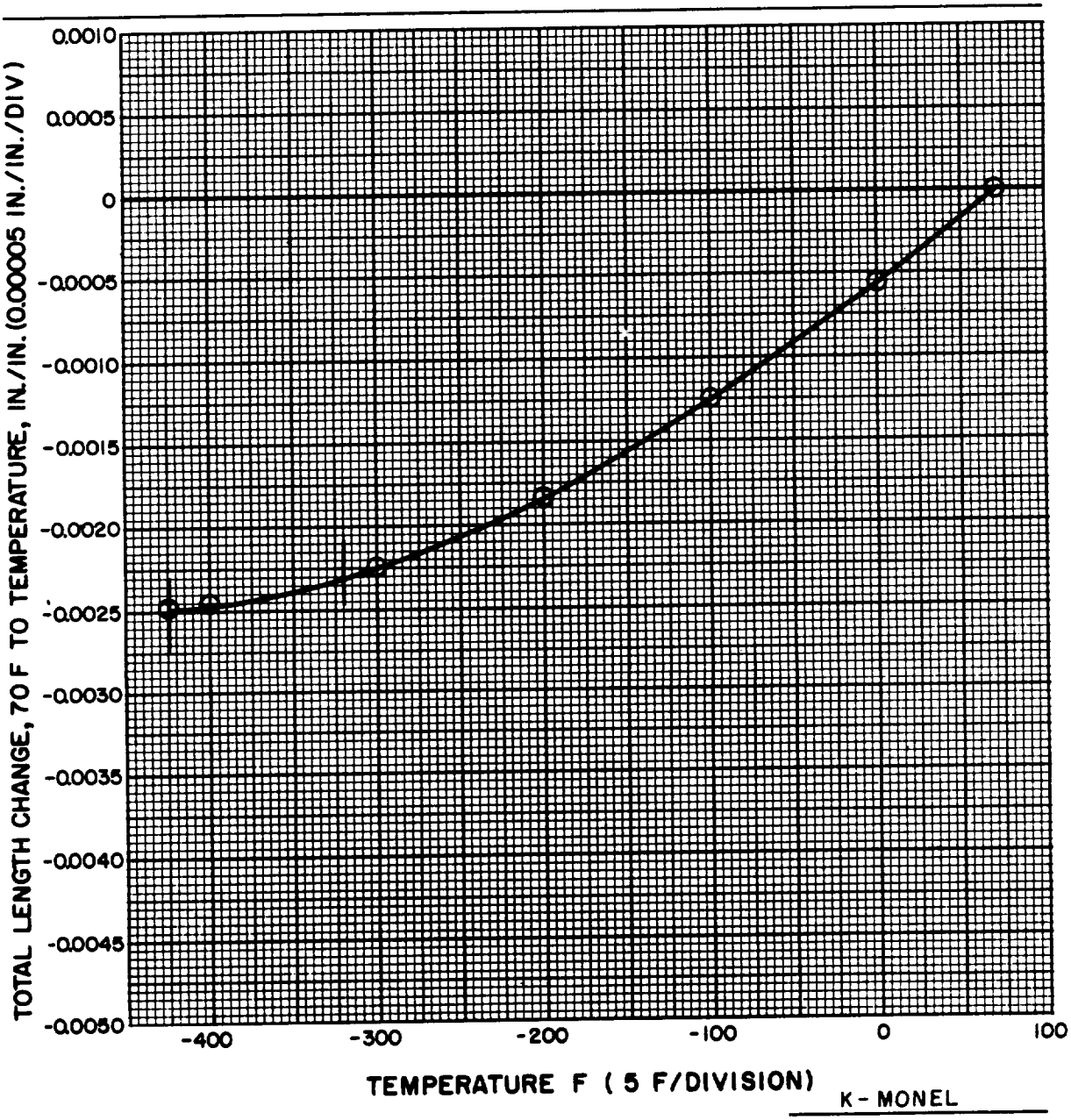
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 10·1·60
MATERIAL K-MONEL
FORM BAR
CONDITION AGED
SPECIFICATION QQ-N-286 A
DATE AUGUST 1965

NOTES:



K-MONEL

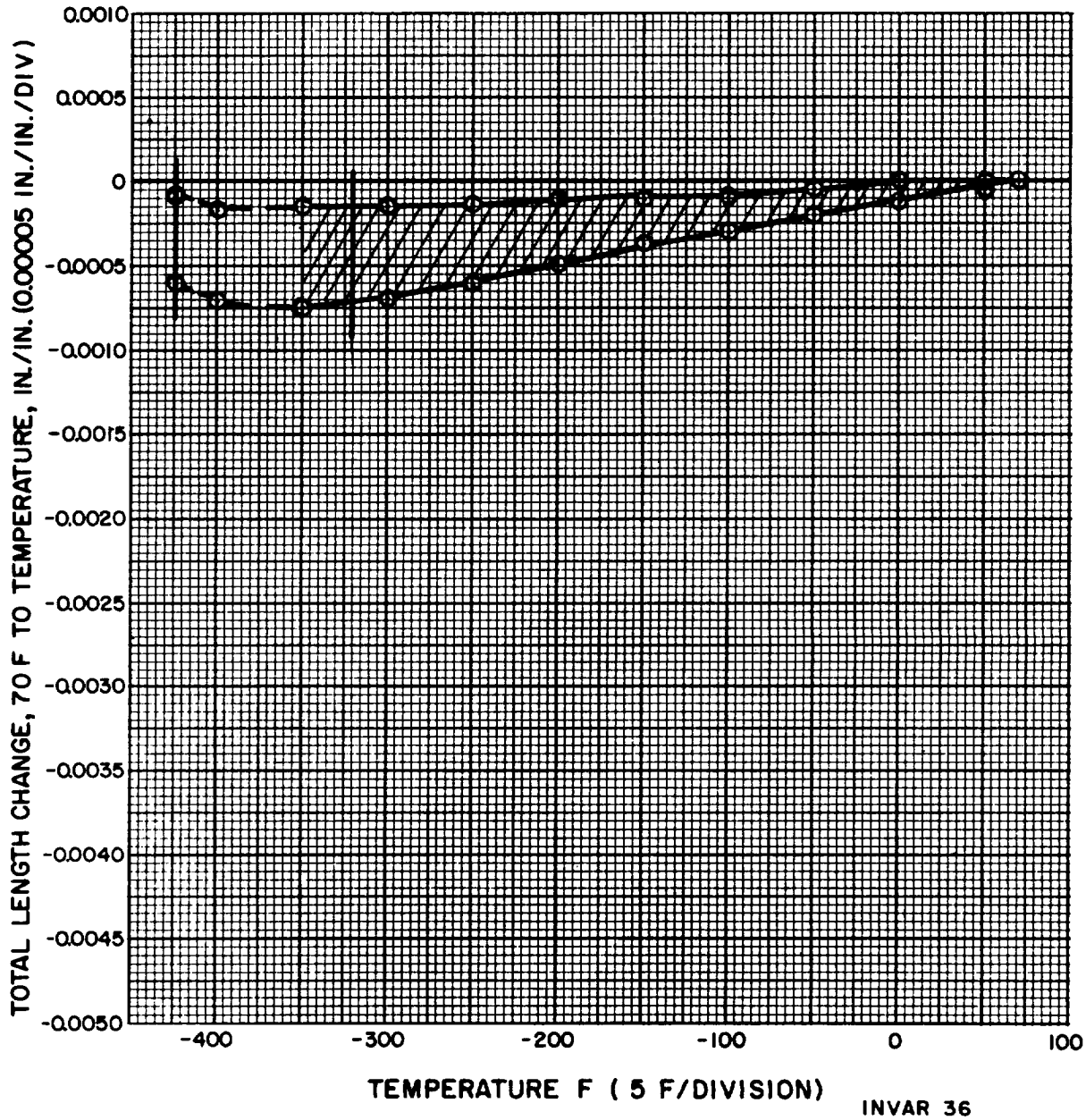
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 10-2-60
MATERIAL INVAR 36
FORM PLATE
CONDITION ANNEALED
SPECIFICATION RB0160-027
DATE AUGUST 1965

NOTES: DATA GIVEN IS A PLOT OF SEVERAL CURVES TO ILLUSTRATE THE MAXIMUM AND MINIMUM IN THE CONTRACTION OF INVAR 36. DATA PLOTTED BELOW -350F WAS VARIABLE ON INDIVIDUAL TESTS.



INVAR 36

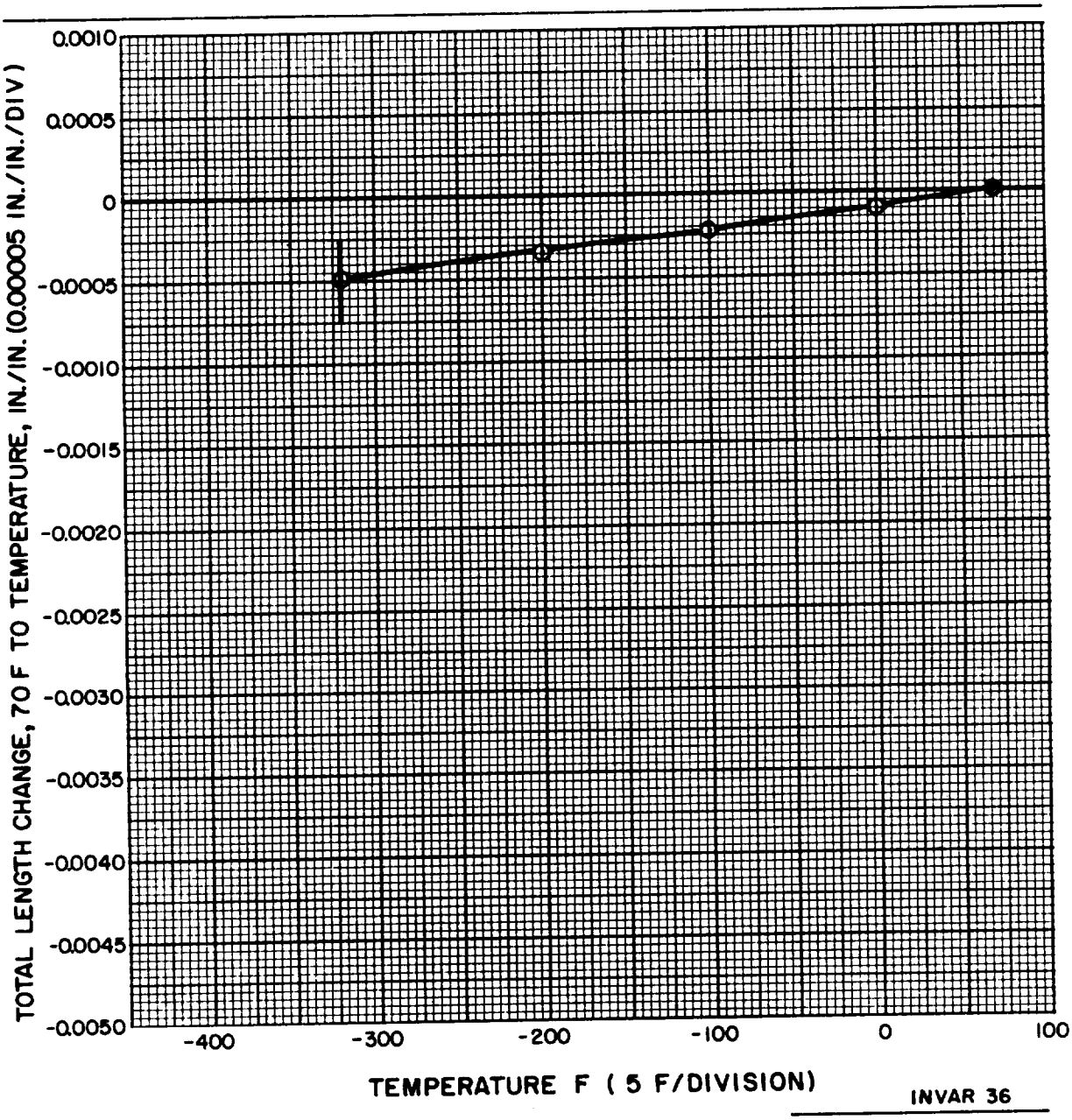
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 10-2A-60
MATERIAL INVAR 36
FORM BAR
CONDITION ANNEALED
SPECIFICATION MIL-S-16598
DATE APRIL 1963

NOTES: FREE MACHINING GRADE



INVAR 36

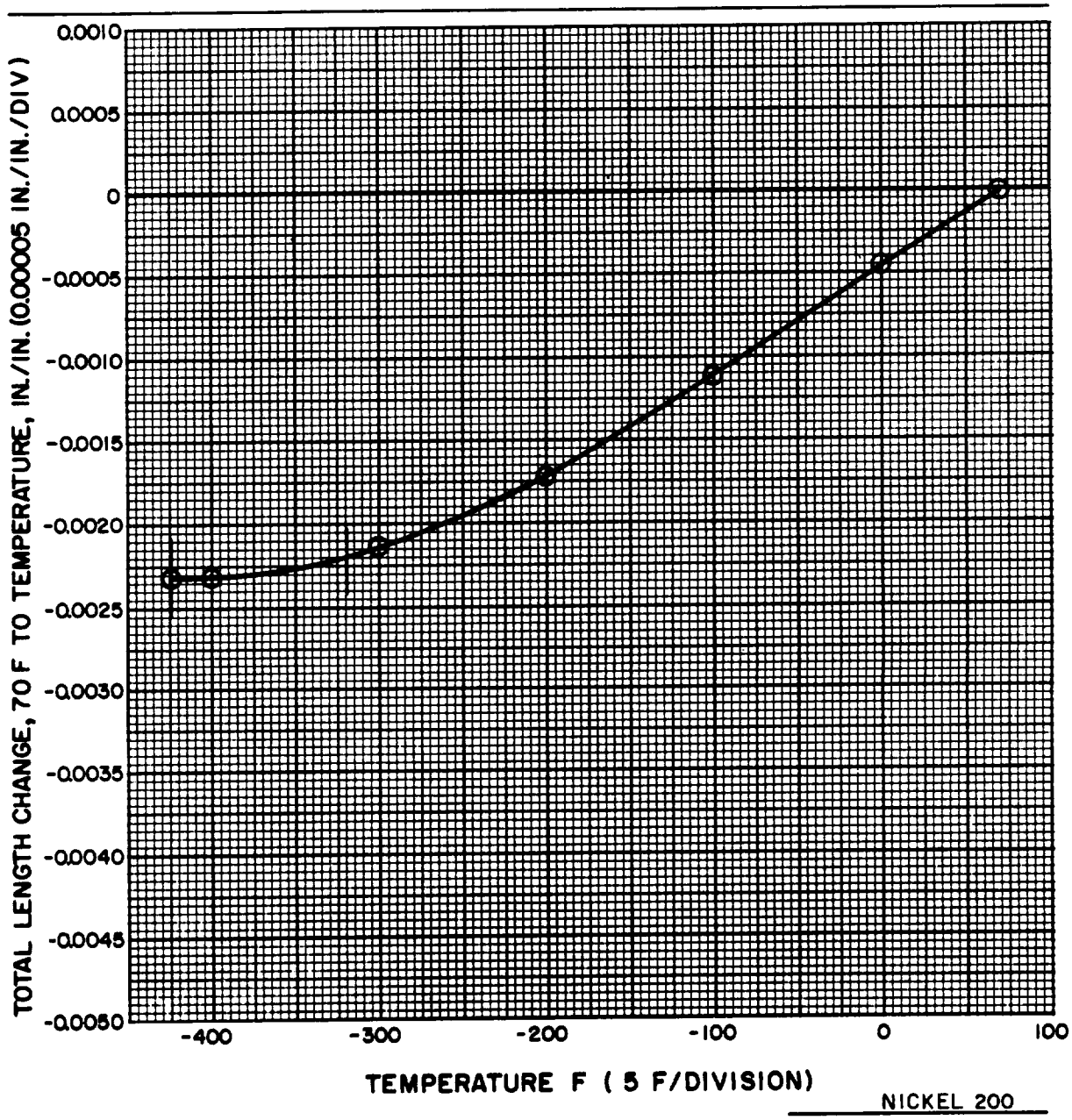
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD TR 60-56 II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 10·3·60
MATERIAL NICKEL 200
FORM WROUGHT
CONDITION
SPECIFICATION
DATE AUGUST 1965

NOTES: 99.5 Ni



NICKEL 200

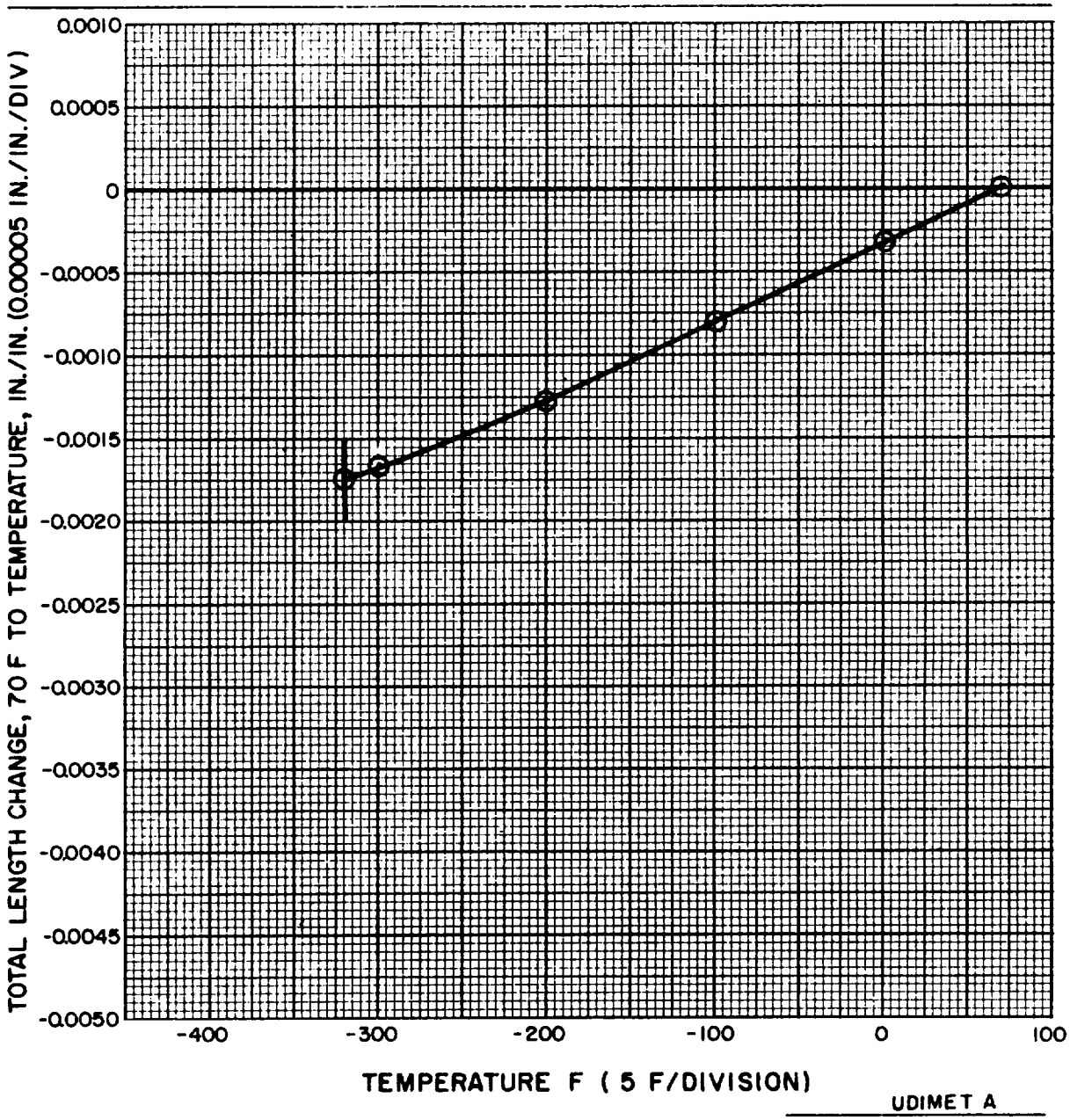
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 10·4·60
MATERIAL UDIMET A
FORM BAR
CONDITION SEE NOTES
SPECIFICATION
DATE DECEMBER 1966

NOTES: 1500 F/1 HR, A.C.; 1300 F/1 HR, A.C.; -100 F/16 HR, A.W.; 900 F/1 HR, A.C.
23 Ni - 1.7 Ti - .3 Al - BALANCE Fe



UDIMET A

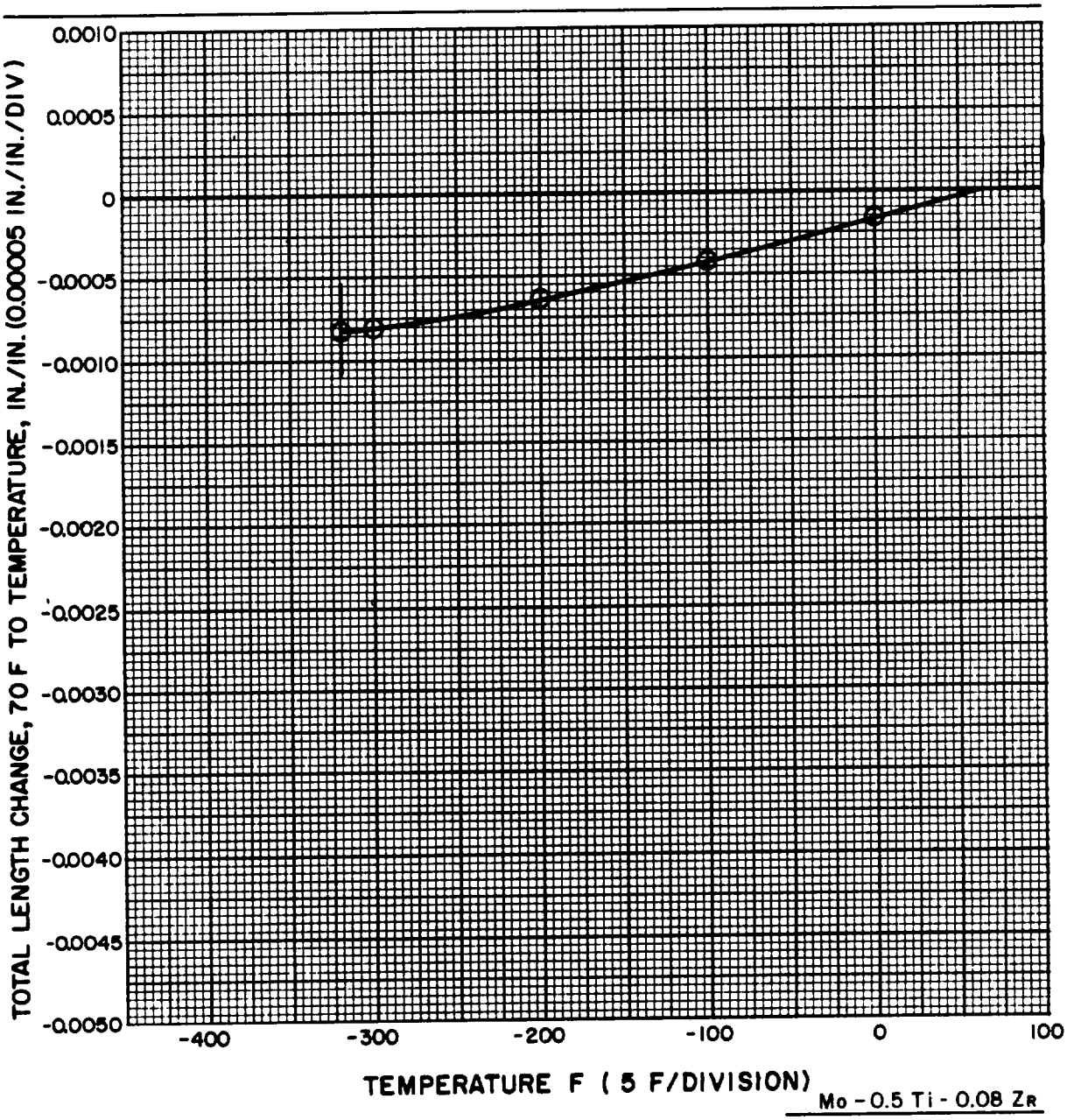
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 11·4·60
MATERIAL Mo - 0.5 Ti - 0.08 Zr
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION -
DATE MARCH 1962

NOTES:



Mo - 0.5 Ti - 0.08 Zr

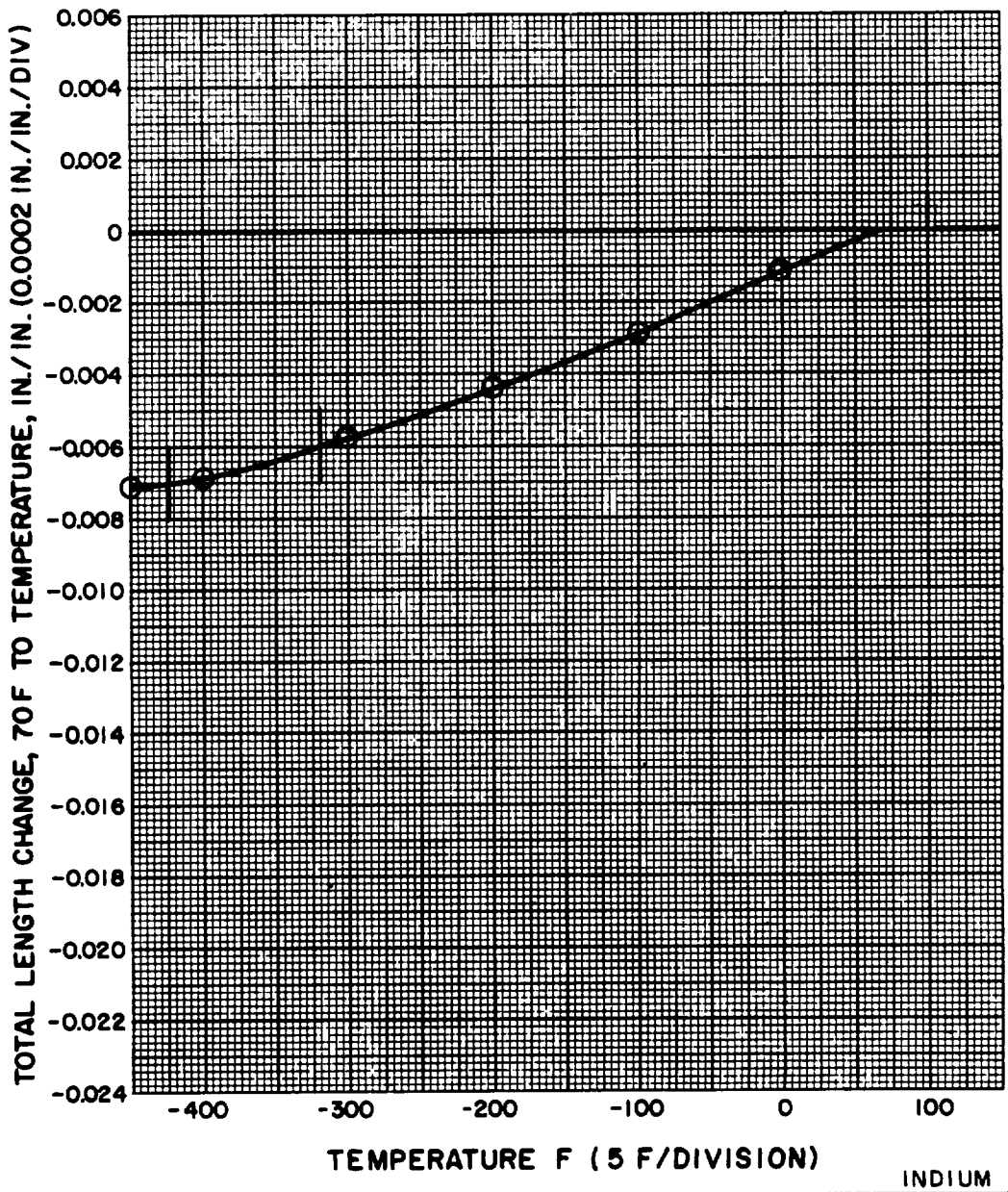
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE WADD TR 60-56 II

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 11·5·60
MATERIAL INDIUM
FORM WROUGHT
CONDITION ANNEALED
SPECIFICATION
DATE AUGUST 1965

NOTES:



INDIUM

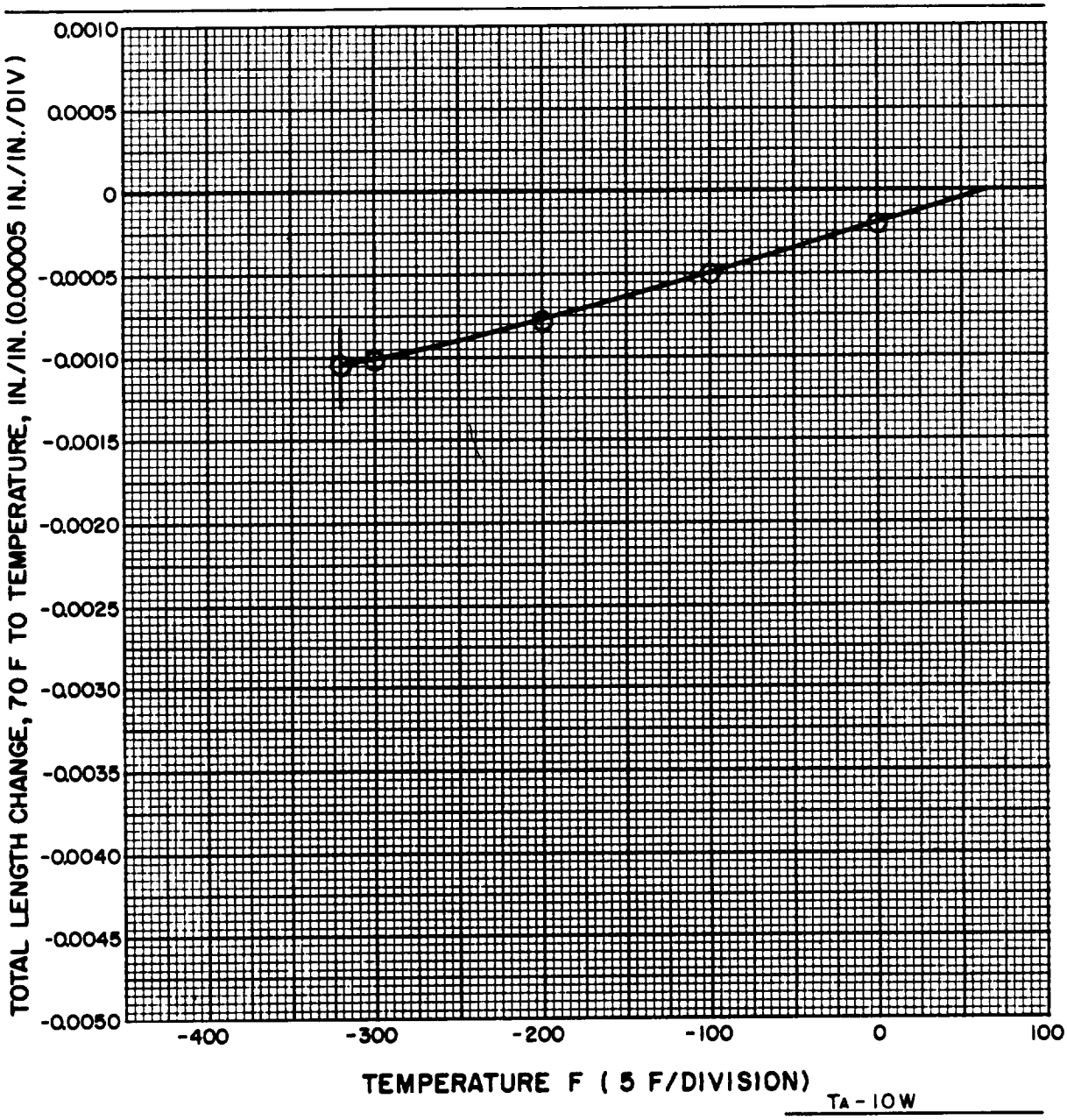
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 11·6·60
MATERIAL Ta-10W
FORM BAR
CONDITION AS RECEIVED
SPECIFICATION AMS 7848
DATE MARCH 1962

NOTES:



Ta-10W

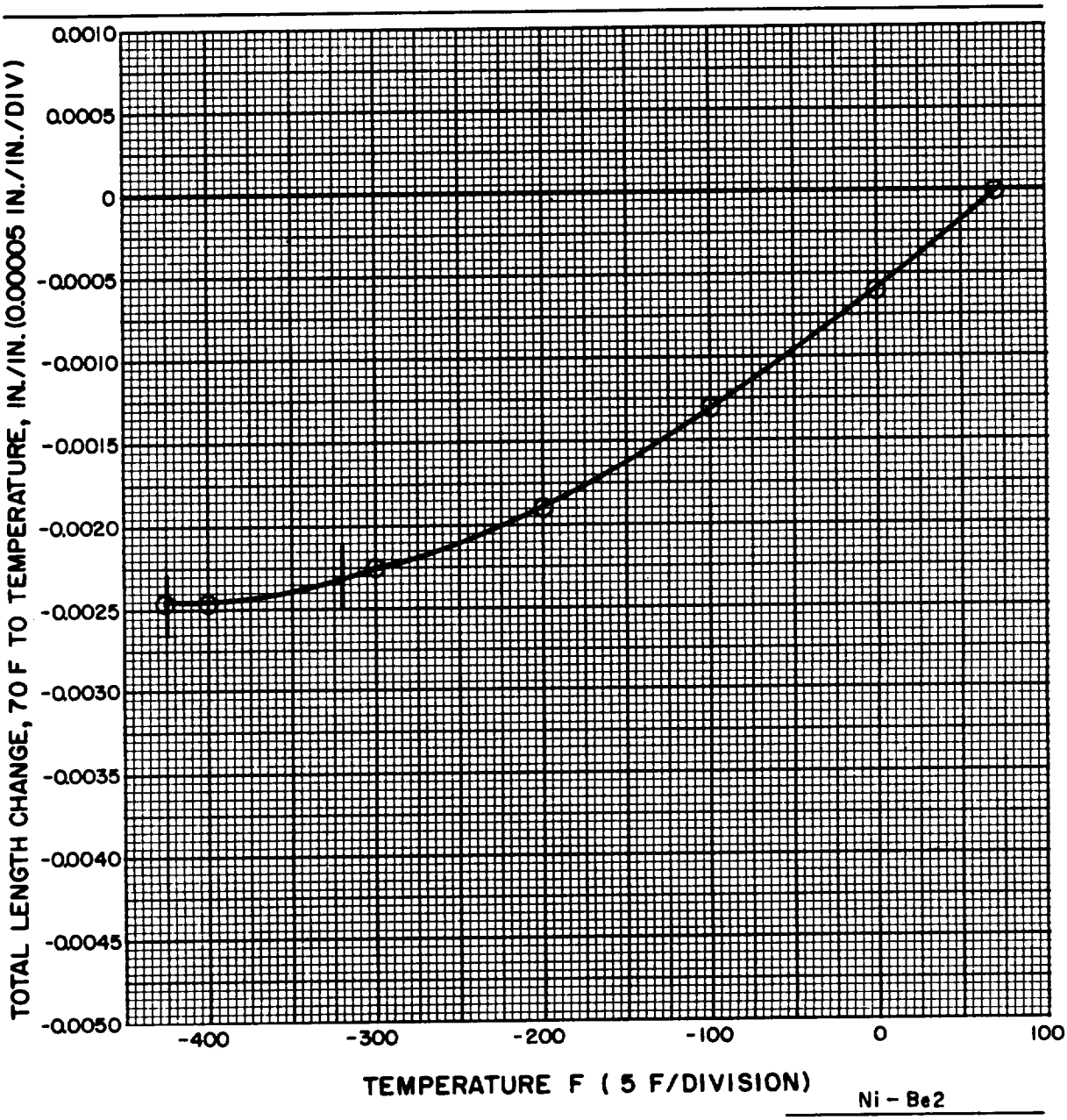
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 11-8-60
MATERIAL Ni - Be2
FORM SHEET
CONDITION SEE NOTES
SPECIFICATION
DATE

NOTES: BERYLCO NICKEL 440 / 1/2 HT, 1/2 HARD PLUS AGE (2 HRS AT 940°F)
UTS = 245000 PSI



Ni - Be2

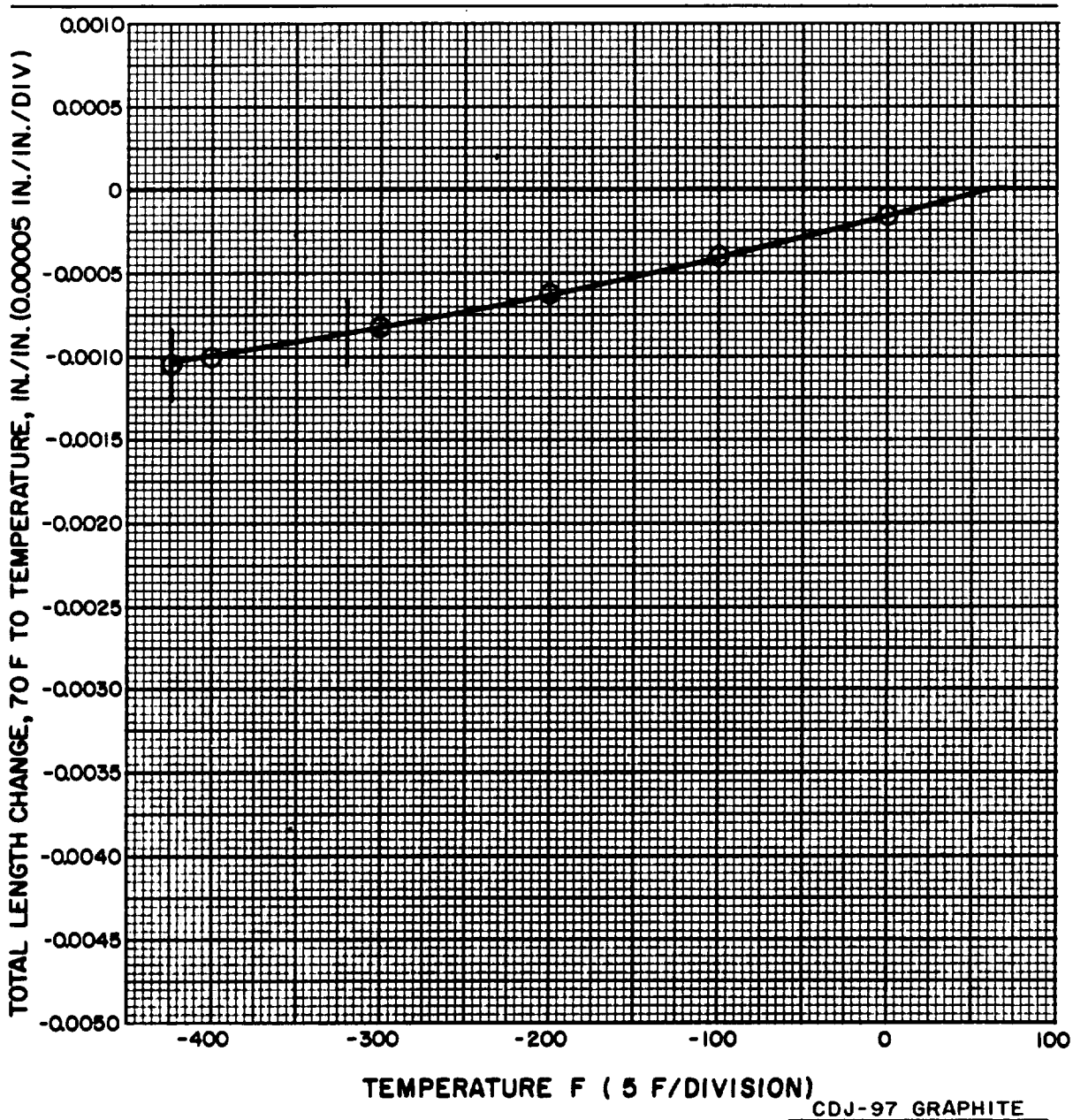
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·1·60
MATERIAL CDJ-97 GRAPHITE
FORM
CONDITION
SPECIFICATION -
DATE AUGUST 1965

NOTES:



CDJ-97 GRAPHITE

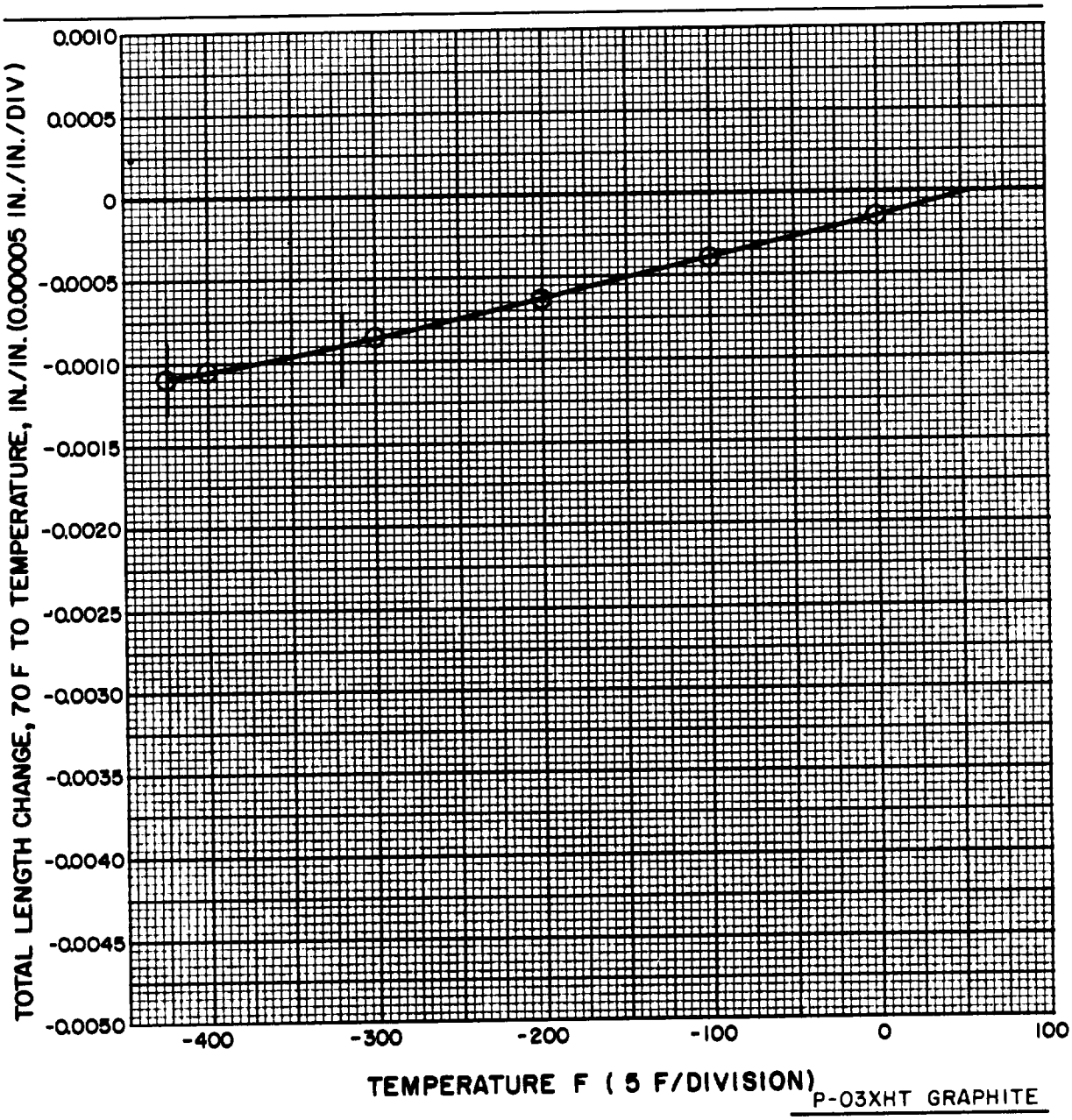
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·2·60
MATERIAL P-03XHT GRAPHITE
FORM
CONDITION
SPECIFICATION –
DATE AUGUST 1965

NOTES:



P-03XHT GRAPHITE

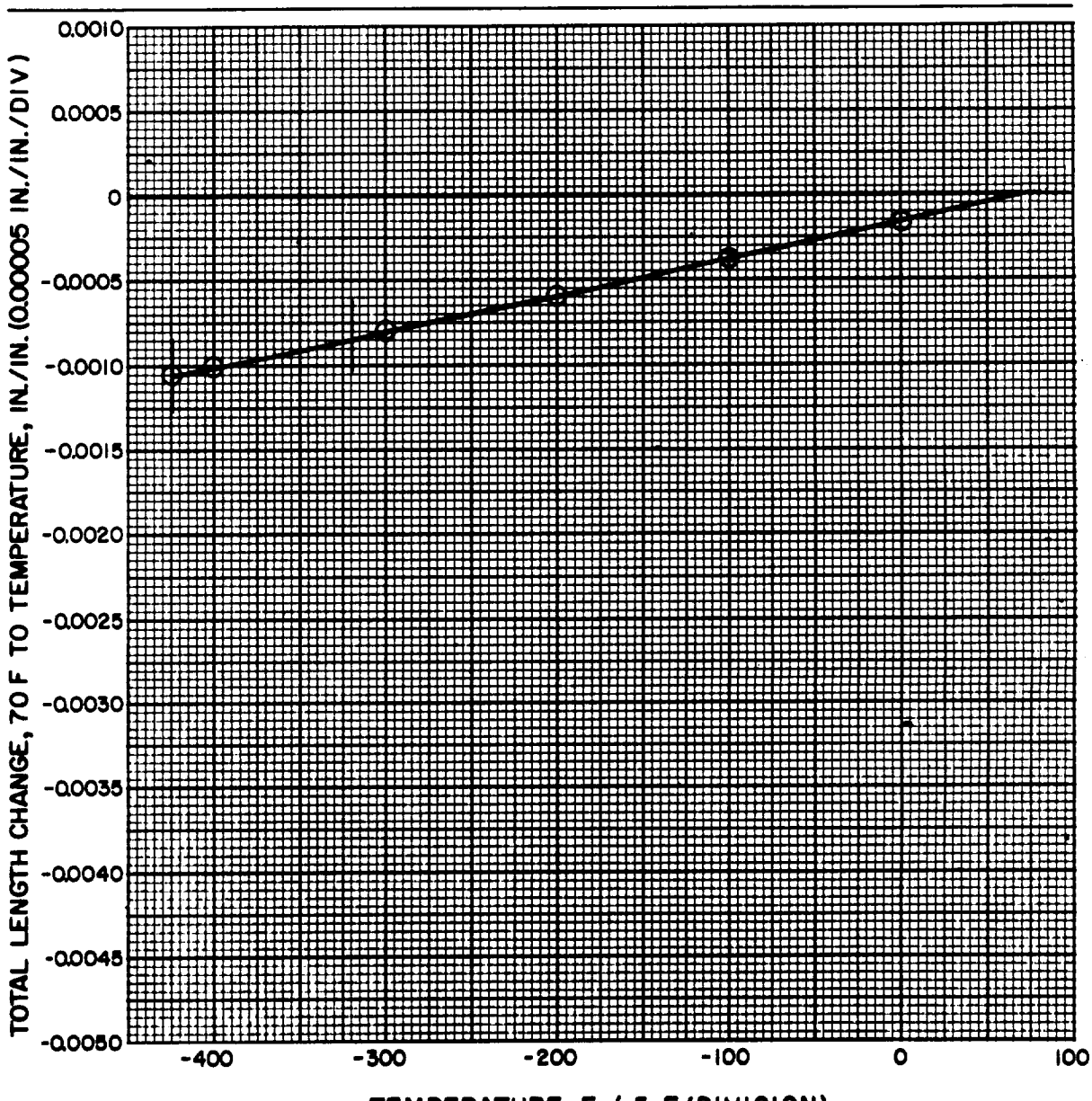
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·3·60
MATERIAL P-303-C GRAPHITE
FORM
CONDITION
SPECIFICATION -
DATE AUGUST 1965

NOTES:



P-303-C GRAPHITE

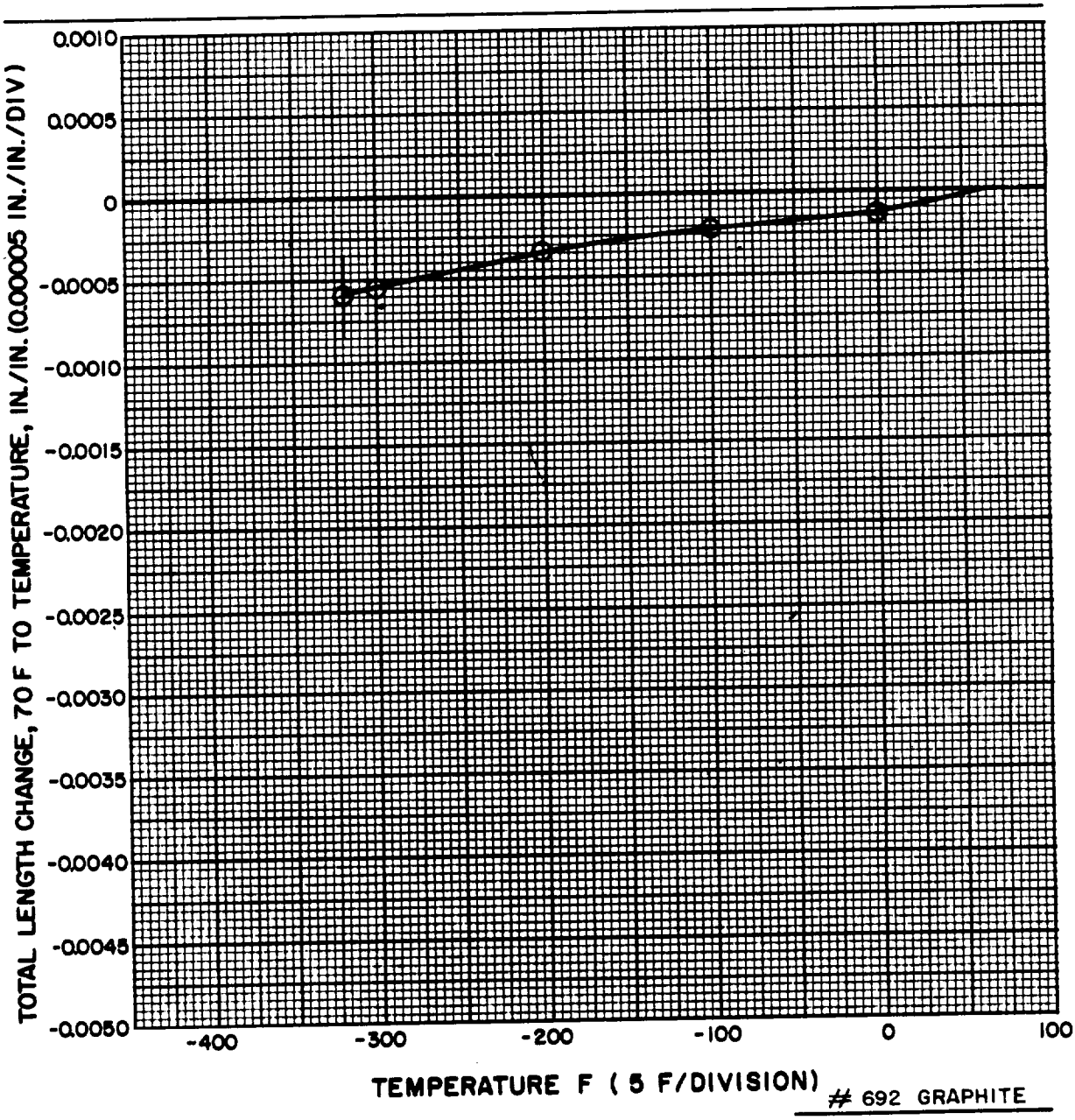
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·4·60
MATERIAL #692 GRAPHITE
FORM
CONDITION
SPECIFICATION -
DATE MARCH 1962

NOTES:



#692 GRAPHITE

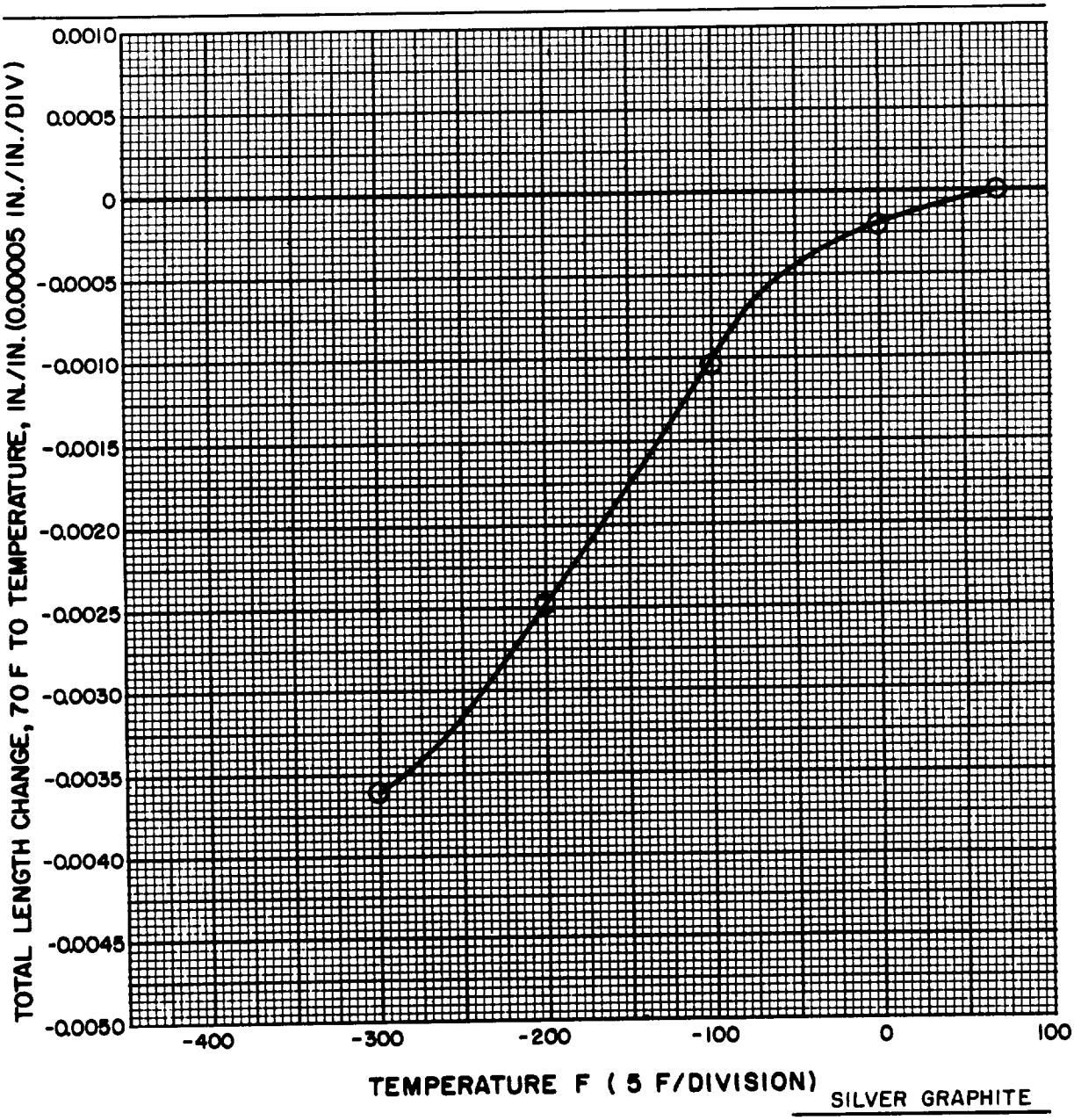
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·5·60
MATERIAL SILVER GRAPHITE
FORM
CONDITION AS RECEIVED
SPECIFICATION ÷
DATE MARCH 1962

NOTES:



SILVER GRAPHITE

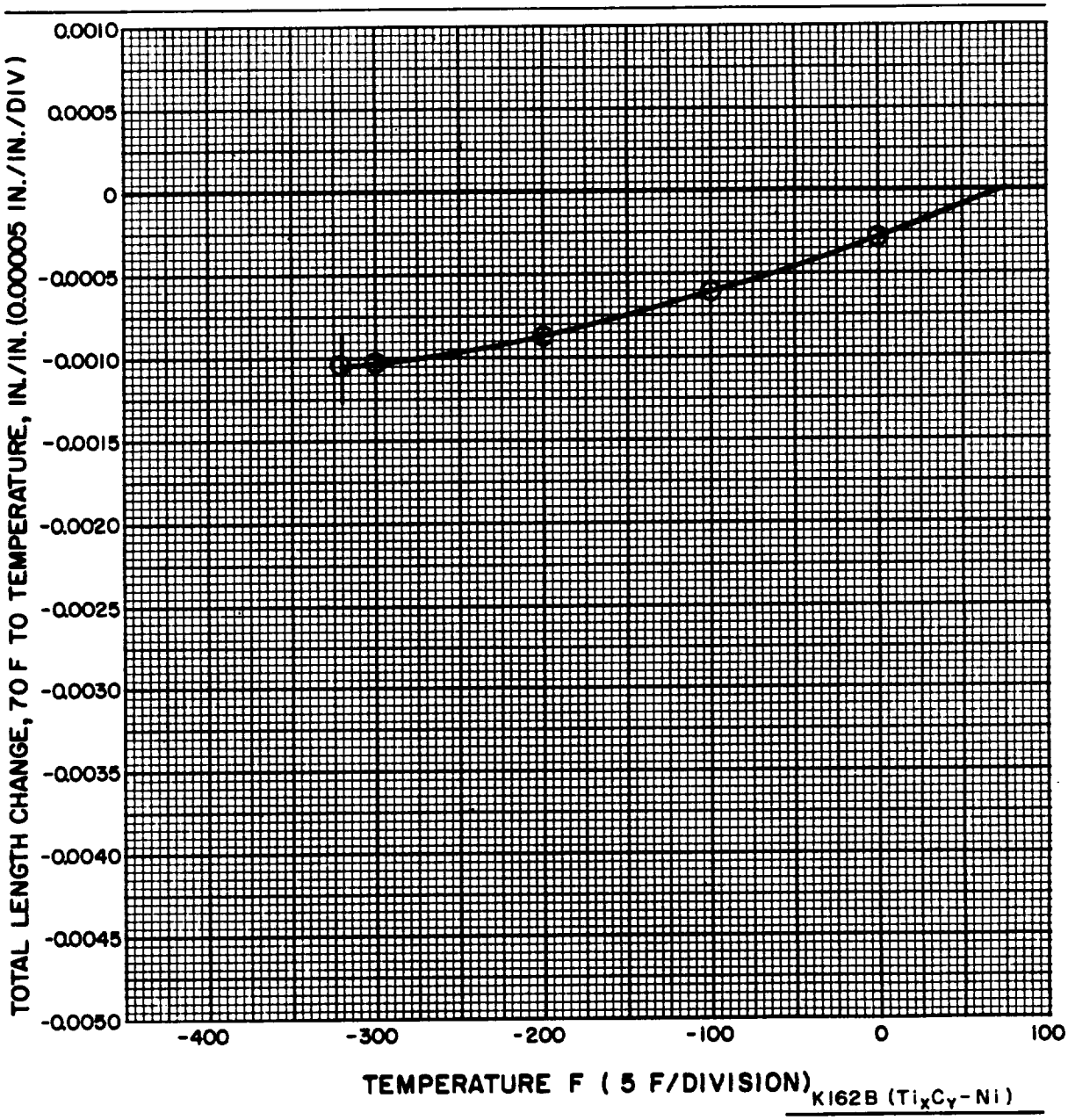
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·6·60
MATERIAL K162B (Ti_xC_y-Ni)
FORM
CONDITION
SPECIFICATION –
DATE AUGUST 1965

NOTES:



K162B (Ti_xC_y-Ni)

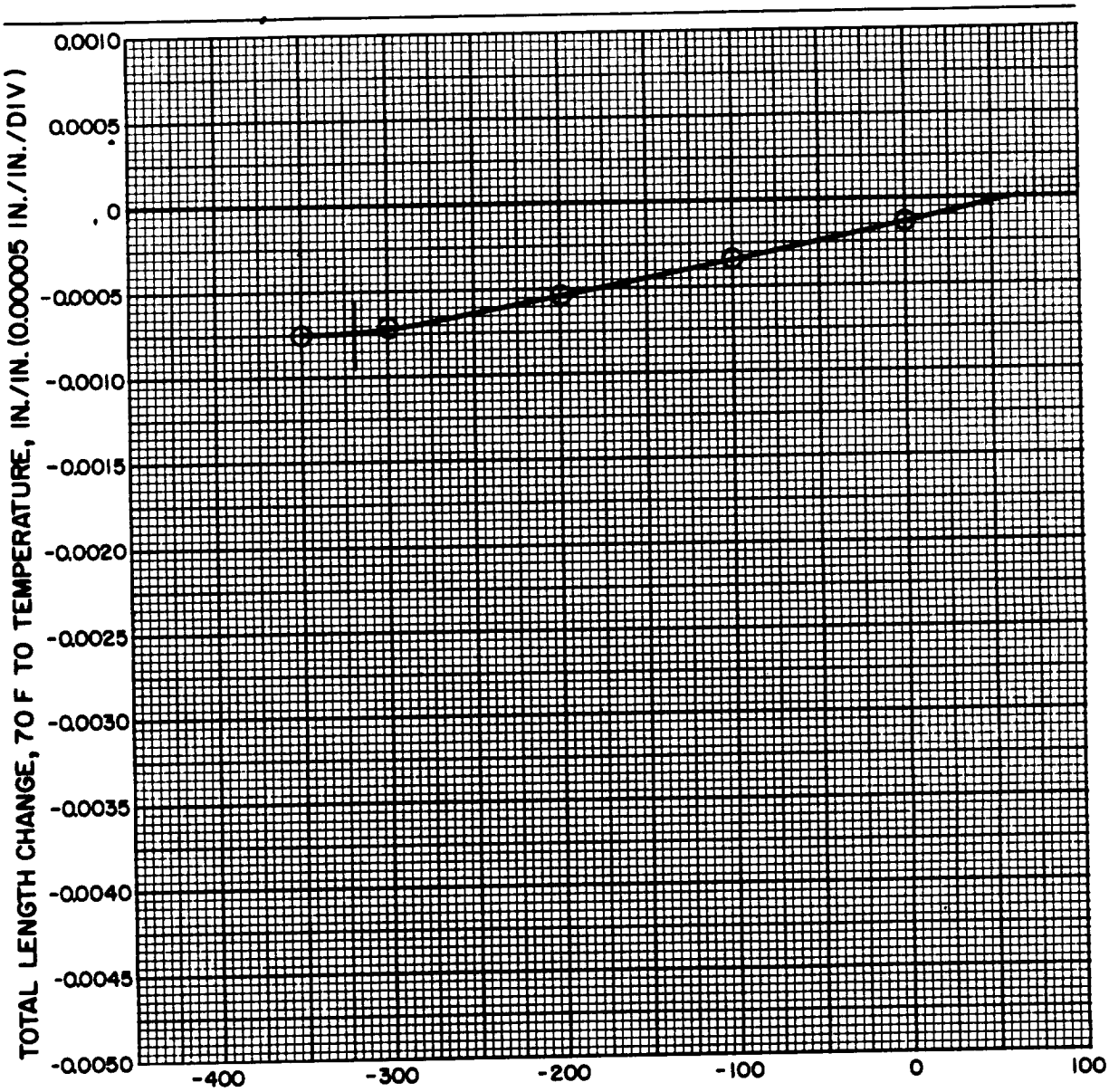
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·7·60
MATERIAL K801 (W_XC_Y - Ni)
FORM
CONDITION
SPECIFICATION
DATE AUGUST 1965

NOTES:



K801 (W_XC_Y - Ni)

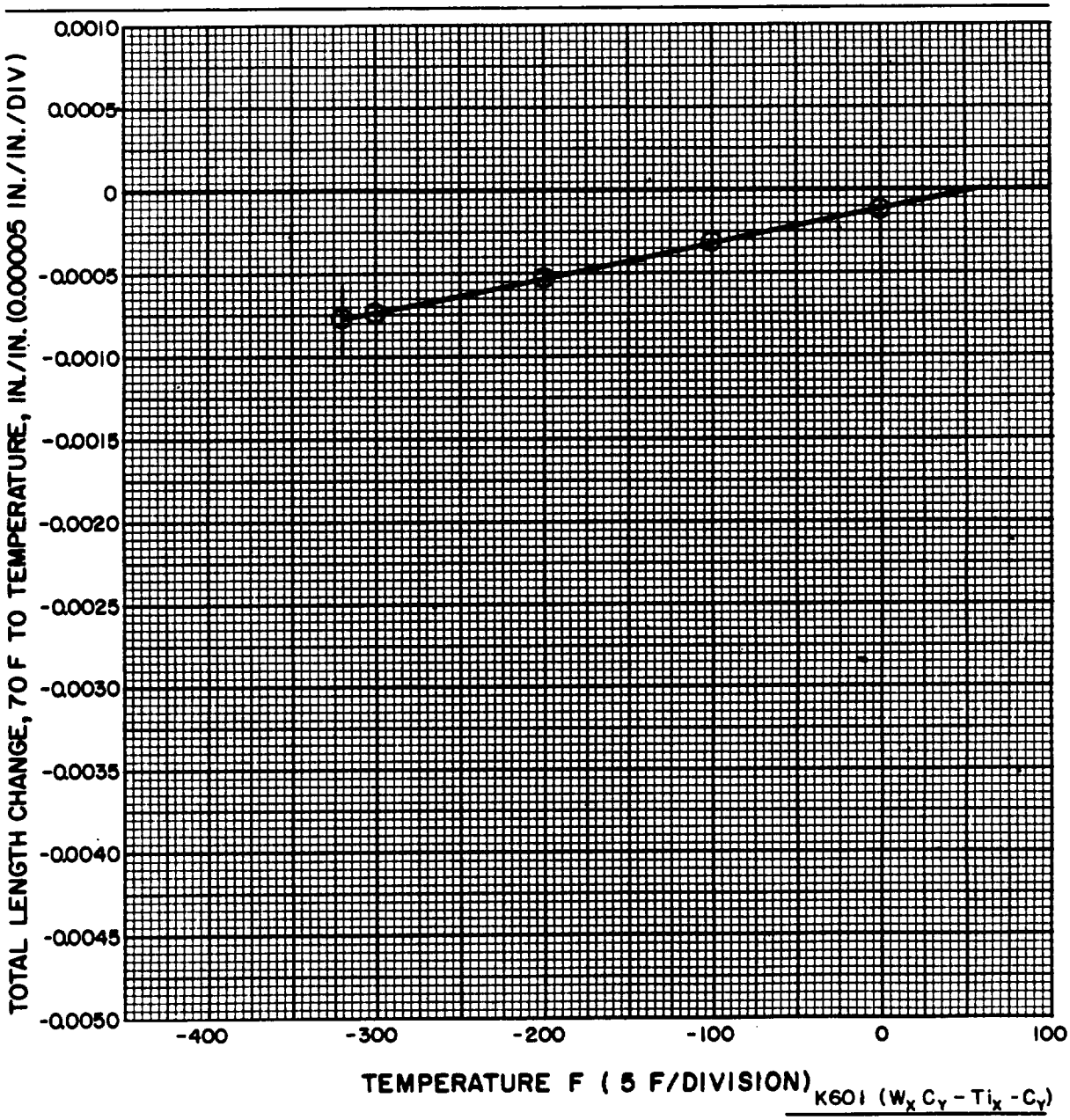
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·8·60
MATERIAL K601 ($W_X C_Y - Ti_X C_Y$)
FORM
CONDITION
SPECIFICATION –
DATE AUGUST 1965

NOTES:



K601 ($W_X C_Y - Ti_X - C_Y$)

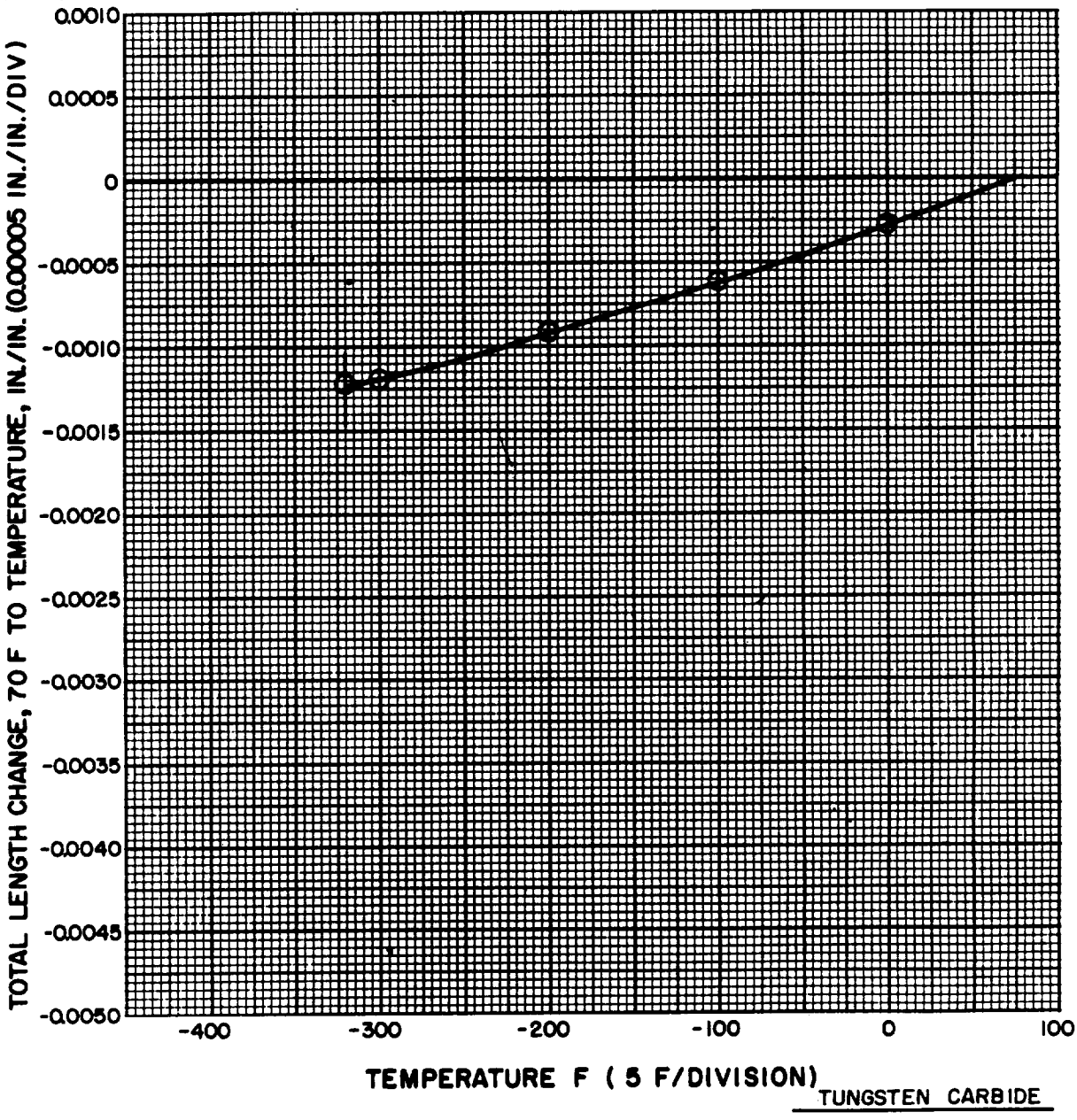
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·9·60
MATERIAL TUNGSTEN CARBIDE
FORM
CONDITION
SPECIFICATION -
DATE AUGUST 1965

NOTES: LINDE FLAME SPRAYED



TUNGSTEN CARBIDE

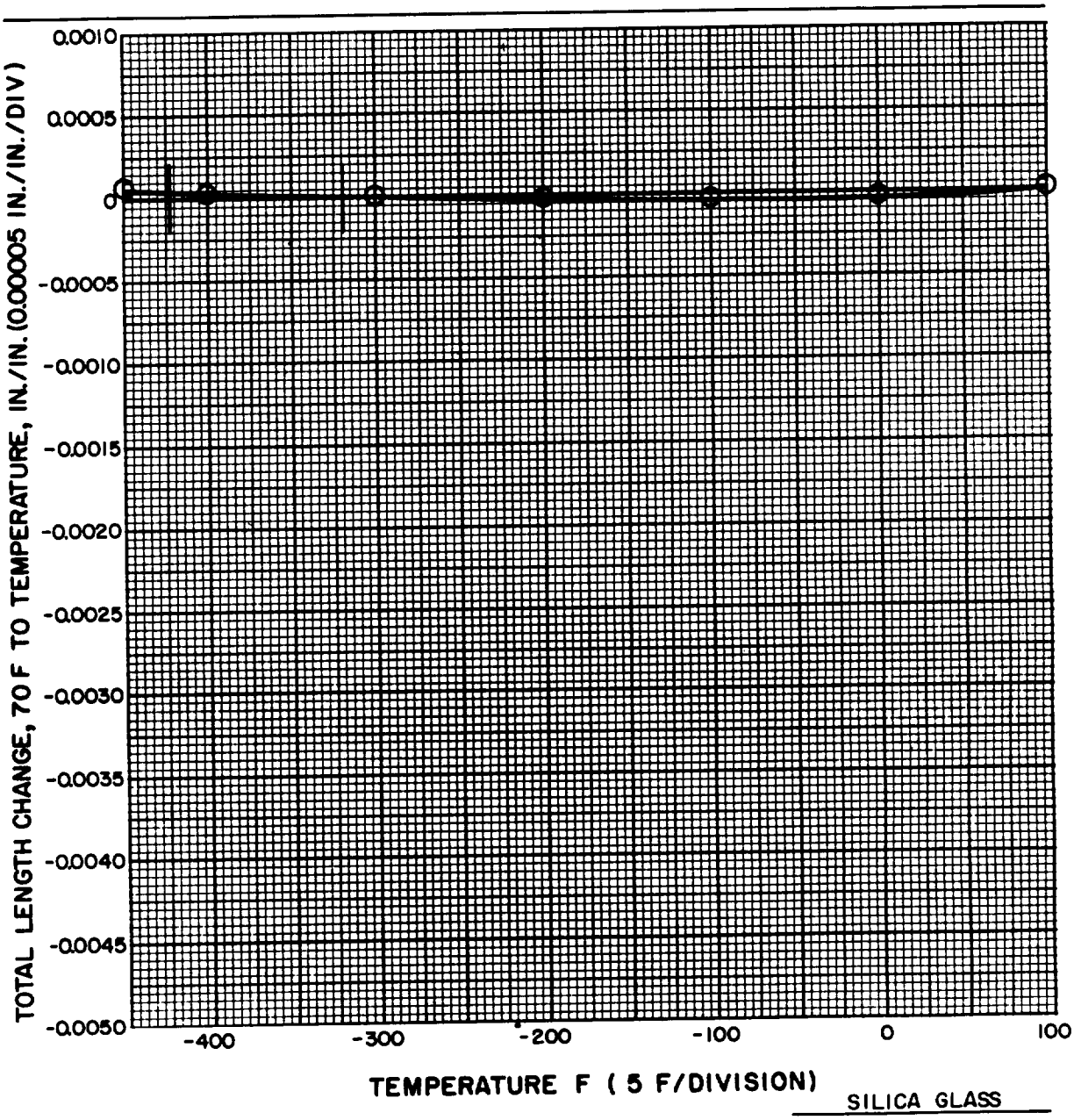
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE LITERATURE
APPROVED
REFERENCE NATIONAL BUREAU OF STANDARDS

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12·10·60
MATERIAL SILICA GLASS
FORM
CONDITION
SPECIFICATION -
DATE AUGUST 1965

NOTES:



SILICA GLASS

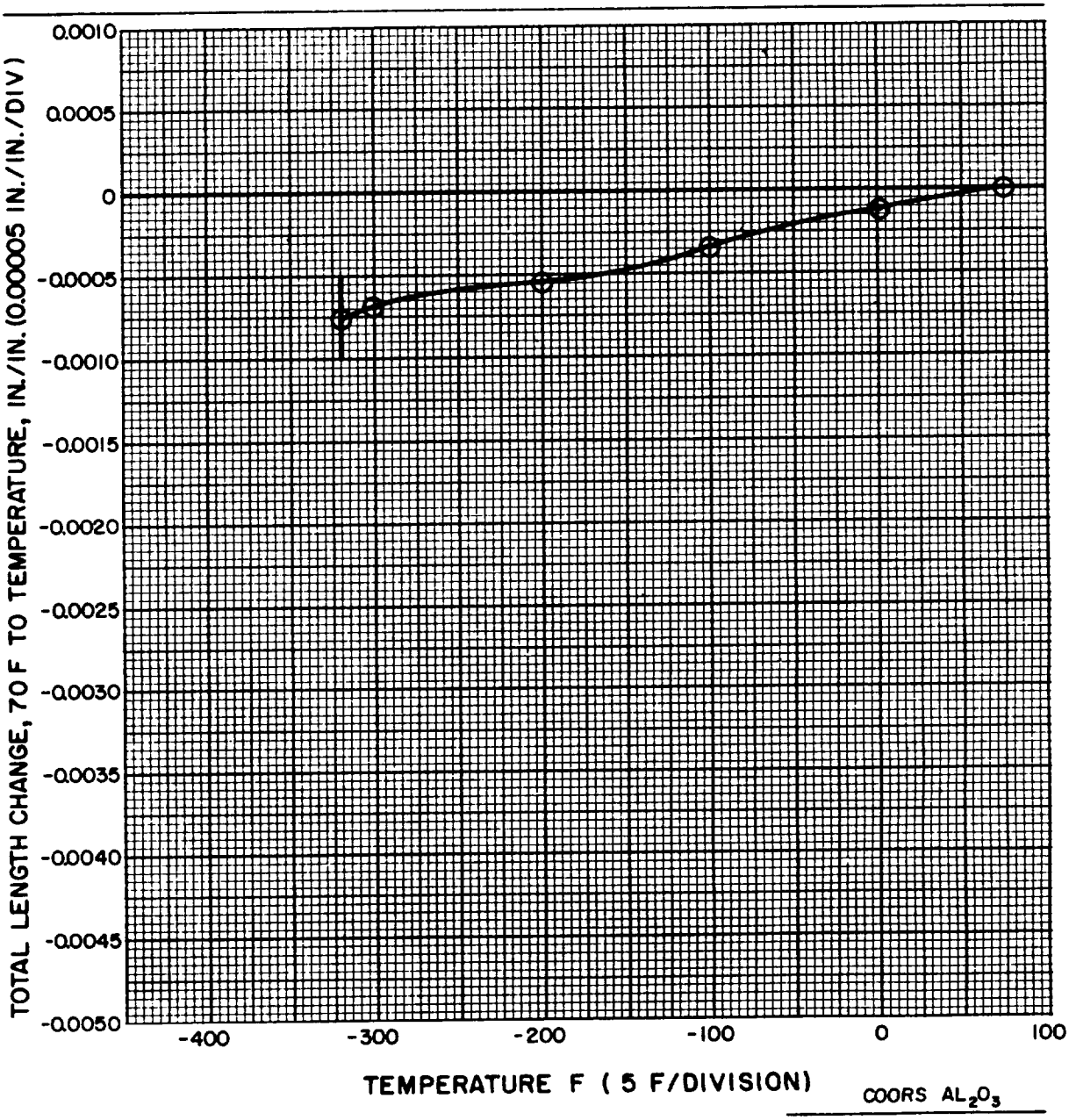
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE COORS DATA SHEET 8-64

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 12-11-60
MATERIAL COORS AL_2O_3
FORM
CONDITION
SPECIFICATION ALUMINUM AD94-AD99
DATE DECEMBER 1966

NOTES:



COORS AL_2O_3

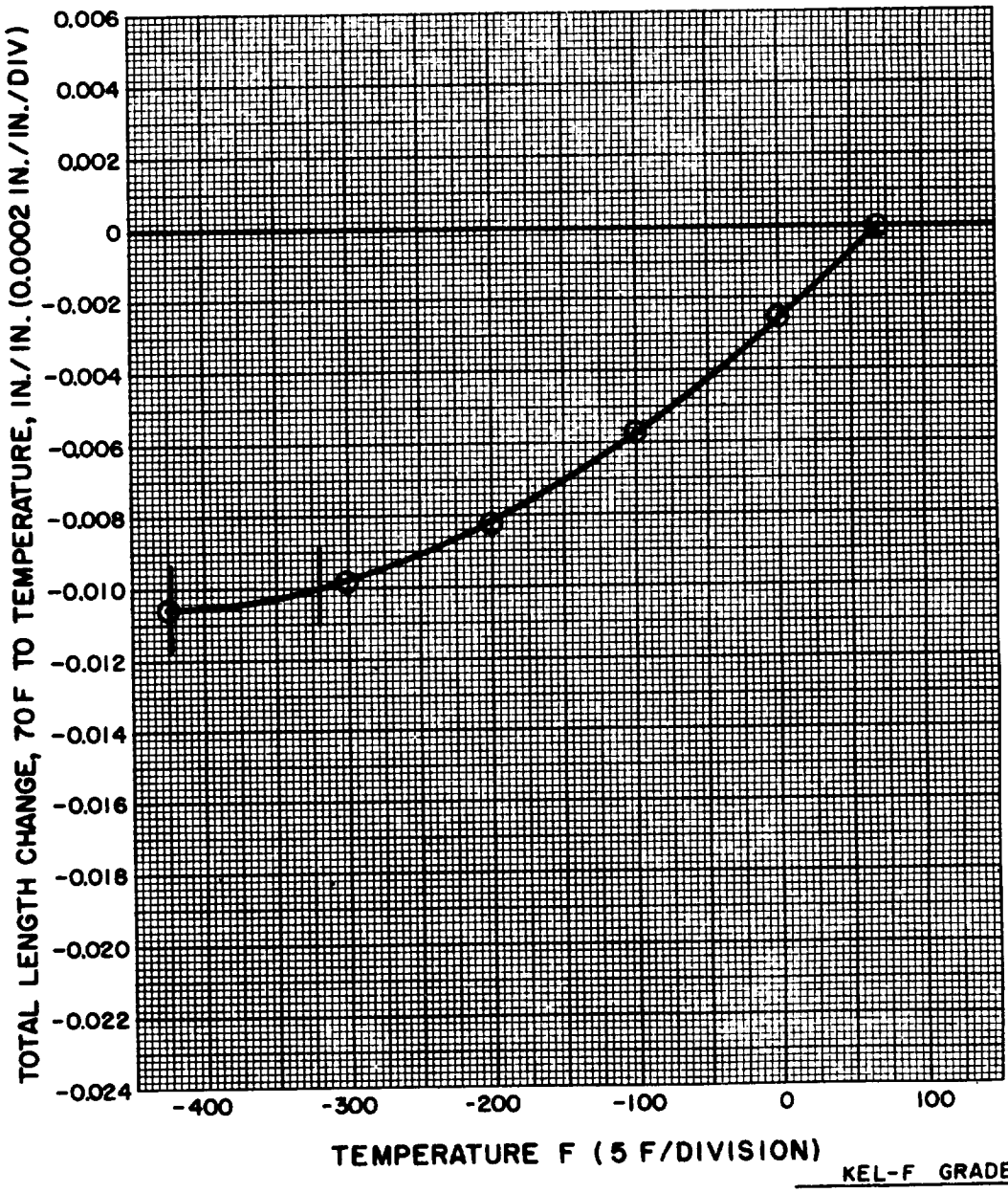
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462
3 M CO.

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·1·60
MATERIAL KEL-F GRADE 81
FORM
CONDITION
SPECIFICATION
DATE MARCH 1962

NOTES:



KEL-F GRADE 81

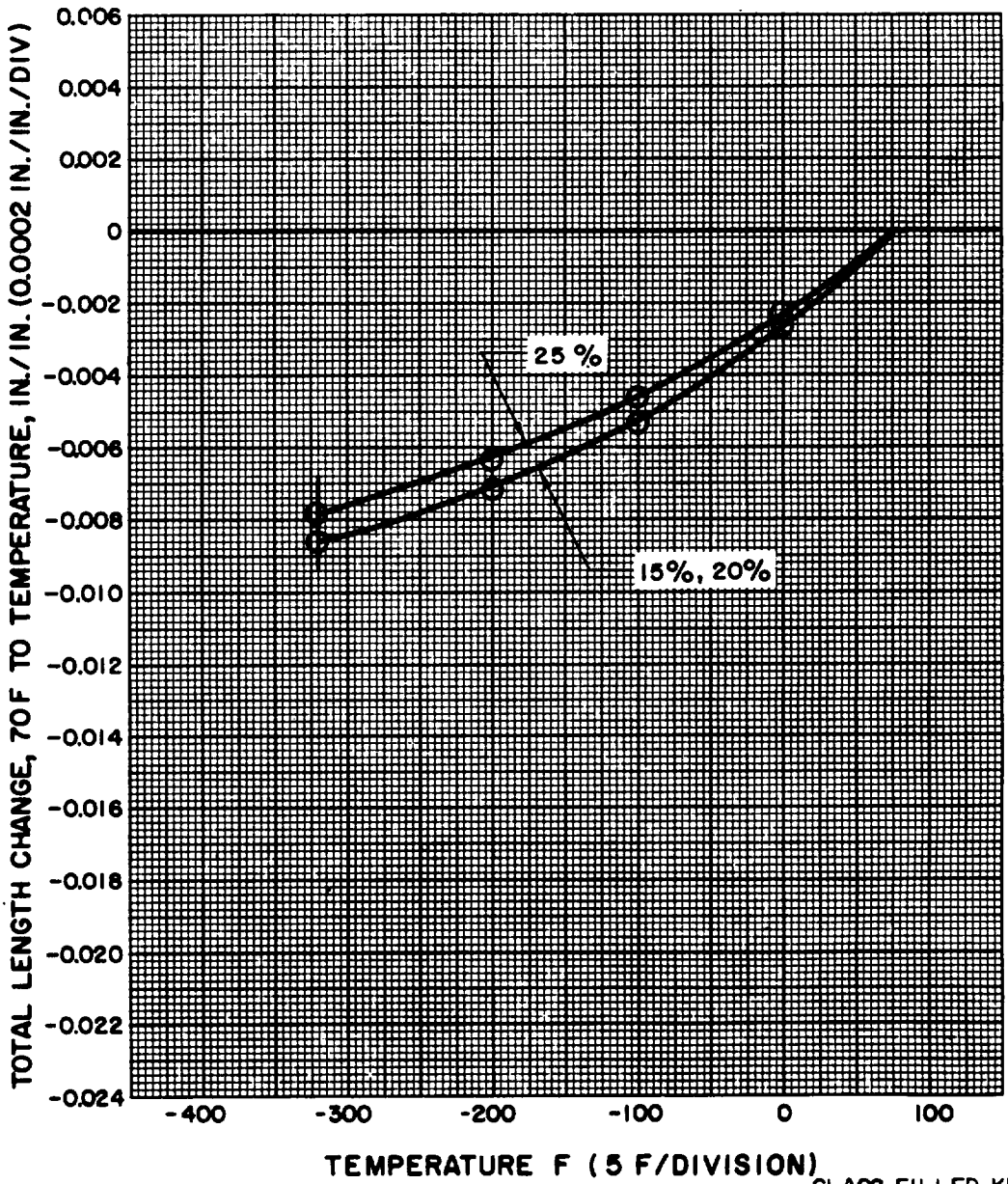
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE 3 M CO.

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·2·60
MATERIAL GLASS FILLED KEL-F
FORM
CONDITION SEE NOTES
SPECIFICATION
DATE JULY 1965

NOTES: 15%, 20%, 25% GLASS FILLED



GLASS FILLED KEL-F

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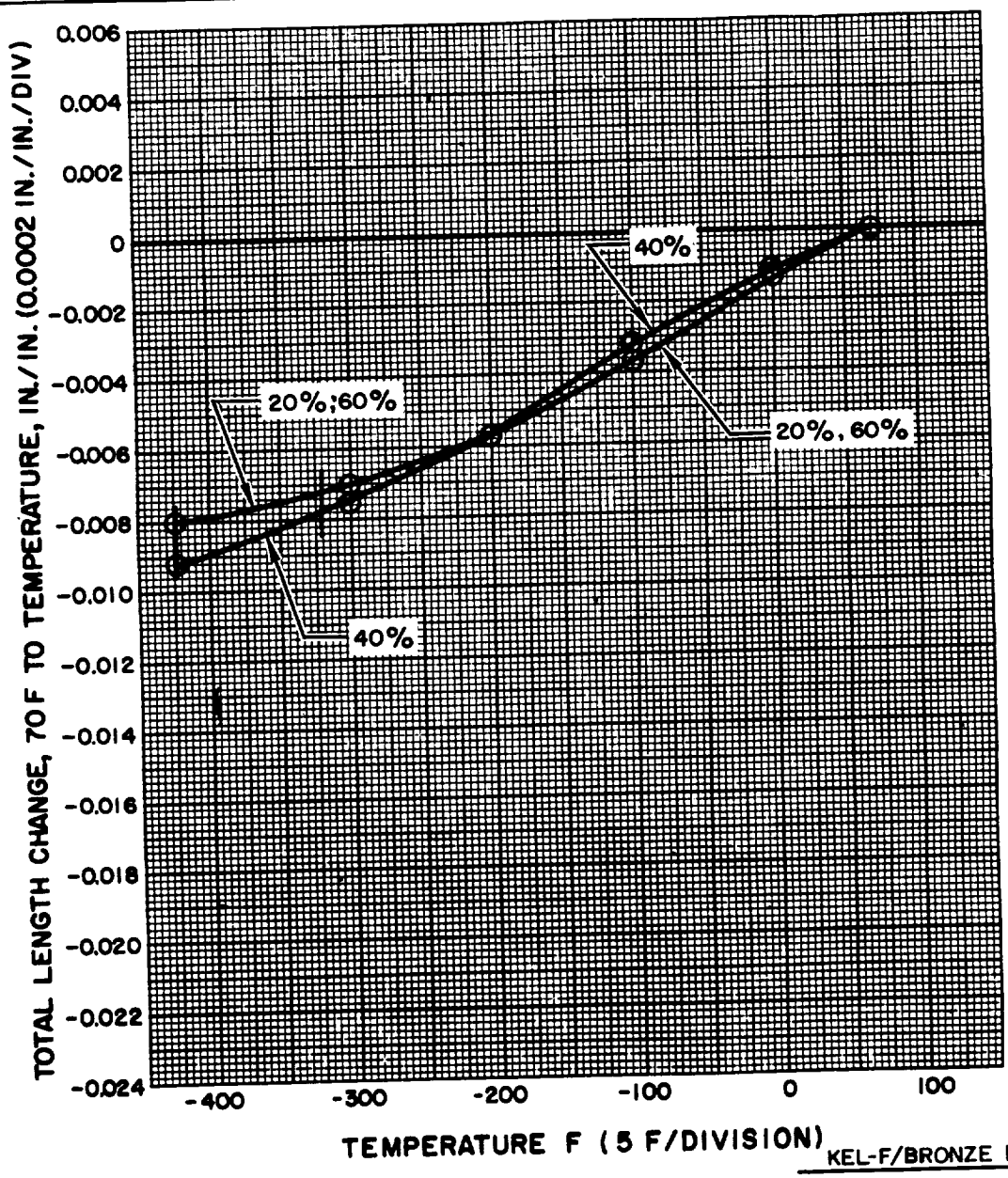
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE 3 M CO.

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·3·60
MATERIAL KEL-F/BRONZE FILLED
FORM
CONDITION SEE NOTES
SPECIFICATION
DATE JULY 1965

NOTES: 20%, 40%, 60% BRONZE FILLED



KEL-F/BRONZE FILLED

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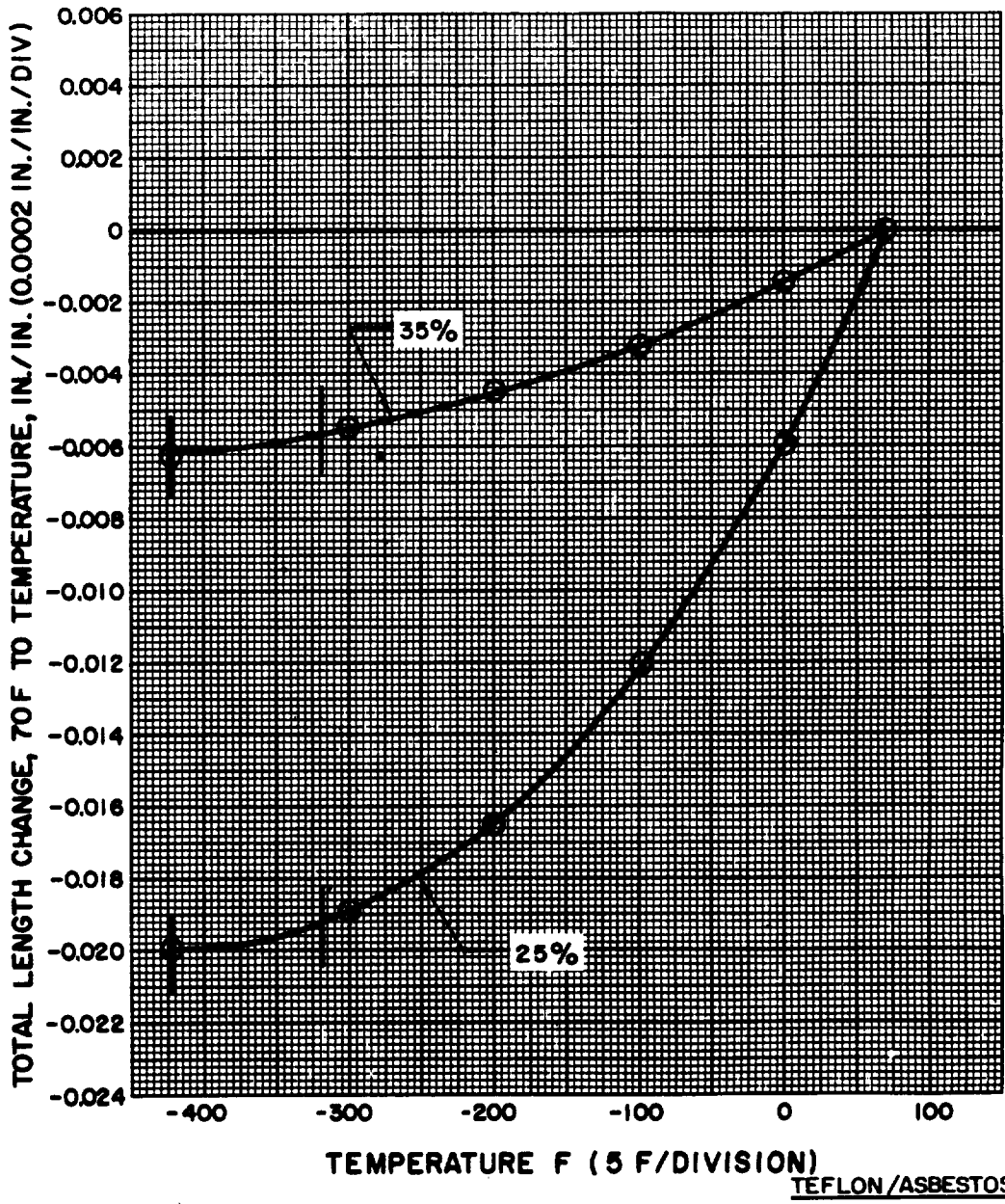
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462
DUPONT/LNP

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·5·60
MATERIAL TEFLON/ASBESTOS FILLED
FORM
CONDITION 25% / 35% ASBESTOS
SPECIFICATION
DATE MARCH 1962

NOTES:



TEFLON/ASBESTOS FILLED

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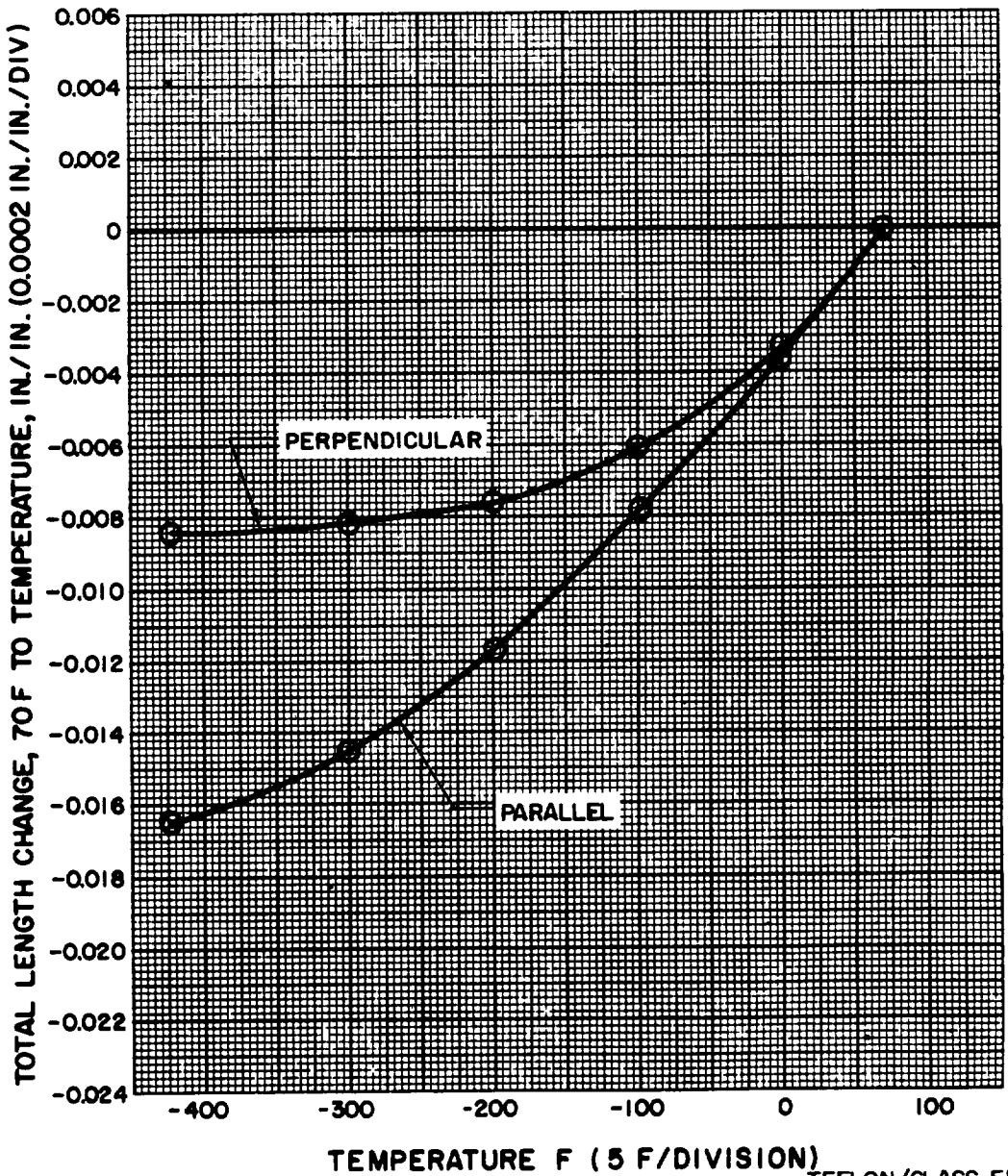
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462
DUPONT/LNP

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·6·60
MATERIAL TEFLON/GLASS FILLED
FORM
CONDITION SEE NOTES
SPECIFICATION
DATE

NOTES: 25% GLASS, PARALLEL/PERPENDICULAR TO MOLD FORCES



TEFLON/GLASS FILLED

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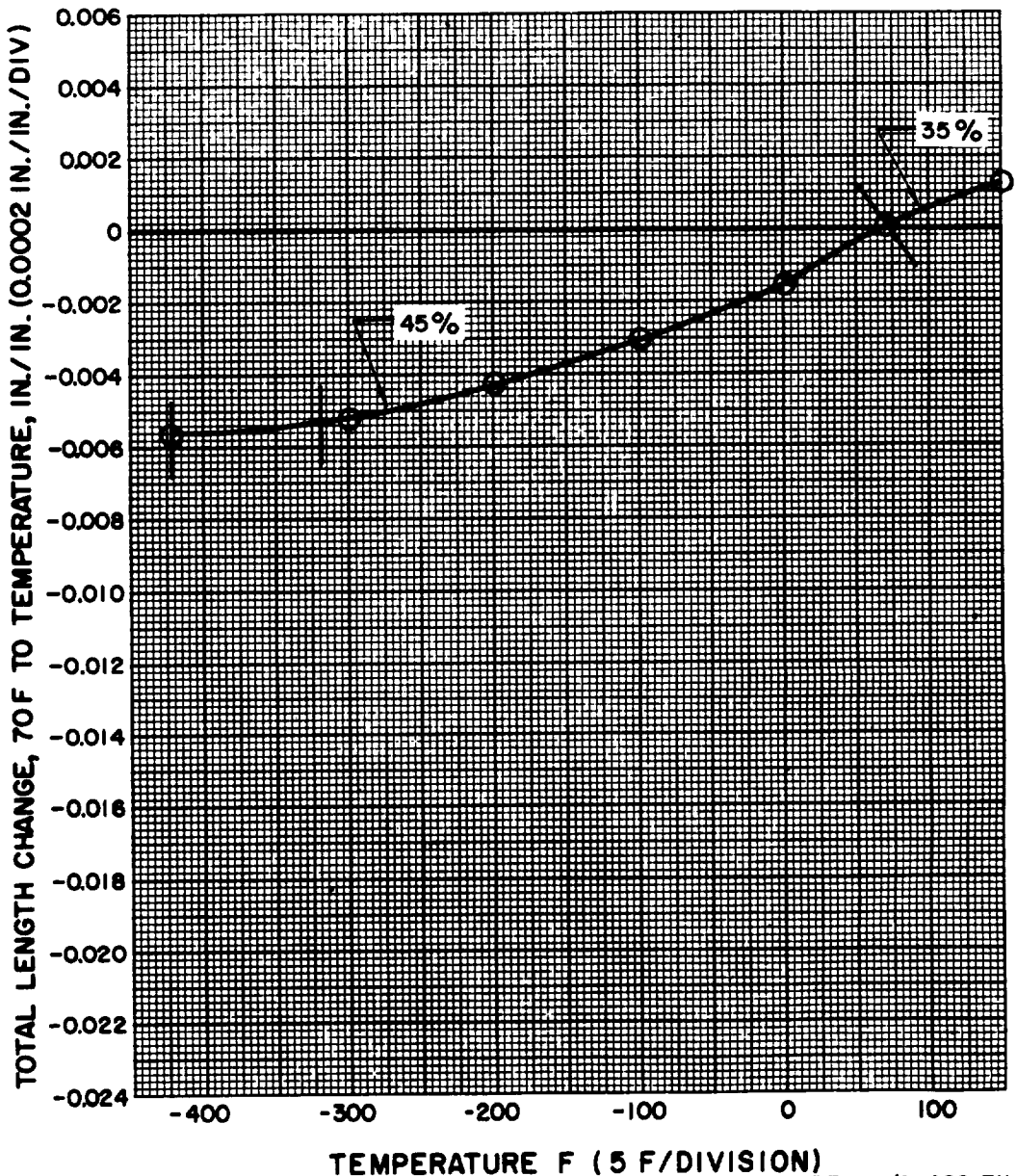
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE DUPONT

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·7·60
MATERIAL TEFLON/GLASS FILLED
FORM
CONDITION SEE NOTES
SPECIFICATION
DATE JULY 1965

NOTES: 35%, 45% GLASS; PERPENDICULAR TO MOLD FORCE



TEFLON/GLASS FILLED

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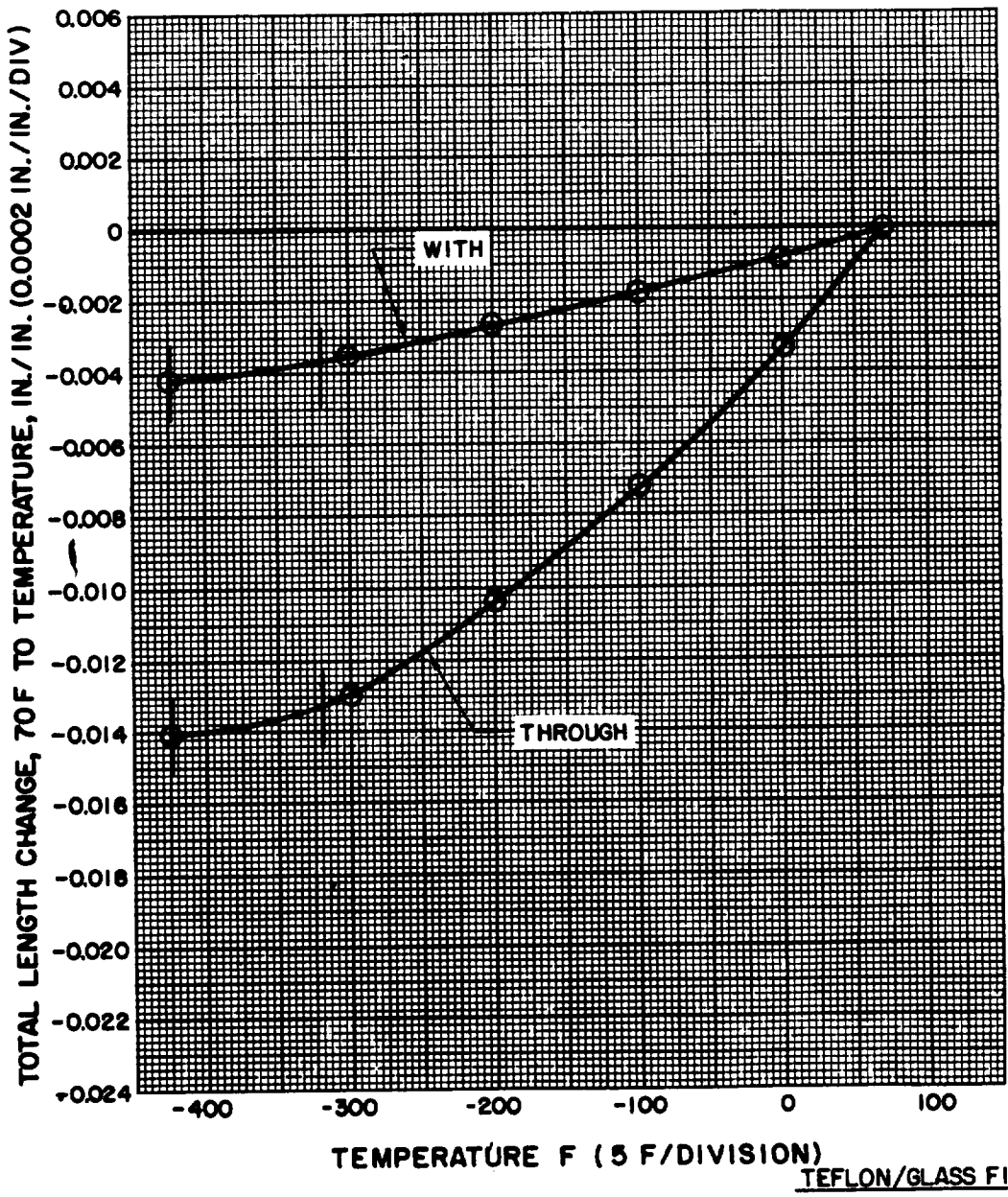
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462
PERMACEL

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13-8-60
MATERIAL TEFLON/GLASS FILLED
FORM
CONDITION SEE NOTES
SPECIFICATION
DATE MARCH 1962

NOTES: WITH/THROUGH FABRIC LAYERS



TEFLON/GLASS FILLED

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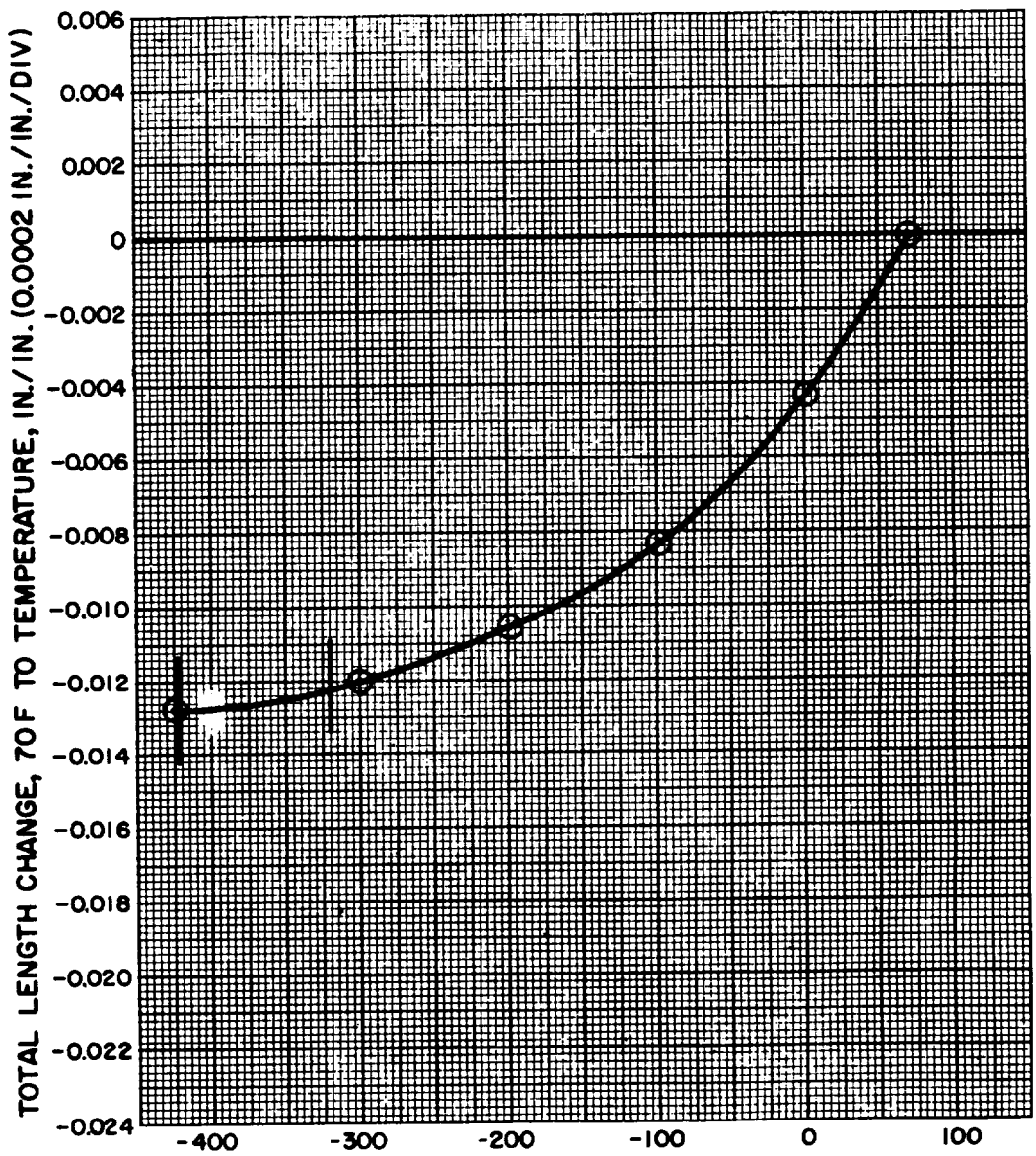
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE
DUPONT/LNP

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·9·60
MATERIAL TEFLON/BRONZE FILLED
FORM
CONDITION 60% BRONZE
SPECIFICATION
DATE JULY 1965

NOTES:



TEFLON/BRONZE FILLED

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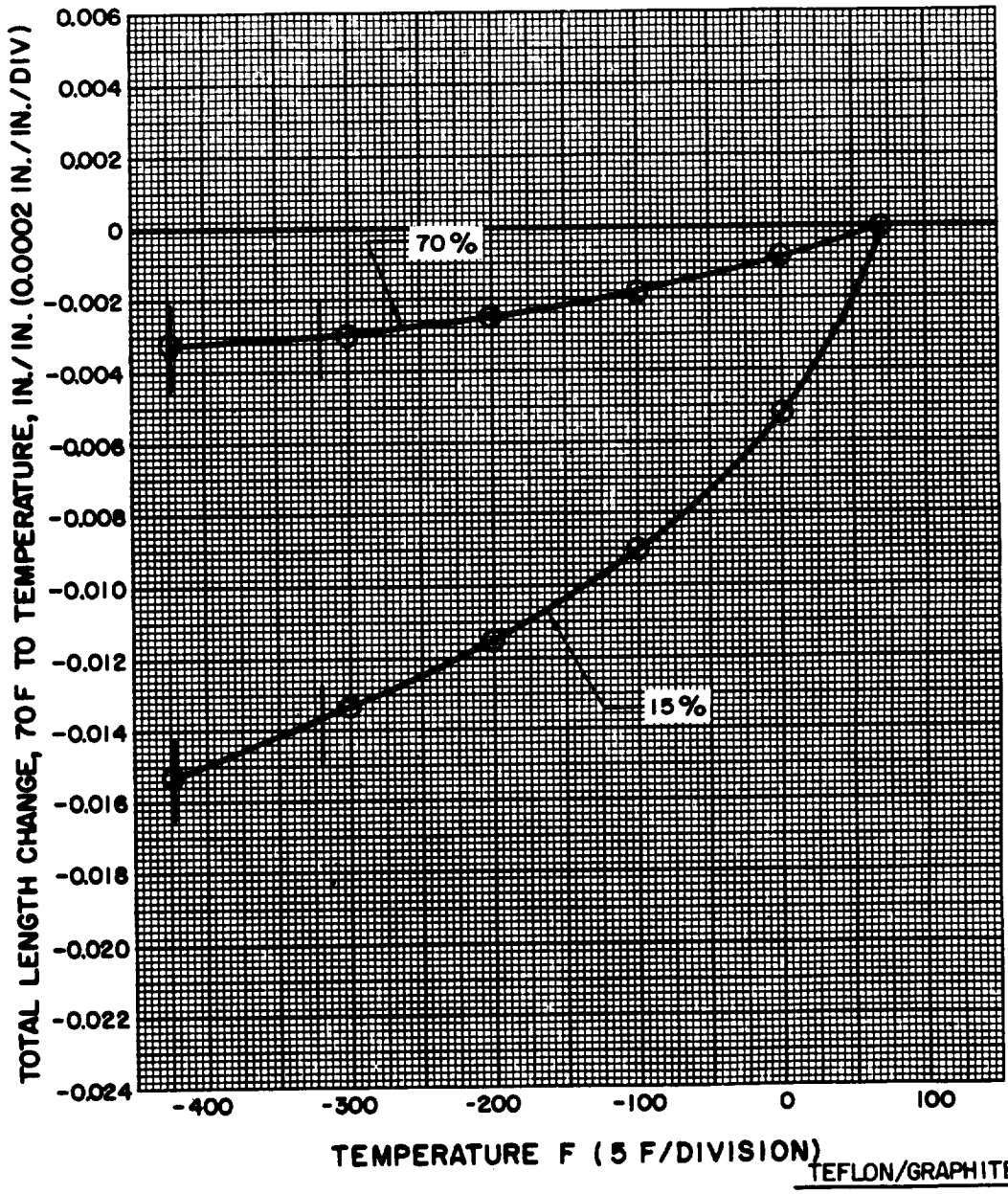
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE DUPONT/LNP

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·10·60
MATERIAL TEFLON/GRAPHITE FILLED
FORM
CONDITION 15% / 70% GRAPHITE
SPECIFICATION
DATE JULY 1965

NOTES:



TEFLON/GRAPHITE FILLED

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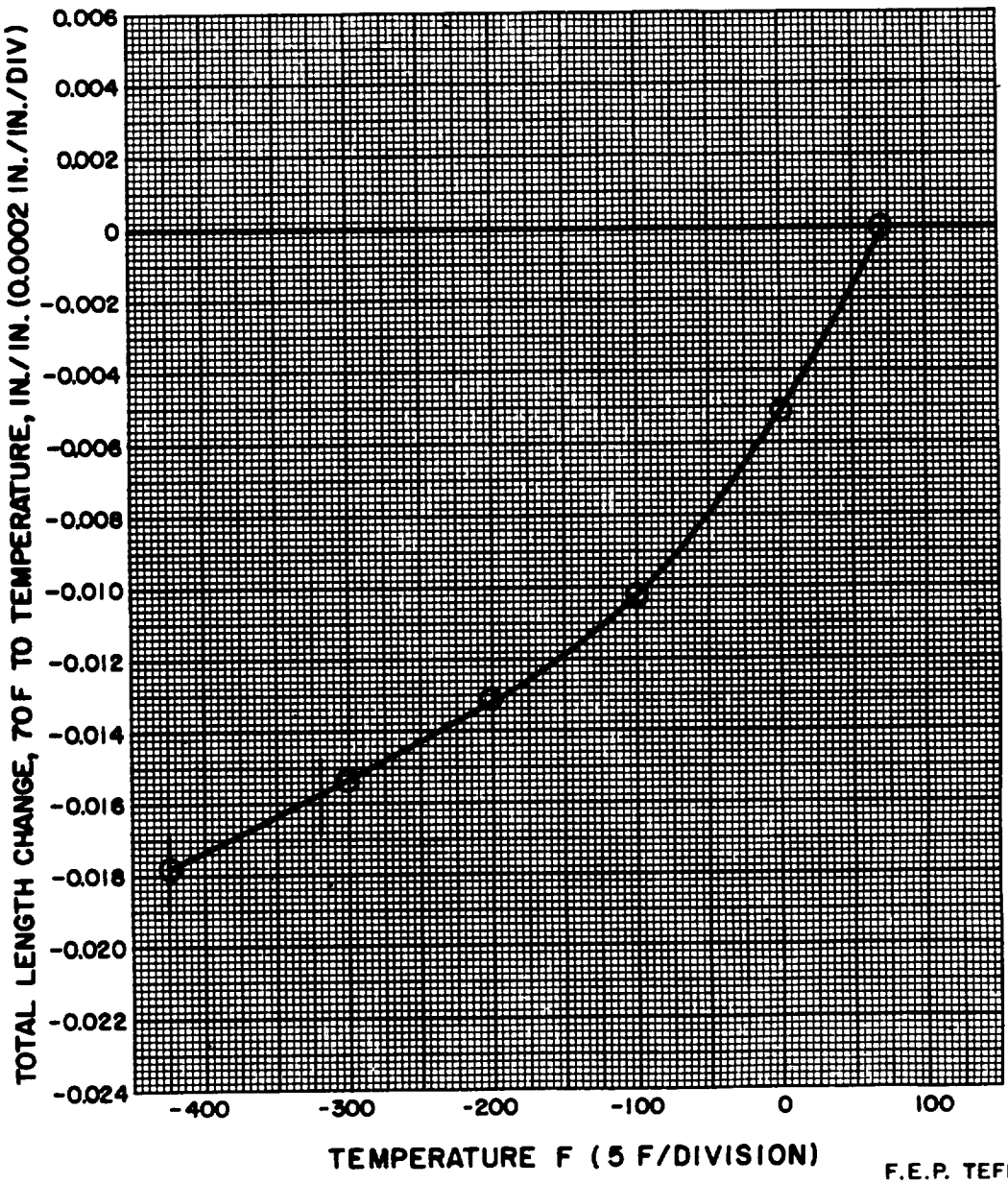
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462
DUPONT

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·11·60
MATERIAL F.E.P. TEFLON
FORM
CONDITION
SPECIFICATION RB0130-007
DATE MARCH 1962

NOTES:



F.E.P. TEFLON

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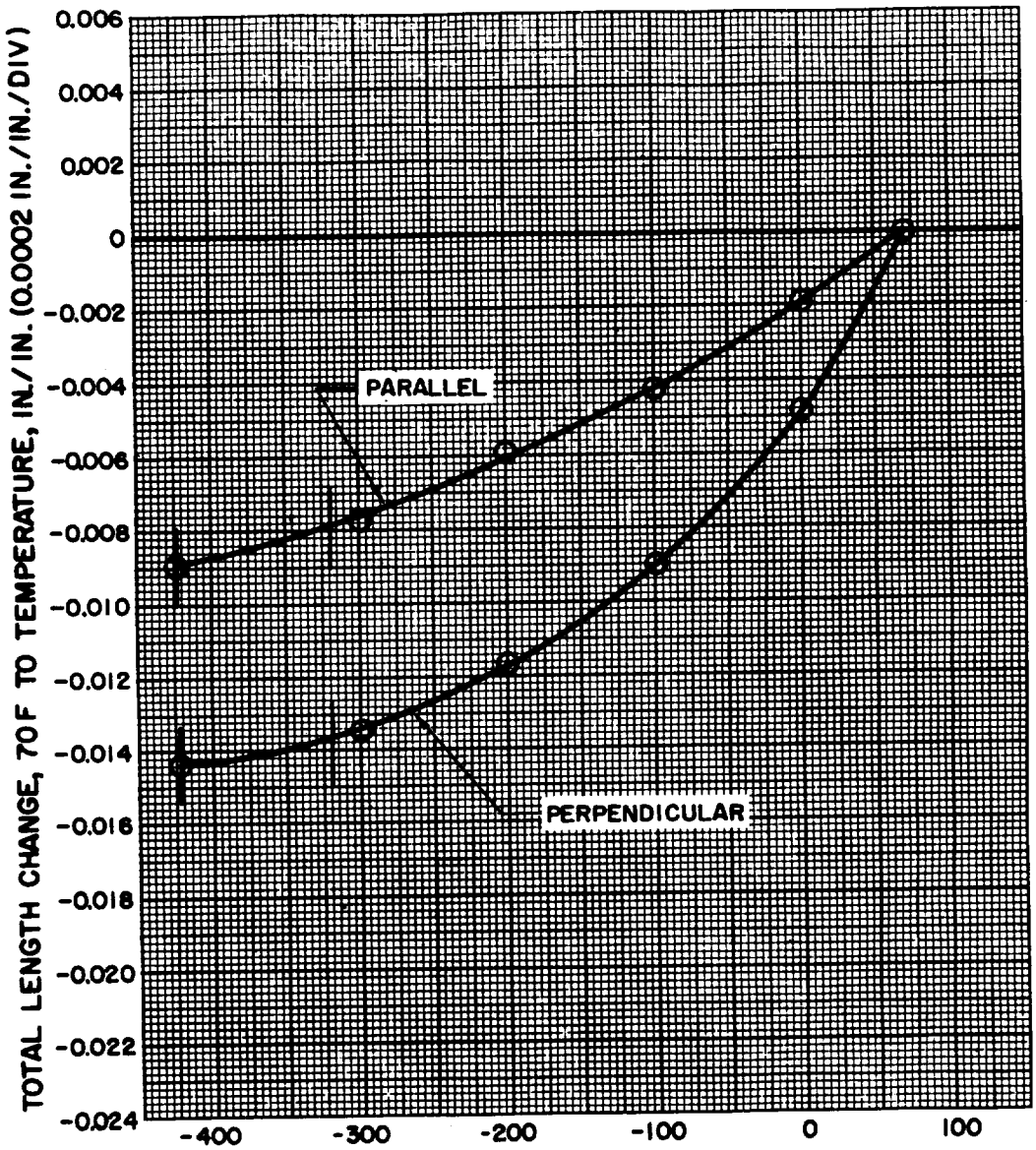
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE R-3462
DUPONT/BELDING-CORTICELLI

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13-12-60
MATERIAL F.E.P./GLASS FILLED
FORM
CONDITION SEE NOTES
SPECIFICATION
DATE MARCH 1962

NOTES: 20% GLASS, PARALLEL/PERPENDICULAR TO MOLD FORCES



F.E.P./GLASS FILLED

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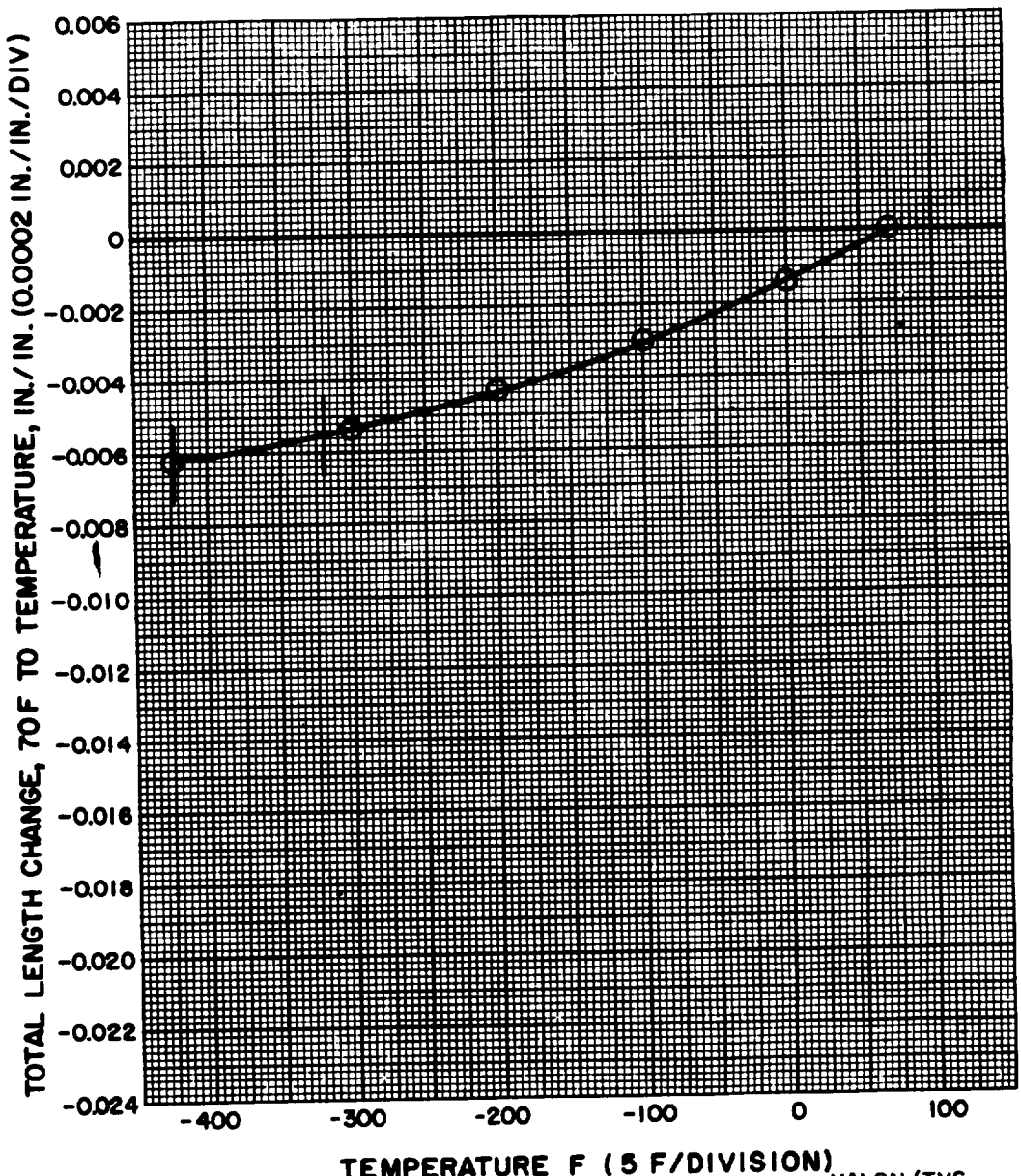
ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE
ALLIED CHEMICAL

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·14·60
MATERIAL HALON/TVS
FORM
CONDITION 35% GLASS FILLED
SPECIFICATION
DATE JULY 1965

NOTES:



HALON/TVS

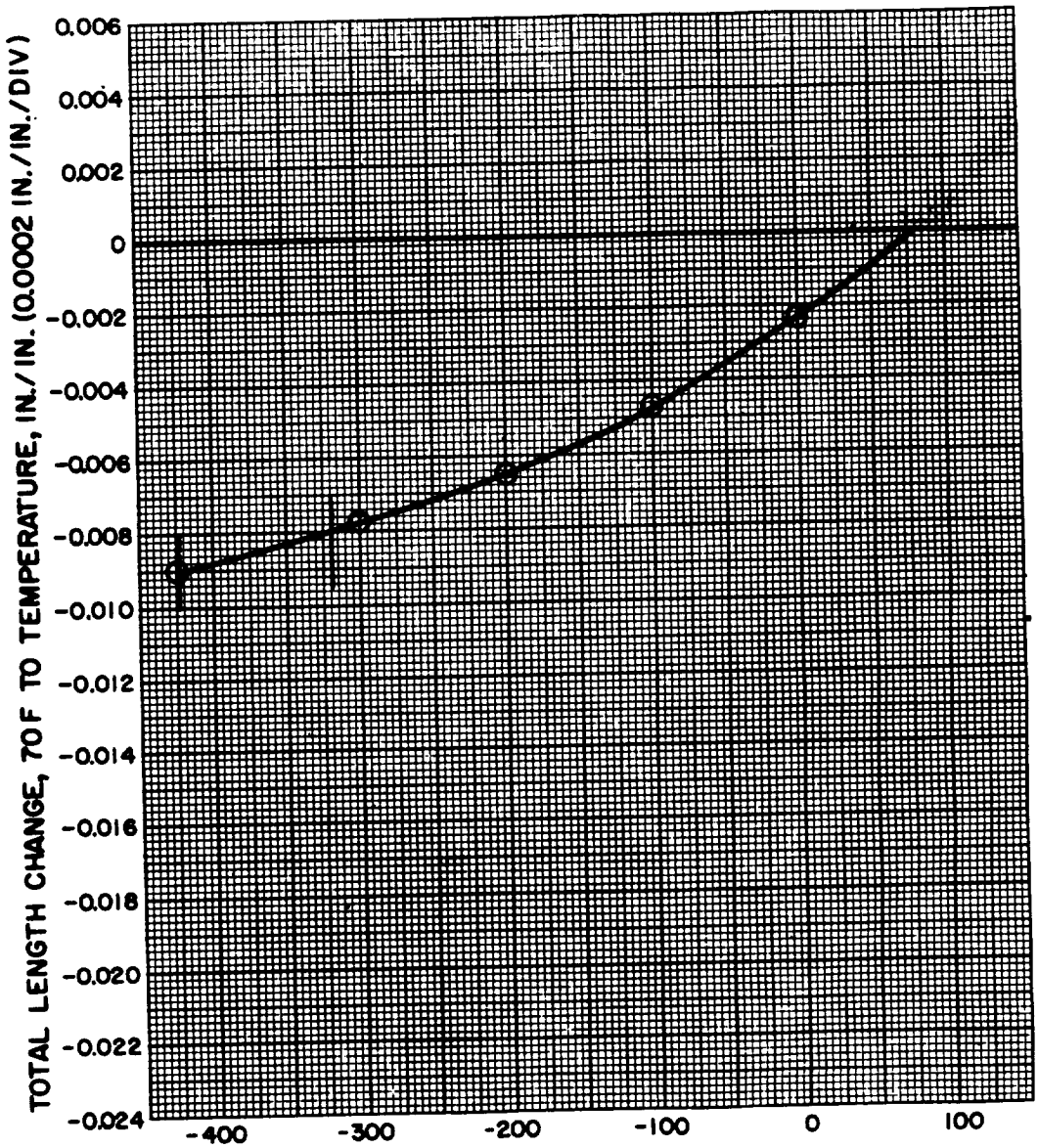
ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

ISSUED BY MATERIALS AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE
ALLIED CHEMICAL

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13·15·60
MATERIAL HALON/TVS
FORM
CONDITION 25% MoS_2 FILLED
SPECIFICATION
DATE JULY 1965

NOTES:



HALON/TVS

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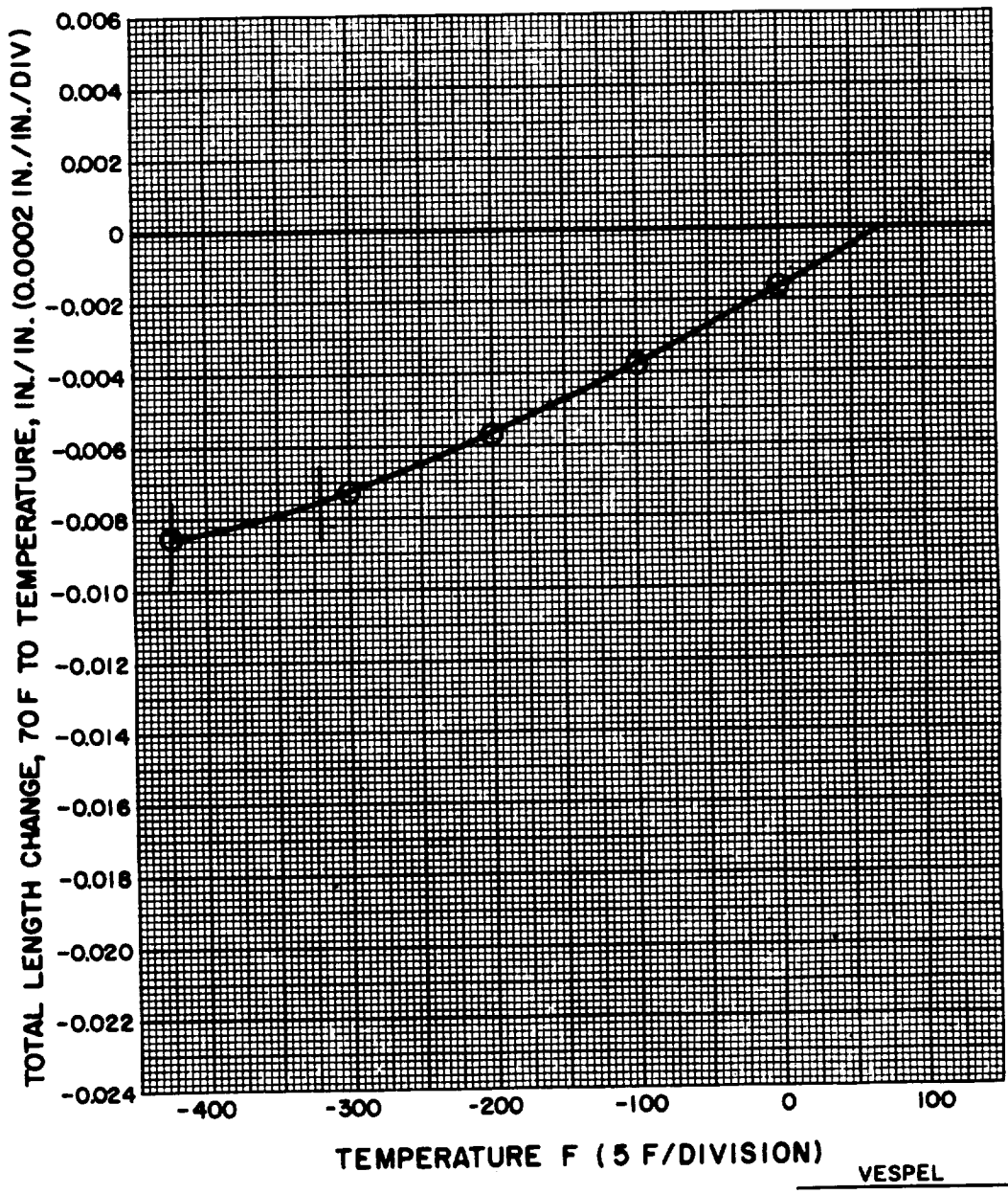
ISSUED BY MATERIALS
AND PROCESSES DEPT.
SOURCE ROCKETDYNE
APPROVED
REFERENCE
DUPONT

THERMAL EXPANSION PROPERTIES AT CRYOGENIC TEMPERATURES

CHART NO. 13-16-60
MATERIAL VESPEL
FORM
CONDITION
SPECIFICATION
DATE JULY 1965

NOTES:



VESPEL

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

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

1. ORIGINATING ACTIVITY *(Corporate author)*

Rocketdyne, a Division of North American Aviation, Inc., 6633 Canoga Avenue, Canoga Park, California

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE Design and Development Engineering Handbook of Thermal Expansion Properties of Aerospace Materials at Cryogenic and Elevated Temperatures.

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

5. AUTHOR(S) *(Last name, first name, initial)*

Williams, Lee R. - Young, John D. - Schmidt, Erwin H.

6. REPORT DATE

30 March 1967

7a. TOTAL NO. OF PAGES

175

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.

NAS 8-19

b. PROJECT NO. 03712-08941-00100

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

R 6981

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

Thermal expansion data are presented for Aerospace materials commonly used in liquid propellant rocket engines. These data cover a range of temperature from -423 F to 2000 F (or lower if limited by melting point). Most of the data were determined at Rocketdyne.

DD FORM 1 JAN 64 1473

Security Classification

Unclassified

Security Classification

KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Thermal Expansion Aerospace Materials Cryogenic Temperatures Elevated Temperatures						

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