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TECHNICAL REPORT

NO. 12441

A VARIABLE FILL FLUID COUPLING FAN DRIVE WITH ELECTRONIC SPEED CONTROL FOR M113A1E1 TEST RIG VEHICLE

1 MARCH 1979

by FMC Corporation
Ordnance Engineering Division
San Jose, California 95108

FMC Technical Report No. 3441

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U.S. ARMY TANK-AUTOMOTIVE
RESEARCH AND DEVELOPMENT COMMAND
Warren, Michigan 48090

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- Modulated Vehicle Cooling Systems
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- Vehicle Cooling Systems
- Internal Combustion Engines/Cooling
- Engine Cooling Control

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The work completed under thi contract included the design, fabrication, and installation of a Variable Fill Fluid Coupling (VFFC) Fan Drive with Electronic Speed Control into the M113A1E Test Rig Vehicle, as well as dynamometer hot room testing of the VFFC in the vehicle. Besides providing the control for modulating fan speed according to coolant temperature, the Electronic Controller (EC) limits the fan speed (overspeed control) to a preset maximum value, regardless of engine speed, and reduces control flow to a preset minimum value during low engine speed operation, regardless of coolant temperature.

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A substantial improvement in cooling system heat rejection capability was achieved. Significant fan drive power savings were demonstrated for normal road load/ambient operating conditions. In summary, the VFFC Fan Drive offers the following advantages over the existing fixed ratio drive:

- Increased cooling capability
- Improved road load fuel economy at normal ambients
- Increased vehicle performance capability at normal ambients
- Reduced fan noise
- Increased belt life
- Improved cold starting/cold weather operation
- Increased engine life.

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SECTION 1
INTRODUCTION

This Final Technical Report is submitted by the Ordnance Engineering Division of FMC Corporation in fulfillment of TARADCOM Contract DAAK30-77-C-0067, Data Item A007. This report covers the Phase I and Phase II scope of work which included the design, fabrication, and installation of experimental hardware for a Variable Fill Fluid Coupling (VFFC) Fan Drive incorporating electronic speed control and coolant temperature modulation into the M113A1E1 Test Rig Vehicle as well as dynamometer hot room testing of the VFFC in the vehicle. The M113A1E1 which includes the X200-3 Transmission, 295 hp 6V53T Engine, and the Improved Cooling System (ICS) (formerly designated as Advanced Design Cooling System) was developed under TARADCOM Contract DAAE07-76-C-3269.

This work was performed under the technical direction of the Systems Integration Group of the Power Train Function, U.S. Army Tank-Automotive Research and Development Command. The technical representative was Mr. Cass Grzeskowiak.

Today's military vehicles are faced with increasingly more stringent cooling requirements (.6 - .75 TE/GVW at 125°F ambient), and have greater power to weight ratios for improved automotive performance. Due to these factors, vehicle cooling systems now require a greater percentage of the overall installed engine power at the maximum cooling point, and occupy more space in the power plant compartment. Operation of this larger cooling system under normal road load/ambient conditions for a directly coupled fixed ratio fan drive system results in considerable loss of power that could otherwise be utilized for vehicle propulsion. Therefore, it is desirable for these high performance cooling systems to be modulating, that is, to provide only the required amount of power to the cooling system to meet the vehicle road load/ambient operating conditions. The power saved would then be available to increase vehicle performance capability under normal ambients, and to improve fuel economy under normal road load/ambient conditions. In addition, a variable rate (modulating) cooling system provides improved cold starting capability by minimizing power drag on the engine, and improved cold weather operation by ensuring proper engine operating temperature, thereby reducing the problem of overcooling, incomplete combustion, and injector sticking.

For the VFFC Fan Drive System in the M113A1E1 vehicle, the cooling power (fan power) is modulated by controlling the fan speed according to engine coolant outlet temperature. That is, as the coolant temperature rises, the output speed of the VFFC which drives the fan is increased by increasing the control flow rate supplied to the VFFC from an Electrical Proportional Flow Control Valve (EPFCV). The EPFCV in turn is modulated by the Electronic Controller (EC) according to the engine coolant outlet temperature. This increased control flow to the VFFC raises the oil level in the unit and therefore increases the unit's torque (or speed) capacity. The converse is true for decreases in coolant temperature. Besides providing the control for modulating fan speed according to coolant temperature, the EC limits fan speed (overspeed control) to a preset maximum value regardless of engine speed, and reduces control flow to a preset minimum value during low engine speed operation regardless of coolant temperature.

SECTION 2
SUMMARY

The Variable Fill Fluid Coupling (VFFC) Fan Drive, Figure 1, with Electronic Controller (EC), Figure 7, is physically compatible with the M113A1E1 Test Rig Vehicle with the Improved Cooling System (ICS), as shown on Figure 2. The actual vehicle installations of the VFFC Fan Drive and EC are shown in Figures 3 and 9, respectively. The contract called for a test rig design that makes use of the same basic (8 inch) coupling unit and EC as developed by FMC during laboratory testing under TARADCOM Contract DAAE07-75-C-0079. A preliminary FMC study shows that a smaller diameter, more compact coupling unit, Figure 25, located at the input of the existing M113A1E1 fan assembly appears feasible for production. This design would simplify the belt drive as well as possibly eliminate the need for a sump pump on the coupling drain line. Also, a compact, low cost, "tamperproof" EC will be possible for production.

Hardware was fabricated for two different maximum fan speed systems (5100 and 5500 rpm); however, due to the X200-3 transmission failure, only the contractually specified 5100 rpm system could be vehicle hot room dynamometer tested.

Test data for high tractive effort/high ambient operation showed close correlation with the predicted results as shown on Figure 22. Note the substantial improvement in cooling system heat rejection capability for the VFFC Fan Drive at 4970 rpm compared to the existing fixed ratio fan drive system at 4425 and 4340 rpm. (YPG data from M113A1E1 Test Rig). This higher fan speed at the cooling point could be achieved because the overspeed control limited the fan speed to the selected 5100 rpm maximum fan speed regardless of engine speed as shown on Figure 18. Note further that with the existing fixed drive system, the maximum fan speed

(power) occurs at the engine governed speed, not at the cooling point.

The VFFC Fan Drive with EC provided excellent coolant temperature modulation performance as depicted on Figures 20 and 24. Because of this modulation capability, the VFFC provided a substantial reduction in vehicle cooling fan drive power, 58-72%, for the tested normal road load conditions at an 80°F ambient as illustrated on Figure 23. Further reduction in fan power at lower road loads and/or ambients can be expected.

In addition to coolant temperature modulation and fan overspeed control, the VFFC Fan Drive with EC automatically throttled the control flow to 1.0 gpm at engine speeds below 1020 rpm regardless of coolant temperature in order to maintain proper transmission operation at low engine speeds. Control flow would return to the higher value as demanded by the EC's coolant temperature modulation circuit whenever the engine speed exceeded 1050 rpm.

In summary, the Variable Fill Fluid Coupling Fan Drive with Electronic Controller offers the following advantages over the existing fixed ratio drive:

- Increased cooling capability
- Improved road load fuel economy at normal ambients
- Increased vehicle performance capability at normal ambients
- Reduced fan noise
- Increased belt life
- Improved cold starting/cold weather operation
- Increased engine life.

SECTION 3
SYSTEM DESCRIPTION

3.1 PRINCIPLES OF OPERATION

Coolant temperature is sensed by a thermistor located in the engine coolant outlet elbow. As the coolant temperature rises above 185°F, the Electronic Controller (EC) decreases the voltage signal to the Electrical Proportional Flow Control Valve (EPFCV). This in turn increases the control flow (charge rate) to the coupling. Thus, the fluid level in the VFFC and the fan speed increase until the output flow through the two fixed sized "bleed-off" orifices (fluid flow restrictors) in the coupling cover equals the charge rate. (Ref. Figure 4.) At that time the fill level and fan speed remain constant. The converse is true for a decrease in coolant temperature.

The EC also provides two other functions. First, it monitors fan speed through a magnetic pickup located at the VFFC output pulley. Whenever the fan speed exceeds a preset value, an electrical signal from the EC causes the EPFCV to decrease the charge rate to the VFFC until the fan speed equals the set point value (speed at cooling point). Secondly, the EC monitors engine speed through another magnetic pickup at the VFFC input pulley. If the engine speed is below 1000 rpm, the EC automatically sets the charge rate to 1.0 gpm by providing full voltage to the EPFCV. This is required since transmission main and/or lube pressure would drop below Detroit Diesel Allison's recommended minimum value for low engine speed operation. It should be noted that the system is "fail safe". That is, in case of loss of electrical power, the EPFCV provides full flow to coupling which results in maximum fan speed for a given engine speed.

3.2 VFFC FAN DRIVE INSTALLATION

The VFFC (Figure 1) with Electronic Controller was designed to be installed in the M113A1E1 Test Rig Vehicle with a minimal number of modifications to the existing power plant compartment and components. The VFFC is located in the aft starboard part of the power plant compartment between the engine and muffler as shown on Figures 2 and 3. The X200-3 transmission lube system is the pressurized fluid source for the coupling control flow (charge rate). Oil from the coupling drain line is returned to the transmission through the aid of a sump pump with this system. There is no need for a separate reservoir and VFFC cooling system since the heat generated by the coupling can be removed through the transmission cooling system. The EC, Figure 7, mounts on the port sponson beside the driver and operates off the vehicle 28vdc system as shown on Figure 9.

A more detailed explanation of the VFFC fan drive subsystems and the required minor modification to existing hardware is provided in the following section.

3.3 VFFC ASSEMBLY

The VFFC test unit assembly FOM 4811 is shown in cross section on Figure 4. Note that the magnetic pickups are mounted on the unit and that both pulleys have been specifically designed to provide a good sensing surfaces for the pickups. It should be noted that a covered access opening in the coupling housing (Cover, Item 41, Figure 4) is provided to permit easy installation and removal of the fluid flow restrictors in the coupling cover while VFFC is installed in the vehicle. Also, a manual lockup provision has been incorporated into the coupling design in order to provide a "get home" capability in case of loss of control flow (valve failure). This lockup feature is achieved by placing two shouldered bolts through the clearance holes

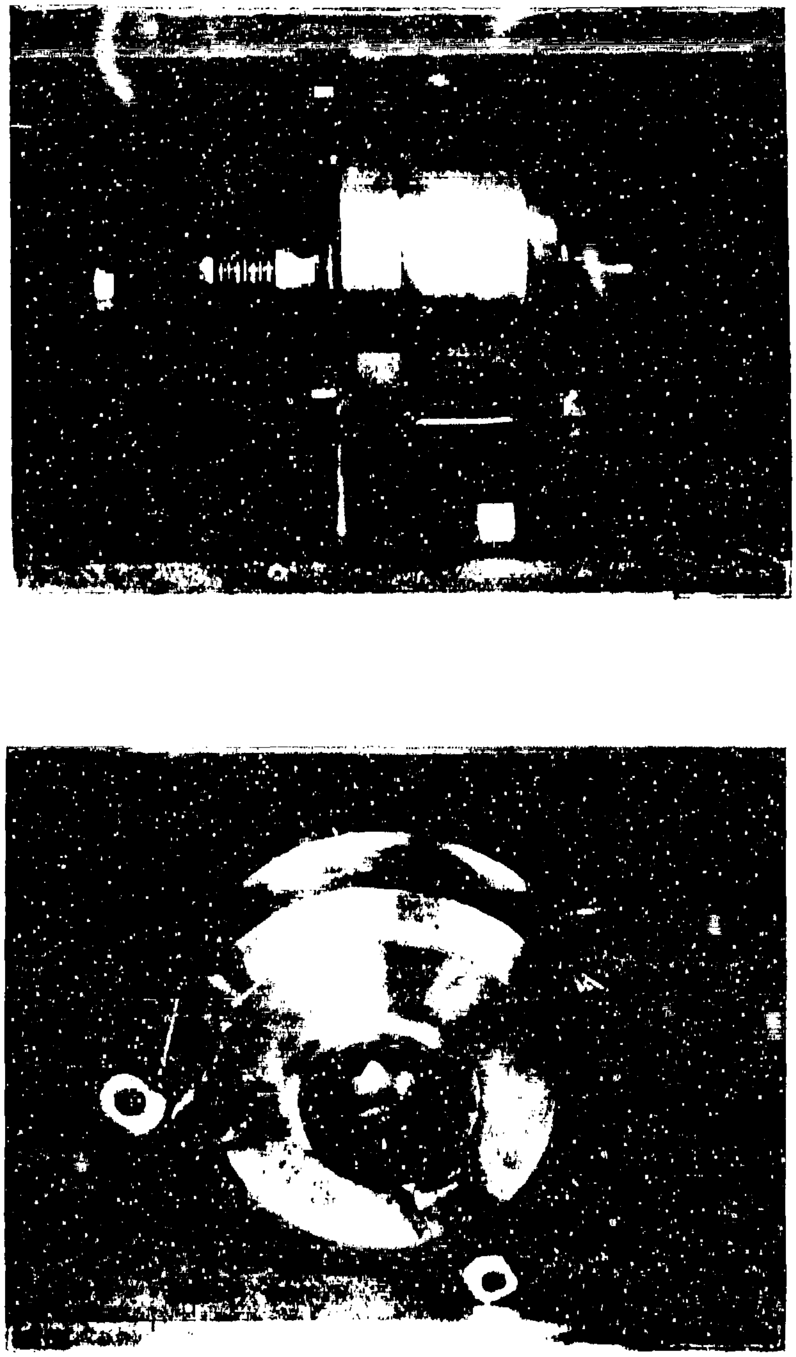


Figure 1. VFFC Test Unit Assembly

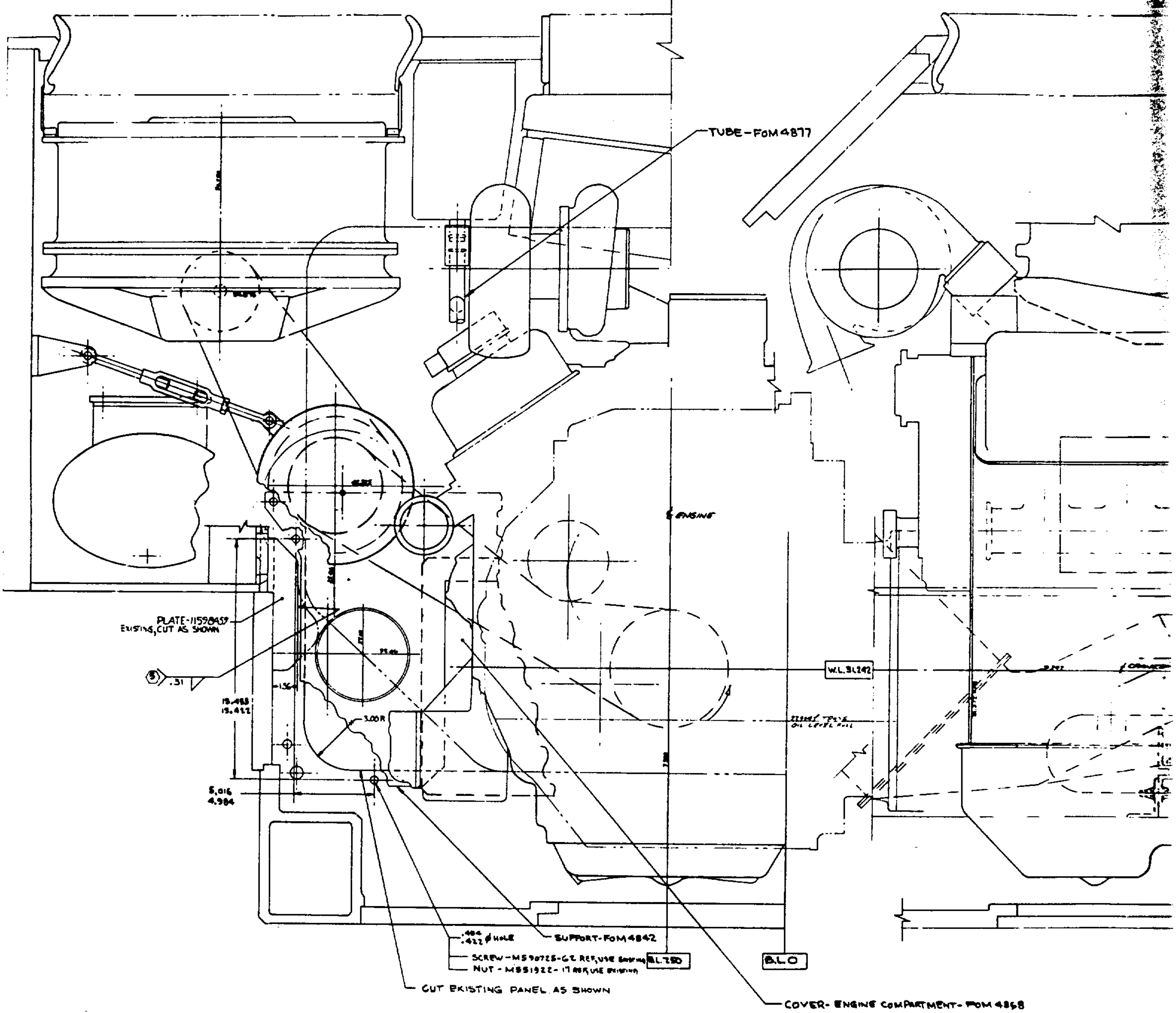
1. INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-STD-100

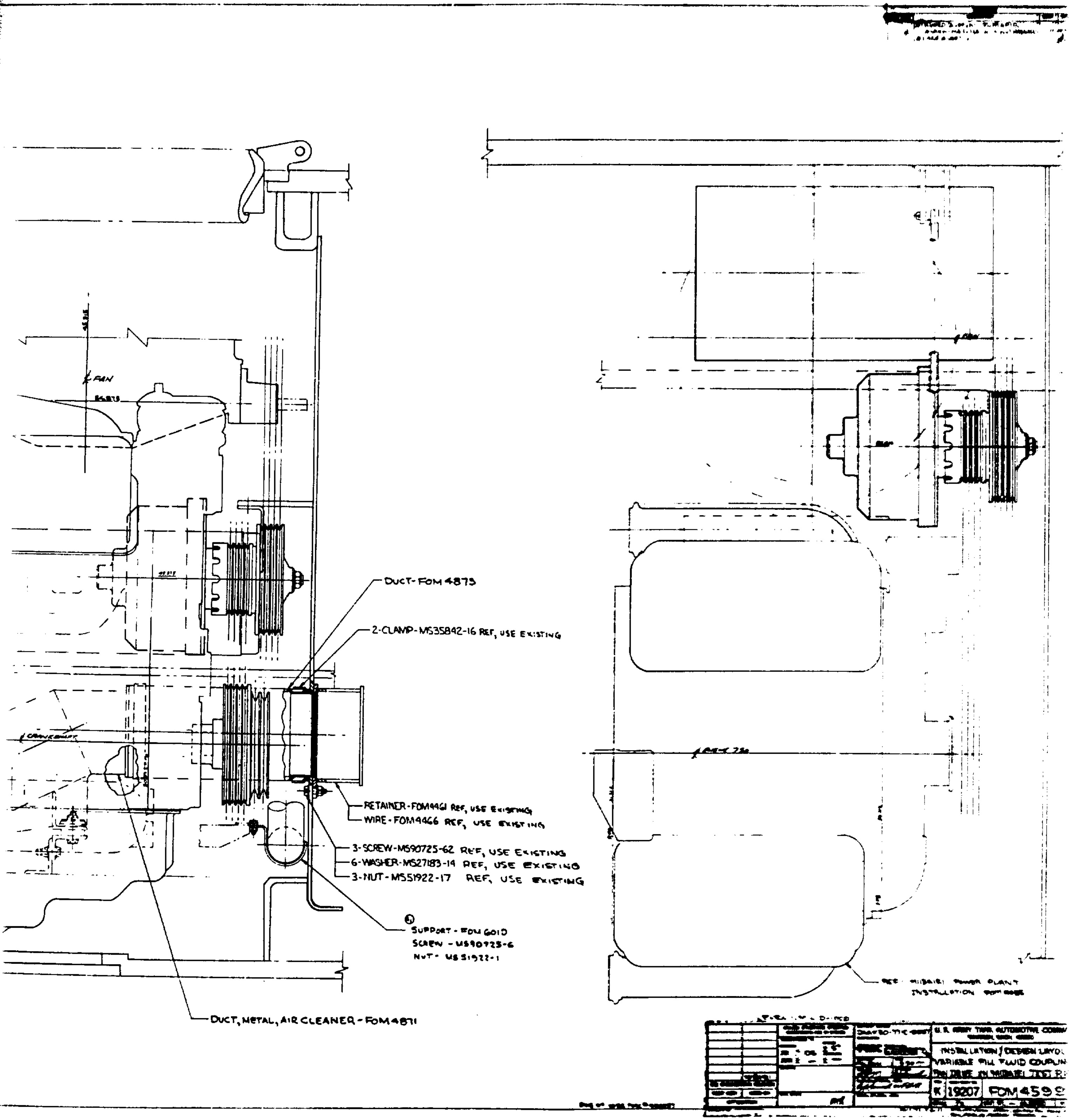
(2) WELD IN ACCORDANCE WITH TYPE A, SPEC MIL-W-45206. USE ELECTRODE TYPE 5856, SPEC MIL-E-16053.

3. ALL WELD SIZES ARE MIN.

4. ALL WELD SIZE SHALL BE PREFERABLY METAL TO METAL FIT, IN NO CASE SHALL THE GAP EXCEED .O3 INCH.

(5) WELD IN ACCORDANCE WITH CLASS A, SPEC MIL-W-45205. USE ELECTRODE TYPE 5856, SPEC MIL-E-16053.





DUCT-FOM 4875
2-CLAMP-MS35842-16 REF, USE EXISTING
RETAINER-FOM4461 REF, USE EXISTING
WIRE-FOM4466 REF, USE EXISTING
3-SCREW-MS90725-62 REF, USE EXISTING
6-WASHER-MS27183-14 REF, USE EXISTING
3-NUT-MS51922-17 REF, USE EXISTING
SUPPORT-FOM 6010
SCREW-MS90725-6
NUT-MS51922-1
DUCT, METAL, AIR CLEANER-FOM4871
℄ FAN
℄ CRANKSHAFT
U.S. ARMY TANK AUTOMOTIVE COMM
INSTALLATION / DESIGN LAYOU
VARIABLE FILL FLUID COUPLIN
19207
FOM459

Figure

-8-

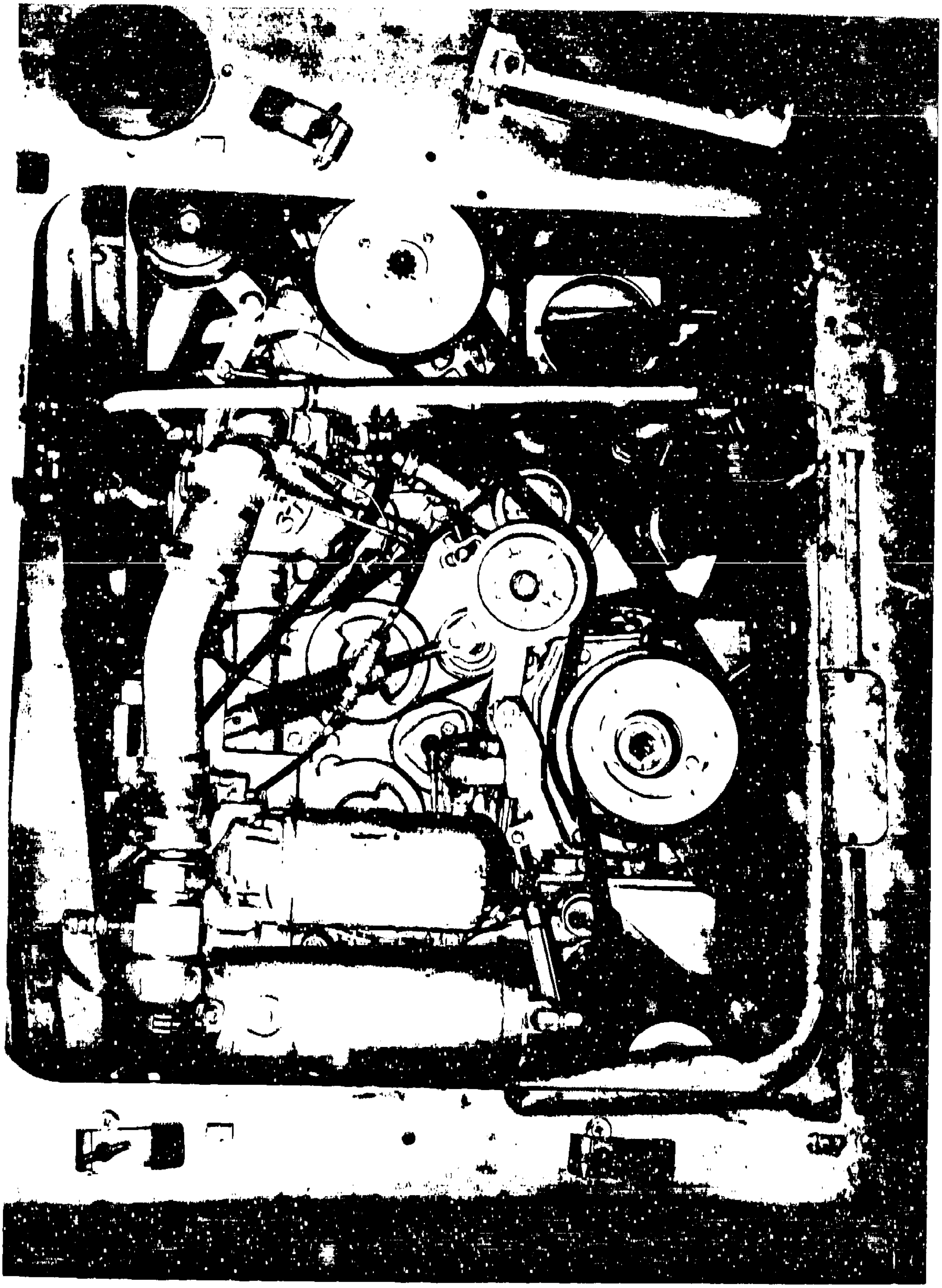


Figure 3. VFFC Fan Drive in M113A1E1 Test Rig

NOTES:

1. INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-STD-100

2. TORQUE TO 15-17 FT-LBS

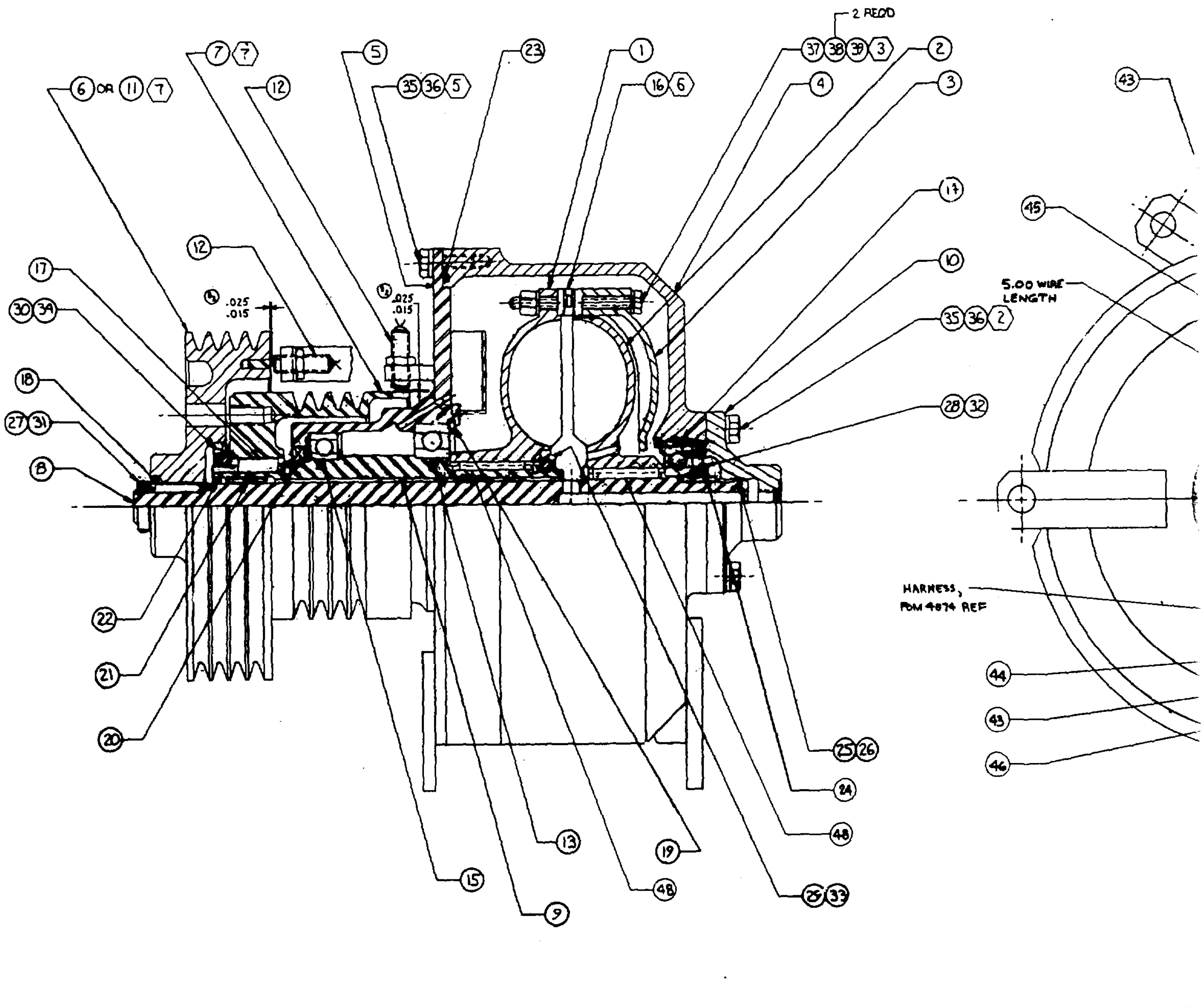
3. TORQUE TO 83-91 IN-LBS

4. TORQUE TO 7-9 IN-LBS

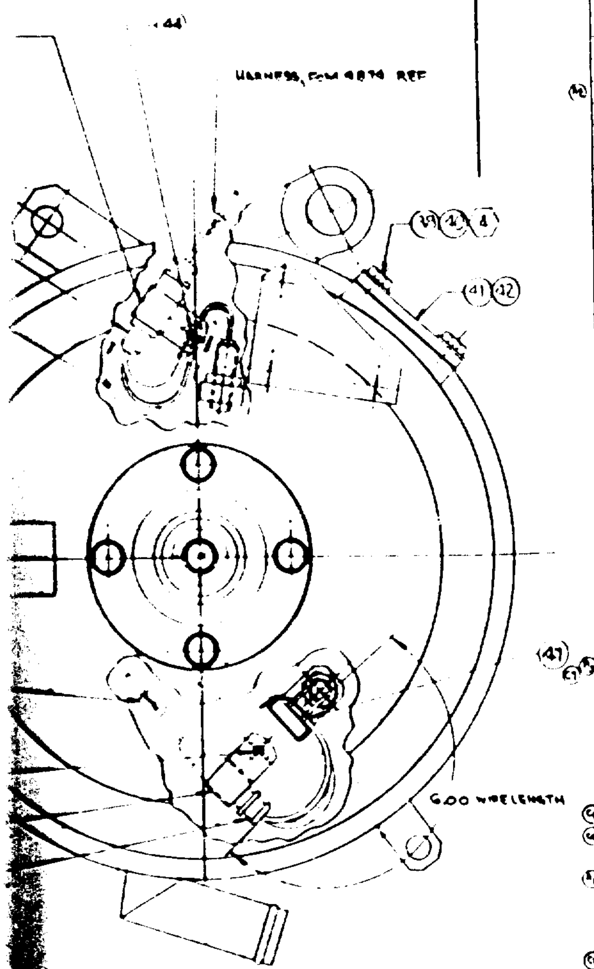
5. TORQUE TO 21-23 FT-LBS

6. INSTALL RESTRICTOR TO A DEPTH WHERE ONE HOUSING THREAD IS VISIBLE. STAKE THIS HOUSING THREAD IN ONE PLACE.

7. PARTS SHOWN AS MODIFIED ON FOM 4875, PROVIDES FOR MANUAL LOCKUP CABABILITY.



ZONE	LTR	DESCRIPTION	DATE	APPROVED
1B	A	(1) ITEMS 6,7 (1) PICTURE REVISED PER DETAILS	3-1-78	
1E		(2) ADDED ITEMS 43 THRU 47		
8G	B	(1) ADDED NOTES ①②③④	3-9-78	
7D		(2) ADDED DIM .025, .015 (2 PLS)		
2C		(3) ITEM 16 WAS 4198881		
2F	C	(1) ADDED ITEM 48	4-11-78	
2B		(2) ITEM 1 WAS FOM4850		
2B		(3) ITEM 2 WAS 4193904		
2B		(4) ITEM 8 WAS FOM 4635		
2B		(5) ITEM 9 WAS FOM 4641		
2C		(6) ITEM 16 WAS FOM FOM4917		
8G		(7) ADDED NOTE ⑦		



	ITEM	QTY	CODE	PART NO.	NOMENCLATURE	ZONE
(5)	48	2		MS20066-1/4x3/16x1.428	KEY	2B
	47	1		MS3367-3-9	STRAP	2C
	46	1	80064	AMPHENOL 18290040-2	CONNECTOR (MALE)	4E
	45	1	80064	AMPHENOL 18290039-2	CONNECTOR (FEMALE)	4E
	44	2		MS35206-299	SCREW	4E
(42)	43	2		MS 21919-DG10	CLAMP	4E
	42	1		FOM4777	GASKET	2D
	41	1		FOM4776	COVER	2D
	40	4		MS35764-1201	BOLT	2E
	39	12		MS21045-C4	NUT, SELF-LOCKING	5F
	38	28		MS20002-4	WASHER	5F
	37	12		MS90726-17	BOLT	5F
	36	13		MS20002-5	WASHER	7E
	35	13		MS35764-1249	BOLT	7E
	34	1		MS19069A09	WASHER-RETAINING	8D
	33	1		MS19069A08	WASHER-RETAINING	5A
	32	1		MS19069A06	WASHER-RETAINING	4D
	31	1		MS19069A04	WASHER-RETAINING	8D
	30	1		MS19067A09	NUT-LOCKING	8D
	29	1		MS19067A08	NUT-LOCKING	5A
	28	1		MS19067A06	NUT-LOCKING	4D
	27	1		MS19067A04	NUT-LOCKING	8D
	26	1		MS28775-17	PACKING, O-RING	5B
	25	1		C/R-714587	RING, SEALING	5B
	24	1		MS28775-141	PACKING, O-RING	5A
	23	1		MS28775-273	PACKING, O-RING	6F
	22	1		TROSTEL [illegible]	SEAL	8C
	21	1		TORRINGTON-J-[illegible]	BEARING, NEEDLE	8B
	20	1		TROSTEL [illegible]	SEAL	8B
	19	1		MS16625-1354	RING, RETAINING	6B
	18	1		MS20066-193	KEY	8D
	17	1		MS20066-279	KEY	8E
(6)	16	2		FOM 4917-4	RESTRICTOR-FLUID FLOW	6E
	15	1		NTN-6010	BEARING, BALL	6A
	14	1		NTN-6206	BEARING, BALL	5E
	13	1		NTN-6210	BEARING, BALL	6B
	12	2		[illegible]-1-0299	MAGNETIC PICKUP	7E
	11	1		FOM4774	PULLEY	8E
	10	1		FOM4644	ADAPTER	4D
(5)	9	1		FOM 4943-4	SHAFT, INPUT	6A
(4)	8	1		FOM 4943-3	SHAFT, OUTPUT	8C
	7	1		FOM4768	PULLEY	8F
(1)	6	1		FOM4765	PULLEY	8E
	5	1		FOM4790	HOUSING, BEARING	7F
	4	1		FOM4771	HOUSING, COUPLING	5E
	3	1		4193905	COVER, INPUT	5E
(3)	2	1		FOM 4943-2	COUPLING, OUTPUT	5F
(2)	1	1		FOM 4943-1	COUPLING, INPUT	6F

LEVEL 1, MR D-1000

DAAK30-77-C-0067

FMC

U. S. ARMY TANK AUTOMOTIVE COMMAND
WARREN, MICH. 48090

COUPLING, FAN DRIVE

FOM4595 | M60A1

E 19207 FOM4811

SCALE 1/1

Figure 4

in the coupling output pulley into the threaded holes in the input pulley. This effectively pins (locks) the input and output shaft together as shown on Figure 6.

Figure 5 shows the VFFC unit disassembled. Note that two output pulleys have been fabricated to facilitate testing of both the 5100 rpm as well as 5500 rpm fan speed systems, however only the 5100 rpm system was tested due to early termination of testing caused by the transmission problems/failure. It should be noted that contractually only the 5100 rpm system required testing.

3.4 BELT DRIVE

Figure 6 shows the dual powerband belt drive system. The belt cross section (Gates 3V-4 strands) is the same as on the present M113A1E1. Note that the existing spring-loaded idler mechanism, except for new bellcrank, is used; however, new crankshaft and generator pulleys are required. A fixed idler (not shown), supported off the coupling unit, is needed to provide proper belt tensioning of the secondary drive. Figure 3 shows the belt drive installed in the vehicle.

Belt alignment between the engine and VFFC assembly is accomplished by loosening the attaching bolts on the slotted support bracket and sliding the coupling fore or aft as required. The other belt is aligned by moving the fan pulley, the same method as used on present system.

3.5 ELECTRICAL SYSTEM

3.5.1 Electronic Controller (EC)

As shown on Figure 7, the Electronic Controller (EC) FOM 4823, is an experimental test unit (ETU) with six potentiometers (pots) to

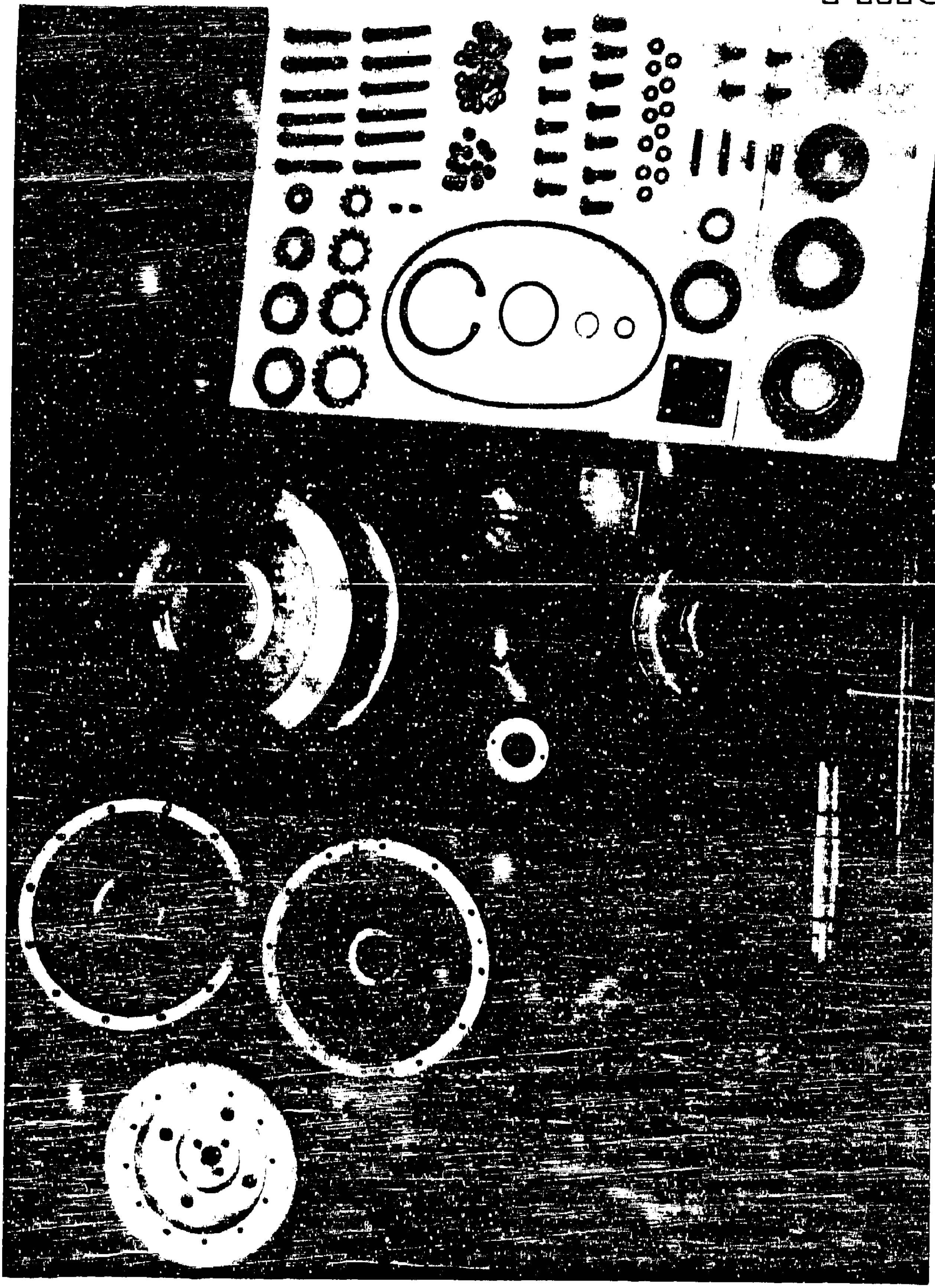


Figure 5. Disassembled VFFC Test Unit

NOTES:

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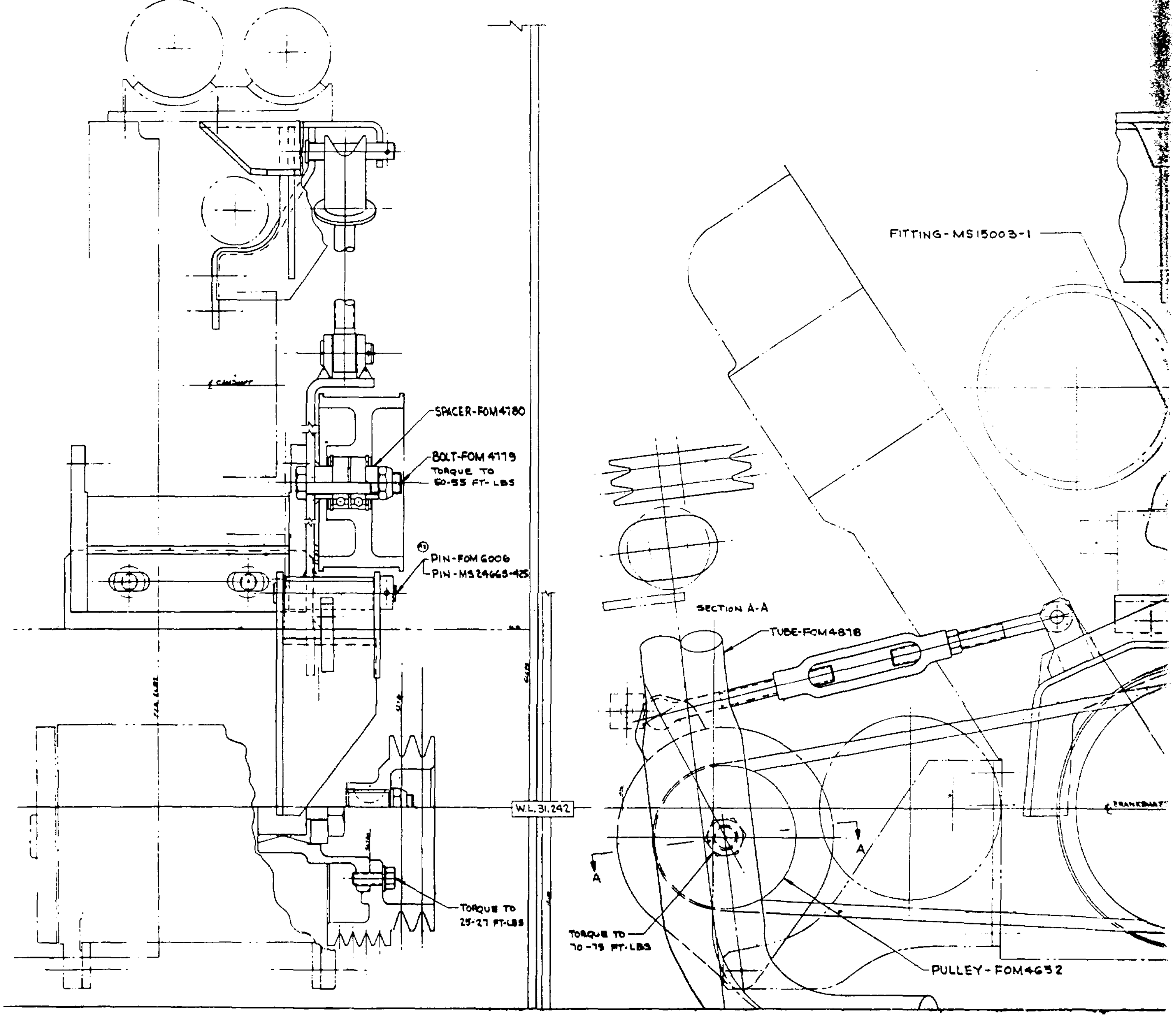


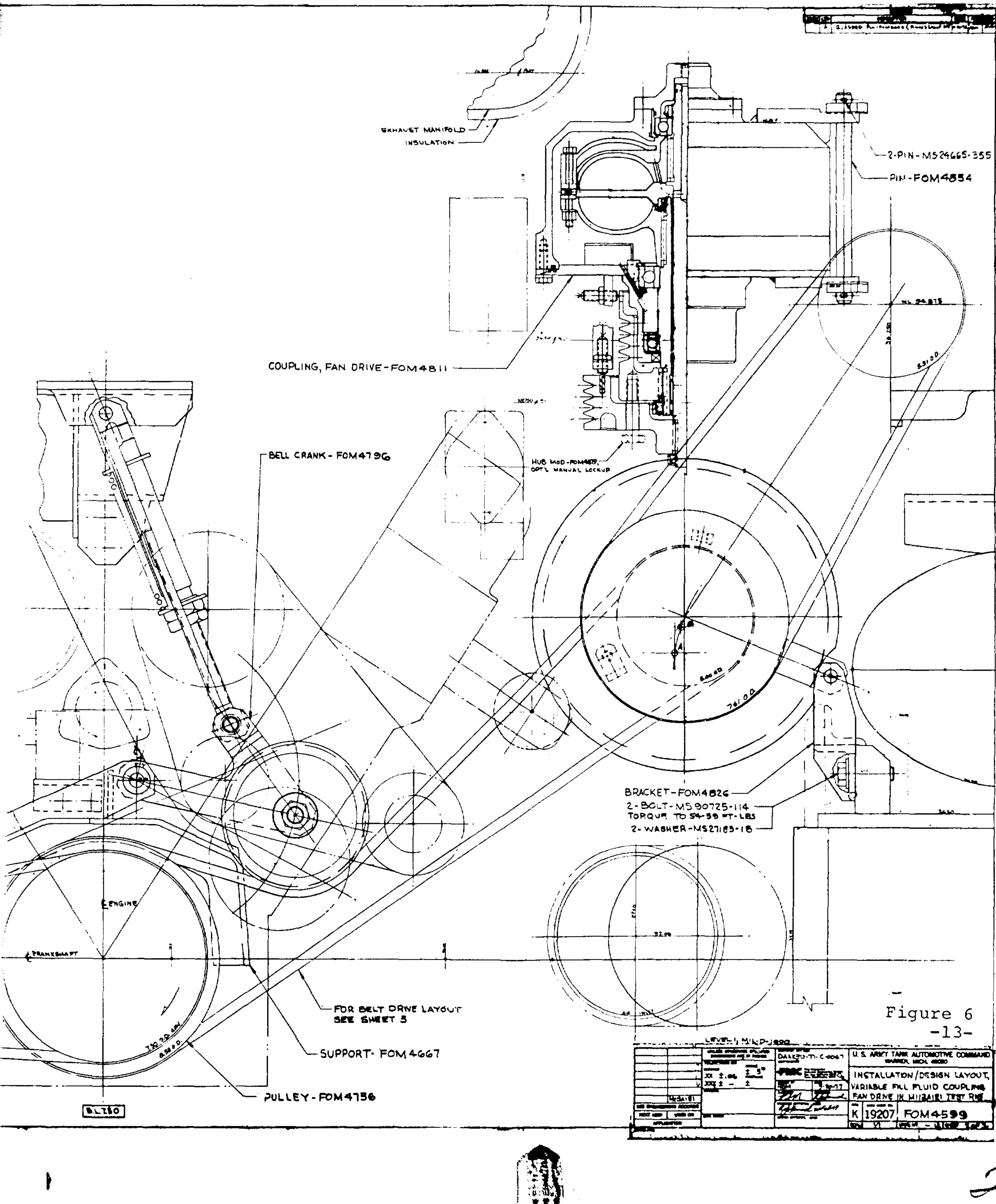

EXHAUST MANIFOLD
INSULATION
2-PIN-MS24665-355
PIN-FOM4854
COUPLING, FAN DRIVE-FOM4811
BELL CRANK-FOM4796
HUB MOD-FOM4677, OPT'L MANUAL LOCKUP
BRACKET-FOM4826
2-BOLT-MS90725-114
TORQUE TO 54-59 FT-LBS
2-WASHER-MS27183-18
ENGINE
CRANKSHAFT
FOR BELT DRIVE LAYOUT SEE SHEET 3
SUPPORT-FOM4667
PULLEY-FOM4756
U.S. ARMY TANK AUTOMOTIVE COMMAND
INSTALLATION/DESIGN LAYOUT, VARIABLE FILL FLUID COUPLING FAN DRIVE IN M113A1 TEST RIG
K 19207 FOM4599

Figure 6

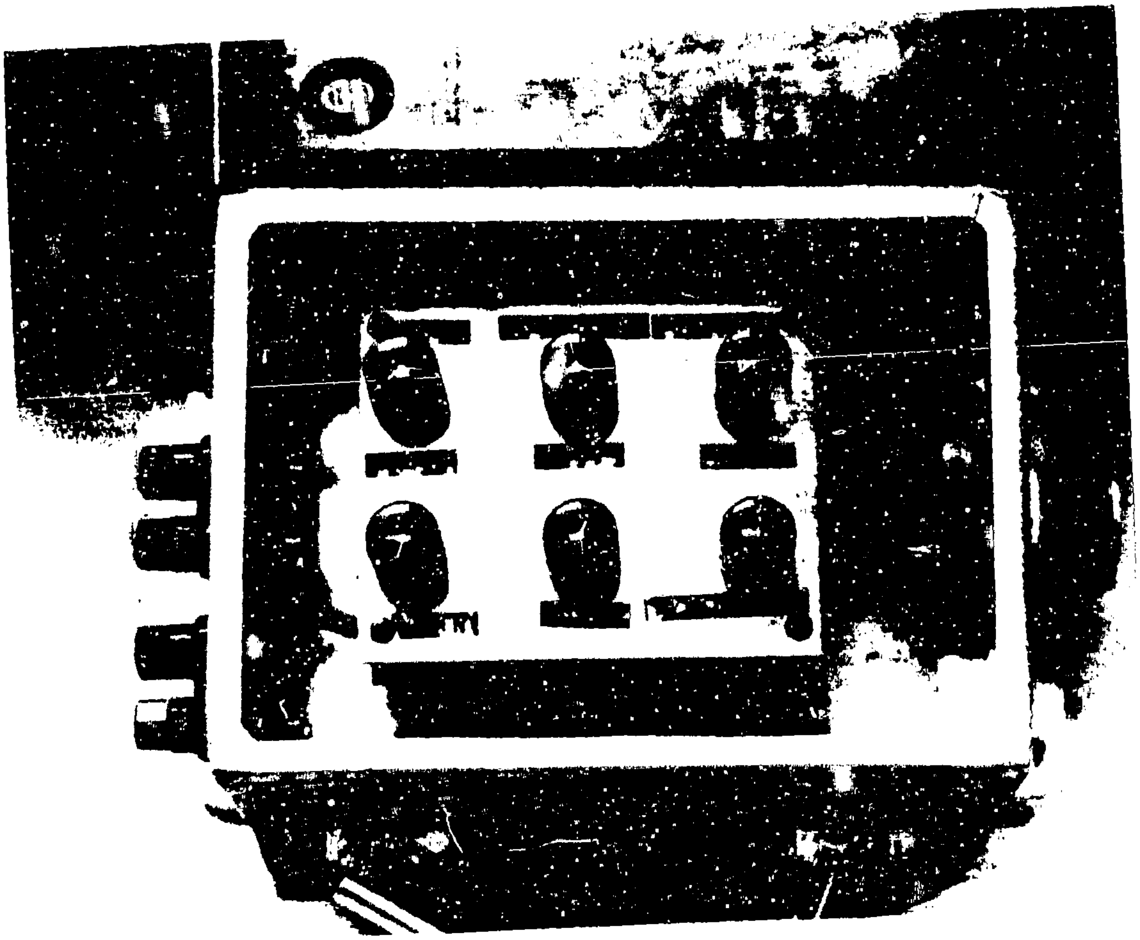


Figure 7. Electronic Controller Test Unit

allow for "fine tuning" of the system during vehicle testing. The parameters that can be varied by those potentiometers are:

- Coolant temperature modulation range (both lower and upper limits)
- Fan overspeed limit (maximum fan speed)
- Control flow (charge rate) depression limits (engine speed and charge rate).

Note that there is a protected switch on the side of the ETU so that power can be cut off in case of an electronic circuitry failure. This would then cause the EPFCV to be fully open, thereby providing maximum fan speed for a given engine speed.

Explanation of the basic EC logic can be found in Section 3.1. Presently, the EC has been designed to provide the following performance:

- Temperature modulation from 185°F to 210°F (at 210°F, system at full couple/minimum slip)
- Fan maximum speed at 5100 or 5500 rpm depending on system being tested
- Control flow throttle to 1.0 gpm below 1000 rpm engine speed.

After laboratory testing, the six potentiometers were to be replaced by fixed resistors, and the printed circuit board to be encapsulated to protect the unit from environmental effects; however, this was not completed due to early termination of laboratory testing caused by transmission problems/failure. (Refer to Section 5.3.) The pot settings as determined from testing are:

Temperature	Fan Speed	1000 rpm
Range-620	Max-290	Level-750
Gain-750	Slope-050	Hysteresis-disconnected

It should be noted that the hysteresis pot has been deleted because hysteresis adjustment was found not to be required.

A compact low cost "tamper proof" EC will be possible for production.

3.5.2. Electrical Installation

The electrical system installation is shown on Figure 8. Note that the Electronic Controller, FOM 4823, is located on the port sponson beside the driver and that it obtains its power from the instrument panel, as shown in Detail H. Figure 9 shows vehicle installation of the EC. Note also that the wiring for the 24V electric sump pump was integrated into the EC and accompanying hardware (magnetic pickups, EPFV, thermistor) wiring harness. Detail J shows how the thermistor is mounted on the existing engine coolant outlet elbow. It should be noted that the magnetic pickups are mounted on the VFFC as shown on Figure 4.

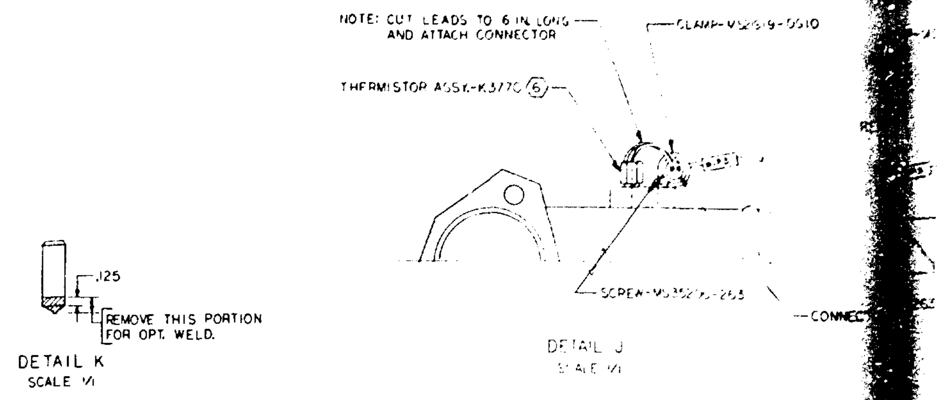
3.6 HYDRAULIC SYSTEM

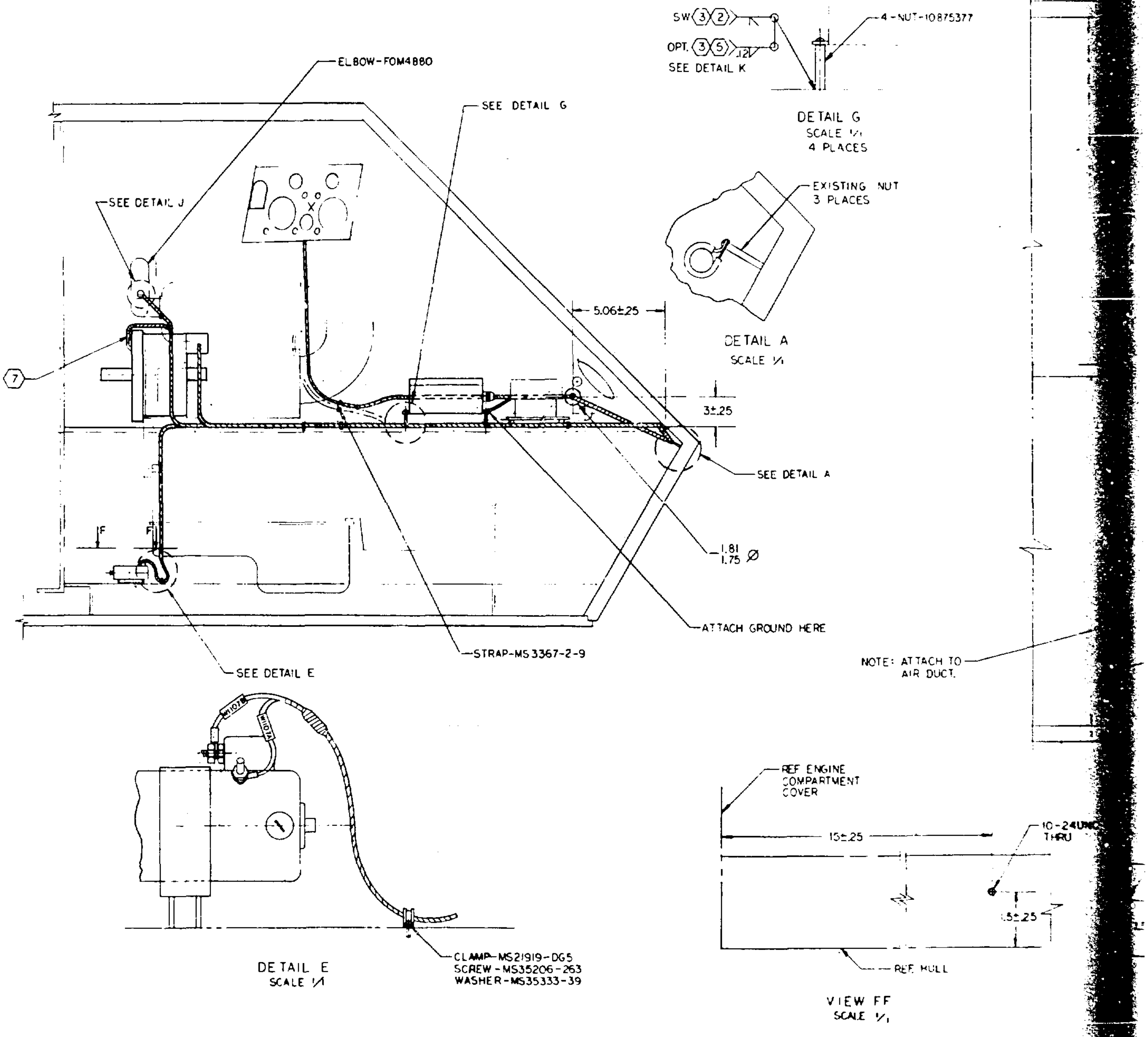
3.6.1 Electrical Proportional Flow Control Valve (EPFCV)

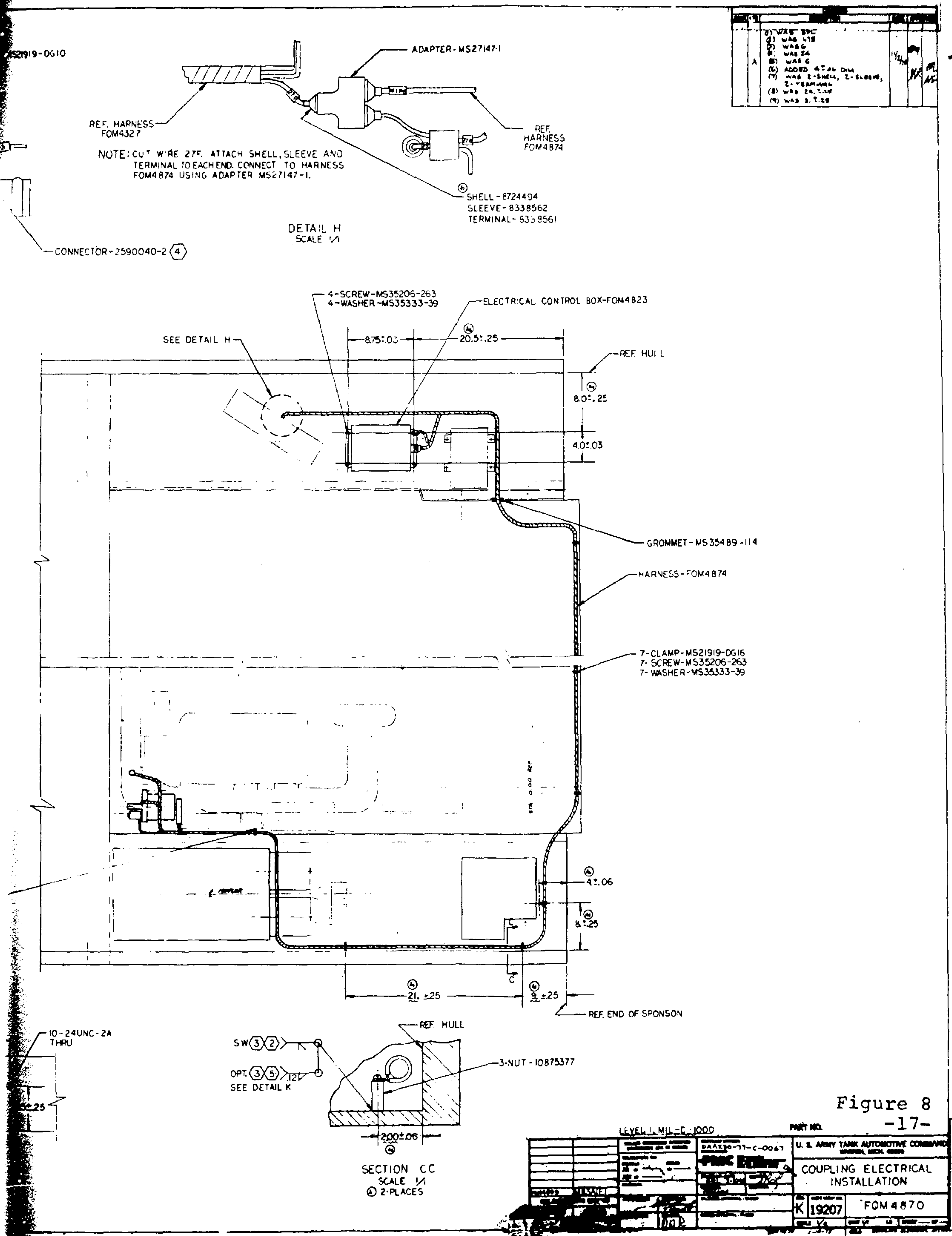
The performance of the FEMA Electrical Proportional Flow Control Valve, P/N 82570, is shown in Figure 10 for various supply pressures. Transmission operating pressure range is nominally 150-210 psi. Note that the valve is a "fail-safe" design in that full flow is provided whenever electrical power is lost and that the minimum flow is 1.0 gpm in order to maintain some minimum air flow through the power plant compartment under all conditions.

NOTES:

1. INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-STD-100
2. WELD IN ACCORDANCE WITH MIL-W-45211.
3. NUT MUST WITHSTAND A PROOF BENDING MOMENT OF 150 LB. IN. MIN IN ANY DIRECTION.
4. AMPHENOL PART NO.
5. WELD IN ACCORDANCE WITH CLASS B, SPEC MIL-W-45205. USE ELECTRODE TYPE 5356, SPEC MIL-E-16053.
6. FENWAL PART NO.
7. THESE TWO PLUGS TO BE CONNECTED TO MAGNETIC PICK-UPS (REF FOM4811)



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REF. HARNESS FOM4327
REF. HARNESS FOM4874
NOTE: CUT WIRE 27F. ATTACH SHELL, SLEEVE AND TERMINAL TO EACH END. CONNECT TO HARNESS FOM4874 USING ADAPTER MS27147-1.
SHELL-8724494
SLEEVE-8338562
TERMINAL-8338561
DETAIL H
SCALE 1/1
CONNECTOR-2590040-2 (4)
4-SCREW-MS35206-263
4-WASHER-MS35333-39
ELECTRICAL CONTROL BOX-FOM4823
SEE DETAIL H
8.75±.03
20.5±.25
REF. HULL
8.0±.25
4.0±.03
GROMMET-MS35489-114
HARNESS-FOM4874
7-CLAMP-MS21919-DG16
7-SCREW-MS35206-263
7-WASHER-MS35333-39
4±.06
8±.25
21.±25
9.±25
REF. END OF SPONSON
10-24UNC-2A THRU
REF. HULL
SW (3)(2)
OPT. (3)(5)
SEE DETAIL K
3-NUT-10875377
.200±.06
SECTION CC
SCALE 1/1
(A) 2-PLACES
LEVEL I, MIL-C-1000
PART NO.
DAAK30-77-C-0067
U. S. ARMY TANK AUTOMOTIVE COMMAND
COUPLING ELECTRICAL INSTALLATION
K 19207
FOM4870

Figure 8

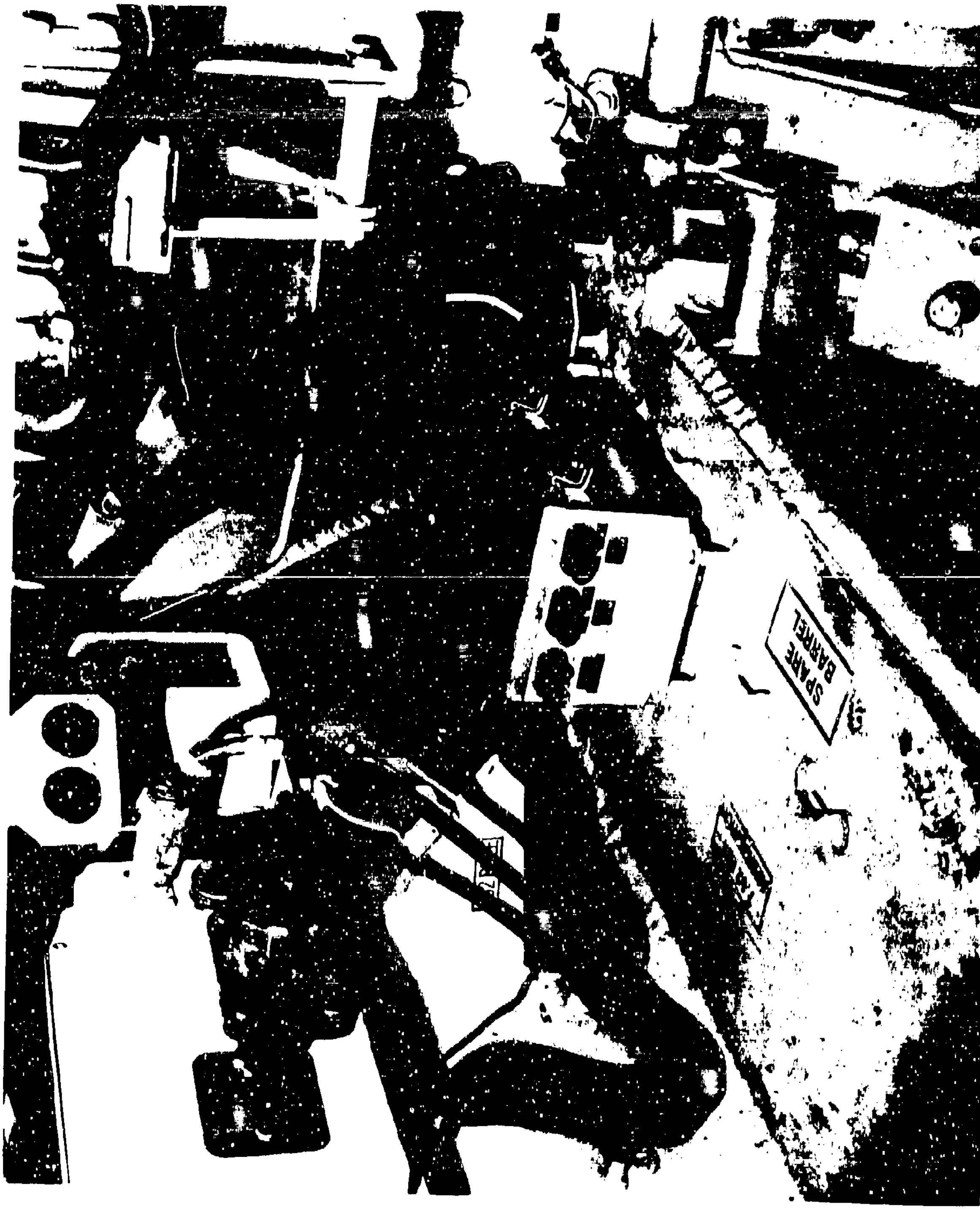


Figure 9. Electronic Controller in M113A1E1 Test Rig

FMC

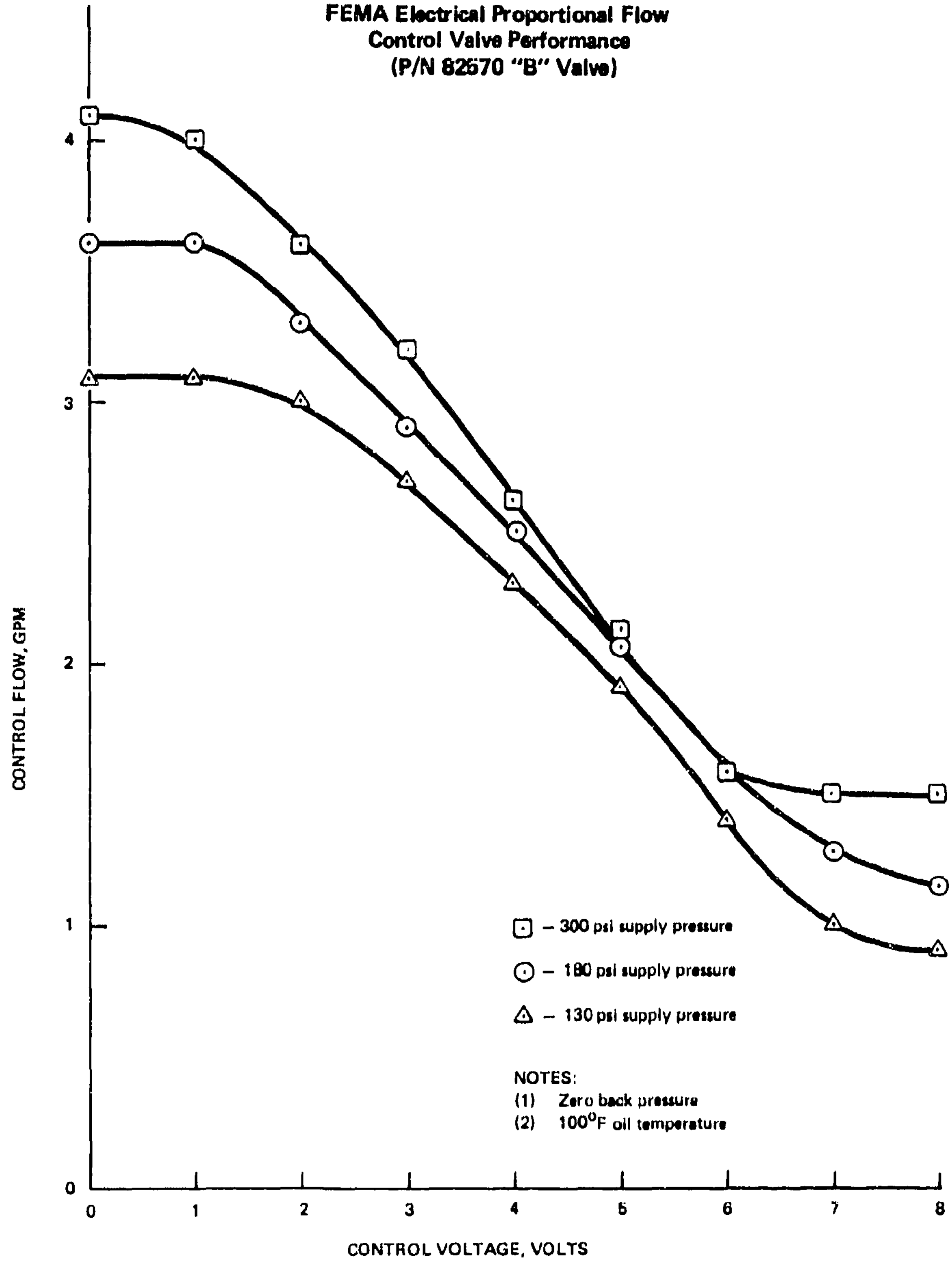


Figure 10

The valve is located on the forward side of the coupling assembly as shown on Figure 11. The drainline oil from the valve, approximately .3 gpm under all conditions, is returned to the coupling housing to provide additional lubrication for the input shaft bearings.

3.6.2 Sump Pump

A sump pump, P/N 10946835, currently used on M113A1 coolant heater kit, is required since the coupling housing will not gravity drain under all vehicle slope conditions due to the relatively high return port provided in the transmission. The power loss due to the coupling halves spinning in an external oil bath would be high. The sump pump is located on the aft portion of the starboard box beam in the power plant compartment, as shown in Figure 11.

3.6.3 Hydraulic Installation

The hydraulic system installation is depicted, Figure 11. Note that the pressurized fluid source for the coupling is the transmission lube system. Even though the control valve will be receiving filtered transmission oil, a secondary 70 micron in-line filter at the valve inlet port has been provided in case of a transmission filter failure (filter blown) or foreign material from connecting line. It should be noted that in the new X200-3 units, S/N's 8, 9, 10, the transmission design has been revised to prevent filter rupture by providing a flow bypass if pressure is too great. As requested by Detroit Diesel Allison, oil from the coupling drain is returned via the sump pump through a 70 micron filter to the transmission left brake adjusting cover.

Because of the relatively low heat generation from the VFFC, the transmission cooling system can handle the added heat load, thus eliminating the need for a separate VFFC cooling system.

NOTES:

1. INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-STD-100
2. SEE DWG 11662995 THRU 11662999 FOR DESCRIPTION.
3. WELD IN ACCORDANCE WITH CLASS 8, SPEC MIL-W-45205. USE ELECTRODE TYPE 5356, SPEC MIL-E-16053 FOR GMAW PROCESS OR USE ROD CLASS 5356, SPEC QQ-R-566 FOR GTAW PROCESS.
4. ALL WELD SIZES ARE MIN.
5. ALL WELD JOINTS SHALL BE PREFERABLY METAL TO METAL FIT, IN NO CASE SHALL THE WELD GAP EXCEED .09-INCH.

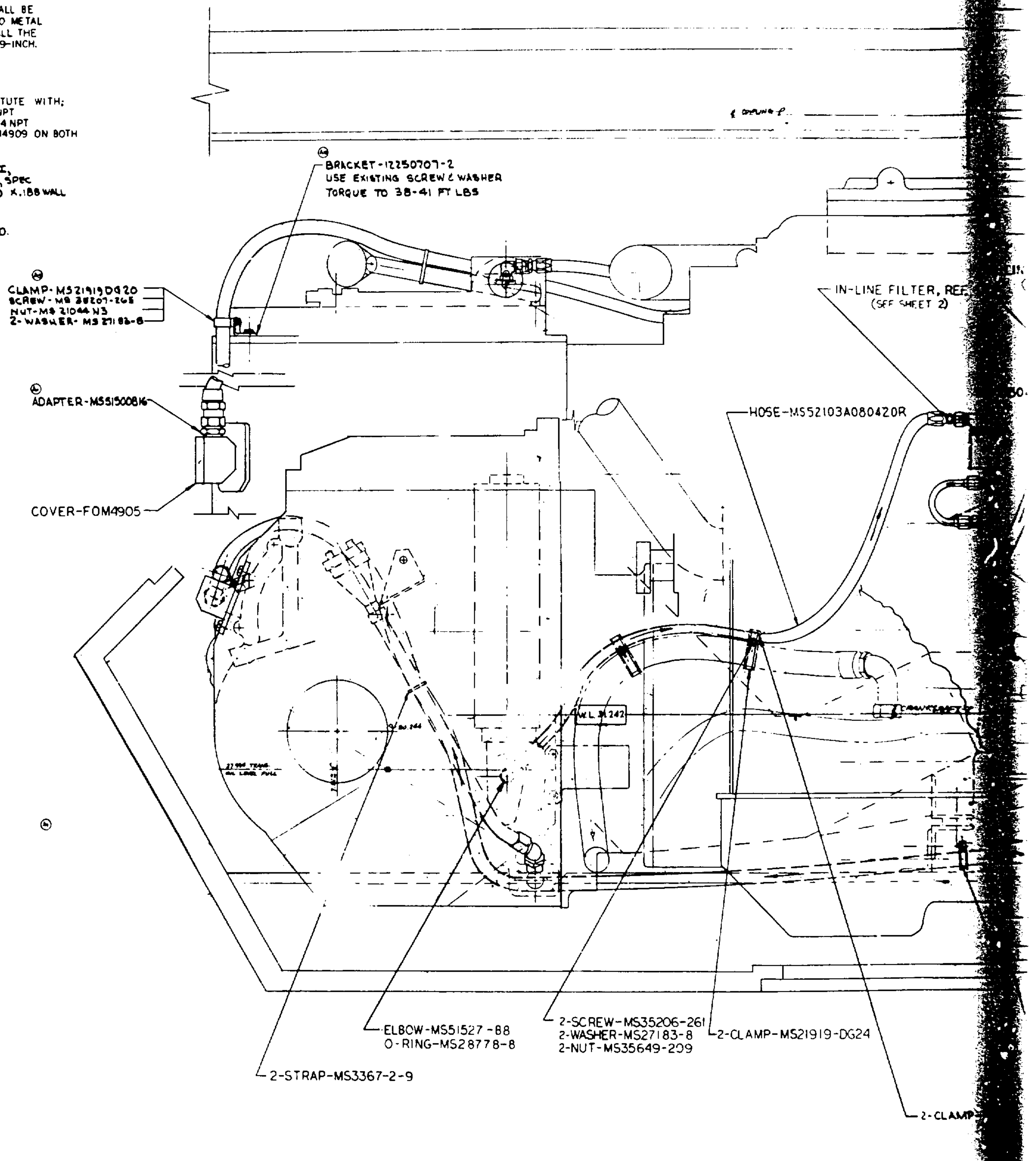
(A) AEROQUIP PART NO.

(B) MECTRON PART NO.

(C) FOR FLANGES, SUBSTITUTE WITH: SUCTION SIDE: 1-11.5 NPT DISCHARGE SIDE: .5-14 NPT INSTALL GASKET-FOM4909 ON BOTH FLANGES.

(D) HOSE, RUBBER, TYPE I, GRADE B, CLASS 2, SPEC ZZ-H-428, 1.00 I.D. X .188 WALL THICKNESS.

(E) FEMA PART NO.



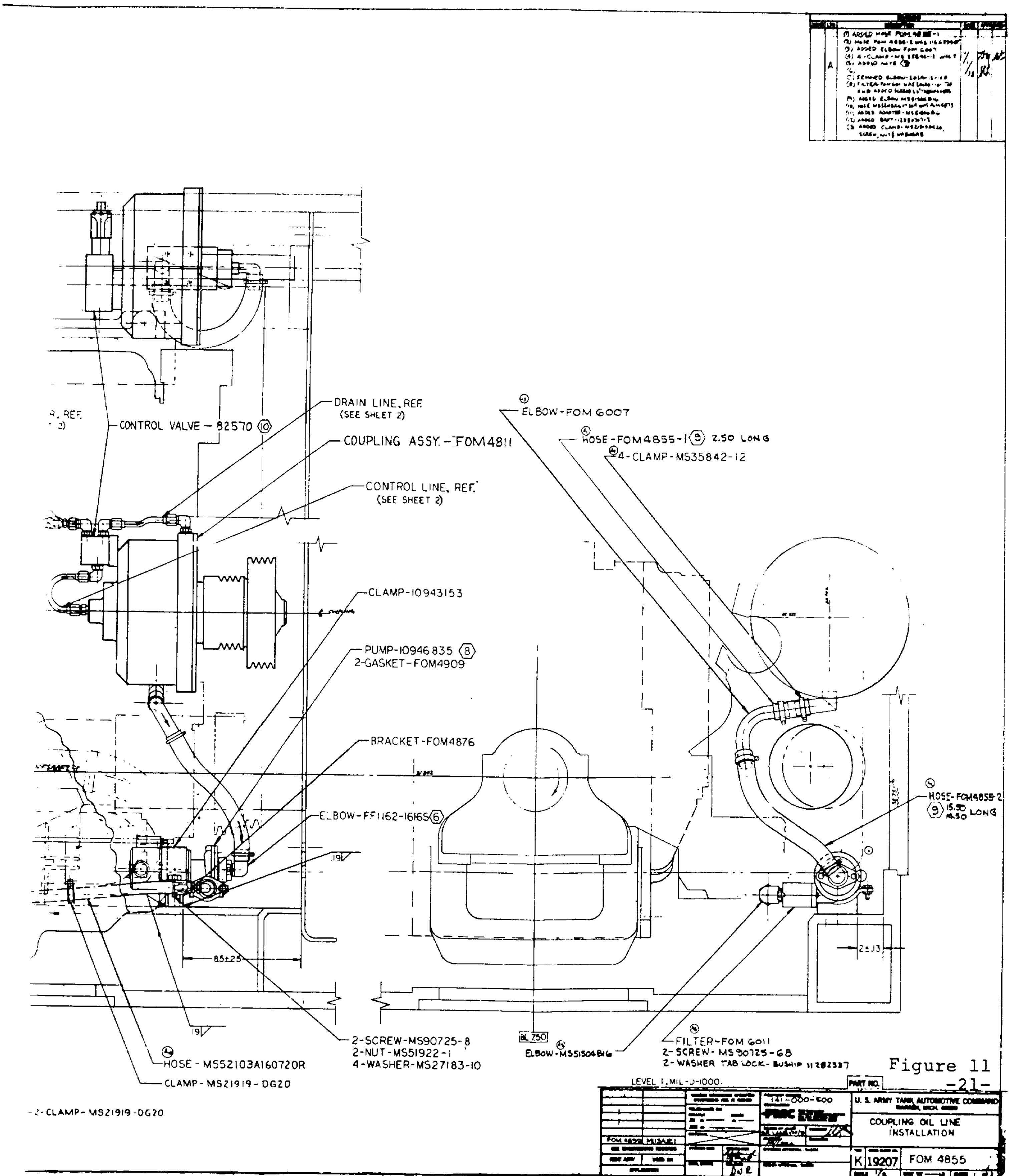

DRAIN LINE, REF
(SEE SHEET 2)
CONTROL VALVE - 82570 (10)
COUPLING ASSY. - FOM4811
CONTROL LINE, REF.
(SEE SHEET 2)
CLAMP-10943153
PUMP-10946835 (8)
2-GASKET-FOM4909
BRACKET-FOM4876
ELBOW-FF1162-1616S (6)
2-SCREW-MS90725-8
2-NUT-MS51922-1
4-WASHER-MS27183-10
HOSE - MS52103A160720R
CLAMP - MS21919 - DG20
2-CLAMP- MS21919-DG20
ELBOW-FOM 6007
HOSE-FOM4855-1 (9) 2.50 LONG
4-CLAMP-MS35842-12
HOSE-FOM4855-2
(9) 15.50 LONG
ELBOW-MS51504B16
FILTER-FOM 6011
2-SCREW-MS90725-68
2-WASHER TAB LOCK-BUSHIP 11282337
LEVEL 1, MIL-D-1000
U. S. ARMY TANK AUTOMOTIVE COMMAND
COUPLING OIL LINE INSTALLATION
K 19207 FOM 4855

Figure 11

3.7 TRANSMISSION

The X200-3 transmission, S/N 5, has been provided with a wider gear (1.125 inch) lube pump. Detroit Diesel Allison has approved a 4.5 gpm maximum coupling flow requirement for engine speeds greater than 1000 rpm and a 1.0 gpm maximum for speeds less than 1000 rpm.

The following minor transmission modifications were required:

- Existing .35 NPT filter out boss reworked to SAE J514 (MS16142) boss for 1/2-inch OD tube (coupling supply port)
- Boss on existing transmission left brake adjusting cover, P/N 80212 4174580 modified to .56 inch height as specified by FMC on FOM 4905 (coupling return port).

3.8 HARDWARE MODIFICATIONS

The VFFC Fan Drive was designed with only minor changes to the existing M113A1E1 Test Rig power plant compartment and components as shown on Figure 2. Besides minor reworking of coolant lines, the only other required change was the relocation of the engine intake air duct due to its interference with the VFFC assembly. This necessitated reworking the rear bulkhead access opening and stiffener as shown on Figure 2 as well as fabricating a new lower power plant access cover and center support for the access covers as shown on Figure 12. Also, the rear bulkhead stiffener above the starboard sponson was redesigned to provide belt clearance, and the fan pulley access opening enlarged to permit installation/removal of the pulley as shown on Figure 12. The existing air cleaner intake plenum has to be modified to accommodate the new lower air inlet opening from the personnel compartment.

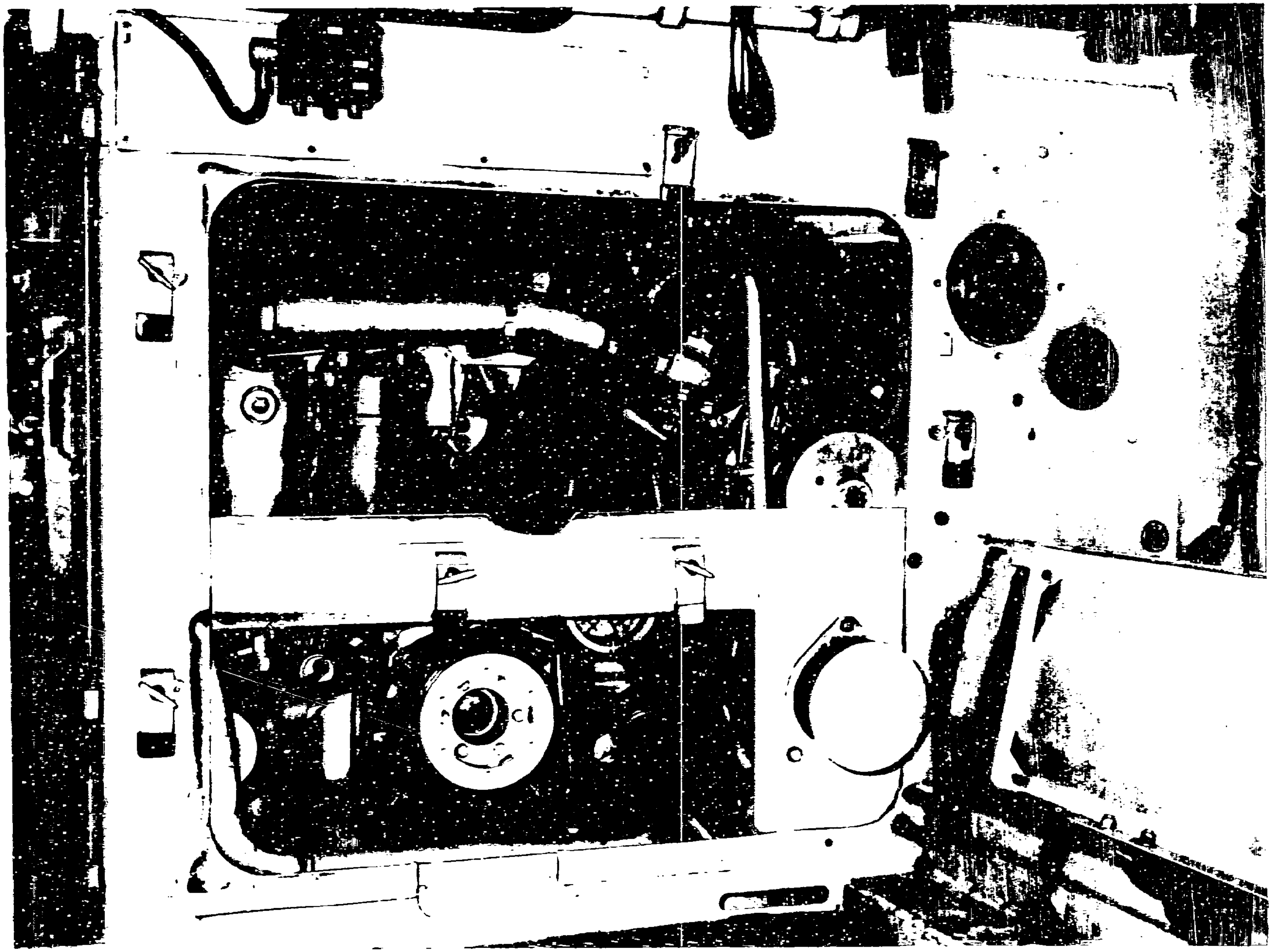


Figure 12. M113A1E1 Engine Compartment (viewed from inside vehicle)

SECTION 4
PREDICTED PERFORMANCE

4.1 VEHICLE COOLING

Hardware has been fabricated for two different maximum fan speed systems (5100 and 5500 rpm). Figure 13 shows the predicted cooling system performance with the VFFC Fan Drive for various GVW's and final drive ratios. Note the substantial cooling improvement shown predicted for the VFFC at the 4725, 5115 and 5500 fan rpm compared to the existing fixed drive system (YPG data from M113A1E1 Test Rig) at 4425 and 4340 rpm. These higher fan speeds at the cooling point can be achieved since the overspeed control limits the fan to those selected maximum speeds regardless of engine speed as shown on Figure 14. Note further that with the existing fixed drive system, the maximum fan speed (power) occurs at engine governed speed and not at the cooling point.

4.2 VFFC TEMPERATURE MODULATION

The VFFC Fan Drive modulation characteristics for the 5100 rpm system are shown on Figure 15. The 5500 rpm system has similar characteristics. The 210° upper limit is considered a maximum for good engine life. The lower limit relates to the engine thermostat rating. Note that for engine speeds greater than 1000 rpm the ratio between maximum to minimum fan speed is approximately 4:1 which results in significant power savings.

A minimum fan speed, at engine idle, has been maintained in order to provide a minimum airflow to (1) flush out the power plant compartment of toxic fumes (exhaust and CBR), (2) provide acceptable compartment air temperature, and (3) maintain a negative power plant compartment.

Predicted
M113A1E1 Cooling System Performance
with
Variable Fill Fluid Coupling Fan Drive
FOM4599 for
125°F Ambient
295 HP Engine
Fan FOM4079–2

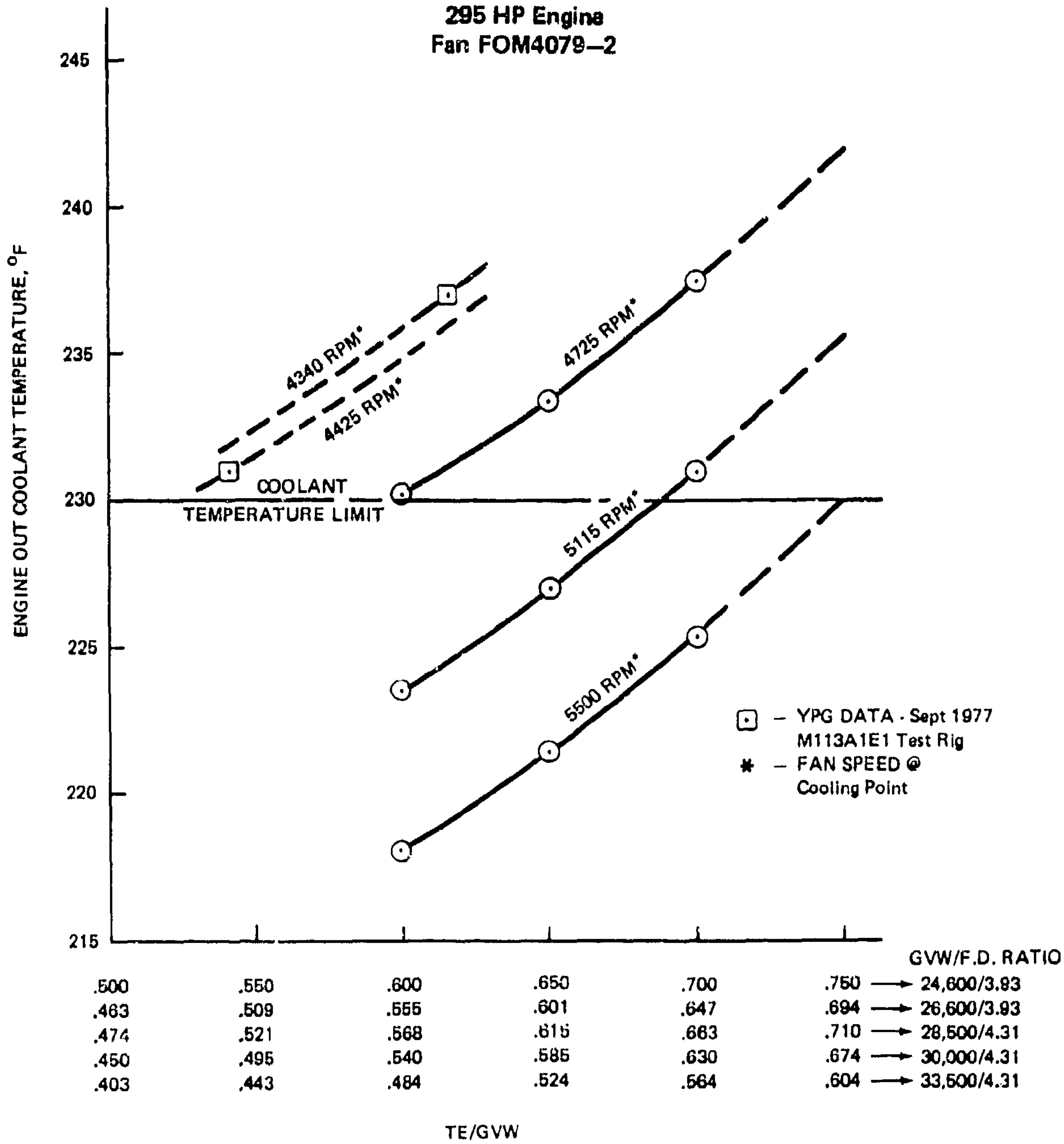


Figure 13

**Predicted
Fan Speed vs Coolant Temperature
for
VFFC Fan Drive
with
Electronic Control**

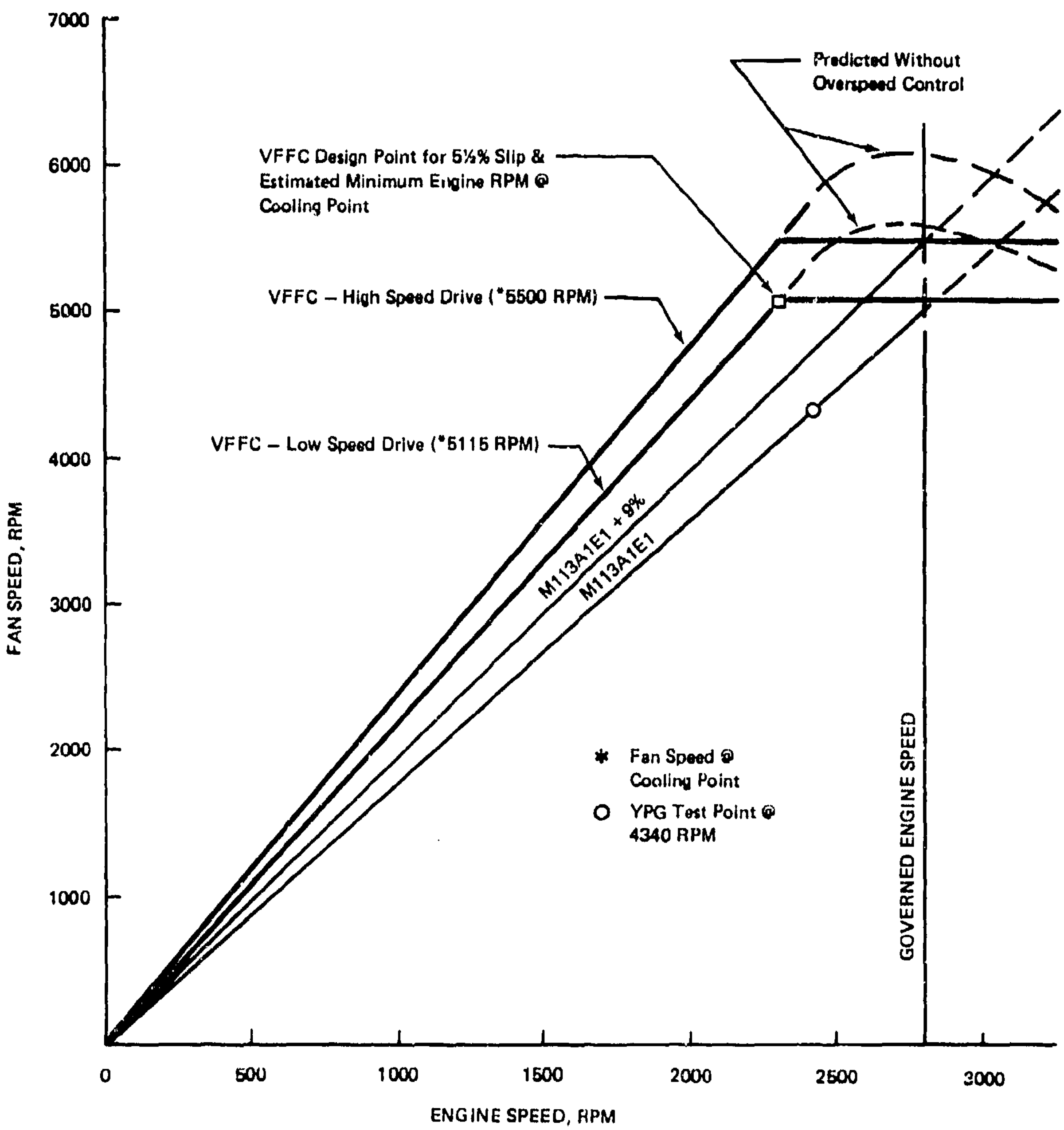


Figure 14

**Predicted Temperature
Modulation Performance
for VFFC Fan Drive w/Electronic Control
for Low Speed System
(5100 RPM. Max.)**

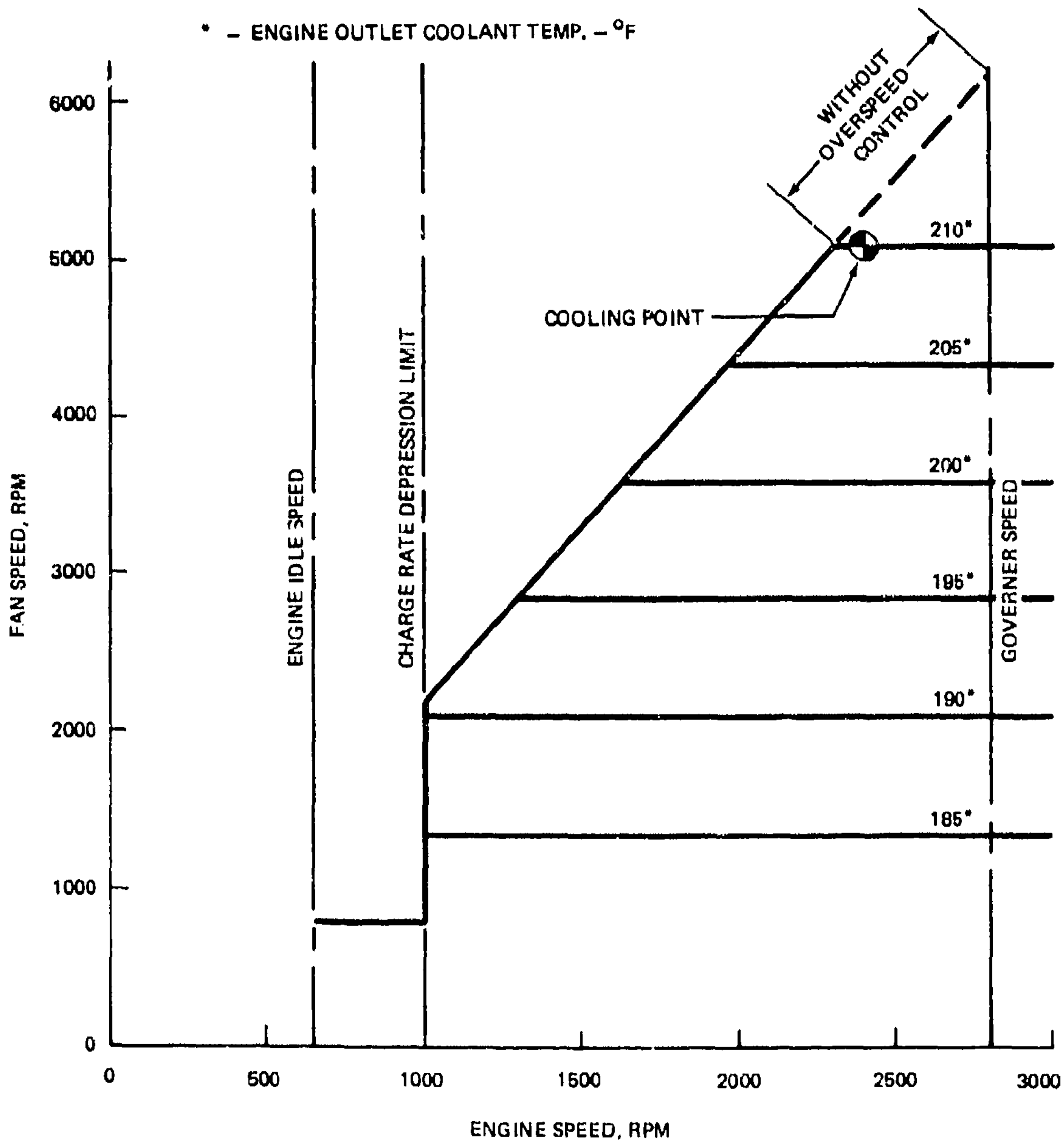


Figure 15

4.3 VFFC COOLING

The heat generated by the VFFC during vehicle full load cooling is approximately 3.5 hp for the 5500 rpm system and 2.2 hp for the 5100 rpm drive. This heat load can easily be handled by the transmission cooling system.

The maximum VFFC cooling heat load occurs at 33% slip and 2800 engine rpm (refer to TACOM Report 12213, Figure 4-8). The heat dissipated by the unit at those conditions is approximately 18 hp for the 5500 rpm drive and 13.5 hp for the 5100 rpm system. The temperature rise in the coupling under the above condition would be 70°F and 50°F respectively. However, since this maximum heat load would only occur at relatively low transmission operating temperatures the VFFC return oil temperature should present no problems.

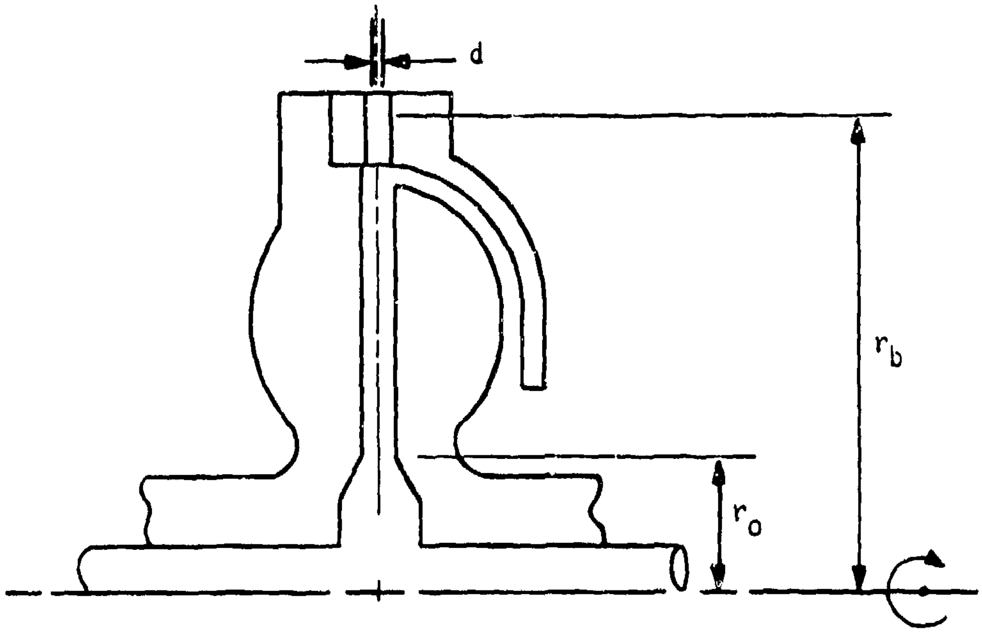
4.4 ORIFICE SIZE

The orifice (flow restrictor) size has been calculated to provide full couple at 2300 engine rpm with a 3.50 gpm control flow rate (charge rate). This permits full couple up to 2500 engine rpm since the maximum charge rate is 4.0 gpm.

As shown on Figure 14, for engine speeds greater than 2500 rpm the coupling has an "inherent overspeed capability" in that it begins to empty itself since the output flow (bleed-off rate) through the flow restrictors in the cover exceeds the charge rate. This condition continues until the fill level reduces enough to cause the bleed rate to equal the charge rate. Thus a reduction in VFFC output speed occurs.

Figure 16 is a copy of the orifice sizing calculation based on the test data obtained during TARADCOM Contract DAAE07-75-C-0079.

ORIFICE SIZING



SPEED RATIO (ENGINE TO COUPLING) = 8.5:5.0

ENGINE SPEED: N_E

FLOW OUT OF COUPLING: Q = 3.5 GPM (2 ORIFICES)

COEFFICIENT OF DISCHARGE FOR ORIFICE: $C_D = 0.66$ (See page 2)

CROSS SECTIONAL AREA OF ORIFICE: $A = \frac{\pi d^2}{4}$

INPUT SPEED: $N_I = (8.5/5)(N_E)$

PRESSURE AT ORIFICE INLET (r_b):

$$\Delta P_b = 1.419 \times 10^{-5} \; \rho N_I^2 \, (r_b^2 - r_o^2)$$

DIAMETER OF ORIFICE: d (2 ORIFICES)

$$Q = C_D A \sqrt{\frac{\Delta P}{\rho} 2g}$$

where C_D = DISCHARGE COEFFICIENT

Figure 16, Sheet 1 of 3

1) COEFFICIENT OF DISCHARGE: (FROM FMC TEST DATA)

INPUT SPEED = 4200 RPM

FLOW (2 ORIFICES) = 4.7 GPM

DENSITY OF SAE 10 WT. @ 150°F = 6.93 LB/GAL

- ORIFICE SIZE: #41 DRILL = .096 IN.

$$\Delta P = 1.419 \times 10^{-5} \rho N^2 (r_b{}^2 - r_o{}^2)$$

$$= (1.419 \times 10^{-5}) \left(\frac{6.93}{231}\right) (4200)^2 (4.32^2 - 1.54^2)$$

$$\Delta P = 122.33 \text{ PSI}$$

$$C_D = \frac{Q}{A\sqrt{\frac{\Delta P}{\rho} \cdot 2g}}$$

$$= \frac{4(2.35)(231)}{\pi(.096)^2 \sqrt{\frac{122.3}{6.93/231} \cdot 2 \cdot 32 \cdot 12 \cdot 3600}}$$

$$C_D = 0.71$$

- ORIFICE SIZE: #44 DRILL = .086 IN.
  FLOW (2 ORIFICES) = 3.8 GPM
  INPUT SPEED = 4800 RPM

$$\Delta P = 1.419 \times 10^{-5} \left(\frac{6.93}{231}\right) (4800)^2 (4.32^2 - 1.54^2)$$

$$\Delta P = 159.77 \text{ PSI}$$

$$C_D = \frac{4(1.9)(231)}{\pi(.086)^2 \sqrt{\frac{159.77}{6.93/231} \cdot 2 \cdot 32 \cdot 12 \cdot 3600}}$$

$$C_D = 0.62$$

∴ AVERAGE C_D FOR THIS ORIFICE SIZE RANGE: $C_D = 0.66$

Figure 16, Sheet 2 of 3

2) ORIFICE SIZE PREDICTION FOR VFFC IN M113A1E1
DESIGN PARAMETERS

SPEED RATIO = 8.5:5.0

N_E = 2300 RPM

Q = 3.5 GPM (2 ORIFICES)

C_D = .66

ρ = 6.61 LB/GAL @ 250°F = .0286 LB/IN.^{3}

r_b = 4.32 IN.

r_o = 1.54 IN.

$$\Delta P_b = 1.419 \times 10^{-5} (.0286)\left(\frac{8.5}{5} \cdot 2300\right)^2 (4.32^2 - 1.54^2)$$

$$\Delta P_b = 101.07 \text{ PSI}$$

— SOLVING FOR SINGLE ORIFICE DIAMETER:

$$d = \left[\frac{4(1.75)231}{\pi(.66)\left(\sqrt{\frac{101.07}{.0286} \cdot 2 \cdot 12 \cdot 32} \cdot 3600\right)} \right]^{1/2}$$

d = .089 IN. (SINGLE ORIFICE DIA.)

≡ DRILL #43

Figure 16, Sheet 3 of 3

SECTION 5
LABORATORY TESTING IN VEHICLE

5.1 INTRODUCTION/BASIC TEST SETUP

As specified in the contract, the Variable Fill Fluid Coupling Fan Drive with Electronic Controller installed in the M113A1E1 Test Rig Vehicle was dynamometer hot room tested as shown on Figure 17. For all tests the vehicle cooling system consisted of the Young Radiator FOM 4070-2 and the FMC Fan 4197073-2 with the Sunstrand Support 12253583. The basic operation of the VFFC Fan Drive has been defined. The coolant temperature modulation characteristics, the speed limiting capability, vehicle high load/high ambient cooling performance, etc., were determined. Results of the testing will be discussed in detail in Section 5.2.

The following primary variables were monitored and/or recorded:

- Coupling Input and Output RPM
- Coupling Inlet and Outlet Oil Temperature
- Control Valve Flow and Supply Pressure
- Control Voltage
- Engine RPM
- Engine Outlet Coolant Temperature
- Transmission Outlet Oil Temperature
- Transmission Output RPM and Torque
- Ambient Temperature.

Due to the transmission problems/failures (refer to Section 5.3), dynamometer hot room operation was fore shortened, which prevented testing of the high speed drive system (5500 rpm). It should be noted that contractually FMC was required only to evaluate (test) the 5100 rpm system. The results of which will be reported in the following sections. No further testing is planned because all contractually specified tests (except for Electronic Controller encapsulation/recheck) have been accomplished, and the basic

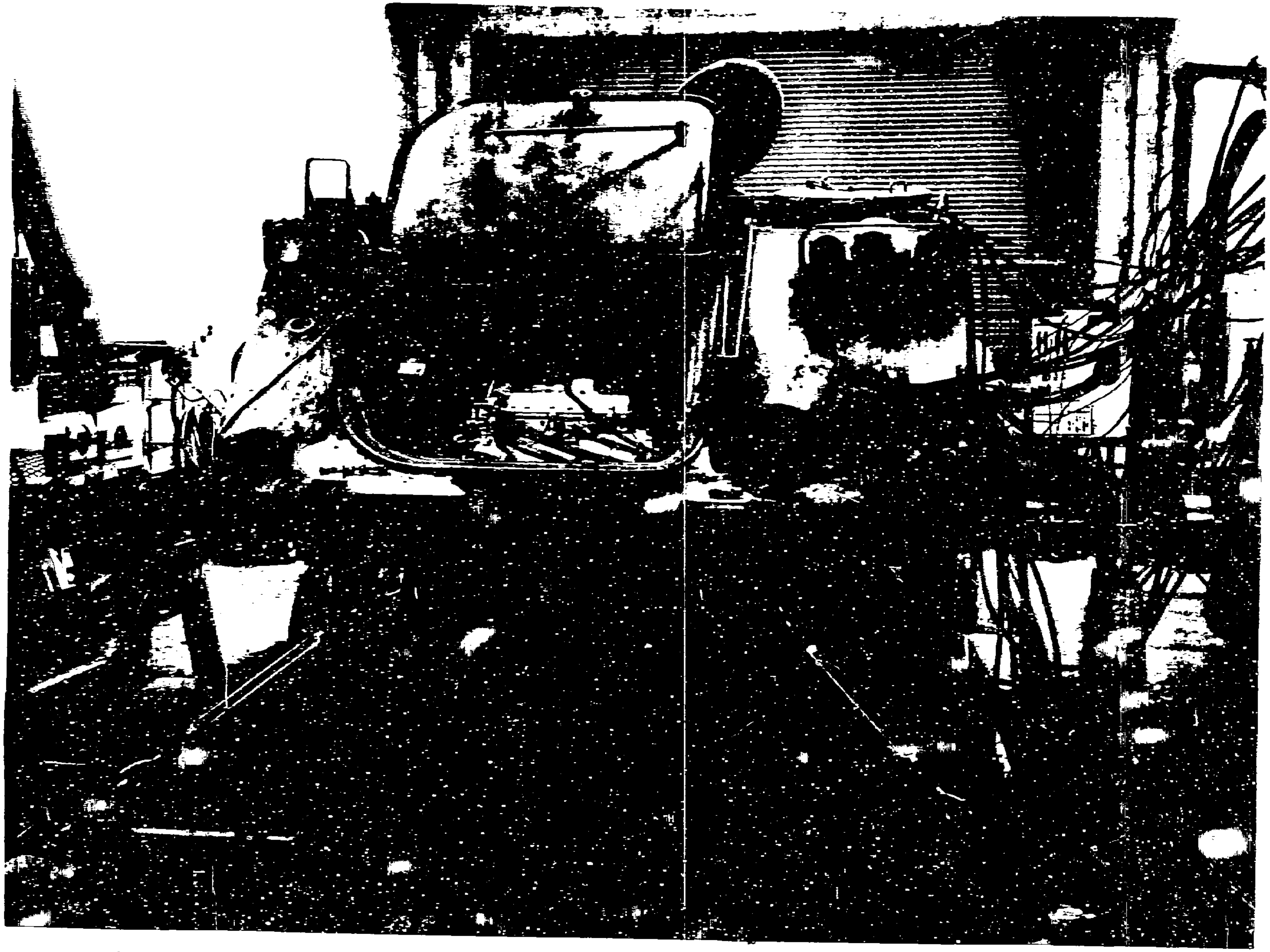


Figure 17. Instrumented M113A1E1 Test Rig in Dynamometer Hot Room Test Cell

operation of the VFFC Fan Drive defined. It should be noted that encapsulation should not affect system performance or operational integrity. Additional runs of certain contractually specified tests would have been performed had the transmission not failed.

FMC feels that the data taken in "converter operation" (lockup clutch disengaged) for the road load/normal ambient cooling runs is probably valid since a full load converter stall check performed just prior to the final transmission teardown was measured at 2550-2630 engine rpm compared to a value of 2580-2600 engine rpm recorded on 23 November 78 prior to the initial transmission failure. Further substantiation will be provided should DDAD teardown inspection show no major problem with the range clutches.

5.2 TEST DESCRIPTION/RESULTS

The following sections provide a detailed explanation of the tests performed and the results obtained.

5.2.1 Reduced Control Flow Below 1000 Engine RPM

While operating at various combinations of coolant temperature and engine speeds greater than 1500 rpm, the engine speed was rapidly reduced to below 1000 rpm, and at 1020 rpm the control flow (charge rate) would automatically be throttled regardless of coolant temperature to 1.0 gpm for control valve supply pressures in the 120-160 psi range (in lockup) and to 1.4 gpm for high pressures in the 280-320 psi bracket (in neutral). This is approximately equal to DDAD desired 1.0 gpm maximum limit at low engine speeds. Note that the 1.0 gpm limit is met when the supply pressures are the lowest which is the more critical transmission operating condition. This feature of the control valve has been discussed with FEMA who feel that with a slight redesign of the pilot stage the minimum flow could be made constant (approximately 1.0 gpm) for all supply pressures should it be required by DDAD. Control flow would return to the higher value as demanded by the electronic controller's coolant temperature modulation circuit whenever the engine speed exceeded 1050 rpm.

5.2.2 Orifice Sizing

Three orifice sizes (diameters) were investigated. The first orifice (.089) resulted in excessive slip (7.5%) at the cooling point since the maximum control flow was not adequate to maintain the coupling at a full level. The second orifice size (.0855) permitted full couple (5.6% slip) at the cooling point; however, the fan speed became zero at low control flows (1.3 gpm or less). The orifice size was then further reduced (.082) which maintained minimum slip (5.6%) at the cooling point and resulted in no loss of fan speed when the flow was at 1.0 gpm or higher for nearly all operating conditions. Lockup operation at 2800 engine rpm at low control flows was the only condition not tested due to premature transmission failure.

Since the original FEMA Electrical Proportional Flow Control Valve (EPFCV) (Valve A) was designed for a 0.5 gpm minimum flow at maximum voltage, a second valve (Valve B) to provide the desired 1.0 gpm minimum flow was ordered and successfully system tested. Refer to Section 3.6.1 for performance curve.

Note that a further reduction in orifice size in order to maintain fan rotation at flows lower than 1.0 gpm would result in narrowing the control flow modulation range (increase coupling sensitivity to flow) since this would lower the minimum flow rate required to provide full couple at the cooling point. Also, this would increase the temperature rise through the coupling which could result in excessive oil temperatures and reduced oil life.

5.2.3 Maximum Fan Speed With and Without Overspeed Control

Proper operation of the electronic overspeed control circuit as shown on Figure 18 was demonstrated by increasing the engine speed above 2300 rpm with the coolant temperature approximately 215°F and observing that the fan speed maintained the 5100 rpm set point value (maximum fan speed limit) after momentarily oscillating about the set point valve. A momentary (1-2 sec) maximum overshoot of approximately 900 rpm fan speed with an undershoot of 1300 rpm and a settling time of between 15-25 seconds was observed when the engine speed was rapidly increased from 2300 to 2800 rpm. It was observed that the smaller the step increase in engine speed above 2300 rpm and/or the slower the rate of increase in engine speed, the lesser the overshoot and the faster the settling time.

Testing at other controller settings was performed. The magnitude and duration of the overshoot was greater with approximately the same settling time; however, the amount of undershoot was less. The transmission failure prevented the planned test of different values for the overspeed control circuit time constant which probably would have reduced the amount of undershoot and shortened the settling time.

The orifice size was selected to provide full couple (minimum slip) up to 2500 engine rpm (cooling point at 2300 engine rpm) with zero voltage to flow control valve (maximum oil flow). Thus, at engine speeds greater than 2500 rpm, the coupling has an inherent (built-in) overspeed capability due to the fact that the maximum control flow (charge rate) is not sufficient to maintain the coupling at a full level which results in additional slip as the fill level is reduced. (Refer to Section 4.4.) Figure 19 presents engine speed versus fan speed for a maximum charge rate of approximately 3.80 gpm to the fluid coupling with the transmission operating in first converter which verifies the inherent overspeed capability. It should be noted that a more pronounced "rollover" at high engine speeds would occur if

Fan Speed vs Engine Speed
for
VFFC Fan Drive
with
Electronic Overspeed Control

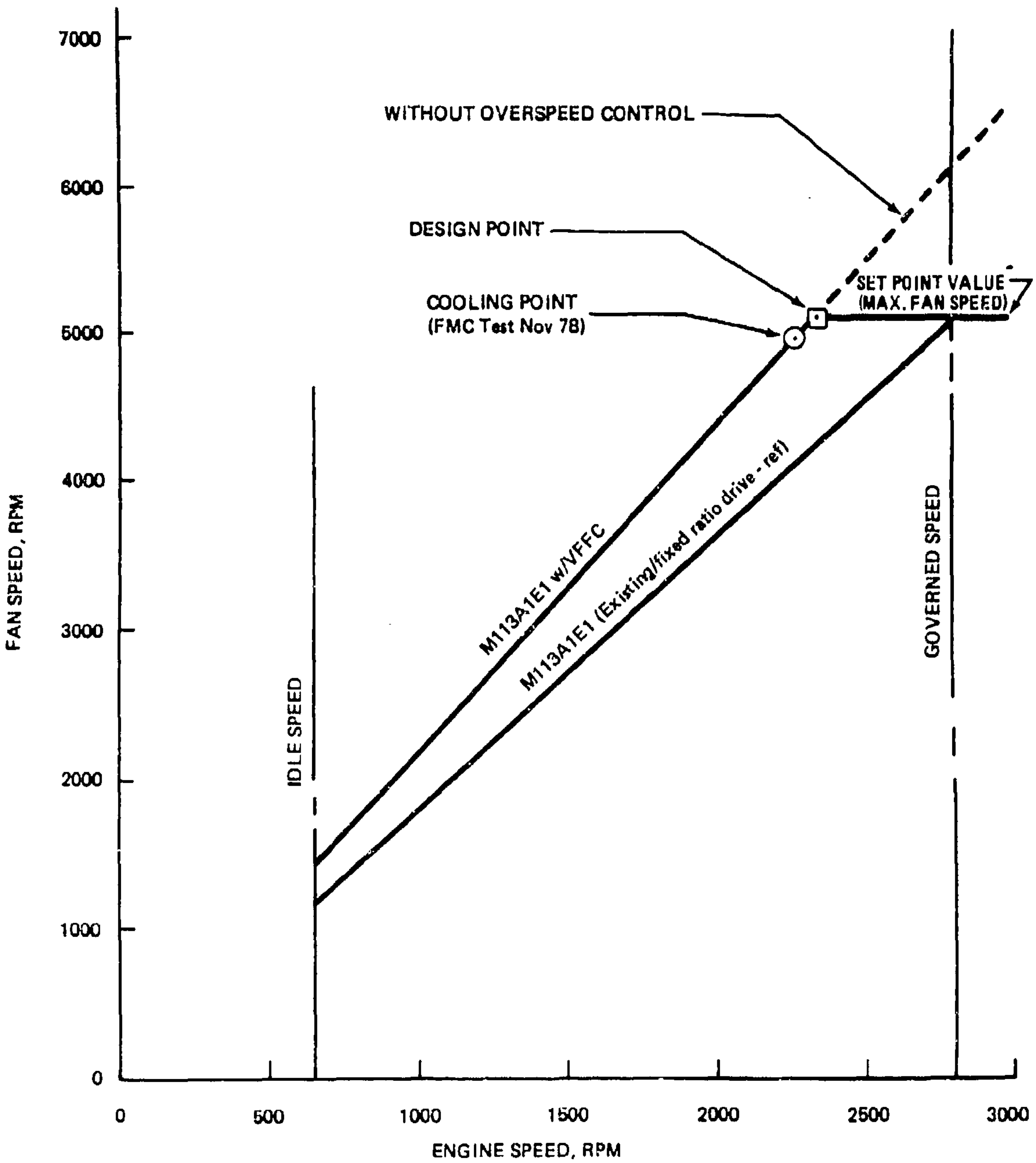


Figure 18

Inherent Overspeed Capability
of
VFFC Fan Drive

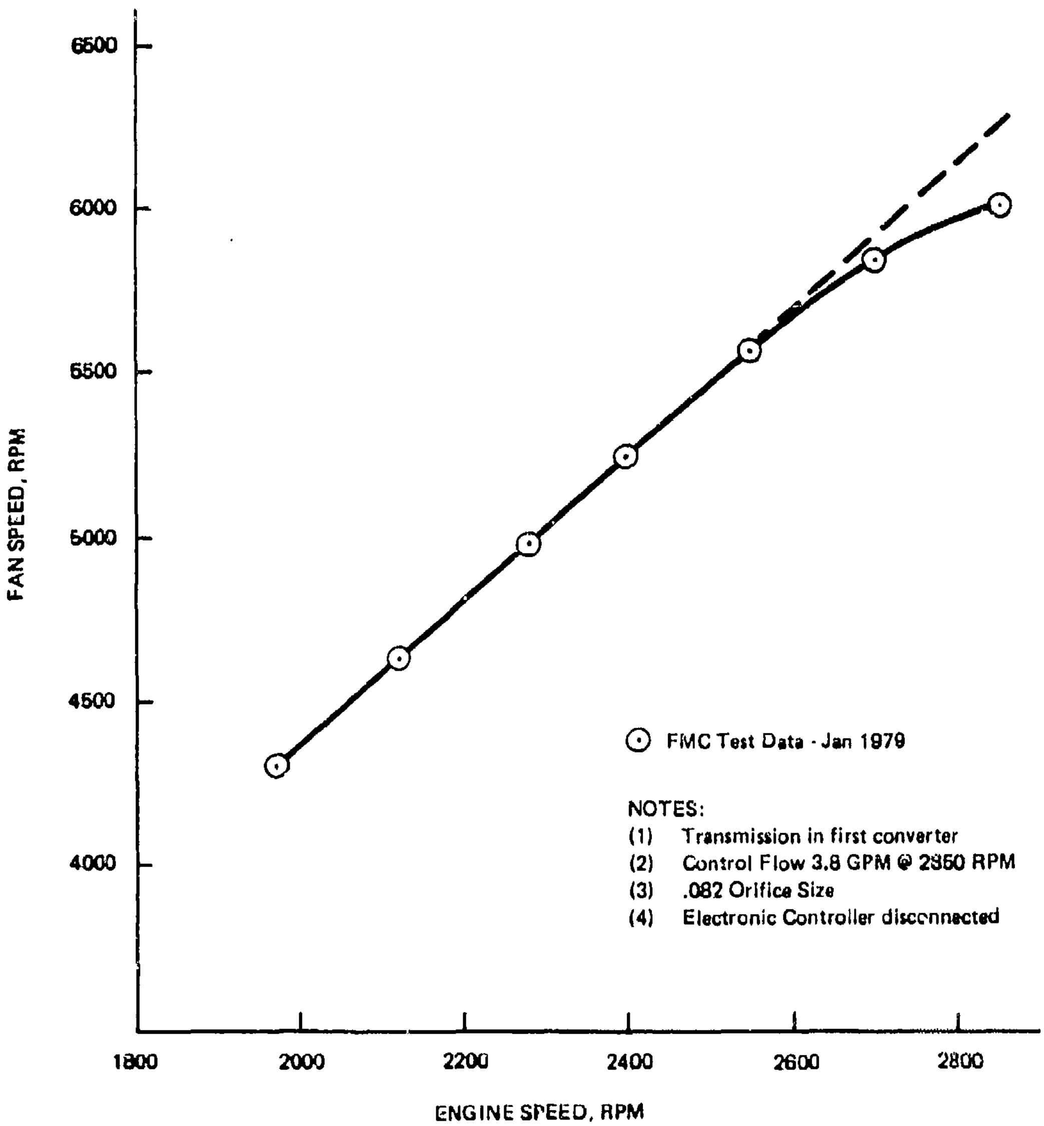


Figure 19

transmission were in lockup mode since the supply pressure and in turn the maximum control flow would be lower. In case of vehicle electrical system failure, this inherent overspeed feature of the coupling provides for lower maximum fan speeds, thus reducing fan noise and increasing belt life.

5.2.4 Coolant Temperature Modulation

Figure 20 illustrates the near straight line modulation that results in the 190-210^{o}F coolant temperature range for the VFFC Fan Drive with Electronic Controller for engine speeds of 2300 and 2750 rpm. Note that the fan overspeed circuit limited the maximum fan speed to the 5100 rpm design value at 2750 engine rpm. Figure 21 is provided only as a reference to demonstrate the trend of operation at lower engine speeds. It was generated with valve A and slightly different controller settings.

A flow of approximately 3.45 gpm was required to provide full couple (minimum slip) at 2300 engine rpm. Also, the flow at 190^{o}F is approximately 2.20 gpm. Further modulation down to 180^{o}F was attempted; however, stabilization of coolant temperatures was not possible for engine speeds greater than 2300 rpm.

Figures 20 and 21 were generated with the transmission in first converter. Since valve performance is somewhat dependent on supply pressure, modulation performance would probably vary slightly for lockup operation. Further testing in lockup was scheduled but due to transmission failure, it was not performed.

A characteristic of the coupling observed during testing was cycling of the coupling output speed at low fill levels. The period of oscillation was approximately 2-3 seconds with the change in fan speed of plus or minus 300 rpm, i.e., fan speed cycled between 1150 and 1700 rpm at a 1.85 gpm flow rate at engine speed of 2130 rpm. For this example, a stabilized fan speed was reached

Fan Speed vs Coolant Temperature
for
VFFC Fan Drive
with
Electronic Control

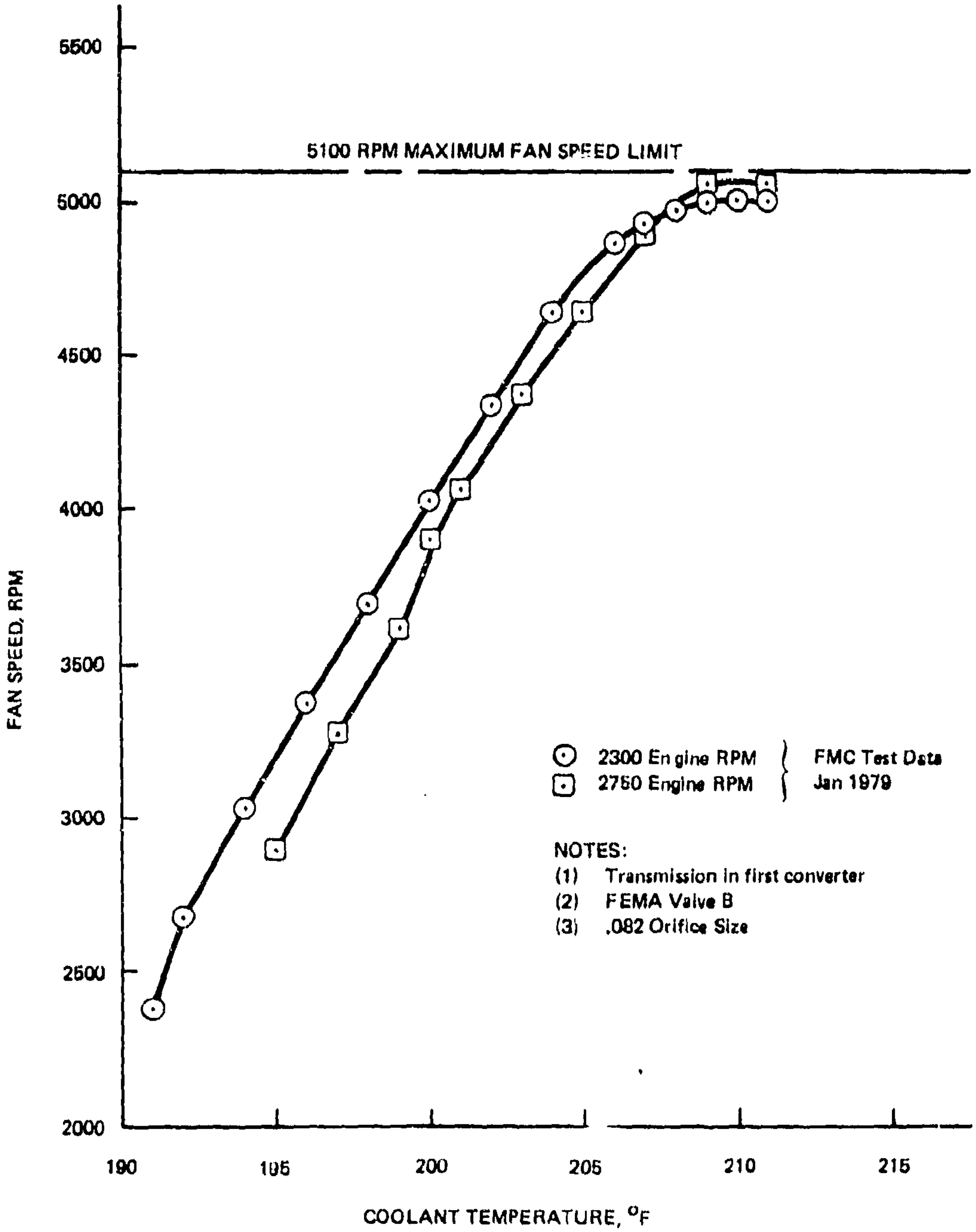


Figure 20

Fan Speed vs Coolant Temperature
for
VFFC Fan Drive
with
Electronic Control

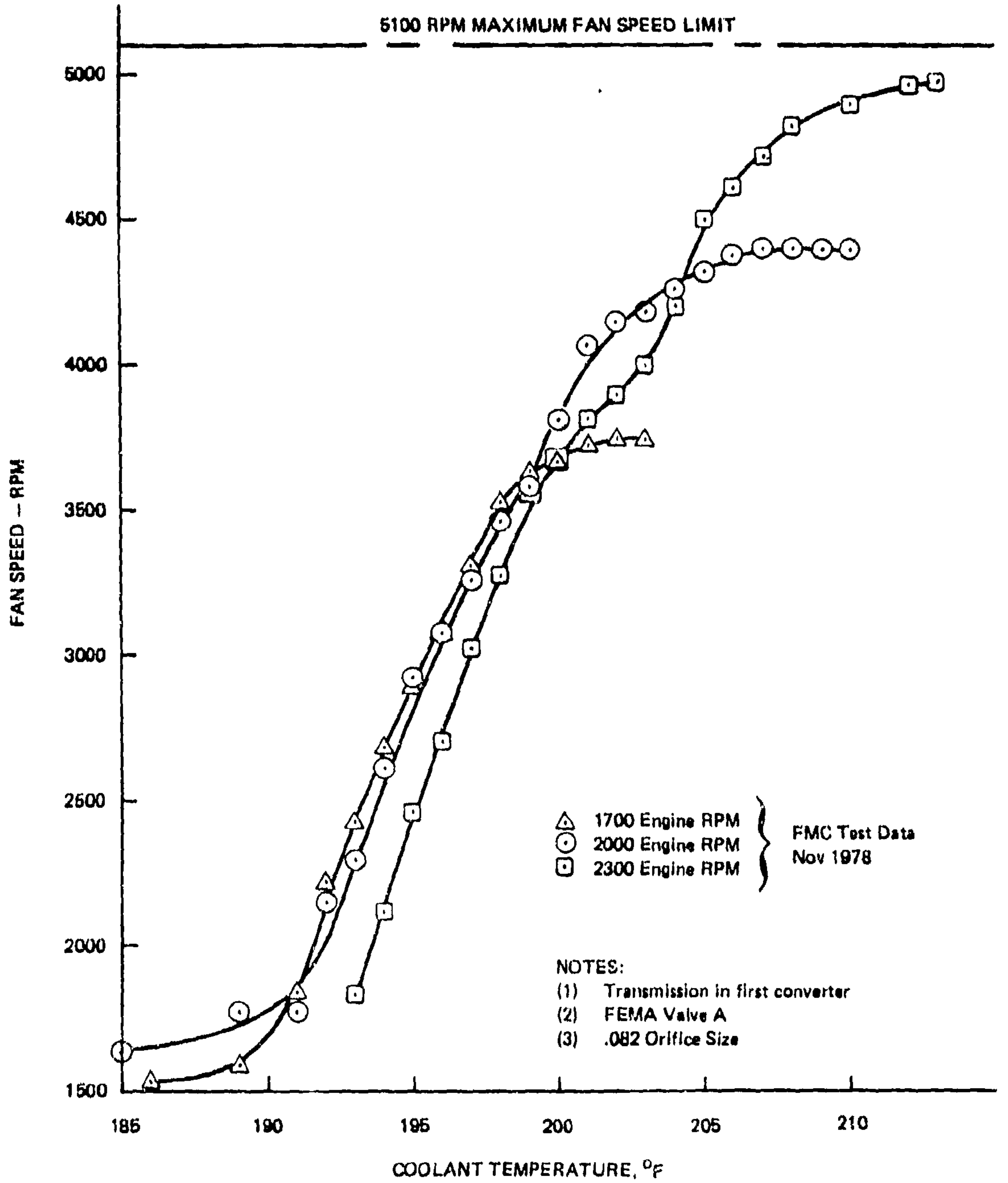


Figure 21

as soon as flow reached 2.0 gpm. Thus, data indicates an instability in the fluid coupling exists when slip is between 55 and 65%. This same instability was observed during testing performed under TARADCOM Contract DAAE07-75-C-0079 (Variable Rate Cooling) for the relieved vane coupling configuration. As reported in that contract, this cycling could be eliminated if vanes are not relieved. However, due to assembly constraints of this design and space limitations, a non-relieved coupling configuration could not be incorporated. In addition due to the fact that the engine speed is constantly changing under normal vehicle operation, it was felt that this cycling would not occur often or would not be objectional during actual vehicle operation. Field testing should verify this.

5.2.5 High Tractive Effort/High Ambient Cooling

Test data shows close correlation with predicted results as shown on Figure 22. As can be seen the VFFC Fan Drive provides a substantial increase in vehicle cooling capability (.525 to .65 TE/GVW). It should be noted that the measured 2270 rpm engine speed at the cooling point is lower than the predicted 2350 rpm which accounts for the fan speed to be nearly 100 rpm less than the 5100 rpm design point value. The 5.6% slip is as predicted for the coupling.

5.2.6 Road Load/Normal Ambient Cooling

As illustrated on Figure 23, the VFFC Fan Drive with Electronic Controller provides a substantial reduction in vehicle cooling fan drive power (58-72%) for the various road load conditions tested at 80°F ambient. Further reduction in fan power at lower road loads and/or ambients can be expected. Figure 24 depicts how fan speed and coolant temperature varies with ambient temperature for a given road load condition. Note that since fan speed increases with ambient, the coolant temperature remains more constant instead of increasing degree for degree with ambient temperature. This should improve engine life. As can be seen from Figures 23 and 24, the temperature modulation capability of the VFFC Fan Drive with EC has successfully been demonstrated.

M113A1E1 Cooling System Performance
with
Variable Fill Fluid Coupling Fan Drive
FOM4599 for
125°F Ambient
295 HP Engine
Fan FOM4079–2

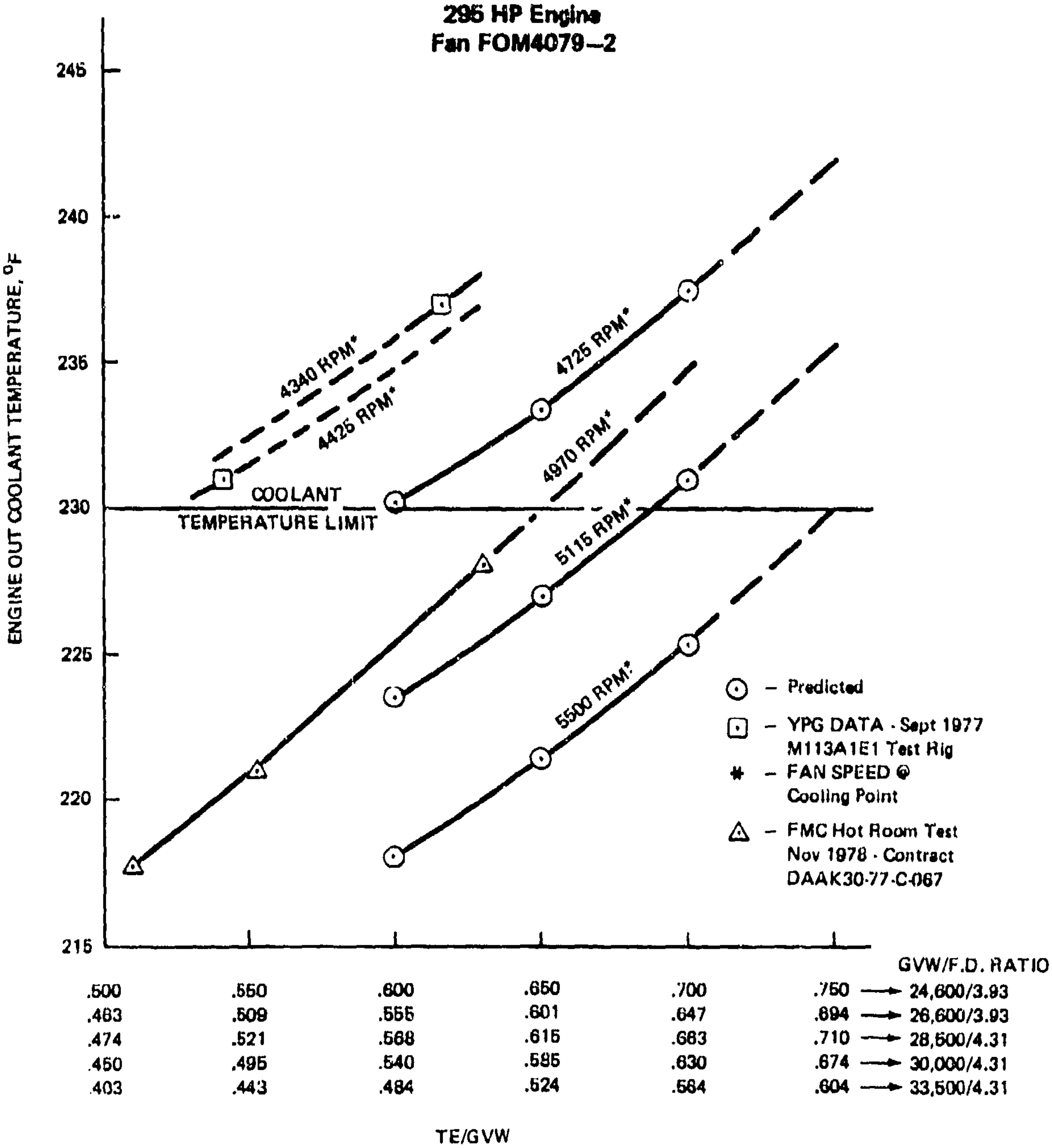
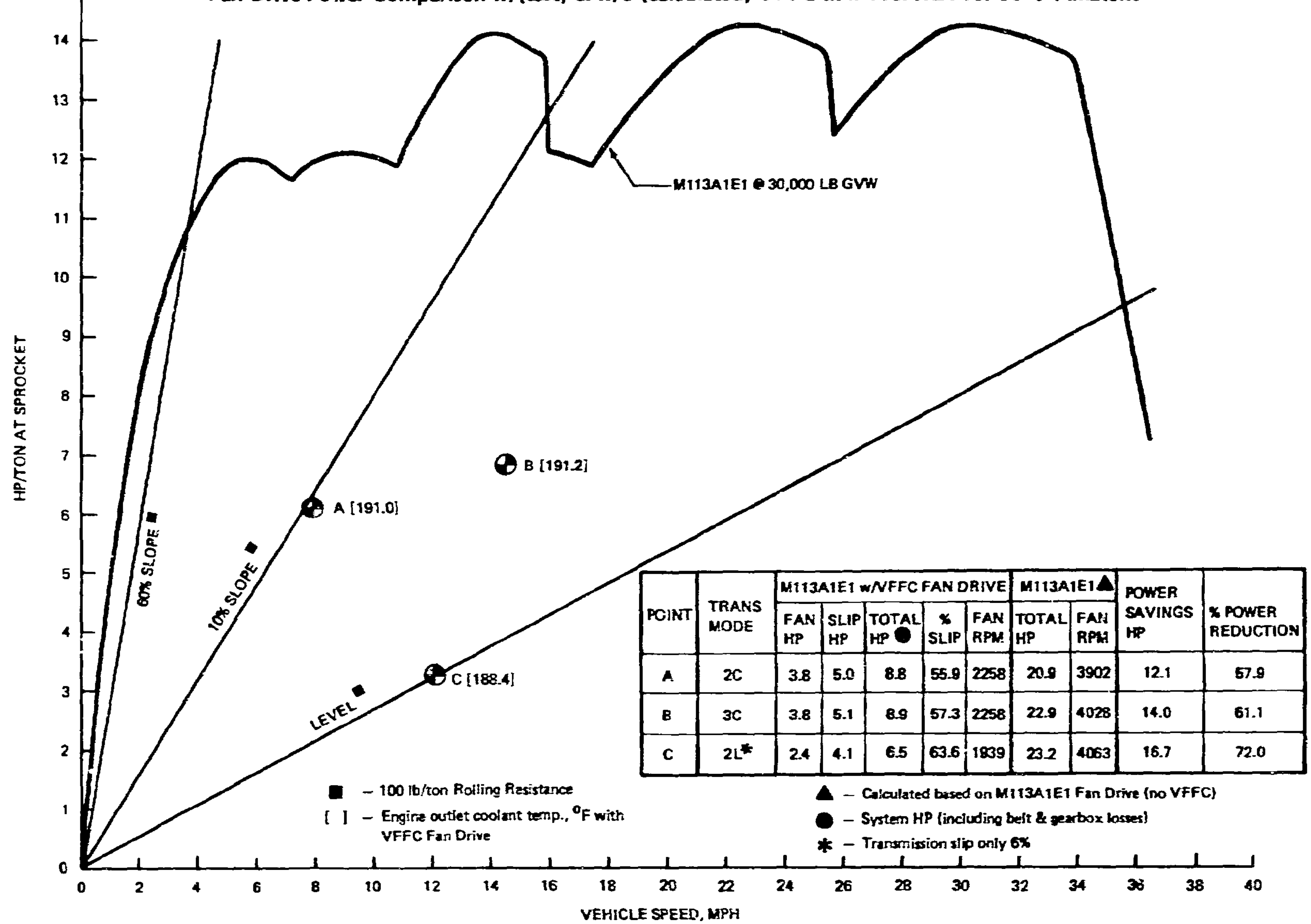


Figure 22

FMC

Fan Drive Power Comparison w/(test) & w/o (calculated) VFFC in M113A1E1 for 80°F Ambient



POINT	TRANS MODE	M113A1E1 w/VFFC FAN DRIVE					M113A1E1 ▲		POWER SAVINGS HP	% POWER REDUCTION
		FAN HP	SLIP HP	TOTAL HP ●	% SLIP	FAN RPM	TOTAL HP	FAN RPM		
A	2C	3.8	5.0	8.8	55.9	2258	20.9	3902	12.1	57.9
B	3C	3.8	5.1	8.9	57.3	2258	22.9	4028	14.0	61.1
C	2L*	2.4	4.1	6.5	63.6	1939	23.2	4063	16.7	72.0

▲ – Calculated based on M113A1E1 Fan Drive (no VFFC)
● – System HP (including belt & gearbox losses)
* – Transmission slip only 6%

Figure 23

Fan Speed Comparison
w/ & w/o VFFC Fan Drive
in M113A1E1 vs
Ambient Temperature
For 2nd Converter Operation
(~8 MPH & 10% Slope)

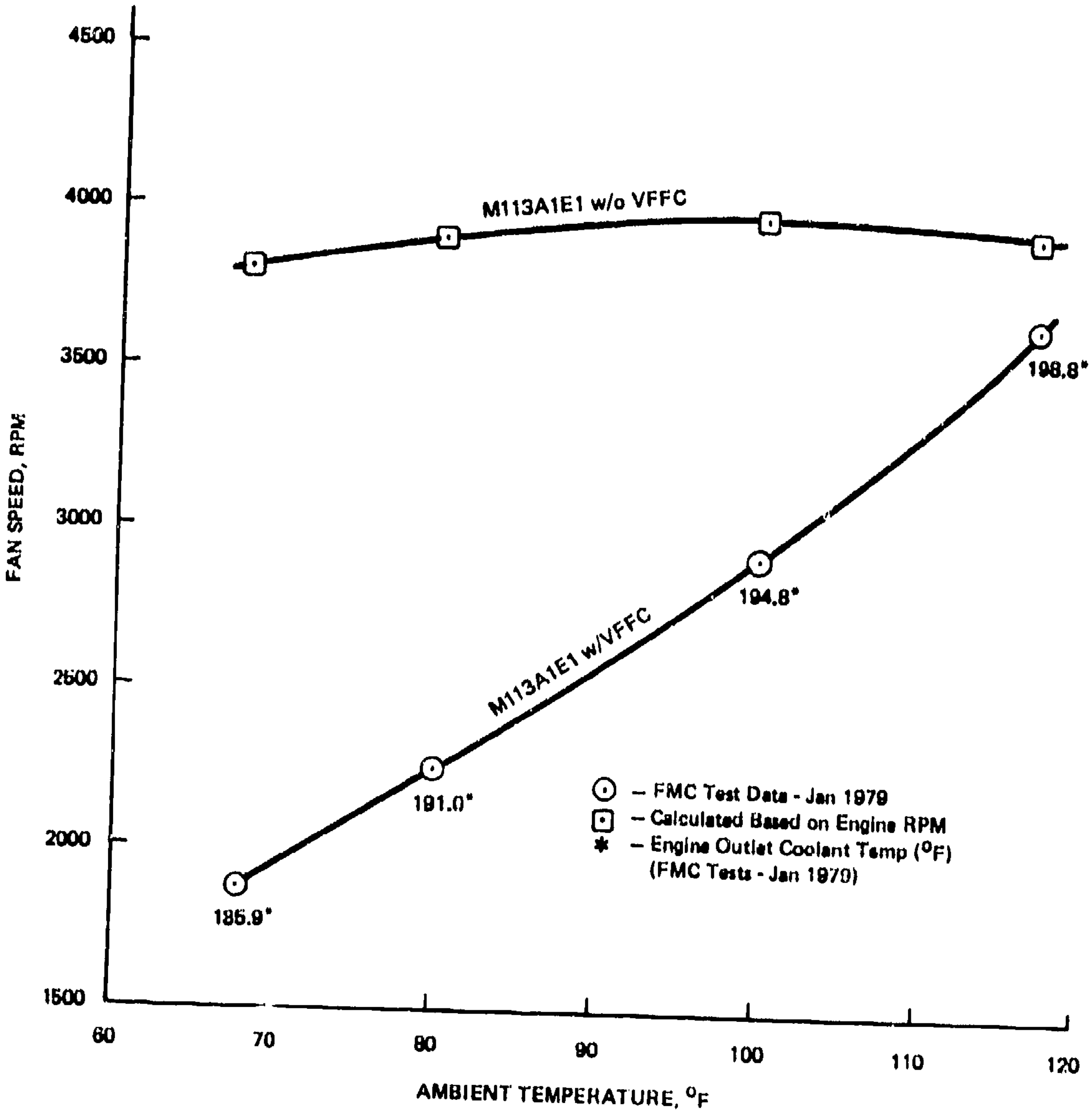


Figure 24

It should be noted that tests were performed for other road load conditions with the transmission in lockup; however, data was omitted due to excessive slip in the transmission which appears to be due to lockup clutch failure. (Refer to Sections 5.1 and 5.3).

5.2.7 VFFC Fan Drive Cooling

During testing it was observed that the temperature rise through the coupling was excessive. In order to further understand this problem, the input and output VFFC pulleys were pinned together through the use of the manual lockup provision discussed in Section 3.3. It was found that the temperature rise was 20-30°F depending on engine rpm (the faster the rpm, the greater the rise). This indicates that the oil is being captured in the coupling housing and churned by the rotating coupling assembly. After studying the housing drain, FMC feels that an improved design to reduce the housing drain restriction to the discharging oil would eliminate this problem.

5.3 Equipment Failures

Vehicle operation was disrupted or delayed during testing due to the following:

- Failed vehicle batteries caused fluctuating supply voltage to the Electronic Controller, resulting in erratic Controller operation.
- Deteriorated fuel line between fuel tank and engine compartment bulkhead resulted in low engine power due to low rail pressure. Also, the -6 line between the engine and bulkhead was replaced with a -8 line which increased the fuel rail pressure by 5-10 psi. (DDAD field service handbook recommends a -8 line).
- Fluid coupling magnetic pickup failed (case cracked at root of threads) due to overtorqueing. The magnetic

pickup, Airpax Model 1-0294, is relatively fragile; a more durable model is recommended with an MS electrical connector.

- Transmission failure occurred twice. The second failure caused termination of all hot room dynamometer testing.

The initial transmission failure was during first converter operation under high load. Teardown inspection revealed that the range output driven gear fractured through the webs, causing separation from hub. Additional damage to several other gears and shafts resulted. The damaged transmission parts were replaced and the transmission reinstalled in the vehicle.

The second transmission failure (excessive slip) was discovered during lockup operation at road loads. Transmission teardown was preceded by three clogged transmission oil filters in less than 40 hours of operation time. The first transmission filter collapsed, sending contaminated oil to the transmission and fluid coupling. After the first transmission oil filter failure, pressure drop across the filter was monitored. The following two filters were replaced when pressure drop across the filter reached 50 psig.

Teardown of the lockup clutch and converter housing revealed the following:

- Excessive foreign material in the lockup cover assembly
- Lockup clutch plate shows loss of clutch plate material at inside diameter. No apparent surface wear.
- Lockup clutch piston seal shows foreign material build-up.
- Cracked outer race of the converter double row ball bearing and loss of ball separator.
- Converter pump surfaces excessively worn by material passing between it and the adjacent surfaces of the turbine which were also worn.

SECTION 6

PRODUCTION TYPE VFFC FAN DRIVE DESIGN

As shown in Figure 25, a smaller diameter, more compact coupling unit, located at the input of the existing M113A1E1 fan assembly (with modified fan support) appears feasible for a production configuration based on preliminary studies conducted by FMC. This design would considerably simplify the belt drive since it consists of a single 4-groove powerband belt (possibly the existing M113A1E1 belt). Because of the relatively high location in the vehicle with respect to the transmission, it appears that the need for a sump pump on the coupling drain line could possibly be eliminated. Further work needs to be performed to completely design/evaluate this compact coupling unit arrangement and the corresponding vehicle installation.

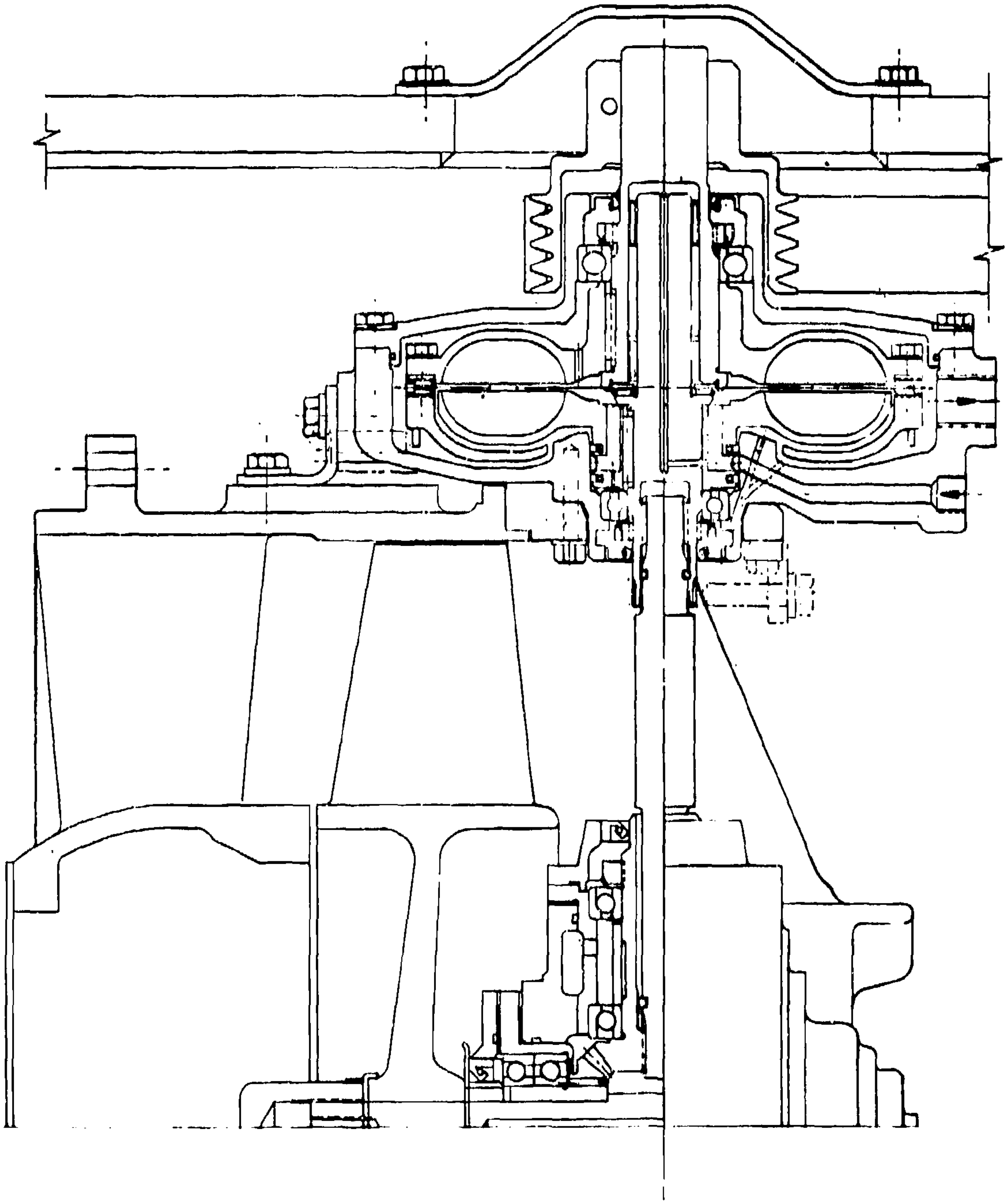


Figure 25. Fan Mounted VFFC Fan Drive for M113A1E1, FMC Dwg 4198471