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Characterization and Analysis of the UEL 1100 Oil Pump

by Logan P. Riley and Albert K. Owen

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14. ABSTRACT

The U.S. Army's Shadow unmanned aerial vehicle (UAV) is an indispensable tool in modern military intelligence acquisition. The Shadow is powered by one UEL 1100 engine, a single-rotor Wankel engine. However, at high-altitude, low-temperature conditions, engine operation may be compromised due to insufficient oil delivery to the engine. To develop a better understanding of the engine system's oil delivery, we have evaluated the performance of the oil pump. Testing consisted of measuring oil pumping capability at various temperatures and speeds, and with different grades of oil.

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1. Background

The UEL 1100 series rotary engines (UEL 1100 and UEL 1101) power the U.S. Army Shadow unmanned aerial vehicle (UAV). This vehicle has been used in situations where it has experienced operational difficulties due to extremely cold conditions (~ –20 ºF). The Aviation Engineering Directorate (AED) of the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) tasked the U.S. Army Research Laboratory's (ARL) Vehicle Technology Directorate (VTD) to provide experimental data to aid in evaluating potential solutions to this problem.

In order to facilitate the development of an adequate solution, oil pumps for the engine used on the UAV underwent extensive laboratory evaluation at VTD. The focus of this research was on the characterization of the pump's performance with various oils and the collection of data to help determine the most appropriate solution to the observed field problem.

In characterizing the pump, we examined several variables to define the pump performance. Pump speed, head pressure, exit back pressure, temperatures of the oil, the oil intake line, the oil pump, and the type of oil were all factors considered and tested. This analysis, however, primarily focused on the different weight oils and the effect of temperature on the oil and oil pump. As the tests progressed, however, interest in not only the temperature of the pump, but of the feed line and oil reservoir, developed.

2. Oil Types

Three oil types were considered in this initial analysis: an 0W-40 automotive oil, a 15W-40 automotive oil, and a turbine oil meeting specification MIL-23699. The 15W-40 is currently in use in the field. We chose the other two oils for their respective viscosity properties. These three oils were tested to assess changes in pump performance with the different viscosity oils.

3. Oil Pump

The five pumps provided for this study are identified in table 1. Of the five pumps, four were field tested. These pumps, numbered two through five, were screened in a 15-min field test, which looked for pumps that did not meet the minimum requirement of pumping 50 mL in

15 min (200 mL/hr). Pumps two and three were tested at VTD and showed comparable results for the typical flow rates. Pump four, one of the pumps that failed the screen, was also evaluated during this project.

Table 1. Oil pumps evaluated.

Pump #	Pump S/N	Field Test
1	FT73-2440	n/a
2	FT73-6353	pass
3	FT73-6383	pass
4	FT73-6350	fail
5	FT73-6356	fail

Figure 1 is a picture of the oil pump. There is one inlet port and four outlet ports (labeled 1 through 4). Outlet ports 1 and 2 feed the shaft bearings and ports 3 and 4 feed the rotator seals.

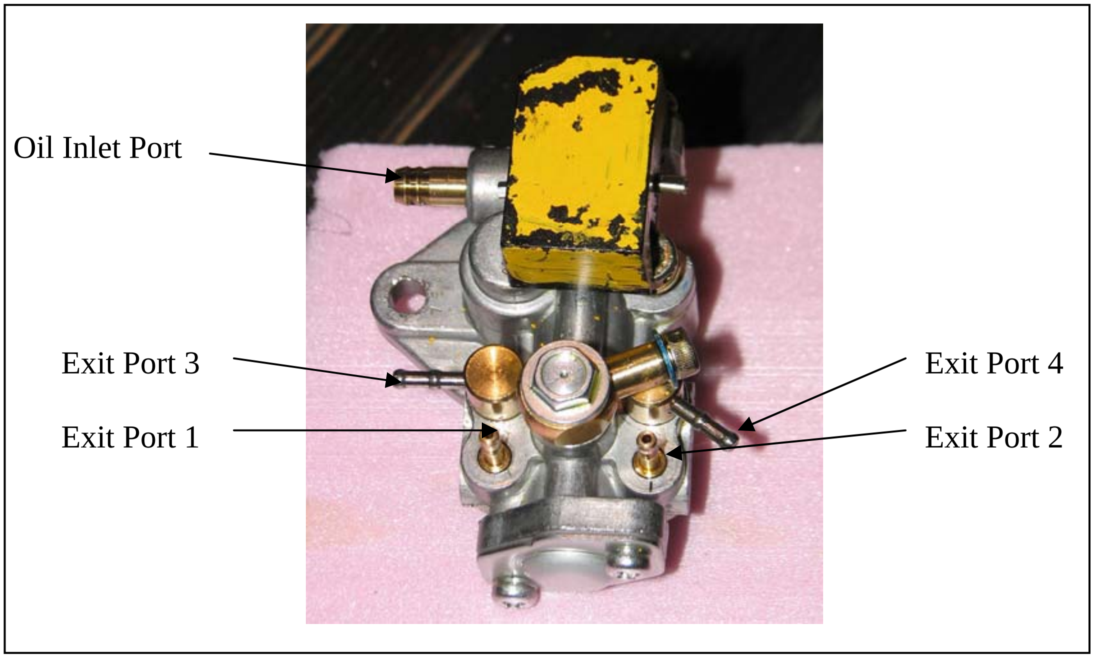

Figure 1. Oil pump showing oil outlets.

To better understand the operation of the pump and to provide information for a computational simulation analysis of pump operation and a further exploration of pump performance using other oils, one of the pumps was disassembled. This disassembly confirmed that the internal pump mechanism is geared down at an 11-to-1 ratio. Thus, for every 11 turns of the pump drive shaft, the cylinder that pumps the oil rotates once.

4. Test Configurations

The pumps were tested using one of two rig configurations. The first configuration provided test data to analyze how speed and head pressure affected flow. However, a key focus of this study was to investigate the influence of temperature on different viscosity oils. Therefore, the first configuration, shown in figure 2, was later altered to create a rig that allowed for the temperature to be lowered using dry ice.

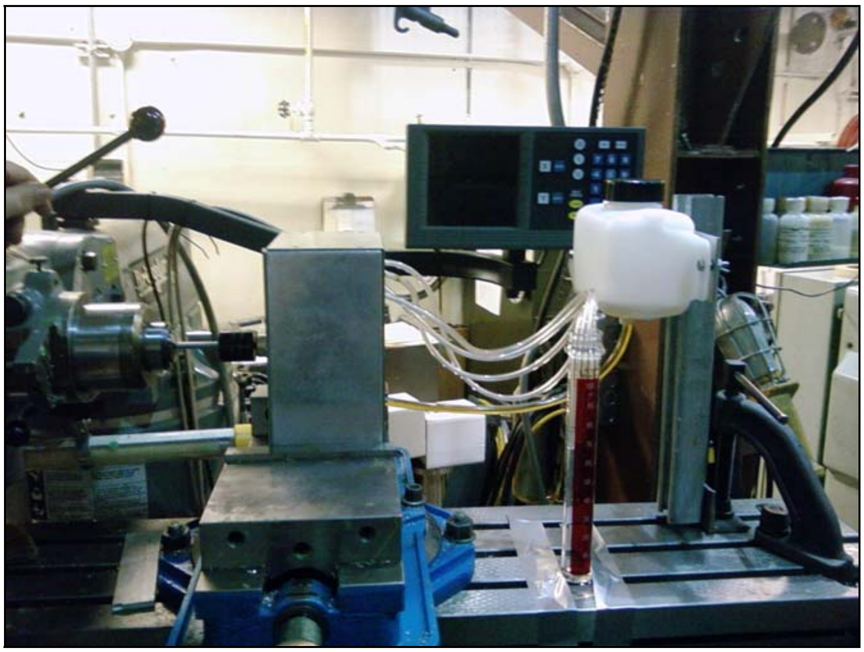

Figure 2. Configuration 1.

The milling machine sits at the left, as shown in figures 2, 3, and 4, with its spindle rotated 90º to horizontal. The milling machine was used to drive the pump. In the center is a metal box to which the pump is mounted. At the right sits a 1.5 qt capacity oil tank and a set of four graduated cylinders for collecting the oil, shown in figure 4. This UEL engine uses a total loss oil system. Thus, in the field, oil is not returned to the oil tank and recirculated. However, in this study of the pump, oil was reused.

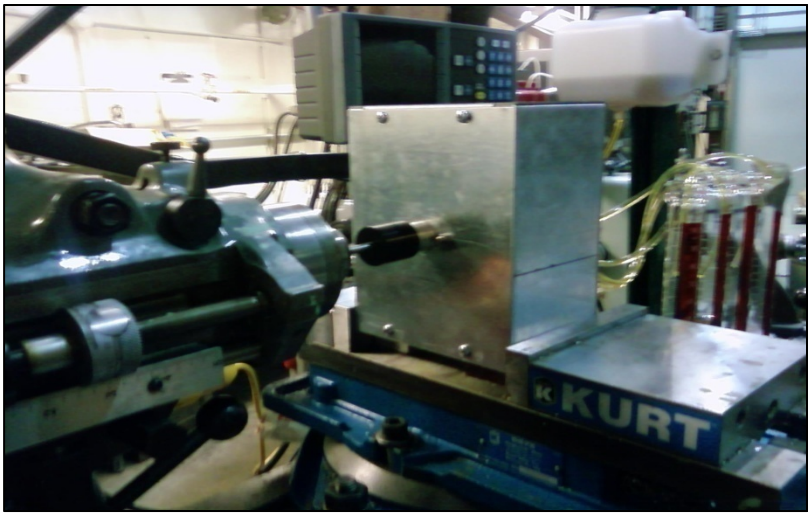

Figure 3. Initial trials used this configuration.

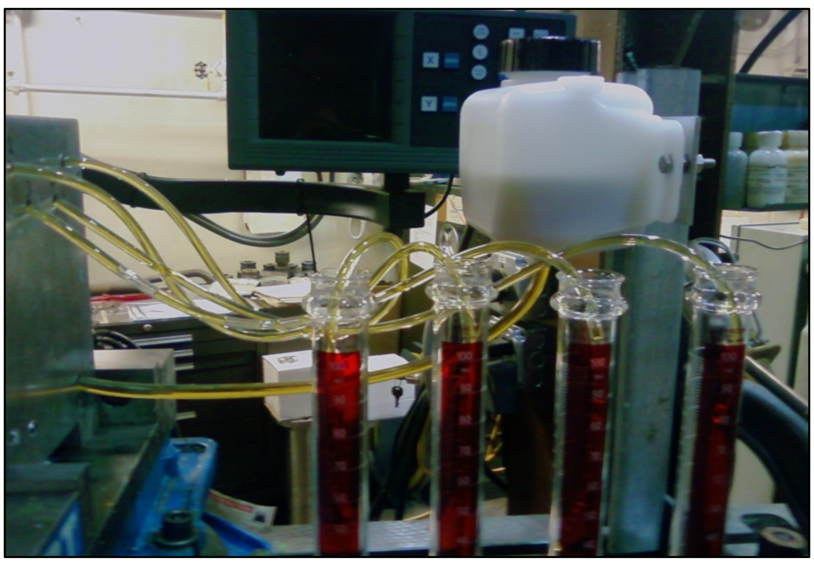

Figure 4. Graduated cylinders collect the oil from their respective lines.

The second configuration of the test rig, as shown in figures 5, 6, and 7, was used for testing the oils and pump at different temperatures. More specifically, oil and oil pump performance below 0 ºC was studied using this configuration. It features a typical beverage cooler set on the milling machine bed with the pump and oil tank mounted within. The pump is driven by a milling machine shaft with a flexible coupling as in the first configuration.

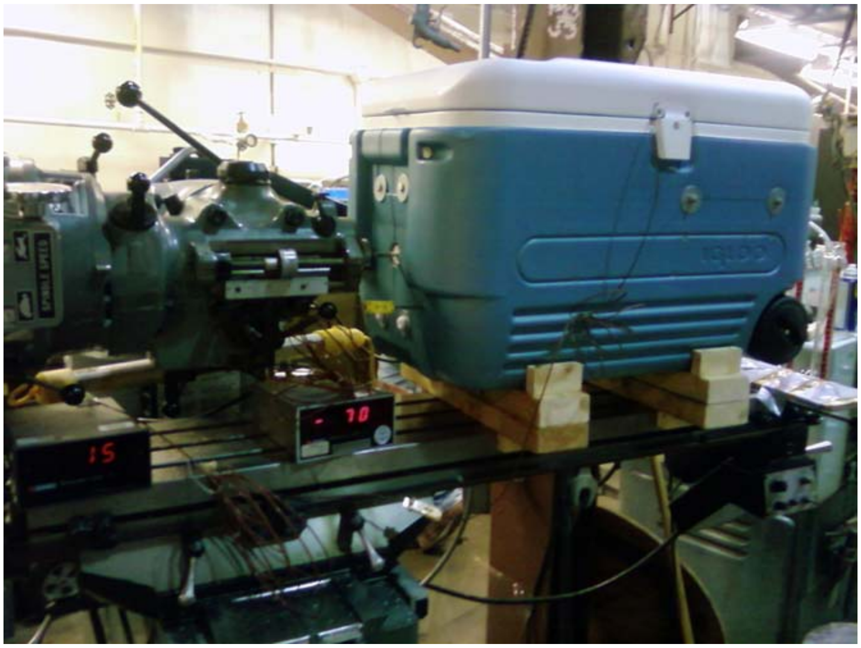

Figure 5. Configuration 2 (side).

Figure 6. Top view of “cold” configuration.

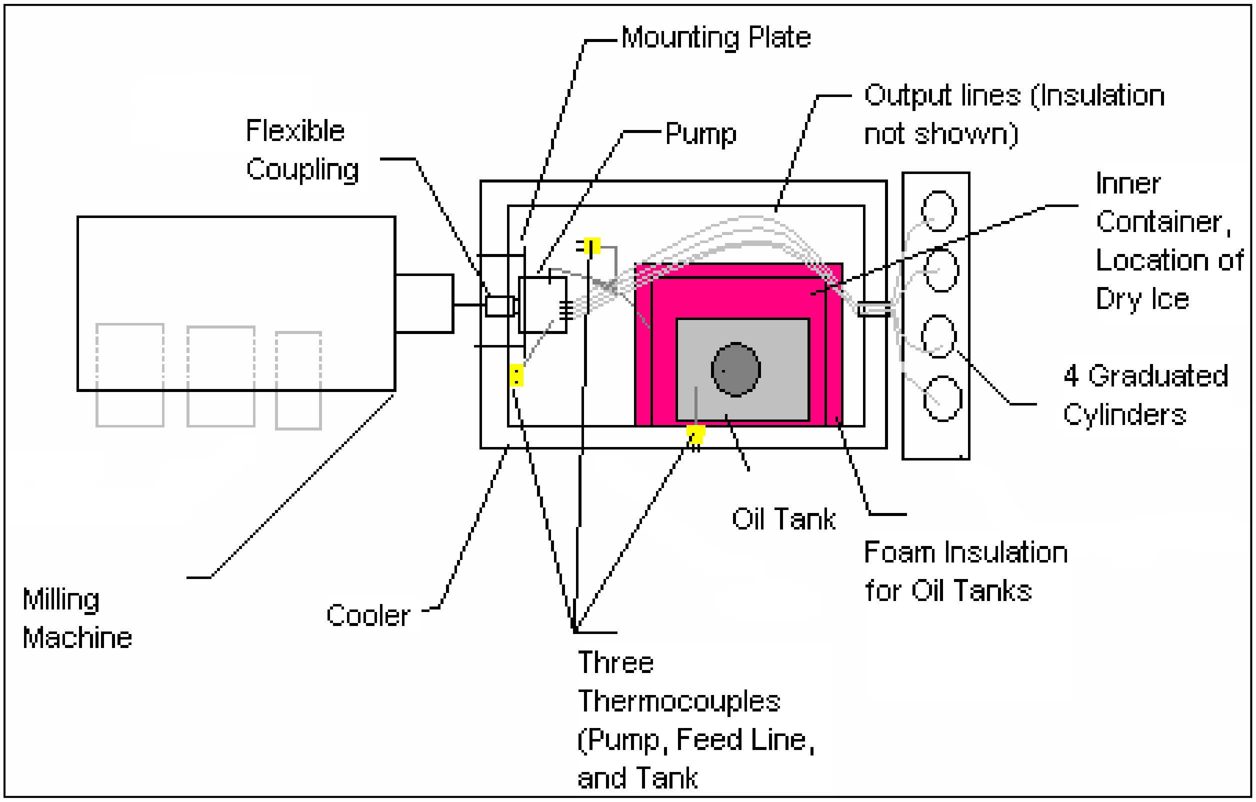

Figure 7. A schematic top view of "cold" rig layout.

Initially, one thermocouple measured the temperature of the oil within the reservoir, and another measured the air temperature inside the cooler, which was assumed to be indicative of the approximate supply line temperature. A third thermocouple was added to measure the temperature of the oil in the supply line and the air temperature thermocouple was moved adjacent to the pump to display its approximate temperature. The oil reservoir temperature continued to be monitored.

The test configuration was cooled using dry ice. In order to effectively regulate the temperature of the oil, foam insulation was added to the partition around the oil tank to aid in cooling the oil reservoir and insulation was placed around the output lines to keep them warmer. The oil in the long 1/8-in plastic tubing on the output lines repeatedly froze during the initial testing, making the insulation around the output lines necessary to effectively measure oil flow. Clearly, in the operation configurations, the output from the pump will go directly into the engine.

5. Test Procedures

For each experiment, or test condition, 30 min of data was typically collected. Table 2 is a representative sample test matrix. For the initial experiments, three 10-min tests were conducted under each condition. As the study progressed, the experiments were refined so by the end of testing, one uniform 30-min test was conducted for each trial.

During these tests, measurements were made every 5 min to record the volume of oil pumped, and the temperatures of the oil in the tank, the supply line, and pump. The chart in table 2 shows the average temperature.

Table 2. Sample test matrix.

Trial	Configuration	Pump No.	Oil Type	Temperature Oil (K) [a]	Temperature Air (K) [a]	Temperature Line (K) [a]	Duration (min.)
22	2	3	0W-40	Ambient	Ambient	Ambient	30
23	2	3	0W-40	Ambient	Ambient	Ambient	30
24	2	3	0W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	30
25	2	3	0W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	30
26	2	3	Turbine	Ambient	Ambient	Ambient	30
27	2	3	Turbine	Ambient	Ambient	Ambient	30
28	2	3	Turbine	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	30
29	2	3	Turbine	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	30
30	2	3	Turbine	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	30
31	2	3	Turbine	244 (–20 °F)	255 (–20 °F)	244 (–20 °F)	30
32	2	3	15W-40	Ambient	Ambient	Ambient	30
33	2	3	15W-40	Ambient	Ambient	Ambient	30
34	2	3	15W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	30
35	2	3	15W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	30

[a]Temperatures vary.

During "cold" tests, dry ice was added to the insulated tank compartment and to the bed of the cooler. Once the oil in the tank was at the desired temperature, tests were conducted. As necessary, ice was moved or removed to keep the temperatures constant. A small handheld electric fan was to regulate the temperature of the system.

6. Preliminary Testing

While most of the tests took a quantitative approach, a few qualitative analyses, like that of the preliminary testing of the pump, or preliminary testing of the "cold" rig were also conducted.

Following the preliminary test, we conducted a series of three 10-min trials tests in which variables like head pressure and speed were investigated.

Preliminary tests and all ambient temperature tests were typically measured at approximately 295 K.

Under the first configuration, the pump designated number one was tested by running it up to speed in small increments. Results of this part speed testing showed that the pump flow is non-existent or extremely low (>50 mL/hr). A minimum pump speed of 3600 rpm was required to move oil through each of the lines. However, ports 1 and 2 moved oil (if intermittently) even at low rpms. Port 1 pumps roughly the same amount of oil as port 2; likewise, port 3 moves the same amount as port 4. Only at full speed do ports 3 and 4 provide oil; however, they move far less oil than ports 1 and 2. Table 3 provides these results with no flow in port 4 until the pump speed was set to 3000 rpm. Indeed, at that speed, the flow in all ports was intermittent and port 4 flow was characterized as weak.

Table 3. Oil flow in preliminary test.

Pump 1		**Flow**			
Time Elapsed	**RPM**	**Port 1**	**Port 2**	**Port 3**	**Port 4**
0–5 min	1000	Y	Y	R	R
10 min	2000	Y	Y	Y	R
15 min	3000	LG	LG	LG	Y
20 min	4000	G	G	G	G
25 min	0	LG	R	LG	R

Chart Color Definitions

Flow Rate		
Continuous Flow	G	Green
Moderate/Intermittent	LG	Light Green
Weak/Intermittent	Y	Yellow
None	R	Red

Ports 1 and 2 are believed to send oil to the engine bearings while ports 3 and 4 provide lubrication for the seals.

Oil flowing from the lines leading from the pump was collected into four graduated cylinder (one for each line) and, during these tests, we observed that having the collection cylinders below the pump (thus reducing exit back pressure) caused a number of side effects. In the first line, it significantly increased the number of air bubbles present in the lines, while the second line continued to have a smooth continuous flow. Flow in the third line was significantly reduced and no flow was observed in the fourth line. It must be noted that air found in the lines of this pump is not indicative of the other pumps and was found to be anomalous behavior at warm temperatures. Seals within the pump may be related to the appearance of air in the outlet lines.

The cylinders were placed roughly level with the pump apparatus so that the pump had to pump slightly uphill to the collection cylinders. This kept a small back pressure on the pump allowing for more uniform flow. This test was done only with this pump.

Initial findings indicate that head pressure and back pressure, though they have an effect on the quality of the flow, do not typically show significant changes in the amount of oil pumped. However, head pressure cannot be expected to change significantly even if the oil reservoir in the aircraft were to be moved (up or down), unless the aircraft executes an unusual maneuver during flight.

Back pressure, though, is important in keeping oil flowing through all of the lines. Low back pressure caused the lines of the first pump to show large increases in the number of air pockets or caused some lines to cease functioning entirely. Although the reason back pressure is required is not known, back pressure is important to oil delivery to the engine.

Thus, these parameters were largely ignored in the later part of the analysis, and the remainder of the study centered on effect of oil on flow rates. Testing showed that the maximum output by any of the pumps under ambient conditions (~295 K) was 300 mL/hr. This served as a point of comparison during the other tests.

7. Ice Testing

The initial "cold" analysis, given in table 4, followed a similar format to that of the preliminary test of the pump.

Table 4. Preliminary ice testing, pump 2, 30 June 2008.

Temperature (K)	Port 1	Port 2	Port 3	Port 4
255	G	G	G	G
250	LG	LG	LG	LG
244	Y	Y	Y	Y
239	R	R	R	R

Chart Color Definitions

Flow rate		
Nominal	G	Green
Moderate	LG	Light Green
Weak	Y	Yellow
None	R	Red

As the oil approaches 244 K (–20 °F) overall output drops considerably, and below this temperature, oil flow ceases entirely. Data from subsequent testing are provided in table 5.

Table 5. Temperature analysis matrix.

Oil Type	Temperature Oil (K) [a]	Temperature Air (K) [a]	Temperature Line (K) [a]	Pump (RPM)	Duration (min)	Average Oil Flow (mL/h)
0W-40	Ambient	Ambient	Ambient	4000	30	288.00
0W-40	Ambient	Ambient	Ambient	4000	30	312.00
0W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	72.00
0W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	36.00
Turbine	Ambient	Ambient	Ambient	4000	30	300.00
Turbine	Ambient	Ambient	Ambient	4000	30	300.00
Turbine	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	24.00
Turbine	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	36.00
Turbine	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	36.00
Turbine	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	36.00
15W-40	Ambient	Ambient	Ambient	4000	30	312.00
15W-40	Ambient	Ambient	Ambient	4000	30	300.00
15W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	48.00
15W-40	244 (–20 °F)	244 (–20 °F)	244 (–20 °F)	4000	30	48.00

[a]Temperatures vary.

Also of note, of the three pumps tested under conditions around 244 K, air appeared in the output lines of all three pumps. Figure 8 is indicative of the extent that air appeared in the oil output lines. During these cold tests 90–95% of the length of the output lines contained air. As the oil warmed the volume of air in the lines decreased. It is hypothesized that seals within the pump do not react well at cold temperatures, thereby allowing air to be introduced into the system.

Figure 8. Air in lines at cold temperatures.

At 244 K, all of the oils became very thick, almost solid substances. After thawing, sediment in the oils was also observed. Extreme temperature changes may bring the heavier elements in the oil out of solution.

Most importantly, in monitoring the temperature of the oil and the pump, the pump was found to generate a considerable amount of heat, even at cold temperatures. Notice in figure 8 that the pump temperature remained at roughly 290 K even at air and oil temperatures of 244 K. Even at this low air temperature, the pump will continue to pump air. This indicates that pump temperature, while it may affect output by a few milliliters, does not inhibit the flow of oil. This implies the temperature of the oil governs the oil flow rates.

The pump has been observed to attain a maximum temperature of 315 K (110 ºF) at ambient temperatures.

Figure 9 shows a comparison of the three oils tested in this analysis (0W-40, 15W-40, and MIL-23699). The comparison of the warm and cold tests in figure 9 show that changing the oils did not affect flow in the pump significantly. In this plot, each oil was tested for 30 min with the flow rate measured every 5 min (tests 1 through 5).

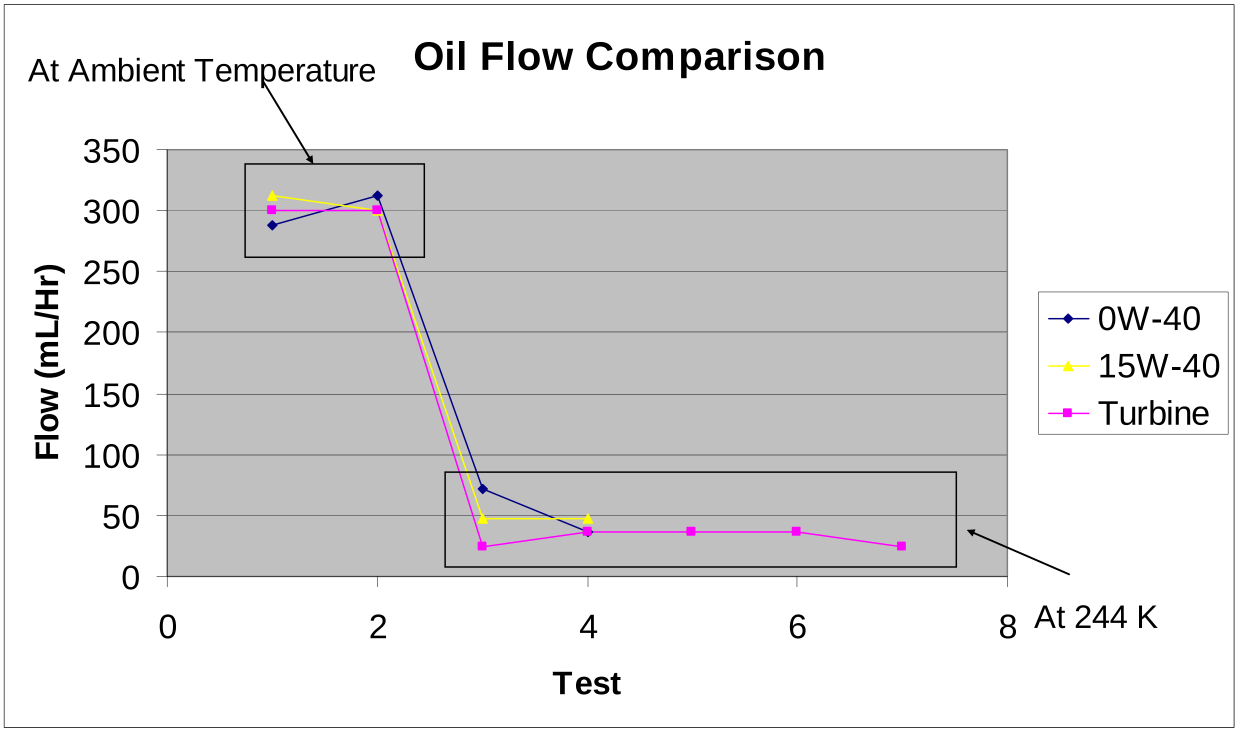

Figure 9. Comparison of the three oils tested in this analysis (0W-40, 15W-40, and MIL-23699).

Figure 10 show a plot of the effects of oil temperature on flow rate for the current oil using the 15W-40 oil. As the oil temperature decreases, the oil flow decreases significantly.

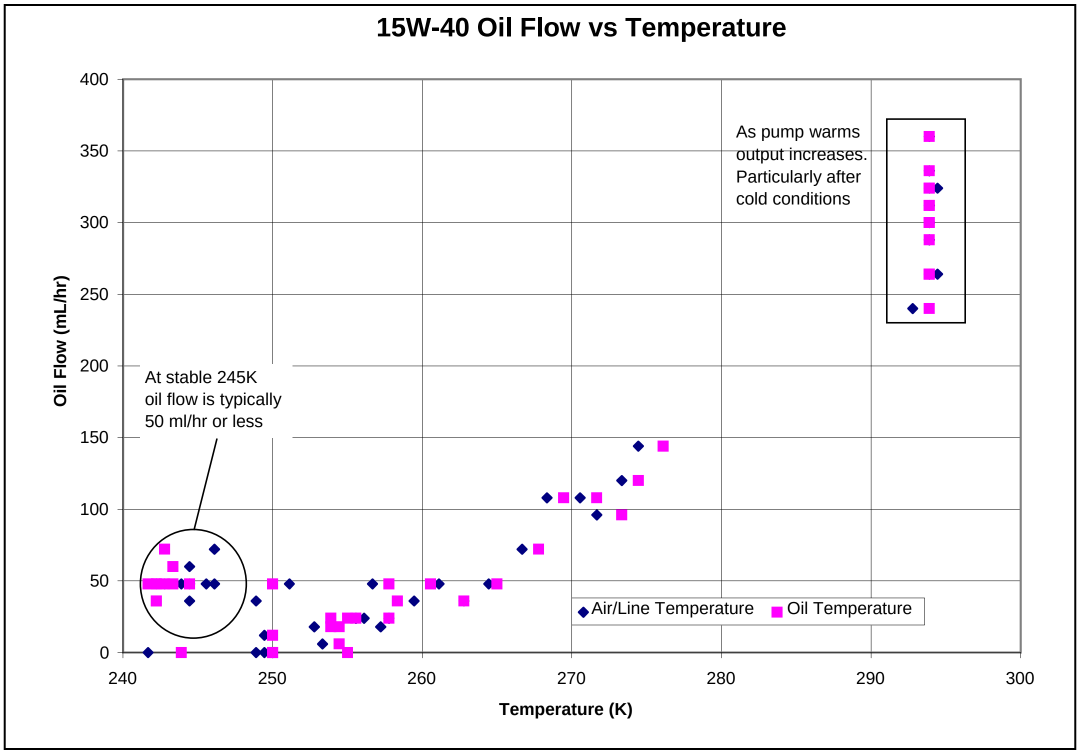

Figure 10. Test of field oil (15-40W) vs. temperature.

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8. Conclusions

In this project, several important factors and characteristics regarding the oil pump used on the Shadow UEL 1101 engine have been determined. First, it appears that different oil viscosities do not have a significant influence over the oil flow. In addition, since the pump warms itself significantly during operation, pump temperature is not significant factor, as originally thought. While fluctuations in pump temperature may influence the flow, it generates considerable heat while running, and will continue to pump, albeit with a significant amount of air in the lines at cold temperatures. Air bubbles in the exit flow lines present a huge loss of oil flow. The air in the output lines is likely related to seals within the pump and should be considered for future analysis of the pump. Also, operating speed plays a significant factor in performance. A very slight reduction in pump speed will stop oil flows to one or possibly two output lines. Furthermore, there exist some instances in which pump performance appears to drop off after 20 min, suggesting longer pump screenings may be needed.

Overall, the pump is typically ineffective in terms of oil delivery during very cold weather operation; thus, an alternative positive displacement pump may be the only effective solution to addressing the oil delivery concerns of the Shadow engine.

List of Symbols, Abbreviations, and Acronyms

AED	Aviation Engineering directorate
AMRDEC	Aviation and Missile Research, development, and Engineering Center
ARL	U.S. Army Research Laboratory
UAV	unmanned aerial vehicle
VTD	Vehicle Technology Directroate

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