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TECHNICAL REPORT NO. 11895

ENDURANCE TEST OF HIGH STRENGTH CAST ALUMINUM TRANSMISSION CASE AND CLUTCH HOUSING

June, 1974

by G. B. SINGH

TIN 26326

TACOM

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VEHICULAR COMPONENTS & MATERIALS LABORATORY

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

20031219014

TECHNICAL REPORT NO. 11895

ENDURANCE TEST OF HIGH STRENGTH CAST ALUMINUM TRANSMISSION CASE AND CLUTCH HOUSING

BY
G. B. Singh

JUNE 1974

AMCMS CODE: 728012.16

MATERIALS FUNCTION

ABSTRACT

Casting technology procedures which had been developed for composition 201 and 224 aluminum alloys under Phase 1 of this project were utilized to sand cast transmission cases and clutch covers of a 2½-ton vehicle. Endurance testing of these components, together with standard cast iron components, revealed that cast aluminum components had a better heat-rejecting capability as compared to cast iron components. Furthermore, composition 224 aluminum alloy transmission assembly had better temperature-lowering characteristics (5.1^{o}F) than that of composition 201 transmission assembly. The mean operating temperature for a standard transmission was 301.4^{o}F; for the 201 transmission, it was 298.8^{o}F and for the 224 transmission, it was 293.7^{o}F. It was also determined that at these operating temperatures stability of OE-50 lubricant was better than GO-90 lubricant. Durability of both aluminum transmissions were better than for standard cast iron transmissions.

FOREWORD

This project has been accomplished as part of the US Army manufacturing Methods and Technology Program, which has as its objective the timely establishment of manufacturing processes, techniques or equipment to insure the efficient production of current or future defense programs.

The entire program had been a TACOM in-house effort. Under Phase 1, the foundry casting technology, heat treatment and fabrication of aluminum sand castings were established for composition 201and composition 224 high strength aluminum alloys. Solutions to technical problems of "hot short" or "tearing" tendencies were accomplished. These findings have been reported in TACOM Technical Report No. 11727.

In the second phase of this project, transmission cases and clutch covers of a 2½-ton vehicle were fabricated and endurance tested at the US Army Yuma Proving Ground, Yuma, Arizona.

The report is based on information furnished by TECOM letter report No. 1-VH-122-342-001 written by Ramon J. Heick.

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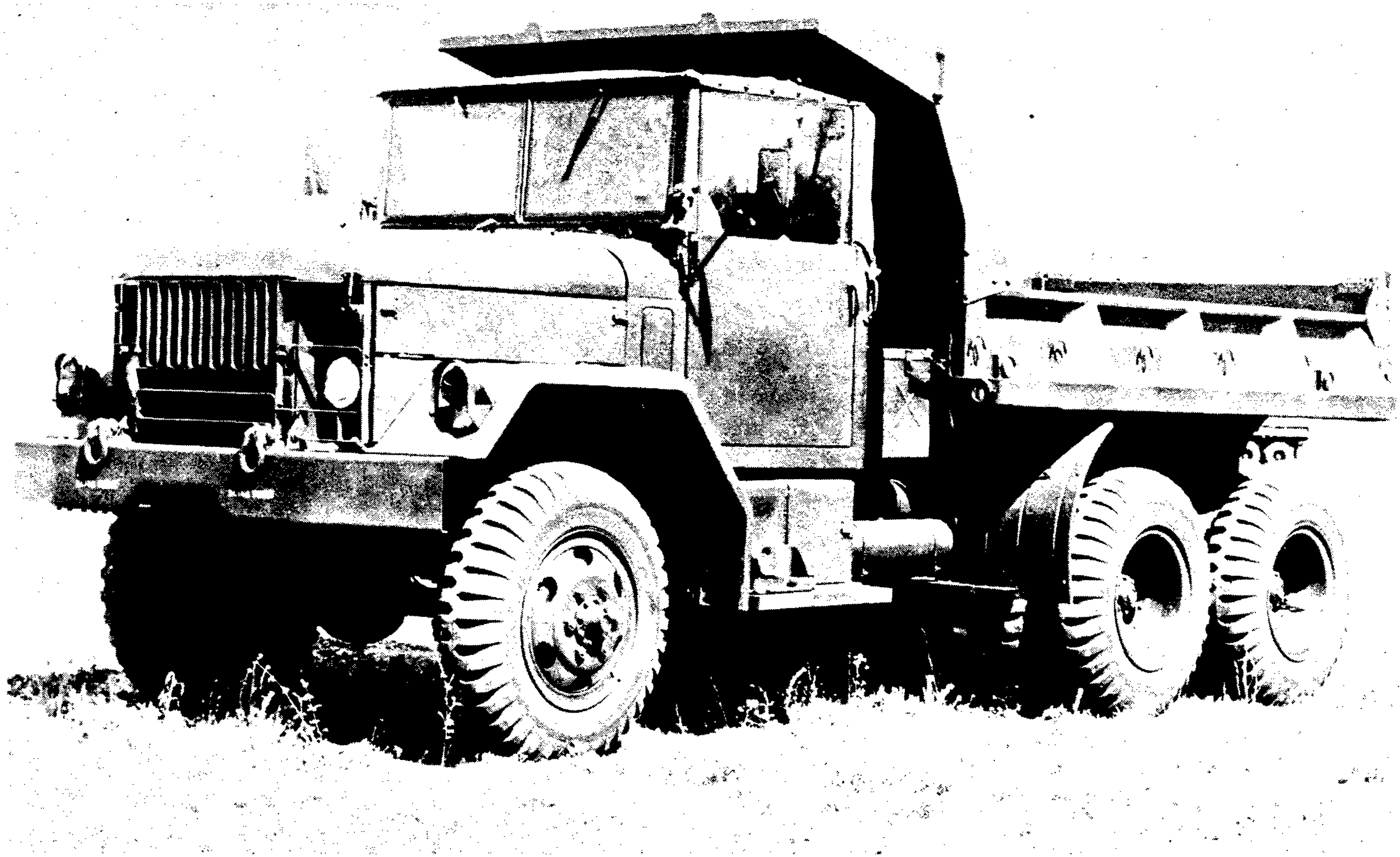
INTRODUCTION

The aluminum casting industry has developed aluminum alloys with improved ductility and strength levels exceeding 50,000 psi. These alloys offer weight savings possibilities coupled with superior heat transfer capabilities. These characteristics can be applied in certain areas where alloy steels and cast iron are used.

In combustion engines, high compression ratios and supercharging have raised both the operating temperature and stresses in many components. Pistons, air cooled cylinder heads, crank cases, transmissions, clutches and supercharger compressor wheels are among the engine components where both temperature and stress levels impose service limitations. For example, at the present time, a ferrous base alloy (ferritic, malleable or nodular iron) is used for the transmission case and clutch housing for the M342A2 2½-ton vehicle, Figure 1. Substitution of this material, with sand cast aluminum alloys in the similar strength range, should provide the military with alternate components, which would be lighter in weight and possess increased thermal conductivity with consequent improved heat rejection capability. The use of high strength cast aluminum in transmission or differential cases would minimize premature lube and/or gear failure due to excessive temperature build up under full load type operation, particularly when ambient temperatures exceed 90°F.

Casting technology procedures were developed under Phase I of this project to provide components with suitable high strength to replace currently-used malleable iron castings. In this second and final phase of the project, the fabricated components were vehicle tested under actual field conditions to verify their better serviceability as compared to conventional cast iron components.



M342A2, 2½-Ton Dump Truck

FIGURE 1

<u>OBJECTIVES</u>

1. Determine the durability of the cast aluminum transmission case and clutch housings as compared to standard cast iron case and housing.

2. Conduct a comparison test of both types of design on similar vehicles (M342A2) under the same operating and environmental conditions.

3. Establish the heat rejection capability at maximum gear case sump temperatures.

DESIGN CRITERIA

Comparable physical characteristics (tensile strength, yield strength, elongation, etc.) of certain aluminum alloys can be obtained with those of cast iron or steel. However, other characteristics, such as modulus of elasticity ($E=10 \times 10^6$ psi) and co-efficient of thermal expansion ($\alpha=13.1 \times 10^{-6}$ in/in^{o}F), greatly differ with those of steel ($E=30 \times 10^6$ psi, $\alpha=6.3 \times 10^{-6}$ in/in^{o}F). These two characteristics (E and α), along with the possibility of galvanic corrosion, require attention before incorporating or substituting aluminum alloys for cast iron.

For this test, the following requirements were established:

1. Redesign of present assembly should consider, but not necessarily be limited to, the following:

   a. Aluminum case and cover shall be interchangeable as an assembly.

   b. Internal dimensions, component positioning and alignment shall not be altered.

   c. Use of inserts and dowels as alignment stiffeners should be considered.

2. Selection of suitable aluminum high strength alloy should consider, but not be limited to, the following:

   a. A sufficient number of castings should be poured to satisfy following minimum mechanical properties (coupons excised from actual casting):

ANY AREA		RANGE	TYPICAL
Tensile Strength	(KSI)	62-72	65
Yield Strength	(KSI)	52-65	55
Elongation	(%)	3.5-9.0	5

b. The established mechanical properties shall be not less than the following values after maintaining at designated temperature levels for stipulated holding times:

TEMPERATURE (^{O}F)	HOLDING TIME IN HOURS	U.T.S.	Y.S.	EL%
300	1000	61	56	7.5
350	"	51	47	8.5
400	"	41	36	12.5

c. Requirements of Military Specification MIL-A-21180 shall apply.

TEST PROCEDURES AND RESULTS

a. Materials:

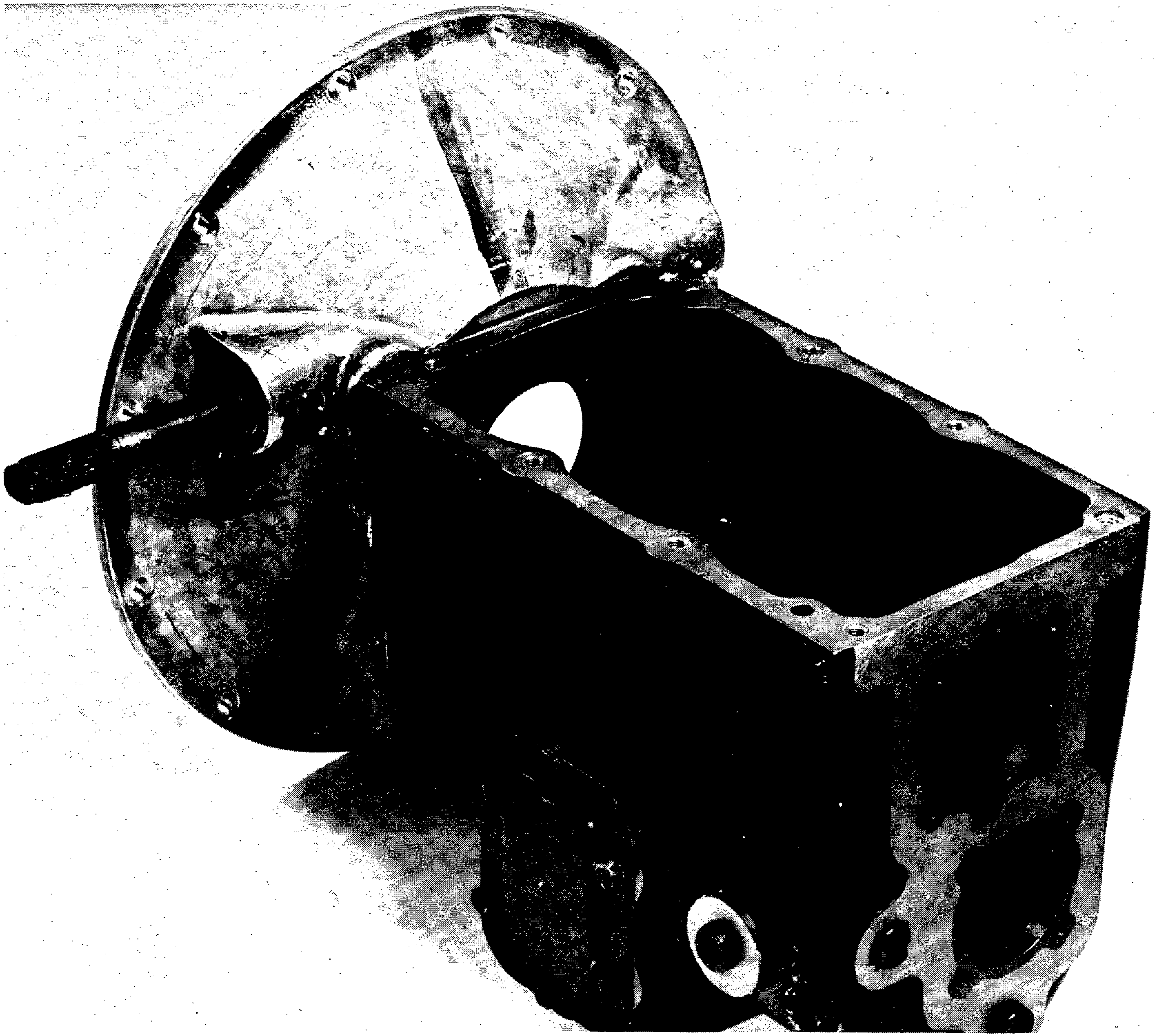
The transmission case for the M342, 2½-ton vehicle, P/N 7520988, and clutch cover, P/N 7520952, were selected as test components. These components were fabricated from 201 and 204 type aluminum alloys. Views of the cast assembly are shown in Figures 2 and 3. The casting and heat treating procedures followed are outlined in TACOM Report No. 11727. Typical chemical analysis was as follows:

	Transmission A 224 Al Alloy		Transmission B 201 Al Alloy	
	Specified	Reported	Specified	Reported
Silicon	0.06 max	0.02	0.05 max	0.01
Iron	0.10 max	0.05	0.10 max	0.01
Copper	4.5-5.5	5.00	4.00-5.00	4.65
Titanium	0.35 max	0.21	0.15-0.35	0.18
Manganese	0.20-0.60	0.26	0.20-0.30	0.19
Magnesium	--	--	0.18-0.35	0.29
Silver	--	--	0.40-1.00	0.62
Vanadium	0.05-0.15	0.08	--	--
Zirconium	0.10-0.25	0.12	--	--

The transmission case and clutch cover interchange is an assembly with the conventional 2½-ton transmission. Cast-in bearing inserts and use of helicoil stud inserts were incorporated in the design of these castings. The finalized assemblies which were sent to Yuma test site for vehicular tests conformed to radiographic standards according to ASTM Specification E155.

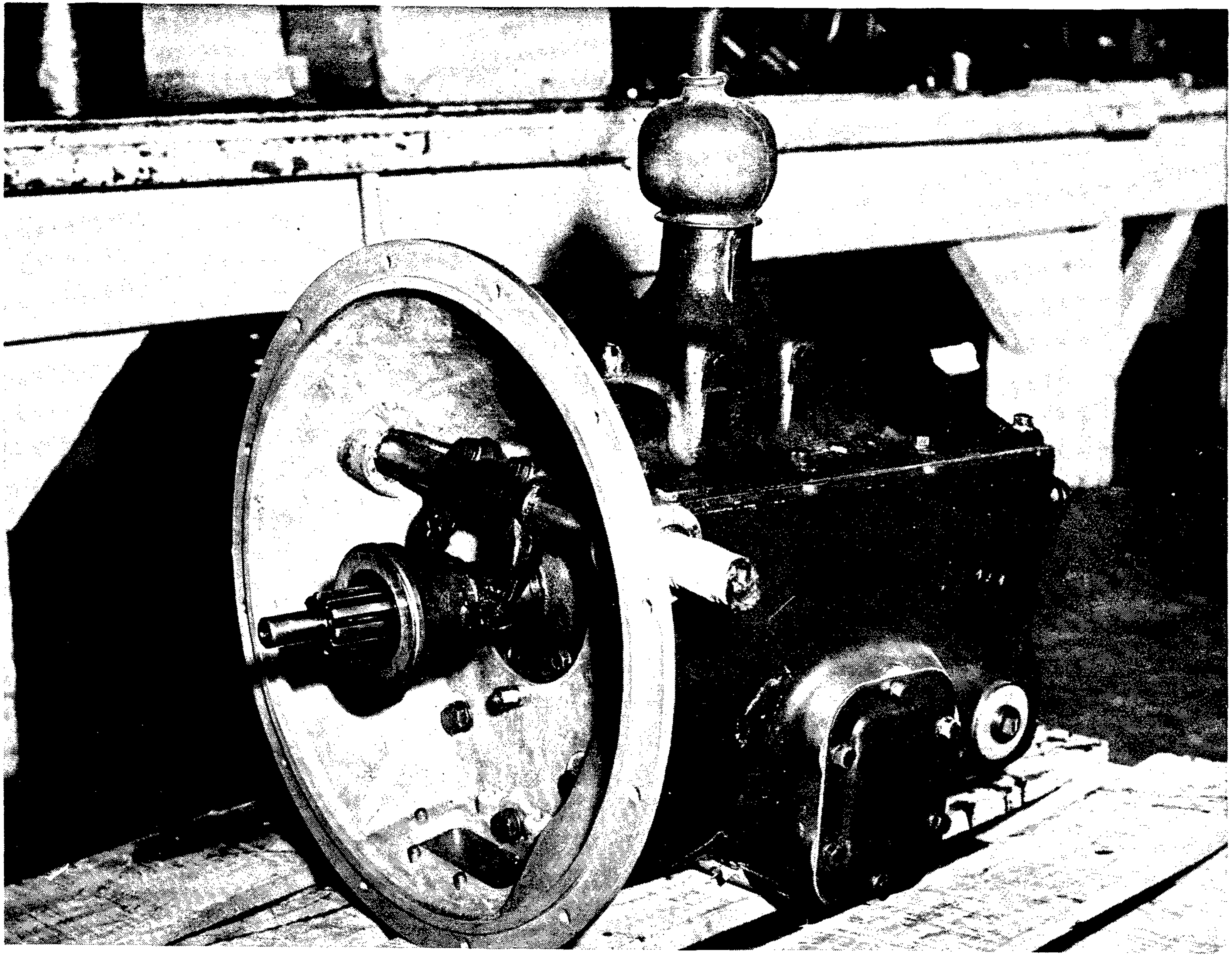
b. Initial Technical Inspection:

Annual maintenance checks and services were performed and inspection was made of the three M342A2 vehicles (characteristic view, Figure 1) prior to the start of testing.



CAST ALUMINUM 2½-TON TRANSMISSION CASE AND CLUTCH HOUSING

FIGURE 2



CAST ALUMINUM 2½-TON TRANSMISSION ASSEMBLY

FIGURE 3

The test transmission cases and clutch housings were installed and instrumented for cooling tests. Details of the initial inspection are contained in Appendix A.

c. Full-Load Cooling Test:

Full-load cooling tests were conducted before the start of endurance testing. Transmission case and clutch housing temperatures were monitored on the three vehicles during the test. The vehicles were payloaded to 2-1/2 tons and the load was supplied by field dynamoter equipment. Three runs in each of the three gear ranges were made in both directions until temperatures were stabilized. The results were averaged and are summarized in Appendix B.

Further full-load cooling tests were conducted under higher ambient temperature conditions. These were a comparison test of the standard transmission and transmission A, and an experiment to compare heat rejection characteristics of OE-50 vs GO-90 lubricants. The results are summarized in Appendix B.

d. Road-Load Cooling Test:

Road-load cooling tests were conducted on the paved dynamometer course with the vehicles payloaded to 2-1/2 tons. Continous operation was maintained until component temperatures were stabilized. Data are presented in Appendix C.

Road-load cooling data were also taken during endurance testing on the various courses. The nature of the courses precluded true field temperature stabilization, i.e., the operating conditions reflected real situations. The data are included in Appendix C.

e. Endurance Testing:

Endurance testing was conducted on a ten-mile continuous course consisting of the following surfaces and terrains.

Paved: 0.9 miles
Secondary: 2.6 miles
Hilly cross-country: 1.3 miles
Level cross-country: 5.2 miles

One dump cycle per circuit was performed to meet the requirement of 100 dump cycles per 1000 endurance miles. During endurance testing, the following mileages were accumulated and dumping cycles performed:

Transmission	Miles	Dump Cycles
224	5032	603
201	4232	523
Standard	4288	528

The requirement for 100 full-load winch cycles per 1000 endurance miles was waived due to problems encountered with shear pin breakage and in one case, a power takeoff (PTO) gear failure, which resulted in damage to the transmission PTO drive gear.

To establish maximum transmission heat buildup, full-load cyclic dump tests were performed on the three vehicles while stationary. This test proved inconclusive since the heat buildup during 100 continuous dump cycles was negligible. (The transmission sump temperatures increased 2°F during the 100 cycles.)

Incidents noted during the endurance phase of operations are as follows:

(1) Both aluminum test transmissions (transmission A—1210 test miles; transmission B—557 miles) developed leaks at the countershaft rear bearing cover. The severity of the leaks ranged from mere seepage when the transmissions were cold to about one drip every two seconds when warmed up. The leak was at the juncture of the aluminum transmission case and the ferrous insert which serves as the rear bearing support. The difference in heat expansion characteristics of the two metals was determined to be the cause of the leak. The leak was stopped by replacing the rear bearing cover-to-transmission-case gasket with a fabricated one of increased diameter (sufficient to cover the troublesome juncture).

(2) Transmission lubricant entered the clutch housing through the input shaft bearing cover of the standard transmission at 792 test miles. The threads on the inside of the cover are designed to prevent entry of oil into the clutch

housing; however, the threads terminated about 180 degrees from the drain hole back into the transmission case. The threads were modified with a file to deliver oil directly to the drain hole and no further problems were encountered during the test.

(3) Three teeth broke on the input shaft gear of the transmission A power takeoff unit. The transmission drive gear also was damaged, and replacement of both the power takeoff unit and transmission drive gear was necessary. The incident occurred at 1947 test miles during a test to determine transmission temperature buildup during winching operations.

The winch is rated at 10,000 pounds capacity, but shear pins were breaking at 5,000 to 6,000 pounds. The PTO failure occurred with about 4,800 pounds cable tension.

(4) The snap ring, which retains the fourth speed gear sleeve, broke on transmission A at 4249 test miles. This allowed the third speed gear to slide forward on the main shaft and disengage. The snap ring was replaced, and no further problems were encountered during the test.

f. Final Inspection

At the conclusion of 5032 endurance test miles, transmission A was subjected to a visual inspection. No cracks, discoloration or other evidence of overheating was detected. Transmission oil samples were taken from all three transmissions. The analyses of these samples are contained in Appendix D.

Upon removal from the vehicle, the clutch housing on the standard transmission was found to be cracked at one of the mounting holes. The crack extended to the midpoint of the length of the clutch housing.

Since there was no evidence of abnormal wear of either aluminum transmissions, no microstructural analysis was performed.

DISCUSSION

Preliminary full-load and road-load cooling data (Appendix B) received from the US Army Yuma Proving Grounds revealed that transmission 224 showed a maximum spread in gear box temperature when compared with the 201 transmission; therefore, the additional full-load cooling comparison test of transmission 224 and the standard transmission was conducted under higher ambient temperature conditions than previous tests. MIL-L-2104 (SAE 50) was used as transmission lubricant because of its greater stability at the projected actual run temperatures (300°F). An additional 800 miles of endurance testing was conducted on the selected 224 transmission.

Application of full-load cooling data to a 3 x 3 x 3 unreplicated factorial design and analysis of variance (ANOVA), discussed in Appendix D, reveals that the type of transmission itself significantly affects transmission temperature, with 99.34 per cent confidence. Both transmissions 224 and 201 differ from the standard type with 98.78 per cent confidence. The 224 transmission shows an average of 5.1° lower temperature compared with that of the 201. This mean difference, favoring 224 over 201 in temperature-lowering capability, is established with 97.03 per cent confidence. Mean temperatures were based on nine thermocouple locations and gear range combinations per type of transmission; standard transmission mean = 301.4°F; transmission 201 = 298.8°F; transmission 224 = 293.7°F.

CONCLUSIONS

a. The transmission operating temperatures are affected by the type of material the transmissions are fabricated from.

b. Sand cast 201 and 224 type aluminum transmissions had better heat rejection capabilities when compared to the standard cast iron transmission.

c. Transmission components fabricated from 224 type aluminum alloy had better temperature-lowering capabilities when compared to the 201 type aluminum transmission.

d. MIL-L-2104, OE 50 lubricant had greater stability at high operating temperatures (300°F) when compared to MIL-L-2105, GO-90 lubricant.

e. Durability of both aluminum transmissions was better than the standard cast iron transmission.

APPENDIX A

INITIAL TECHNICAL INSPECTION DATA

Group	USA Reg No. 04M46771	USA Reg No. 04M31171	USA Reg No. 04M27971
01, Engine	Drained engine oil and replaced engine oil filters. Refilled engine with OE-30 as per Lubrication Order.		
03, Fuel System	Cleaned air filter. Fuel system satisfactory.		
04, Exhaust System		Satisfactory	
05, Cooling System		Satisfactory	
06, Electrical System	Replaced headlight sealed beam on right side due to broken lens. Instruments and panel lights satisfactory.	Satisfactory	Satisfactory
07, Transmission	Removed transmission and clutch housing of standard ferrous base cast alloy and installed transmission and clutch housing of high strength aluminum cast alloy (transmission A, 04M46771; transmission B, 04M31171). The test transmission case and clutch housing was instrumented for full-load and road-load cooling tests and filled to proper level with GO-90 lubricant.		Retained standard ferrous base cast alloy transmission in vehicle. Instrumented case and clutch housing for full-load and road-load cooling tests. Drained and refilled transmission to proper level with GO-90 lubricant.
08, Transfer	Drained and refilled transfer case with GO-90 lubricant.		
10, Differential	Drained and refilled differentials with GO-90 lubricant.		

*Transmission A = 224
Transmission B = 201

INITIAL TECHNICAL INSPECTION DATA (Concluded)

<table>
<tr><th>Group</th><th>USA Reg No. 04M46771</th><th>USA Reg No. 04M31171</th><th>USA Reg No. 04M27971</th></tr>
<tr><td>12, Brakes</td><td colspan="3">Satisfactory</td></tr>
<tr><td>13, Wheels, Hubs and Drums</td><td colspan="3">Packed and adjusted wheel bearings.</td></tr>
<tr><td>14, Controls</td><td colspan="3">Satisfactory</td></tr>
<tr><td>15, Frame and Frame-Mounted Parts</td><td colspan="2">Satisfactory</td><td>Rear cross member on frame was bent.</td></tr>
<tr><td>16, Springs and Shock Absorbers</td><td colspan="3">Satisfactory</td></tr>
<tr><td>17, Fenders, Hoods, Shield, and Aprons</td><td colspan="3">Satisfactory</td></tr>
<tr><td>18, Hull</td><td colspan="3">Not applicable</td></tr>
<tr><td>22, Miscellaneous Body, Cab, Hull, Accessories</td><td colspan="3">Lubricated vehicle as per Lubrication Order</td></tr>
</table>

APPENDIX B

FULL-LOAD COOLING SUMMARY

(Temperatures Extrapolated to 125°F)

Date (October-November 1972)	3 Nov	26 Oct	24 Oct	7 Nov	7 Nov	6 Nov	9 Nov	8 Nov	26 Oct
Transmission *	A	A	A	B	B	B	Std	Std	Std
Gear Range	1-L	1-H	2-H	1-L	1-H	2-H	1-L	1-H	2-H
Road Speed (mph)	2.8	5.9	11.2	2.9	5.9	11.1	2.9	5.9	11.2
Engine Speed (rpm)	1800	1800	1800	1800	1800	1800	1800	1800	1800
Drawbar Pull (lb)	9750	4900	2480	9050	4650	2350	9550	4850	2440
Drawbar Horsepower	73	77	74	70	73	70	74	76	73
Ambient Temperature (°F)	92	73	89	85	82	82	85	75	73
Extrapolation Factor	+33	+52	+36	+40	+43	+43	+40	+50	+52
Temperatures (°F)									
1. Transmission Oil Sump	323	315	292	326	303	291	331	320	300
2. Transmission Case (Tapped Hole), T_2	308	302	281	305	282	272	304	292	278
3. Transmission Case (Skin)** T_3	303	294	271	309	284	271	315	297	276
4. Clutch Cover (Skin)	263	260	242	270	250	243	258	250	240
5. Engine Oil Sump, T_1	245	258	246	252	253	250	248	256	255
6. Coolant to Radiator	223	238	225	228	230	227	227	236	237
(T_1-T_2)	15	13	11	21	21	19	27	28	22
(T_1-T_3)	20	21	21	17	19	20	16	23	24

*Transmission A = 224
B = 201

**Near Drain Plug

FULL-LOAD COOLING SUMMARY (Concluded)

Transmission A vs Standard Transmission

GO-90 vs OE-50

Date	3 Nov 72	19 Jul 73	26 Oct 72	19 Jul 73	24 Oct 72	19 Jul 73	9 Nov 72	18 Jul 73	8 Nov 72	18 Jul 73	26 Oct 72	19 Jul 73
Transmission	A	A	A	A	A	A	Std	Std	Std	Std	Std	Std
Lubrication Type	GO-90	SAE 50	GO-90	SAE 50	GO-90	SAE 50	GO-90	SAE 50	GO-90	SAE 50	GO-90	SAE 50
Gear Range	1-L	1-L	1-H	1-H	2-H	2-H	1-L	1-L	1-H	1-H	2-H	2-H
Road Speed (mph)	2.8	2.9	5.9	5.7	11.2	11.1	2.9	3.0	5.9	6.1	11.2	11.1
Engine Speed (rpm)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Drawbar Pull (lb)	9750	9100	4900	4375	2480	2215	9550	9175	4850	4075	2440	2250
Drawbar Horsepower	73	73	77	71	74	66	74	73	76	66	73	67
Ambient Temperature (°F)	92	108	73	108	89	107	85	104	75	104	73	107
Extrapolation Factor	33	17	52	17	36	18	40	21	50	21	52	18
Temperatures (°F)												
1. Transmission Oil Sump	323	320	315	307	292	279	331	322	320	313	300	291
2. Transmission Case (Tapped Hole)	308	308	302	295	281	270	304	296	292	289	278	271
3. Transmission Case (Skin)*	303	290	294	270	271	241	315	290	297	252	276	235
4. Clutch Cover (Skin)	263	270	260	254	242	238	258	259	250	251	240	238

*Near drain plug

APPENDIX C

ROAD-LOAD COOLING SUMMARY

Transmission Oil Sump Temp (°F)			Transmission Case Temp (Tapped Hole) (°F)			Transmission Case Temp (Skin) (°F)			Clutch Cover Temp (Skin) (°F)			Engine Oil Sump Temp (°F)			Coolant to Radiator Temp (°F)		
A	B	Std	A	B	Std	A	B	Std	A	B	Std	A	B	Std	A	B	Std

Time of Run: 30 May 1973 - All vehicles began run at 1250 hours. Paved Dynamometer course. Temperature readings recorded at 5-minute intervals.

Ambient Temperature: 102°F Extrapolation Factor: +23°F

196	205	213	196	195	208	186	-	199	186	188	189	-	232	219	211	214	211
207	211	215	178	203	209	203	-	184	186	190	191	-	234	229	209	213	209
210	217	221	187	207	214	205	-	189	189	194	193	-	235	231	212	211	210
215	222	224	183	213	216	209	-	191	189	195	194	-	235	230	210	212	213
221	226	227	186	215	219	213	-	196	193	197	196	-	236	231	211	212	214
223	229	230	194	219	221	216	-	194	195	200	194	-	237	231	212	213	212
225	232	233	198	223	224	218	-	197	198	202	196	-	238	232	214	213	211
227	233	234	200	223	229	221	-	200	200	203	199	-	237	230	214	214	211
229	235	236	195	225	229	222	-	201	200	203	200	-	238	229	214	215	212
230	236	236	195	226	231	224	-	206	199	204	201	-	238	230	213	213	207
232	238	236	197	227	231	226	-	207	201	204	203	-	239	227	214	213	216
233	239	239	199	228	231	226	-	201	202	206	200	-	239	229	214	214	215
232	240	240	205	230	230	226	-	206	204	207	205	-	239	230	216	215	216
233	240	241	204	230	231	226	-	203	204	207	202	-	241	233	215	215	217
234	241	242	203	231	237	227	-	206	204	210	205	-	239	232	215	216	215
235	241	242	200	231	238	229	-	208	203	210	206	-	240	232	215	216	216

Time of Run: 30 November 1972 - All vehicles began run at 1400 hours. Field Test. Temperature readings recorded at 5-minute intervals.

Ambient Temperature: 74°F Extrapolation Factor: 51°F

195	204	196	196	205	196	-	-	185	189	196	-	221	235	232	229	228	223
198	206	199	199	207	202	-	-	184	191	199	-	240	242	241	230	231	228
201	210	203	203	210	206	-	-	188	197	201	-	240	245	242	232	231	227
202	211	205	204	210	208	-	-	189	195	200	-	240	243	238	228	233	226
201	208	208	202	208	212	-	-	194	195	201	-	241	244	242	230	230	228
205	213	214	206	212	216	-	-	204	202	205	-	246	246	240	230	229	231
210	214	214	210	213	218	-	-	207	202	206	-	238	239	240	228	230	226
209	213	215	209	213	218	-	-	201	199	202	-	224	231	234	228	232	231

NOTES: All temperatures extrapolated to 125°F.
Temperature data of 30 November 1972 were recorded during one circuit of a 10-mile endurance course.

APPENDIX D

ANALYSIS OF VARIANCE (ANOVA) TO STUDY THE EFFECTS OF TYPE OF TRANSMISSION AND GEAR RANGE ON COMPONENT TEMPERATURE EXTRAPOLATED TO 125°F

1. OBJECTIVE

The objective of this analysis is to determine if a significant difference exists in the temperatures observed in two experimental transmissions and one standard transmission under full-load conditions.

2. PROCEDURE AND COMPUTATIONS

The field data have been set up in the format for a 3 x 3 x 3 factorial design and analysis of an unreplicated experiment is presented below in Table 1.

TABLE 1. FULL-LOAD COOLING SUMMARY

Thermocouple Location, i	Gear Range j	Type of Transmission Alum A,K = 1	Alum B,K = 2	Std K = 3
Transmission	1 - Low, j = 1	X_{111} = 123	X_{112} = 126	X_{113} = 131
Oil Sump	2 - High, j = 2	X_{121} = 115	X_{122} = 103	X_{123} = 120
i = 1	3 - High, j = 3	X_{131} = 92	X_{132} = 91	X_{133} = 100
Transmission	1 - Low, j = 1	X_{211} = 108	X_{212} = 105	X_{213} = 104
Case (Tapped	2 - High, j = 2	X_{221} = 102	X_{222} = 82	X_{223} = 92
Hole) i = 2	3 - High, j = 3	X_{231} = 81	X_{232} = 72	X_{233} = 78
Transmission	1 - Low, j = 1	X_{311} = 103	X_{312} = 109	X_{313} = 115
Case (Skin)	2 - High, j = 2	X_{321} = 94	X_{322} = 84	X_{323} = 97
i = 3	3 - High, j = 3	X_{331} = 71	X_{332} = 71	X_{333} = 76
TOTALS		889	843	913

Each temperature in Table 1 has been coded by deducting 200 from it to simplify computation and decrease rounding error. This type of additive coding will not affect final results, such as the F-statistics and mean squares. Only the means should be decoded by adding 200 to each mean. The main factors are the three dimensions having possible effects on observed temperatures, X_{ijk}. These are elements of the three dimensional array of Table 1. Thermocouple locations are the i-dimension, gear ranges are the j-dimension and transmission types are the k-dimension. There are three thermocouple locations (i = 1,R; R = 3), three gear ranges (j = 1,T; T = 3), three transmission types (k = 1,U; U = 3). There is a total N of 27 elements or cells of the array ($N = R \times T \times U = 3^3 = 27$). These values are used in computation of the sums of squares for the sources of variation.

ANALYSIS OF VARIANCE (ANOVA) TO STUDY
THE EFFECTS OF TYPE OF TRANSMISSION
AND GEAR RANGE ON COMPONENT TEMPERATURE
EXTRAPOLATED TO 125°F (Continued)

3. RESULTS

The sum of squares due to variation among types of transmission is computed from the formula:

$$SS_{TRANS} = \frac{\sum_{k=1}^{U} \left(\sum_{i=1}^{R} \sum_{j=1}^{T} X_{ijk}\right)^2}{R \times T} - C$$

where:

$$C = \frac{1}{N} \left(\sum_{i=1}^{R} \sum_{j=1}^{T} \sum_{k=1}^{U} X_{ijk}\right)^2$$

substituting from Table A-1 into the above equations:

$$C = \frac{1}{27} (123 + 126 + 131 + 115 + 103 + 120 + 92 + 91 + 100 + 108 + 105$$
$$+ 104 + 102 + 82 + 92 + 81 + 72 + 78 + 103 + 109 + 115 + 94$$
$$+ 84 + 97 + 71 + 71 + 76)^2 = \frac{1}{27} (2645)^2$$

$$C = 259{,}112.037$$

$$SS_{TRANS} = \frac{889^2 + 843^2 + 913^2}{3 \times 3} - C$$

$$= 259{,}393.222 - 259{,}112.037$$

$$SS_{TRANS} = 281.185$$

Similarly, the sum of squares due to variation among thermocouple locations is computed from the formula:

$$SS_{TC} = \frac{\sum_{i=1}^{R} \left(\sum_{j=1}^{T} \sum_{k=1}^{U} X_{ijk}\right)^2}{T \times U} - C$$

$$= \frac{1{,}002{,}001 + 678{,}976 + 672{,}400}{3 \times 3} - 259{,}112.037$$

$$SS_{TC} = 2374.293$$

ANALYSIS OF VARIANCE (ANOVA) TO STUDY
THE EFFECTS OF TYPE OF TRANSMISSION
AND GEAR RANGE ON COMPONENT TEMPERATURE
EXTRAPOLATED TO 125°F (Continued)

The sum of squares due to variation among gear ranges is computed from the formula:

$$SS_{GEARS} = \frac{\sum_{j=1}^{T} \left(\sum_{i=1}^{R} \sum_{k=1}^{U} X_{ijk} \right)^2}{R \times U} - C$$

$$= \frac{1{,}048{,}576 + 790{,}321 + 535{,}824}{3 \times 3} - 259{,}112.037$$

$$SS_{GEARS} = 4745.853$$

In this unreplicated experiment it is not possible to estimate or test the interactions for **their significance because of confounding with** experimental error. The interaction sums of squares are computed here to assure the residual is zero merely as a check of the computations. The type of transmission X thermocouple location interaction sum of squares is computed from the formula:

$$SS_{TRANS \times TC} = \frac{\sum_{i=1}^{R} \sum_{k=1}^{U} \left(\sum_{j=1}^{T} X_{ijk} \right)^2}{T} - C - SS_{TRANS} - SS_{TC}$$

$$= \frac{1}{3} [(123 + 115 + 92)^2 + (126 + 103 + 91)^2$$
$$+ (131 + 120 + 100)^2 + (108 + 102 + 81)^2$$
$$+ (105 + 82 + 72)^2 + (104 + 92 + 78)^2$$
$$+ (103 + 94 + 71)^2 + (109 + 84 + 71)^2$$
$$+ (115 + 97 + 76)^2] - 259{,}112.037 -$$
$$- 281.185 - 2374.293$$

$$SS_{TRANS \times TC} = 166.818$$

ANALYSIS OF VARIANCE (ANOVA) TO STUDY
THE EFFECTS OF TYPE OF TRANSMISSION
AND GEAR RANGE ON COMPONENT TEMPERATURE
EXTRAPOLATED TO 125°F (Continued)

The degrees of freedom DF is computed from:

$$DF = (R-1)(U-1)$$

$$= (3-1)(3-1)$$

$$DF = 4$$

The type of transmission X gear range interaction:

$$SS_{TRANS\ X\ GEARS} = \frac{\sum_{j=1}^{T} \sum_{k=1}^{U} (\sum_{i=1}^{R} X_{ijk})^2}{R} - C - SS_{TRANS} - SS_{GEAR}$$

$$SS_{TRANS\ X\ GEARS} = 203.258$$

The degrees of freedom:

$$DF = (T-1)(U-1)$$

$$= (3-1)(3-1)$$

$$DF = 4$$

The thermocouple location X gear range interaction:

$$SS_{TC\ X\ GEARS} = \frac{\sum_{i=1}^{R} \sum_{j=1}^{T} (\sum_{k=1}^{U} X_{ijk})^2}{U} - C - SS_{TC} - SS_{GEARS}$$

$$SS_{TC\ X\ GEARS} = 46.817$$

The degrees of freedom:

$$DF = (R-1)(T-1)$$

$$DF = 4$$

The interaction among all three factors:

ANALYSIS OF VARIANCE (ANOVA) TO STUDY
THE EFFECTS OF TYPE OF TRANSMISSION
AND GEAR RANGE ON COMPONENT TEMPERATURE
EXTRAPOLATED TO 125°F (Continued)

$$SS_{TC \times GEARS \times TRANS} = \sum_{i=1}^{R} \sum_{j=1}^{T} \sum_{k=1}^{U} (X_{ijk})^2 - C$$

$$- SS_{TRANS} - SS_{TC} - SS_{GEARS}$$

$$- SS_{TRANS \times TC} - SS_{TRANS \times GEARS} - SS_{TC \times GEARS}$$

$SS_{TC \times GEARS \times TRANS} = 14.739$

The degrees of freedom:

DF = (R-1)(T-1)(U-1)

= 2 x 2 x 2

DF = 8

The total sum of squares:

$$SS_{TOTAL} = \sum_{i=1}^{R} \sum_{j=1}^{T} \sum_{k=1}^{U} (X_{ijk})^2 - C$$

= 266,945 - 259,112.037

$SS_{TOTAL} = 7832.963$

The degrees of freedom:

DF = N-1

= 27-1

DF = 26

The residual or error sum of squares:

ANALYSIS OF VARIANCE (ANOVA) TO STUDY
THE EFFECTS OF TYPE OF TRANSMISSION
AND GEAR RANGE ON COMPONENT TEMPERATURE
EXTRAPOLATED TO 125°F (Continued)

$$SS_{RESIDUAL} = SS_{TOTAL} - \Sigma \text{ (all previous SS)}$$

$$= 7832.963 - (281.185 + 2374.293$$

$$+ 4745.853 + 166.818 + 203.258 + 46.817 + 14.739)$$

$$SS_{RESIDUAL} \approx 0$$

In factorial experiments without replication (number of observations per sample N=1) the sum of squares for residual is necessarily zero since such residual experimental error results only from replication (N>1) or repetition of the experiments under the same essential conditions.

The summary ANOVA is given below in Table 2. Then, with Tables 1 and 2 as the source, Table 3 partitions the sums of squares and degrees of freedom for the transmission main factor into contrasts of major interest. The contrasts are based on totals rather than means but the results are comparable either way.

TABLE 2. Summary Analysis of Variance (ANOVA) to Evaluate Effects on Full-Load Cooling Temperatures Ascribable to the Main Factors of Transmission Type, Thermocouple Location and Transmission Gear Range

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (DF)	Mean Square MS (SS/DF)	Mean-Square Ratio=F=MSR (MS/$MS_{RESIDUAL}$)
Among Main Factors:				
Transmissions	281.185	U-1 = 2	140.5925	6.51**
Thermocouple Locations	2374.293	R-1 = 2	1187.1465	55.01**
Gear Ranges	4745.853	T-1 = 2	2372.9265	109.95**
Interactions:				
Transmission X Thermocouple Location	166.818	(U-1)(R-1) = 4	All four interactions combined as residual or error of experiment 21.5816	
Transmission X Gear Range	203.258	(U-1)(T-1) = 4		
Thermocouple Location X Gear Range	46.817	(R-1)(T-1) = 4		
All Three Factors	14.739	(U-1)(R-1)(T-1) = 8		
Residual or Error Term	431.632	(4+4+4+8) = 20		

NOTE: F = 6.51** exceeds the tabulated F = 5.85 for 2 and 20 DF, the $\alpha = 0.01$ upper probability point of the F-distribution; but F = 6.51 falls short of the tabulated F = 6.99 for $\alpha = 0.005$ point. The difference among the three transmission means is significant at $\alpha = 0.01$; or this statement may be rephrased as meaning 0.99 (=99 percent) confidence, at least, that the difference among transmissions is real. The other two F-ratios far exceed the 9.95 required for $\alpha = 0.001$ probability.

ANALYSIS OF VARIANCE (ANOVA) TO STUDY
THE EFFECTS OF TYPE OF TRANSMISSION
AND GEAR RANGE ON COMPONENT TEMPERATURE
EXTRAPOLATED TO 125°F (Continued)

SOURCE:

In this particular experiment, the systematic (as opposed to random assignment of treatment combination) appears to have deflated the second-order interaction often used to estimate residual error from replication had such replication been provided. Uncontrolled background variation among treatments tends to inflate mean squares for both main effects and interactions, but not the residual mean square. In this experiment, therefore, the preferred estimate of uncontrolled variability in the mean square composed of all four interactions, together with their degrees of freedom, as it appears in the residual or error term above in Table 2 and again in Table 3 below.

TABLE 3. Summary ANOVA to Evaluate Effects on Full-Load Cooling Temperatures of Main Factors and to Contrast A and B Transmissions with Standard, and A versus B

Source of Variation	Sum of Squares (SS)	DF	Mean Square MS (MS/DF)	Mean-Square Ratio=F=MSR ($MS/MS_{RESIDUAL}$)
Among Main Factors:				
Transmissions:				
((A + B)/2) vs Std	163.629629	1	163.629629	7.58**
A vs B	117.555371	1	117.555371	5.45*
Subtotal Transmissions	281.185000	2	140.5925	6.51**
Thermocouple Locations	2374.293	2	1187.1465	55.01***
Gear Ranges	4745.853	2	2372.9265	109.95***
Residual or Error Term				
(Pooled Interactions)	431.632	20	21.5816	
Total	7832.963	26		

NOTE: F = 7.58** exceeds the tabular F = 5.87 for 1 and 20 DF, $\alpha = 0.025$ upper probability point of the F-Distribution; this F falls short of the tabular F = 8.10 for $\alpha = 0.01$ point, however. Therefore

ANALYSIS OF VARIANCE (ANOVA) TO STUDY
THE EFFECTS OF TYPE OF TRANSMISSION
AND GEAR RANGE ON COMPONENT TEMPERATURE
EXTRAPOLATED TO 125°F (Concluded)

TABLE 3. Summary ANOVA to Evaluate Effects on Full-Load Cooling Temperatures of Main Factors and to Contrast A and B Transmissions with Standard, and A versus B (Concluded)

both A and B transmissions differ from the standard transmission. The A vs B experimental transmission contrast is significant at $\alpha = 0.05$ probability or less; tabular $\alpha = 0.05$ requires $F = 4.35$. Note that $F = 5.45$ attained falls short of $F = 5.87$ to be exceeded for the $\alpha = 0.025$, DF of 1 and 20.

SOURCE: Tables 1 and 2 and calculations to partition sums of squares and degrees of freedom for transmission main effects into SS and DF due to comparison, mean of A and B versus standard; and A versus B. No presentation of interactions is given, as these are already displayed in Table 2 together with the rationale for pooling.

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DOCUMENT CONTROL DATA - R & D		
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1. ORIGINATING ACTIVITY (Corporate author) Metals Sub-Function (AMSTA-RKMC, Materials Function, Armor, Materials and Components, Div US Army Tank-Automotive Command, Warren, MI	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
	2b. GROUP	
3. REPORT TITLE Endurance Test of High Strength Cast Aluminum Transmission Case and Clutch Housing		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (First name, middle initial, last name) GAJINDER B. SINGH		
6. REPORT DATE June 1974	7a. TOTAL NO. OF PAGES 35	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 11895	
b. PROJECT NO.		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. DISTRIBUTION STATEMENT Approved for public release; Distribution Unlimited		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY	

13. ABSTRACT

Casting technology procedures which had been developed for composition 201 and 224 aluminum alloys under Phase 1 of this project were utilized to sand cast transmission cases and clutch covers of a 2½-ton vehicle. Endurance testing of these components, together with standard cast iron components, revealed that cast aluminum components had a better heat-rejecting capability as compared to cast iron components. Furthermore, composition 224 aluminum alloy transmission assembly had better temperature-lowering characteristics (5.1°F) than that of composition 201 transmission assembly. The mean operating temperature for a standard transmission was 301.4°F; for the 201 transmission, it was 298.8°F and for the 224 transmission, it was 293.7°F. It was also determined that at these operating temperatures stability of OE-50 lubricant was better than GO-90 lubricant. Durability of both aluminum transmissions were better than for standard cast iron transmissions.

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Aluminum Alloys						
Sand Castings						
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Durability						
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