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No. 13539

DEVELOPMENT OF A KIT FOR IMPROVED
PERFORMANCE OF THE MOST VEHICLE IN
SEVERE COLD ENVIRONMENTS

April 1991

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A kit and methodology for improved severe cold environment performance of the Mobile Over Snow Transport (MOST) System was developed using "off-the-shelf" itmes. Together with a literature search and laboratory tests in a cold room of temperatures down to -50°F, a kit and techniques were developed for cold starting capability. A discussion of several suggestions for preparations of components on the MOST vehicle prior to conducting a mission in severe cold envioronments is also presented.

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DEVELOPMENT OF A KIT FOR IMPROVED PERFORMANCE OF THE MOST VEHICLE IN SEVERE COLD ENVIRONMENTS

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EXECUTIVE SUMMARY

The Keweenaw Research Center (KRC) was contracted by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the U.S. Army Tank-Automotive Command (TACOM) to develop a kit and methodology for improved severe cold environment performance of the Mobile Over the Snow Transport (MOST) System using current "off-the-shelf" items. Together with a literature search and laboratory tests in a cold room at temperatures down to -50^{0}F, a kit and techniques were developed for cold starting capability. A discussion of several suggestions for preparations of components on the MOST vehicle prior to conducting a mission in severe cold environments is also presented. The appendix contains a draft of a procedure that the soldier may follow in preparation for a mission with the MOST vehicle in severe cold environments.

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Introduction

The Mobile Over Snow Transport (MOST) system will provide Special Forces (SF) an increased capability, through organic mobility, to conduct unconventional warfare, strike and perform strategic intelligence operations in basic cold and severe cold environments. This will allow SF to infiltrate/exfiltrate areas and navigate over long distances with enough subsistence and equipment to perform the mission with an increased probability of survival. The MOST will be used by SF in a clandestine role performing operations before, during, and after the declaration of hostilities and during training missions. The MOST will be used in extremely deep battle fronts to allow SF to provide strategic intelligence and strike/interdiction missions as directed by the Theater Commander for National Command Authority for periods up to 30 days. The MOST will be used to conduct missions primarily during limited visibility or darkness.

The MOST is a two component system consisting of a small, fast over snow vehicle (snowmobile) and a sled/ahkio to be used by the SF.

Early Technical Feasibility Tests conducted at Ft. Greely, Alaska demonstrated that the MOST snowmobile may have problems starting and operating reliably in severe cold environments (below -40^{0}F). The purpose of this study was to develop a kit that will allow the vehicle to start and operate in temperatures as low as -50^{0}F.

The Keweenaw Research Center (KRC), a research agency of Michigan Technological University (MTU), was contracted by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the U.S. Army Tank-Automotive Command (TACOM) to perform tests on government furnished snowmobiles and to develop a kit, using current off-the-shelf items and technology, and a methodology for reliable cold starting and operation of the MOST vehicle in severe cold environments.

Testing was conducted at KRC and most of the research was done using the KRC coldroom to produce temperatures down to at least -50^{0}F.

In Alaska, both a Skidoo 503R Cheyenne Safari and a Yamaha ET400 TRN Enticer were tested for cold starting capability, using standard cold start procedures from the manufacturer, as candidates for the MOST system. At KRC, a Yamaha ET400 TRN Enticer, from the Alaska test, was used for developing the cold start kit and procedures, as a typical example of a MOST vehicle.

Background

Although the entire MOST vehicle is subjected to severe cold environments, the cold starting of the two-stroke engine posed the greatest problem. Other problem areas include lubrication points (locations where grease is concentrated and may stiffen when cold), the rubber composite drive belt and the rubber composite track.

In Alaska, while attempting to start the MOST's engine, either it would not start or if it did start at -50^{0}F, the pistons "screeched" on the cylinder walls indicating a lack of lubrication (oil flow into the cylinders). A literature and telephone search revealed that most two-stroke oils available have a high viscosity at -35^{0}F and below. Telephone calls to Belvoir Fuels and Lubricants Laboratory (Belvoir, Virginia) revealed that there was not an arctic oil for two-stroke engines in the military system. Several calls to various snowmobile manufacturers and oil supply companies resulted in the possibility of one company having an oil available within a year. Only at the end of testing was an oil finally found that was advertised to flow adequately at temperatures down to -45^{0}F. CRREL had produced a report (1) in May of 1989 discussing various oils and lubricants available for arctic conditions. Most of the oils for severe cold conditions are made up of synthetic products and can not be used in two-stroke engines because the oil is burned in the two-stroke engine and the by-product of the synthetic oil burning may cause damage to the cylinder walls and piston rings.

Prior to the beginning of testing at KRC, three of the four major snowmobile manufacturers were contacted to find out what they would recommend for more reliable cold starts at temperatures down to -50^{0}F. The three were Polaris, Arctic Cat and Yamaha. Their recommendations were as follows:

Polaris:

- Dilute oil with kerosene (no amount of kerosene given)
- Recommend use of a primer pump
- Inject large amounts of fuel in cylinders
- Install hotter burning spark plugs
- Running engine at high rpm before turning off
- Choke engine before turning off to prevent ice formation

Arctic Cat:

- Recommended use of a primer pump
- Dilute oil with gas or use a pre-mix instead of oil injection. (No amount of gas per tank of oil given)

- Reduce compression ratio
- Use different jets (they didn't say larger or smaller but it seems likely they meant to use larger jets for more fuel in cylinders)

Yamaha:

- Recommended use of a primer pump
- Install hotter burning spark plugs
- Recommended dilution of oil with no more than 5% gas/oil mixture.
- Could possibly use ether but using too much may result in engine damage.

All manufacturers recommended the use of isopropyl alcohol gas deicer (Iso-Heet) in the gas tank to prevent ice formation in the tank and fuel lines. From this background search a test plan was developed.

Test Plan

The test plan developed by TACOM and CRREL called for three cold starts after the vehicle was cold soaked at -50^{0}F for 48 hours. This had to be extended to include warmer temperatures later on in the study as it was difficult to make any progress running tests at just -50^{0}F. The plan also called for monitoring temperatures (using thermocouple instrumentation) of the following:

- Fuel Tank
- Oil Reservoir
- Cylinder Head Temperature
- Ambient Air Temperature

Figures 1, 2 and 3 show the fuel, oil and cylinder head thermocouple installations, respectively. A thermocouple was installed on the engine block early in the testing but it was disgarded later in the test program. The number of pulls on the starter rope required to start the engine was also recorded. Some of these procedures changed slightly as testing went on because the engine sometimes quit running or it was desired to document when full choke, half choke or no choke was used.

Originally, KRC used K type thermocouples and a Diana chart data recorder to record data in the early tests because our computerized data acquisition system was not ready at the time. The K type thermocouples were not accurate at the very cold temperatures so T type thermocouples were ordered at the very beginning of the project. These did not arrive until after the early tests were completed. It is the author's

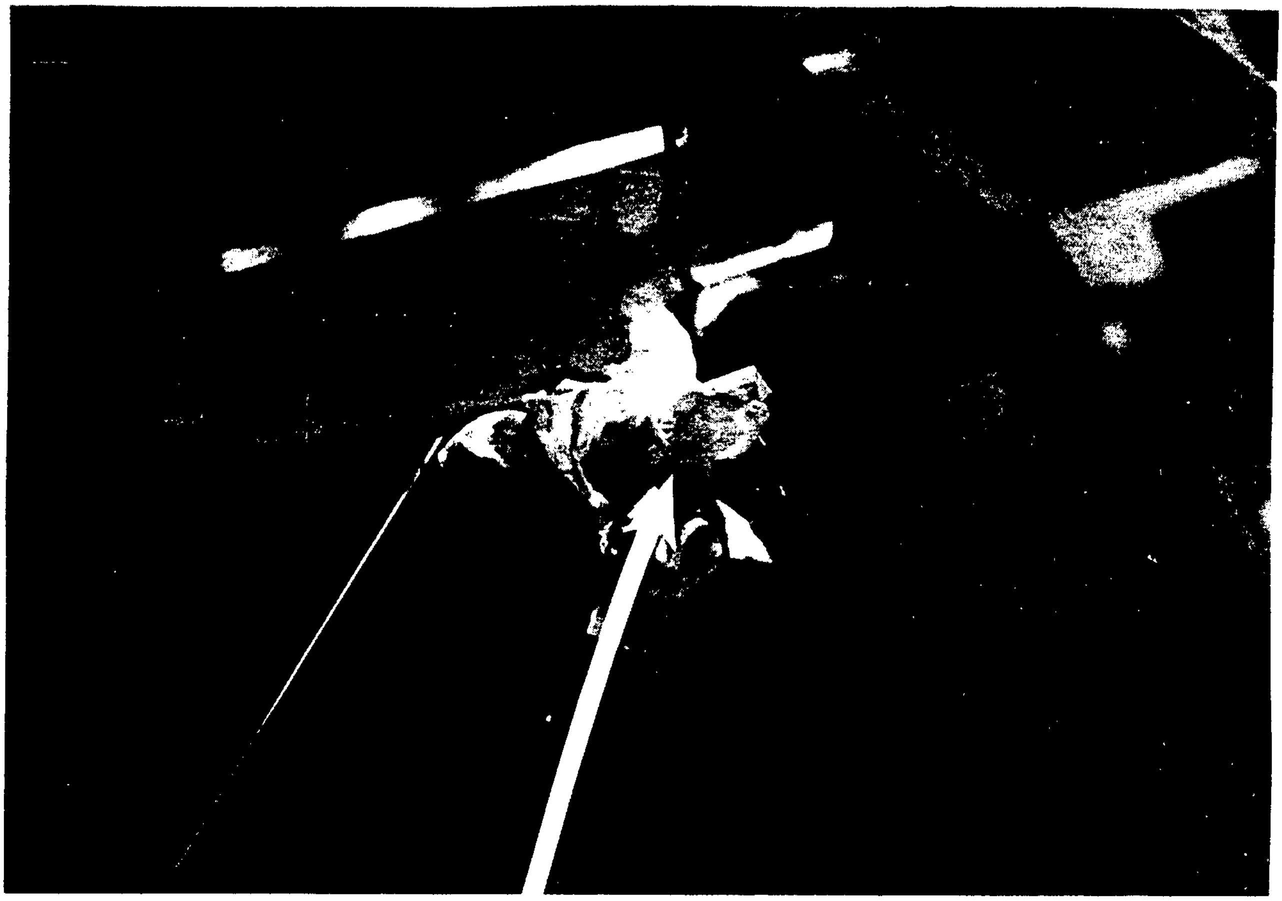

Figure 1 Photograph showing location of fuel thermocouple on MOST vehicle. (Note: Paper towel was used to keep thermocouple from grounding to metal gas tank and keep dirt out of fuel)

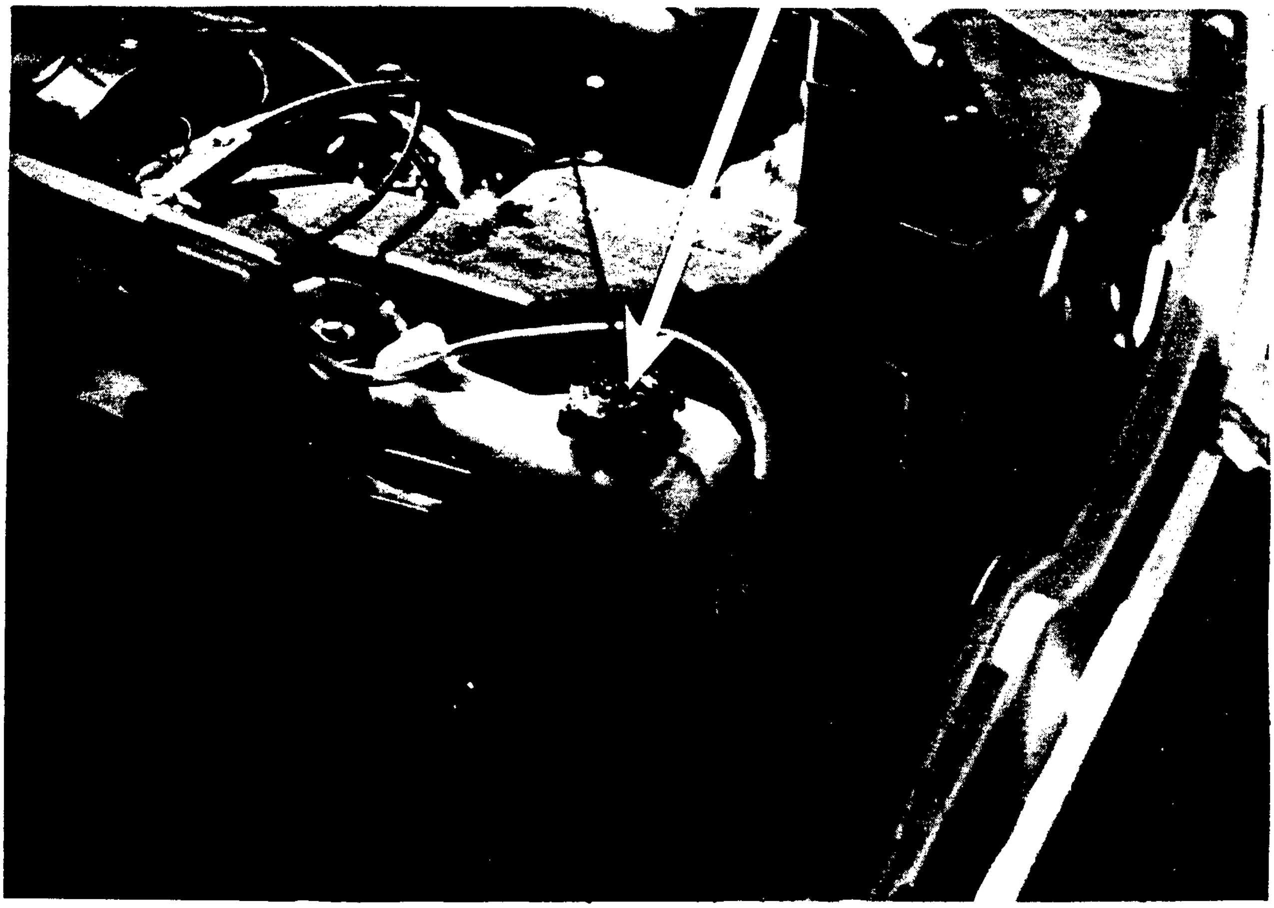

Figure 2 Photograph showing location of thermocouple in oil reservoir.

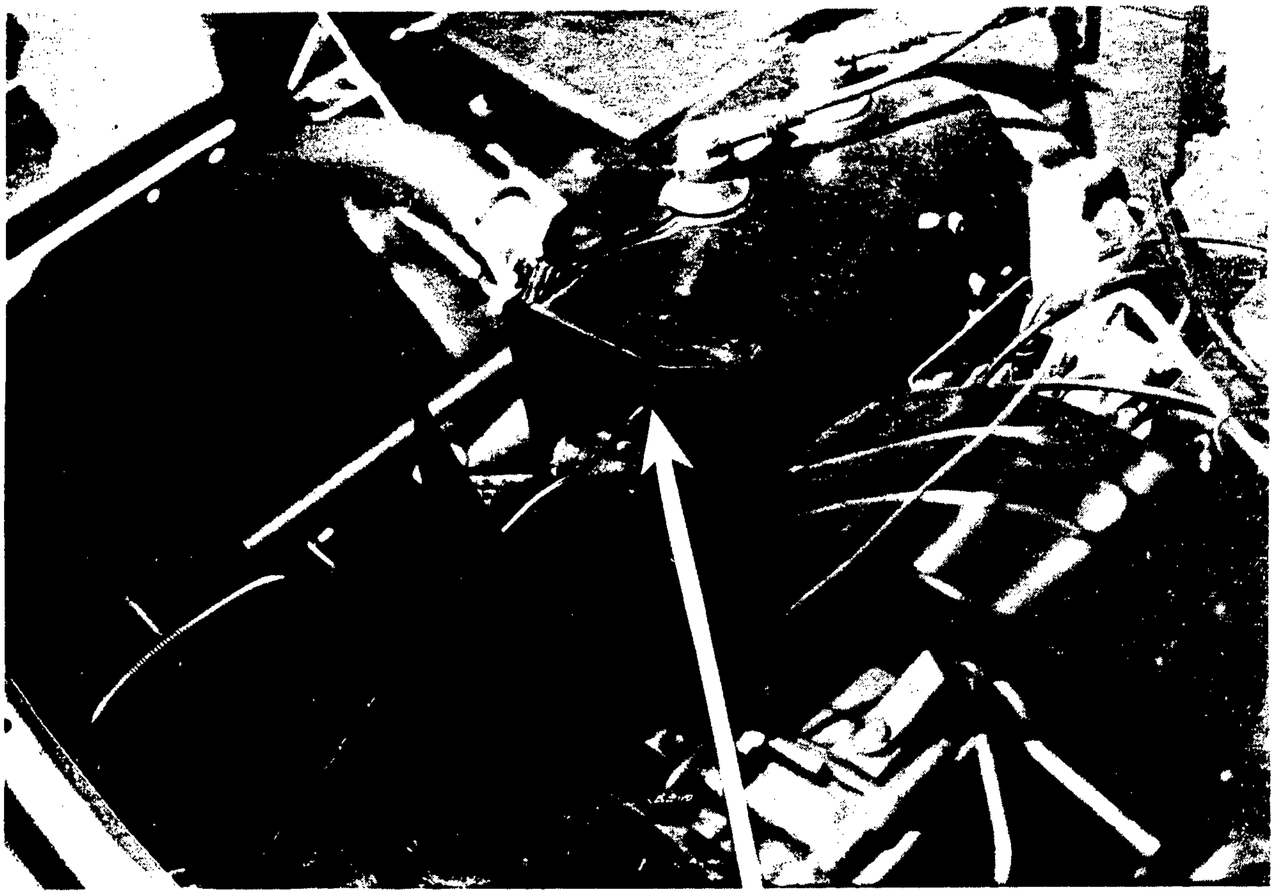

Figure 3 Photograph showing location of head thermocouple. Cooling air shroud hides actual location.

opinion that the early test data was not critical and therefore the lack of highly accurate thermocouples and data acquisition did not cause a major problem.

A Yamaha Enticer ET400TRN snowmobile with a single carburetor was supplied by the government for the development of the cold start kit. The engine in this vehicle is a Yamaha 400. The serial number for this machine was 85V-001139, machine number Y1, which was used as the performance machine in the tests conducted in Alaska. This machine had 654 miles on its odometer at the time of the cold start tests. The compression in the left cylinder was 113 psi and 115 psi was recorded in the right cylinder before testing began. KRC's original plan was to investigate the following for kit modifications:

1.) Conduct 3 tests at -50^0F with nothing more than new plugs, warm plugs and isopropyl alcohol in the fuel.

2.) Order and install a primer pump kit for this engine.

3.) Attempt cold starts with hotter burning spark plugs. Hotter burning spark plugs generally allow the fuel in the cylinders to burn more completely but also allow higher cylinder and piston temperatures which may cause engine failure.

4.) Attempt cold starts using butane fueled handwarmers near the engine block, fuel tank and oil reservoirs.

5.) Attempt cold starts using a butane fueled microtorch to warm engine block and intake air before and while starting.

6.) Mix 5% gas (approximately 4 ozs.) with the oil in the oil reservoir.

7.) Add gasoline to the cylinders before starting.

Since it was known that the machines would have problems with oil flow at the severe cold temperatures, gas was mixed with the oil from the very start of testing. The following describes the tests that were performed.

During these tests we used two brands of spark plugs, Champion and NGK. We did not test for differences between plugs nor did we notice any significant difference in performance of the two spark plug brands. Champion spark plugs were used at first because they were the easiest to obtain at the time. NGK spark plugs were used later on in the study because a large number of these spark plugs had been purchased resulting in a lower cost than the Champion spark plugs. It should also be noted that although a higher number on the Champion spark plugs indicates a hotter burning spark plug, a lower number on the NGK spark plugs indicates a hotter burning spark plug. The user should always check with the dealer before specifying which spark plug to purchase as each spark plug manufacturer has its own method of indication.

Another area of investigation was recommended in the scope of work. In some instances the MOST vehicle may be operated in a very wet, slushy type of snow and then allowed to freeze after sitting for extended periods of time. Also, extremely cold temperatures may cause the drive belt and track to stiffen, making the vehicle difficult to move. The cold room does not allow for any types of vehicle movement and therefore tests with the drive belt and track could not be accomplished. The ambient temperatures at KRC are not as severe as in Alaska and other northern parts of the world. Some simple tests were run where the vehicle was left outside after operating all day in snow. Some of the snow had melted and was left in the undercarriage overnight and subjected to subzero temperatures. Each time the vehicle started easily and moved relatively easily, although at first the track was stiff until the vehicle moved a short distance.

<u>Description of Tests</u>

The test directive from TACOM stated that all cold starts should be conducted at $-50^{0}F$, nowhere did it say that tests could be run at warmer temperatures. However, in order to develop this kit it was necessary to first get the machine running in order to find out why it would not run at the colder temperatures. Table 1 lists all the tests and temperatures conducted for development of this cold start kit.

The first two cold starts were conducted at $-44.9^{0}F$ and $-50.8^{0}F$, respectively. At the time of these tests the cold room at KRC was relatively new and there were some difficulties in bringing the temperature down to $-50^{0}F$. Both of these cold starts were performed as baseline cold starts, i.e., following the owners manual, full choke and standard spark plugs. Both failed to start after 40 pulls each. The spark plugs were checked for spark and were found to be functioning. It appeared that there was fuel on the plugs meaning that fuel was getting to the cylinders. It was decided at this time to attempt starts at a warmer temperature and then proceed to reduce the temperature until the vehicle could not be started using standard procedures. The two initial tests were not included in our analysis since both were failed starts.

Table 1 List Of Tests Conducted During The Development Of The Cold Start Kit			
Test No.	**Temp.(°F)**	**Description of Test/No. of Pulls**	**Start/Fail**
1	-44.9	Std. Start Procedure & Equipment / 40	Failed
2	-50.8	" " " " " " / 40	Failed
3	+14	" " " " " " / 2	Started
4	-4	" " " " " " / 4	Started
5	-22	" " " " " " / 27	Started
6	-40	" " " " " " / 50	Failed
7	-49	" " " " " " /couldn't pull	Failed
8	-40	Std. Procedure, Cold Std. N3C Plugs / 40	Failed
9	-40	Std. Procedure, Cold N4C Plugs / 40	Failed
10	-40	Std. Procedure, Cold N5C Plugs / 40	Failed
11	-40	Std. Procedure, Warm N4C Plugs / 40	Failed
12	-40	Std. Procedure, Warm N5C Plugs / 40	Failed
13	-40	Std. Procedure, Warm Std. NgC Plugs / 40	Failed
NOTE: Installed primer pump on vehicle at this time but did not use unless indicated.			
14	-20	Std. Start Procedure & Equipment / 80	Failed
15	-10	" " " " " " / 80 Then Pumped Primer	Failed Start
16	-21	Std. Procedure, pumped primer & warm plugs, (190 pulls but required heating plugs w/torch because they had fouled before starting.	Start
17	-35	Std. Procedure, primed, & used ether / 150	Failed
18	-35	Std. Procedure, primed & Handwarmers / 100	Failed
19	-35	Std. Procedure, 1/2 choke, no primer, heat on intake manifold, handwarmers and fuel added to cylinders / 3	Started
20	-40	Heat on intake, add fuel to cylinders, warm plugs and primed continuously / 100	Fired but no start
21	-40	Heat on intake, add fuel to cylinders, warm plugs, primed continuously / 8	Started but ran rough

Table 1 Continued			
Test No.	**Tem. (°F)**	**Description Of Test/No. of Pulls**	**Start/Fail**
22	-50	Heat intake, head and exhaust, add fuel to cylinders, warm plugs, primed continuously / about 50	Start
Note: At this point machine exhaust was cleaned out and fuel line leak was repaired. Cold room exhaust was cleaned out.			
23	-58	Cold plugs, no heat, pumped primer, no fuel added / 20. Then added fuel to cylinders & heated intake /31.	Fired every pull, started & ran rough
24	-50	Added fuel, warm plugs, no heat, pumped primer / 20. Then heated intake, added more fuel / 53	Failed, fired every pull, started
25	-50	Added fuel, heated 1.5 minutes, warm plugs, pumped primer continuously / 2	Started
26	-50	Added fuel, heated 1.0 minutes, warm plugs, pumped primer continuously / 26	Started

The next start attempt was made at $+14^{0}F$ and the machine started after 2 pulls. Upon adjusting to half choke for 2 minutes the engine quit running. It started at half choke and quit 3 more times about 1 minute apart and then ran after the fourth pull. No plots are shown because this test was at a relatively warm temperature.

The next cold start was at $-4^{0}F$. The engine started and ran after 4 pulls on the starter rope. This followed with a cold start at $-22^{0}F$ which required 27 pulls before starting. The engine quit running soon after but started again after 5 more pulls. The engine quit running again but started after 6 more pulls at half choke and slight pressure on the throttle. No plots are shown because this was not part of the original test plan.

The following cold start was done at $-40^{0}F$. Two separate times the machine failed to start after 25 pulls each time. Another cold start was attempted with the ambient at $-58^{0}F$, fuel and oil at $-49^{0}F$. This time the engine was very difficult to turn over with the pullcord. This was considered a failed start so no plots are shown.

The next set of tests were all conducted at $-40^{0}F$ and were done in uninterupted succession. The standard spark plug for the Yamaha is the Champion N3C. The next hotter burning spark plug is the N4C and two steps hotter is the N5C. A hotter burning spark plug is one that is less apt to foul out and more likely to result in more complete combustion in the cylinder than a colder burning spark plug. In general, when the proper spark plug is specified for the engine by the engine manufacturer, it is one that will provide the most complete combustion without making the engine run too hot such that it may cause an engine failure. If a hotter burning spark plug is used the combustion and cylinder temperatures will be hotter in the steady state condition, (i.e. when the cylinders have reached their normal operating temperatures after the initial warm-up time), as compared to the spark plug specified by the engine manufacturers. In these tests all spark plugs were tested both at coldroom temperatures ($-40^{0}F$) and at warm temperatures ($65^{0}F$) which would be a typical temperature if the spark plugs were being carried close to a SF personnel's body. First, cold-soaked ($-40^{0}F$) standard plugs were used and the engine failed to start after 40 pulls. The cold-soaked ($-40^{0}F$) N4C plugs were installed and after 40 pulls the machine still failed to start. Cold-soaked ($-40^{0}F$) N5C plugs were installed and the machine again failed to start after 40 pulls. Next, warm ($65^{0}F$) N4C plugs were installed and the machine failed to start after 40 pulls. Warm ($65^{0}F$) N5C plugs were installed and the machine failed to start after 40 pulls. Finally, warm ($65^{0}F$) standard plugs were installed and they also failed to start the machine after 40 pulls. It was noted that there was very little fuel on the plugs each time they were changed. It was obvious that hotter burning plugs alone do not help the snowmobile start at severe cold temperatures. This test also suggested that the engine needed more fuel to start in very cold temperatures, which is exactly what the snowmobile manufacturers recommended. No plots are shown for this series of tests, but Figure 4 shows a photograph of the different spark plugs used during this test.

The primer pump was installed next in order to get more fuel into the cylinders. After installation, but before using the pump, some cold starts were attempted at warmer temperatures. A photograph of the primer pump knob location is shown in Figure 5.

At -20^{0}F after 40 pulls the machine failed to start. New, warm plugs were installed and after 40 pulls the machine failed to start. This was interesting because earlier it started at -20^{0}F without the primer pump installed. No plots are shown due to a failed start.

The next test was a no start but may have been due to a plugged exhaust system in the cold room. After the exhaust system was repaired another cold start was made at -10^{0}F. The machine failed to start after 80 pulls. The spark plugs were removed and heated with a heat gun and after 25 pulls the machine still failed to start. Finally, the primer was used. The primer was pumped three times, the machine fired but didn't start after one pull. The primer was pumped 3 more times and on the next pull the machine started and ran. This indicated that the primer pump is definitely needed to get more fuel into the cylinders but because the engine would not start at temperatures where it normally would have started when the primer was not installed, it was thought that the primer pumps presence may reduce fuel flow to the cylinders when it is in place on the vehicle but not used. When it is used it definitely assists in sending more fuel into the engine.

The next start was at -21^{0}F. The following transpired:

Primed 6 times, 40 pulls - no start.
Primed 3 times, 20 pulls - no start.
Primed 3 times, 10 pulls - no start.
Installed clean, warm plugs.
20 pulls - no start.
Primed 3 times, 20 pulls - no start.
(Plugs looked very wet).
Used two squirts of ether.
20 pulls - no start.
Disconnected exhaust (thought it may be blocked).

Figure 4 Photograph showing from left to right the standard spark plugs, the next step hotter N4C and the two step hotter N5C spark plugs.

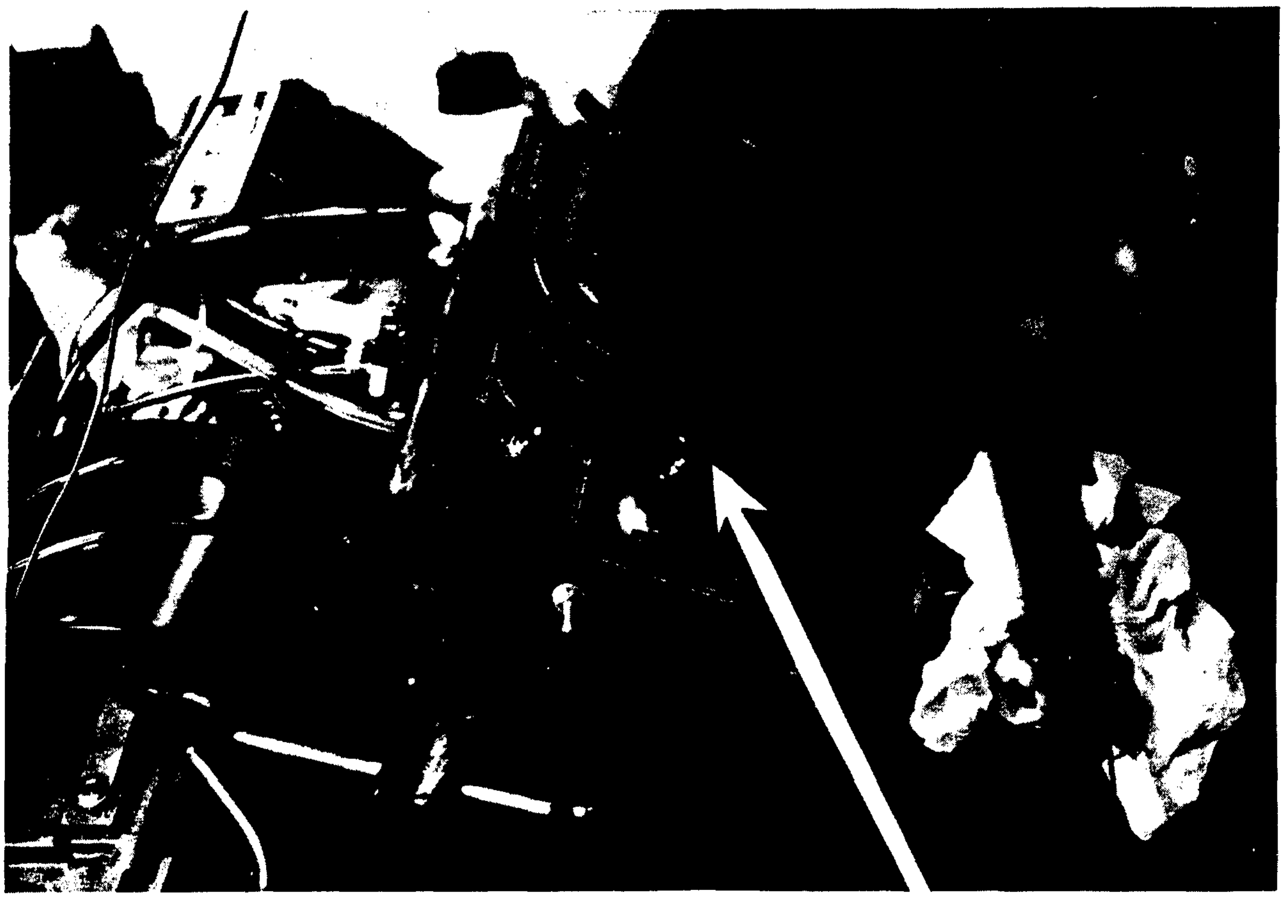

Figure 5 Photograph showing location of primer pump on the vehicle. Note that the primer pump is the item with round, large black knob.

20 pulls - no start.
Removed plugs, heated with butane micro-torch, 2-4 min.
20 pulls - no start.
Primed 3 times, 2 pulls - fired.
3rd pull - fired.
4th pull - ran.
Ran 2 minutes before running with no choke

Figure 6 shows a plot of all temperatures monitored during this start. At this point, it was difficult to determine if the warm plugs were needed or just a lot of priming was needed to get the machine running.

The next cold start was performed at -35^0F. The following events took place:

Primed 3 times, 10 pulls - no start.
Primed 3 times, 10 pulls - no start.
Primed 3 times, 10 pulls - no start.
Pulled plugs, they didn't look very wet.
Primed 3 times, 20 pulls - no start.
Primed 3 times, 20 pulls - no start.
Checked plugs, they didn't look very wet.
Primed 3 times, 1/2 throttle, 20 pulls - no start.
Primed 3 times, 1/2 throttle, 20 pulls - no start.
Heated plugs with torch.
Primed 3 times, 1/2 throttle and 3 squirts of ether,
40 pulls - no start.

No plots are shown due to a failed start. At this point it was decided to install the butane fueled handwarmers on the vehicle in an attempt to supply some form of external heat to the engine and injection oil. The idea was to mount some handwarmers on the oil reservoir, fuel tank, engine block and intake manifold. Velcro sticky tape was used to keep the handwarmers next to the parts that are critical for starting in severe cold conditions. The handwarmers fit in cloth bags and can be removed and put back in place with relative ease. The personnel that would use these could light the handwarmers, put them on the various parts of the vehicle and they would keep the components at a warmer temperature than the ambient overnight. They would only require a small packet of fuel and a lighter or match. One problem with this method was that it was difficult to mount a handwarmer very close to the fuel tank. Fuel temperature is very critical to starting. If the fuel is too cold it will not vaporize and thus is difficult to ignite in the cylinder. Figure 7 is a photograph of the handwarmers that were used during this project. The next test was conducted after the handwarmers

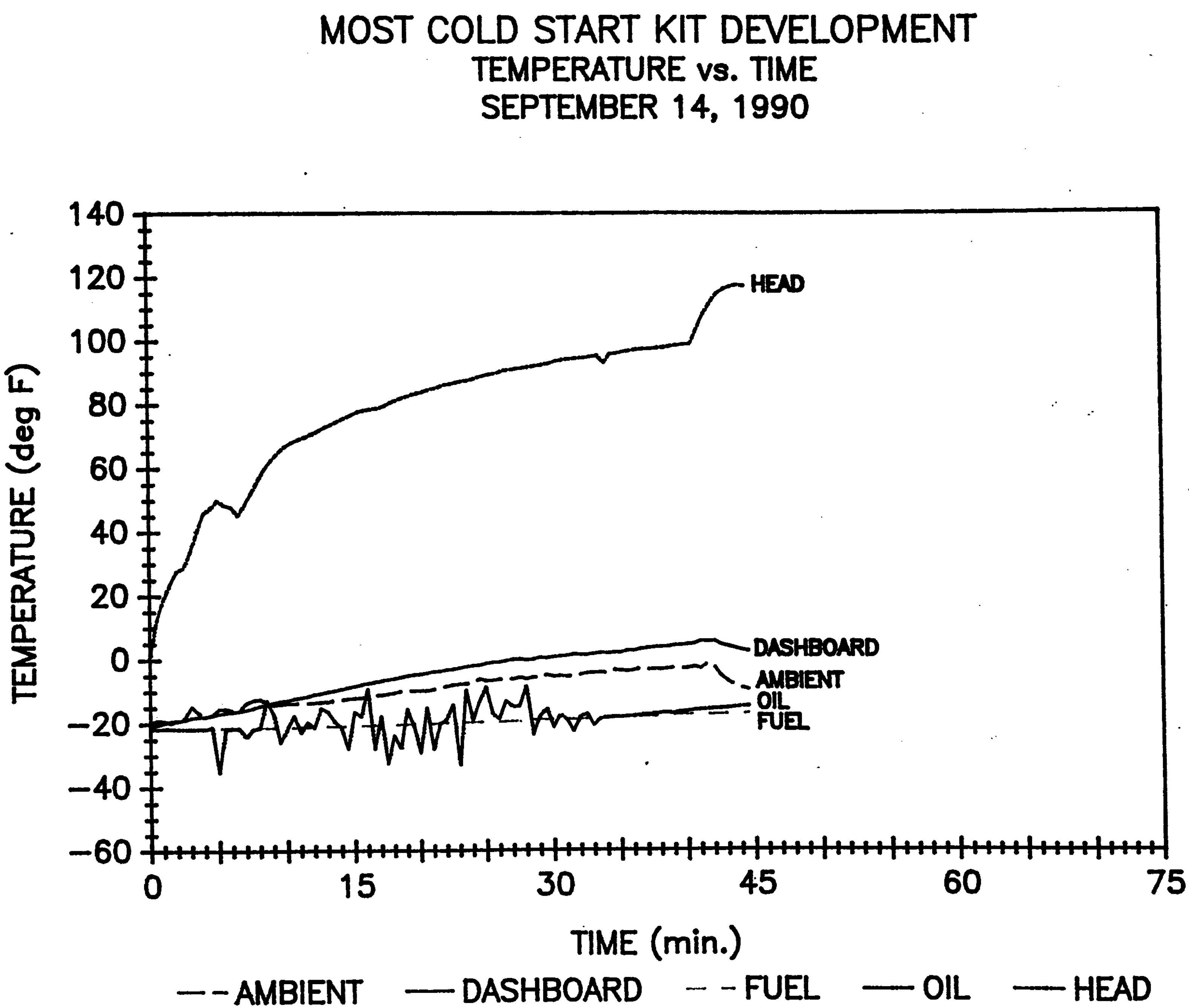

Figure 6 Graph of vehicle and ambient temperature data from cold room cold start at −21°F.

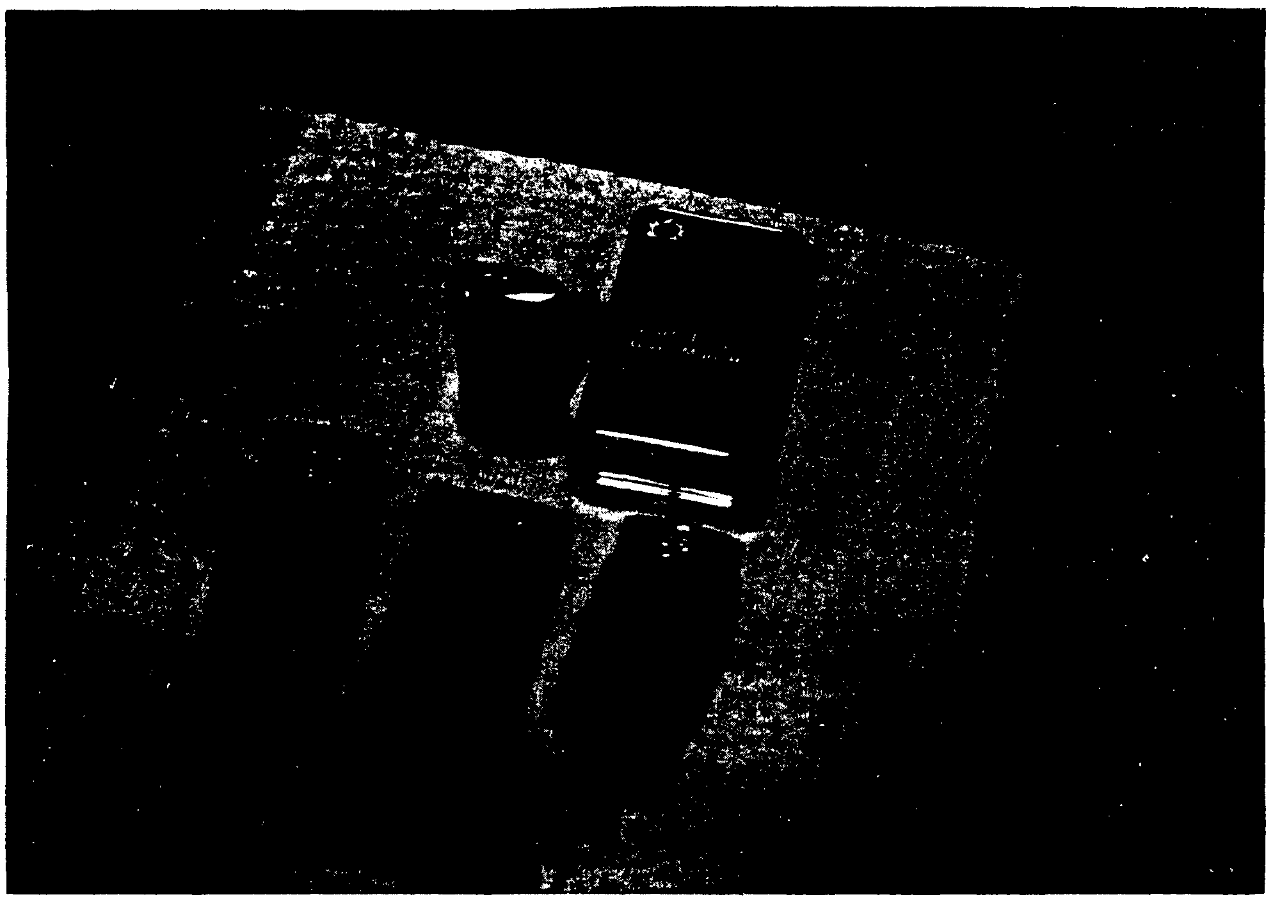

Figure 7 Photograph showing the handwarmers used in these tests.

had been installed overnight. The ambient temperature was -35^0F but the oil had risen to -14^0F and the head went to -29^0F. The following was done:

Primed 3 times, 20 pulls - no start.
Primed 3 times, 20 pulls - no start.
Pulled plugs, heated plugs, reinstalled plugs.
Full choke, no prime, 40 pulls - no start.
No choke, 1/2 throttle, primed 3 times,
20 pulls - no start.

The handwarmer concept, although good in theory was not very practical and they did not seem to heat the engine enough. It was then decided to try the handwarmers in combination with a heating torch. Butane fueled micro-torches were purchased for heating the cylinder block and manifold. These torches proved to be difficult to work with and could never produce a consistent, reliable flame. Figure 8 is a photograph of the butane fueled microtorches used during this project. Ultimately, a propane torch shown in Figure 9 was used instead because it produced a reliable, hot flame. In practice a soldier could keep a small torch next to his body until he was ready to use it. This would keep the propane warm enough to light even at severely cold temperatures. It was also decided to put a small amount of fuel into each cylinder to see if additional fuel would help the cold starting capability. This test was conducted at -35^0F. The following took place:

Handwarmers left in place on head, oil reservor and near air intake.
Heated fuel intake with propane torch for 1.0 minute.
Put small amount of 100 octane fuel in each cylinder.
Put in new, warm standard NGK sparkplugs prior to starting.
1/2 choke, 1 pull, fired - no start.
1/2 choke, 1 pull, fired - no start.
1/2 choke, 1 pull, started, went to full choke.
Ran for 30 seconds, tried to go to no choke and machine quit running. Went to full choke and started in 1 pull. After 1 minute went to half choke and then after two minutes went to no choke.

Figure 10 is a plot of the temperatures from this test. The heat from the propane torch on the intake manifold seemed to be a big help along with warm fuel in the cylinders. At this point, it was felt that the propane torch did more than the handwarmers. Seeing that the intake manifold is a cast aluminum it tends to hold the heat for a long period of time once it is warmed up even in cold temperatures. The propane

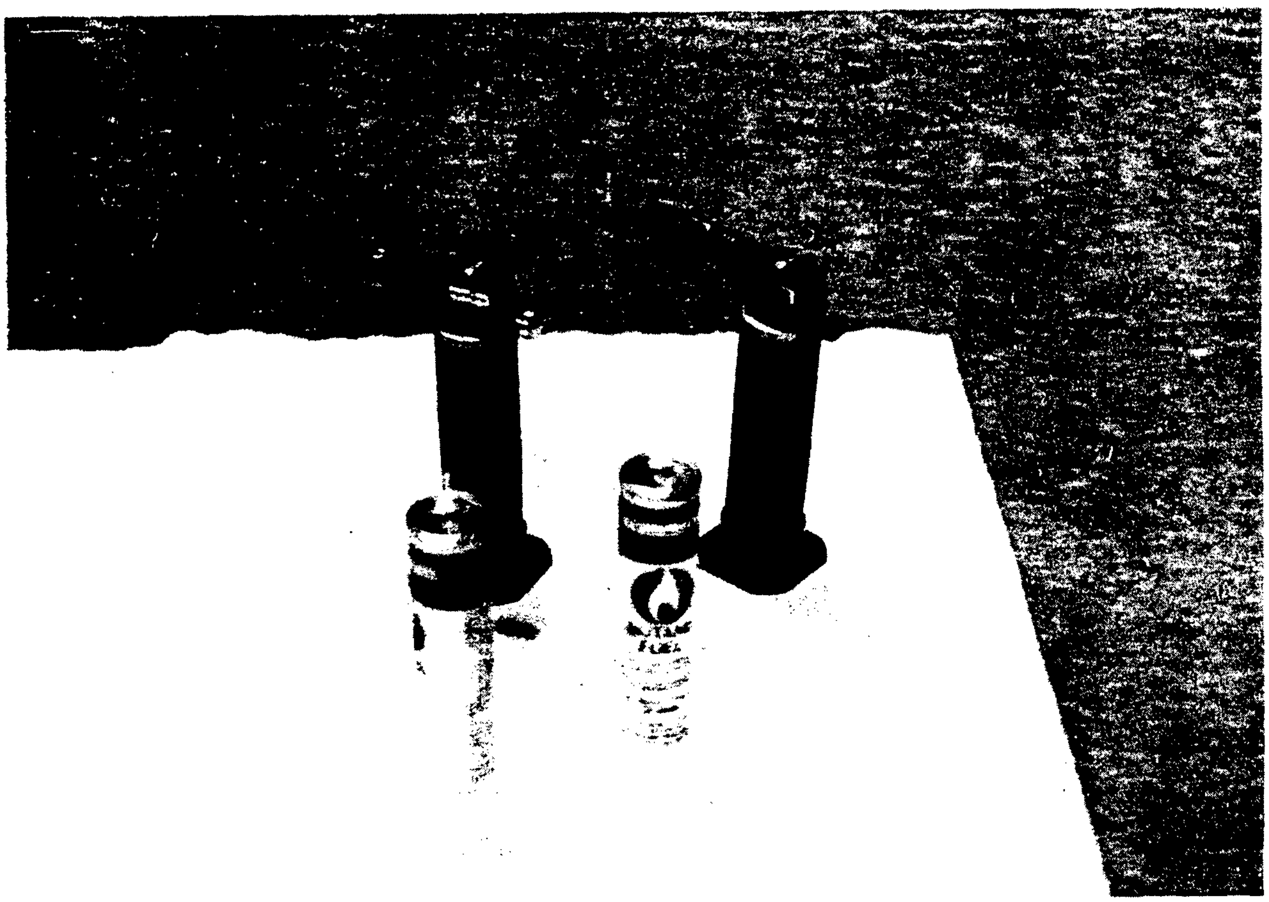

Figure 8 Photograph showing the butane fueled microtorches used as a part of this test.

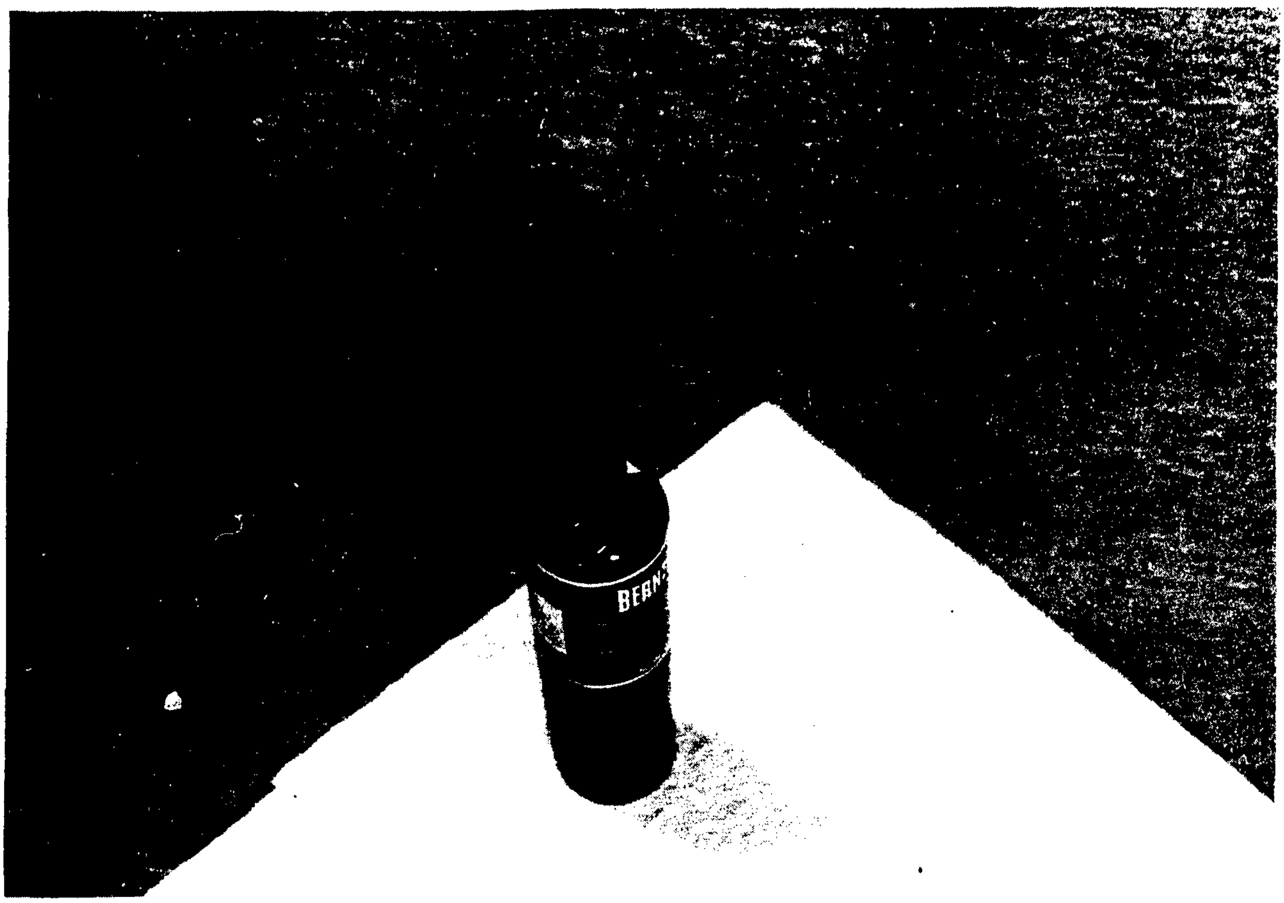

Figure 9 Photograph showing the propane torch used as part of the MOST cold start kit.

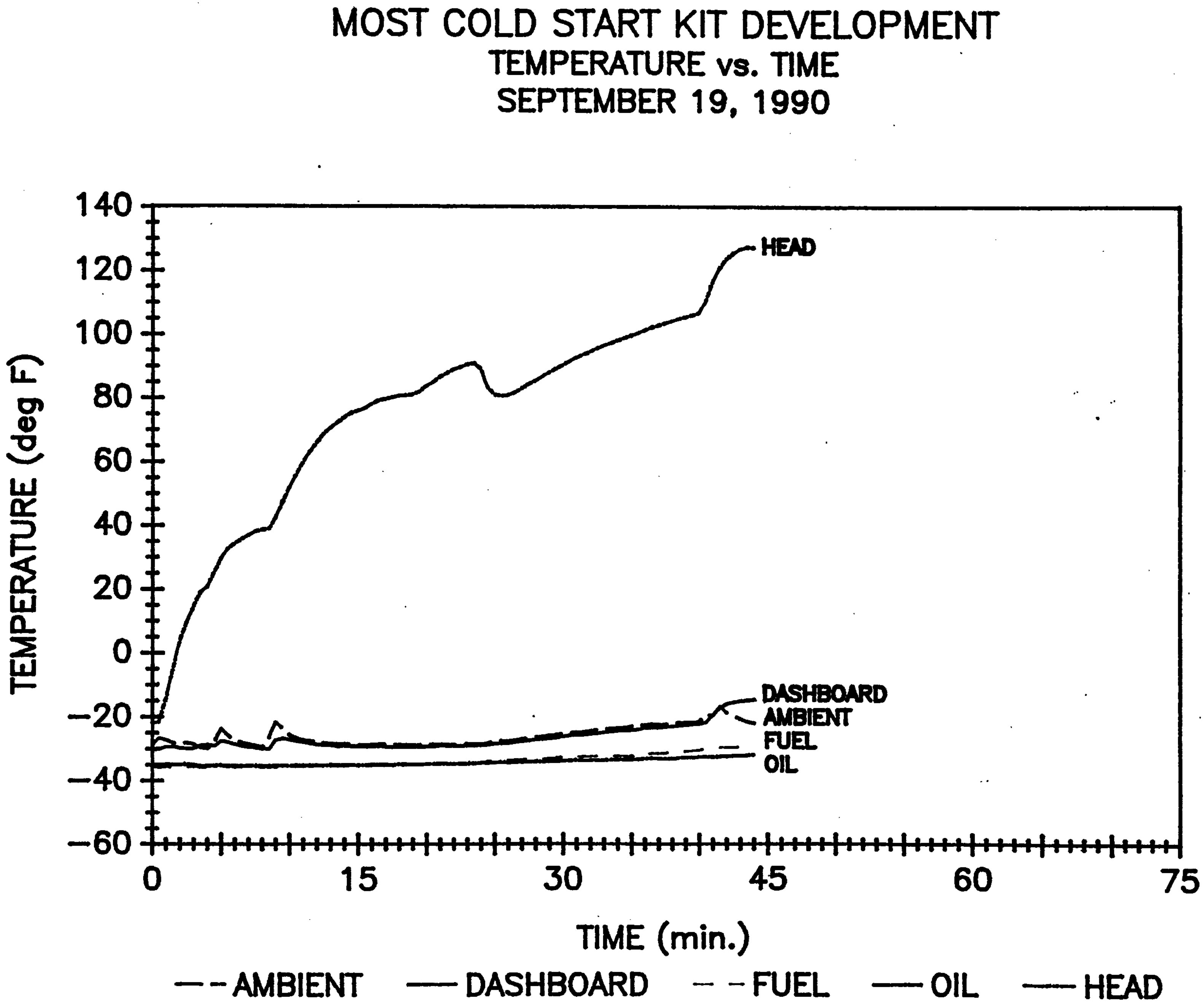

Figure 10 Graph of vehicle and ambient temperature data from cold room cold start at -35°F using handwarmers, heating with propane torch, putting fuel in cylinders and new, warm spark plugs.

torch provides more heat in a relatively short amount of time as compared to the handwarmers. The next test was performed at -40°F without handwarmers. The following events occured:

Heated head and intake manifold with torch.
Put fuel in cylinders.
Installed warm spark plugs, full choke.
10 pulls - no start.
3 primes, 10 pulls - no start
3 primes, 10 pulls - no start
Pulled plugs, warmed with torch.
Put fuel in cylinders.
Put in plugs and set to 1/2 choke.
Fired 1st pull then quit.
10 pulls, full choke and 3 primes - no start.
Pulled plugs, put fuel in cylinders.
Fired 1st pull then died.
Primed 3 times, full choke, 20 pulls, no start.
Installed new, warm plugs, fuel in cylinder - started 1st pull at full choke, then quit running, 2nd pull, started and died. 20 pulls while priming continuously. No start. 20 pulls while priming, no start. By this time everything warmed up in the cold room so it was decided to let machine and room cool down.

By this time it was a known fact that a lot of fuel was required in the cylinders with some heat on the engine at -35°F and below. The primer pump pushes a small amount of fuel into the intake manifold on each stroke of the pump. If the primer is pumped when the engine is not being pulled over, a small amount of fuel sits in the intake manifold but doesn't enter into each cylinder because chances are that the intake ports on each cylinder are not both open. It only seemed logical that in order to get fuel into both cylinders the primer should be pumped continuously while pull starting the engine. The amount of fuel pumped each time the primer is pumped was measured to be 1.22 ml per stroke.

The next test was conducted at -40°F. Approximately 25 ml of fuel was poured into the cylinders (divided equally), the intake manifold was heated with a propane torch and warm plugs were installed. At full choke the engine fired on each of the first three pulls but did not start. Primed 3 times and pulled 20 times but it did not start. Next, another 25 ml of fuel was poured into the cylinders and the primer was pumped while pulling. After 4 to 5 pulls the machine started. The engine ran very rough. The following events occured:

Ran on full choke for 45 seconds.
Ran on 1/2 choke for 90 seconds.
Tried no choke but machine quit running.

Tried several pulls at full choke and at half choke and priming while pulling. The machine would start and quit running. Then after several starts the machine finally stayed running and it seemed to run at a slightly higher rpm as if it finally reached a certain temperature for continuous operation. After the machine started to run smoothly, a leak was noticed in the fuel lines and the head gasket. This could have been part of the problem when starting during the previous tests.

Figure 11 is a plot of the temperatures from this successful start. The next test was conducted at -50^{0}F. The intake manifold, head and exhaust pipe were heated, 25 ml of fuel was put in the cylinders and warm plugs were installed just before starting. Figure 12 is a photograph of the beaker of fuel and funnel used to put fuel in the cylinders and Figure 13 shows the fuel being poured directly into the engine. Figure 14 shows the propane torch being used to heat the intake manifold prior to starting the engine. When starting, one person would prime continuously while turning the engine over with the pull cord. The engine fired on every pull but it took about 12 minutes to get started. The engine ran at full choke for about 2 minutes and then it quit running. The primer was pumped and the starter rope pulled 10 more times before the machine started again. After it started, it again ran faster as in the previous test. Again the engine ran for awhile on 1/2 choke before it could be switched to no choke. This was one successful start at -50^{0}F. Once running with no choke, the oil seemed to flow well and the machine appeared to run well. The five percent gas in the oil mixture probably helped the oil flow. Figure 15 shows the temperature plots for this successful cold start.

After performing several successful cold starts at -40^{0}F and below, a large amount of oil-gas and water-ice mixture had accumulated in the exhaust pipe and the exhaust lines in the cold room. At this point the cold room was shut down to clean out the exhaust systems. The Yamaha was also moved out of the cold room. One of the head bolts had loosened (leak noted earlier) and was torqued to the specifications in the manual. The fuel line leak was also repaired at the same time. The snowmobile was run hard for about an hour to clean out the carburetor and exhaust pipe. It is expected that the machine used by Special Forces personnel would not have this type of accumulation because it would probably be run hard after a cold start. The types of problems seen here are due to idling the engine for long periods of time without high speeds, loads and temperatures.

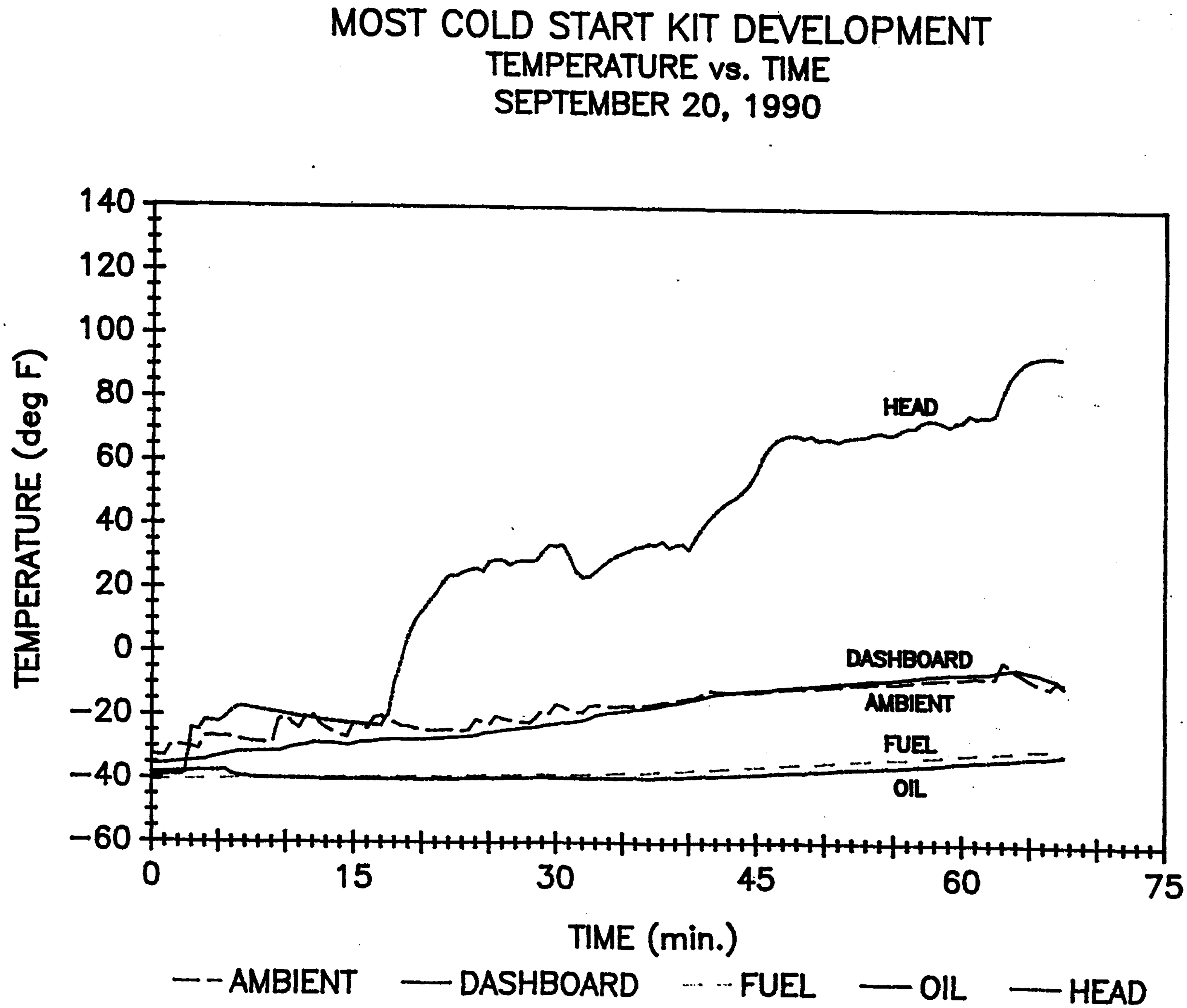

Figure 11 Graph of vehicle and ambient temperature data from cold room cold start at -40°F using fuel in cylinders, heat from propane torch and new, warm spark plugs.

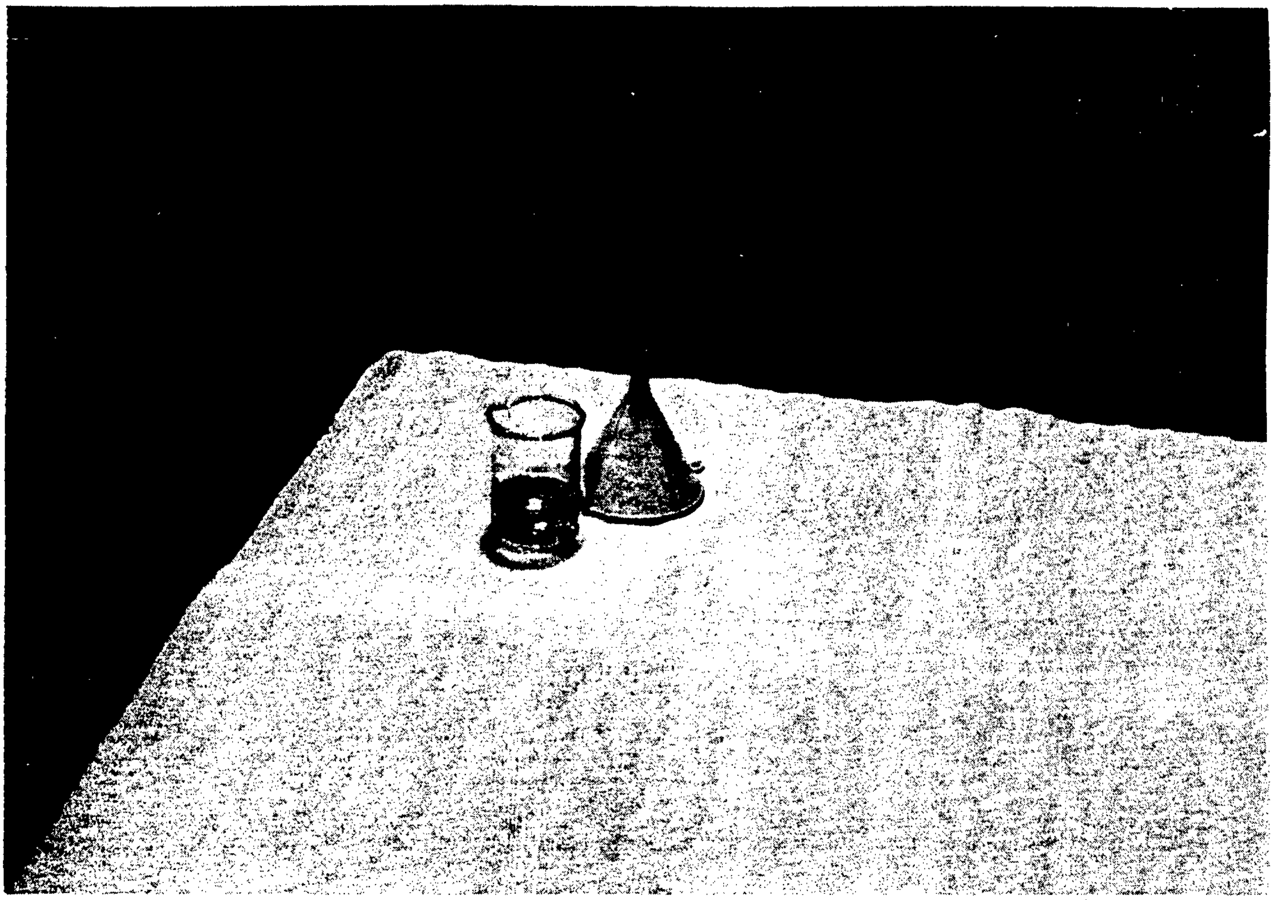

Figure 12 Photograph of beaker and funnel used for adding fuel to the cylinders.

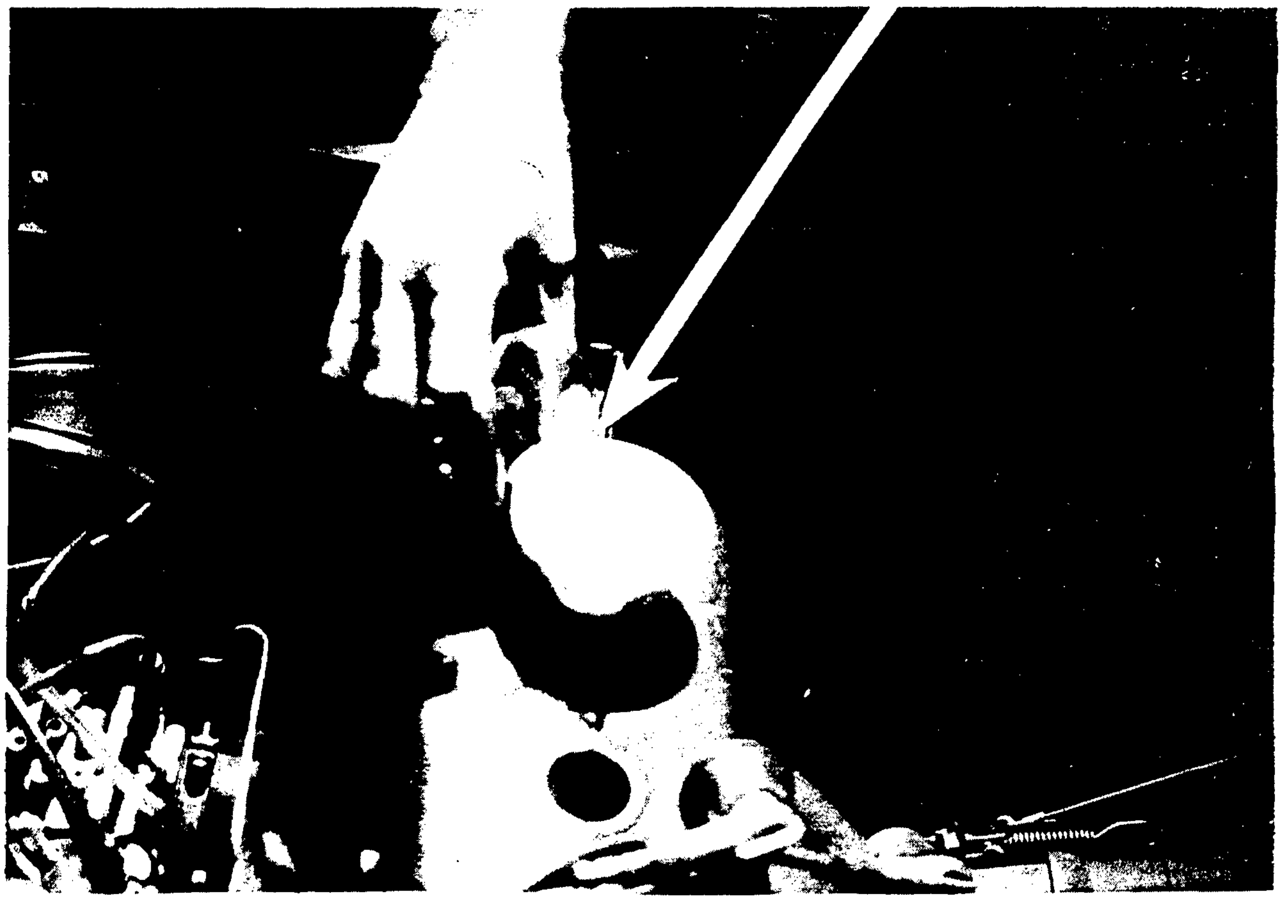

Figure 13 Photograph showing fuel being added to the cylinder prior to conducting the cold start test.

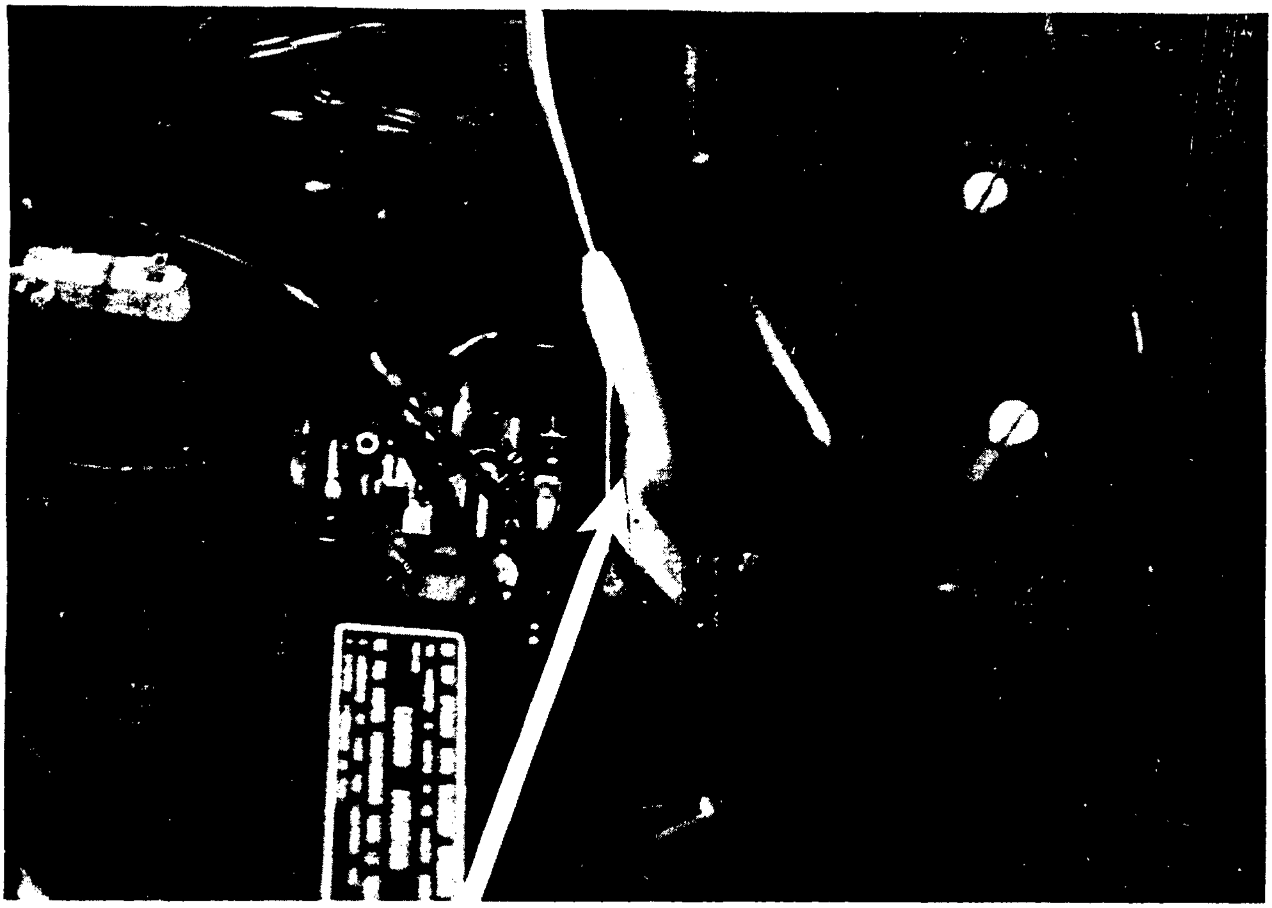

Figure 14 Photograph showing the propane torch being used to heat the intake manifold prior to the cold start test.

MOST COLD START KIT DEVELOPMENT
TEMPERATURE vs. TIME
SEPTEMBER 21, 1990

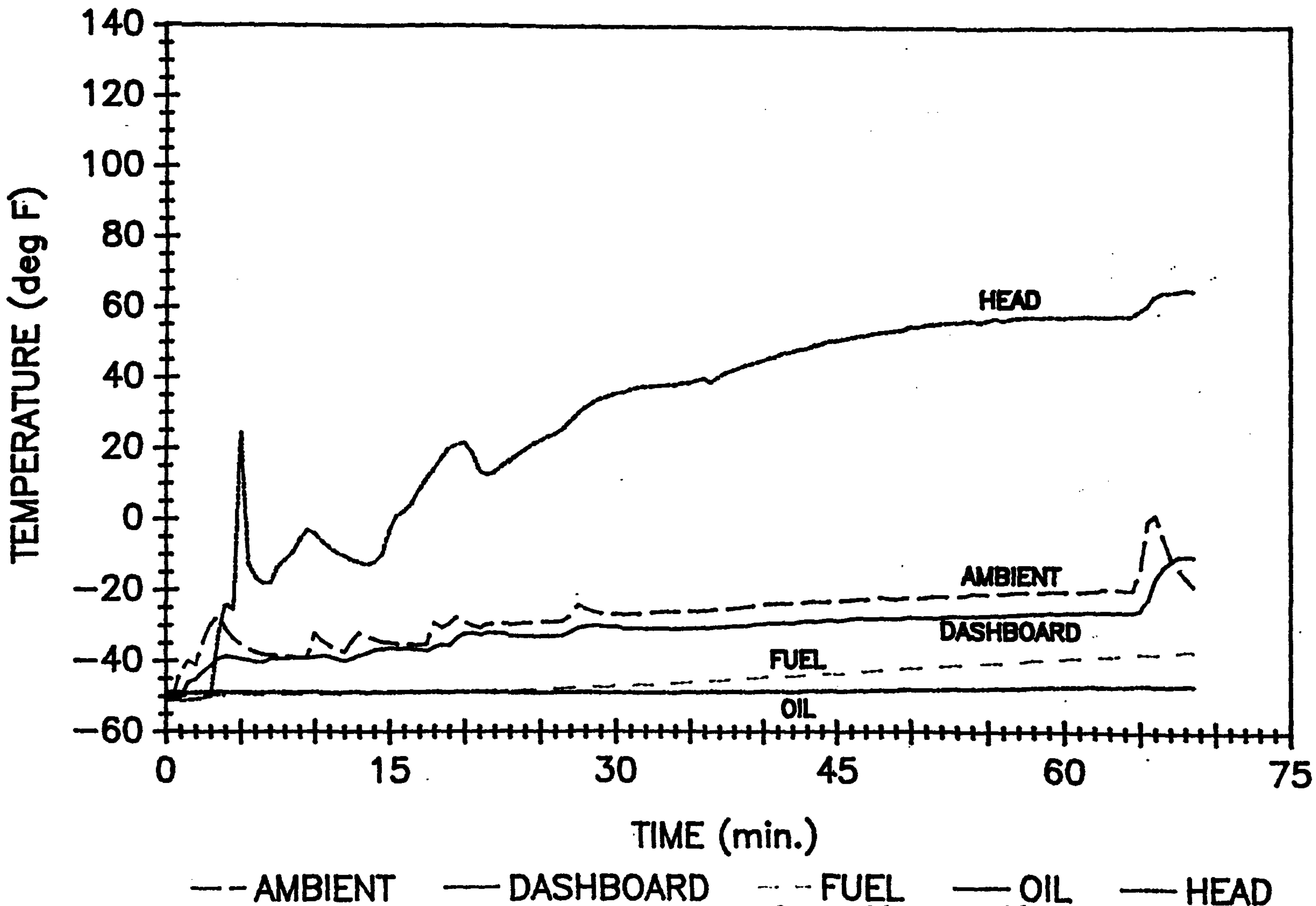

Figure 15 Graph of vehicle and ambient temperature data from cold room cold start at -50°F using fuel in cylinders, heating with propane torch, warm new spark plugs and pumping the primer continuously.

The next start was conducted at $-58^{0}F$. This cold start was attempted with cold plugs, no heat, full choke and pumping the primer to see if just continuously pumping the primer could eliminate the need for adding fuel to the cylinders. After 20 pulls the engine had failed to fire or start. Next the intake manifold was heated, 30 ml of fuel was added to the cylinders and warm plugs were installed. The engine fired on every pull but it required 31 pulls before it would run continually at full choke. The engine ran at full choke for 2 minutes and then quit. It required six more pulls before running again. The machine ran at full choke for another 2 minutes before switching to half choke. After 5 minutes of running at half choke the machine was switched to no choke to complete the test. This was the second successful cold start at $-50^{0}F$ or below. Figure 16 is a plot of the temperatures from this successful cold start test.

The next test was conducted to determine if the vehicle could be started at $-50^{0}F$ or below without heating the intake manifold. Approximately 30 ml of fuel was put in the cylinders, warm plugs in the engine, and at full choke the primer was pumped continuously while pull starting. After 20 pulls the machine failed to fire or start. The intake manifold was heated for about 1 to 2 minutes with the propane torch and another 30 ml of fuel was added to the cylinders. Warm plugs were installed and the machine was still on full choke. The primer was pumped continuously while pull starting. The engine fired on the first pull and every pull until starting. It required about 53 pulls before starting and running. The choke was set to half choke after about 5 minutes of operation and then switched to no choke after 5 more minutes of operation. This was the third successful cold start at $-50^{0}F$ or below. This test indicated that heat was required on the intake manifold to successfully start the engine at $-50^{0}F$ or below. The data for this test are shown in Figure 17.

The next two cold starts were performed to determine the minimum time required to heat the intake manifold for a successful cold start at $-50^{0}F$ or below. The following are the results of the final two cold starts.

Heated intake manifold for 1.5 minutes.
Added cold 87 octane gas (30 ml) to cylinders.
Installed warm, new plugs.
Machine was set to full choke and primed continuously while pulling.
1st pull, no fire, no start.
2nd pull, started, continued pumping primer for about 15 seconds until the machine ran continuously.

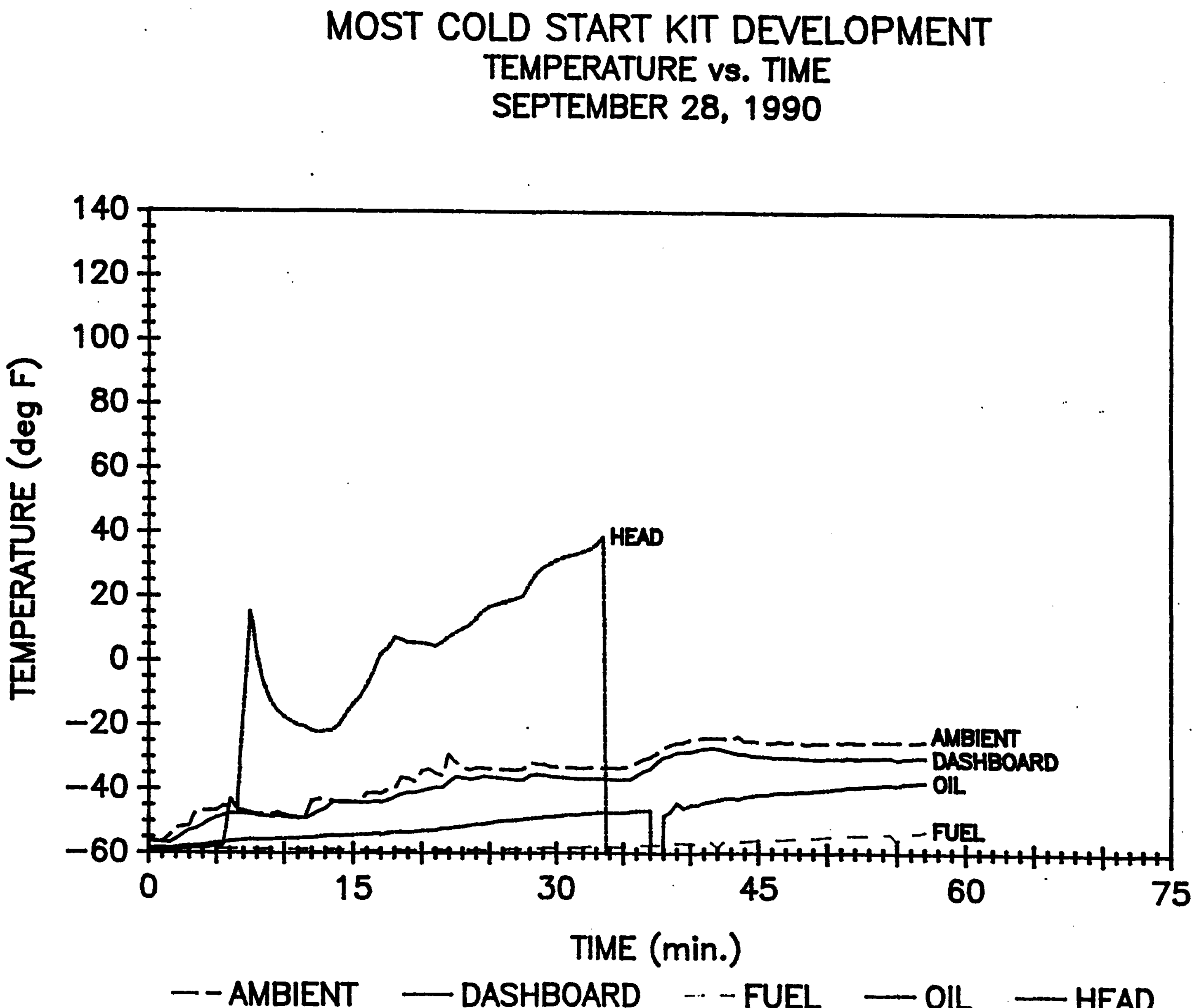

Figure 16 Graph of vehicle and ambient temperature data from cold room cold start at -58°F. Attempted to not add fuel to cylinders and use cold spark plugs but could not start until fuel was added and warm plugs were used along with other kit methods.

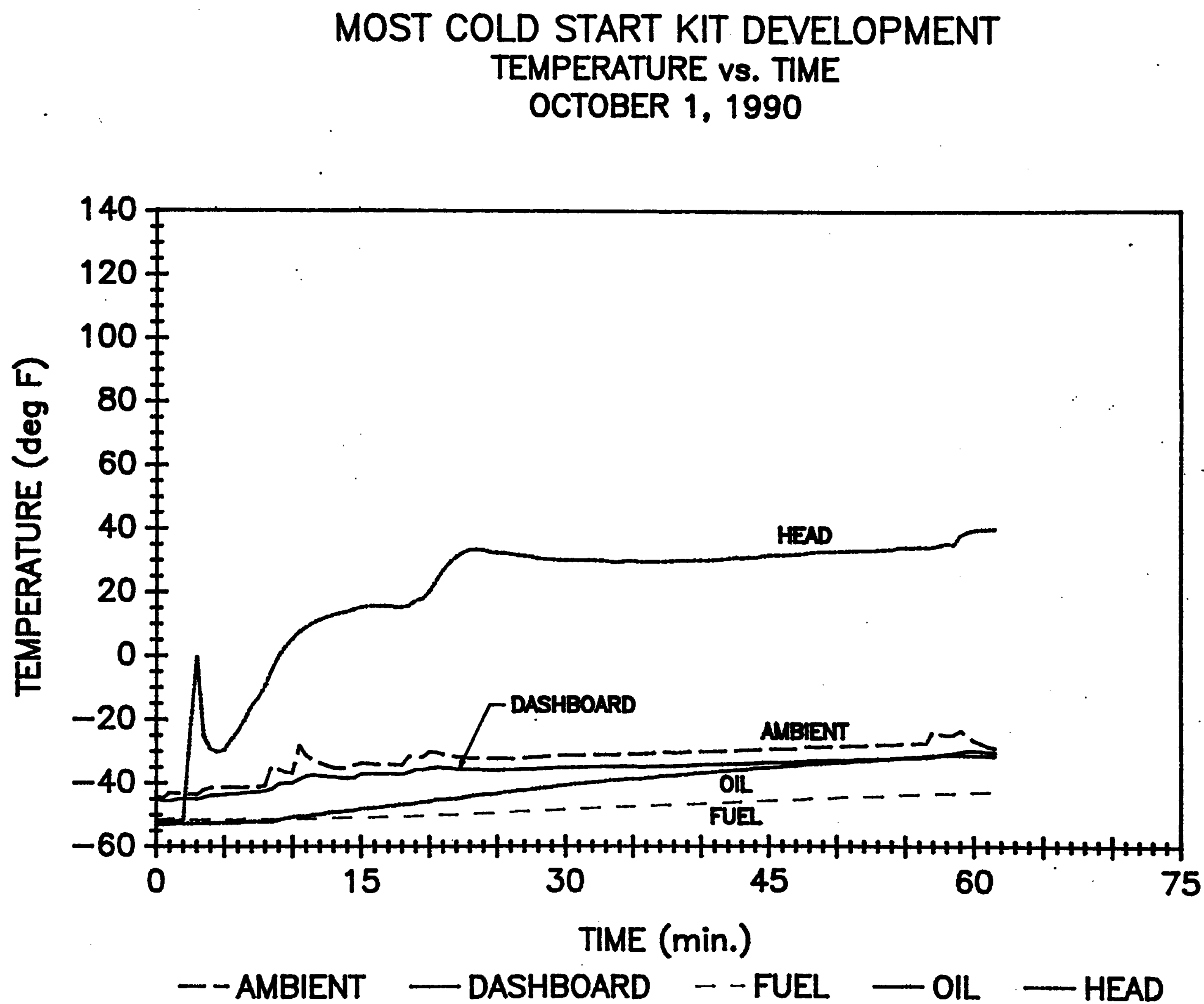

Figure 17 Graph of vehicle and ambient temperature data from cold room cold start at -50°F. Attempted to start without heating intake manifold but had to use heat to start engine.

Ran on full choke for 5 minutes and then went to no choke and the machine quit running. Ran for 5 more minutes at full choke and tried half choke but the engine would begin to falter. By this time the cold room filled with exhaust because the exhaust vent system came apart. Because there was so much exhaust the machine may have not been able to get enough air to continue running. The temperature plots for these data are shown in Figure 18.

The next test involved reducing the heating time of the intake manifold with the propane torch to less than the previous test.

This time we heated the intake manifold for 1.0 minute, added 30 ml of 87 octane gas to the cylinders, installed new, warm plugs, set machine to full choke and primed continuously while pull starting.
1st pull, fired but did not stay running.
Required 25 more pulls before it stayed running.
Ran at full choke for 5-6 minutes and then it was able to stay running at no choke for the remainder of the test.

The temperature plots for this test are shown in Figure 19. This was the end of the tests in the cold room.

Other Cold Environment Guidelines

In 1989 a CRREL Special Report (1), preliminary design guide for arctic equipment was, published. This report contained a great deal of information that can be applied to the MOST System in severe cold environments. Listed below are critical components to the MOST System, how they may be affected by severe cold environments and suggested methods of reducing or eliminating the possibility of problems or failures.

Filters (Fuel, Oil and Air) - May clog with ice particles due to condensation of moisture in the local area. To prevent or remedy this situation water should be drained if possible, preheat fuel if possible and use isopropyl deicer in the fuel tank.

Fittings - May loosen due to thermal expansion. Check fittings as often as possible.

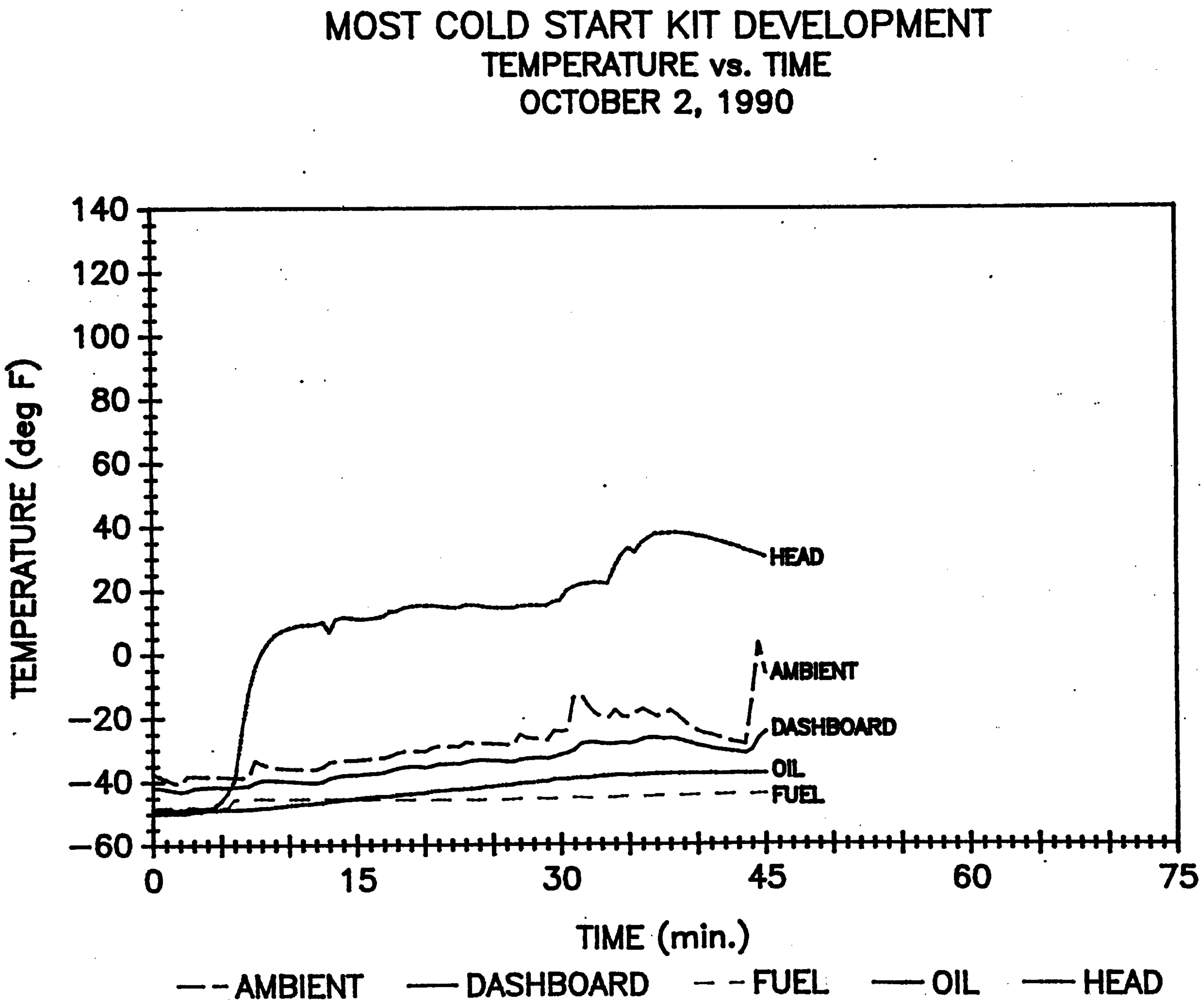

Figure 18 Graph of vehicle and ambient temperature data from cold room cold start at −50°F. Heated intake manifold for 1.5 minutes along with other cold start kit methods.

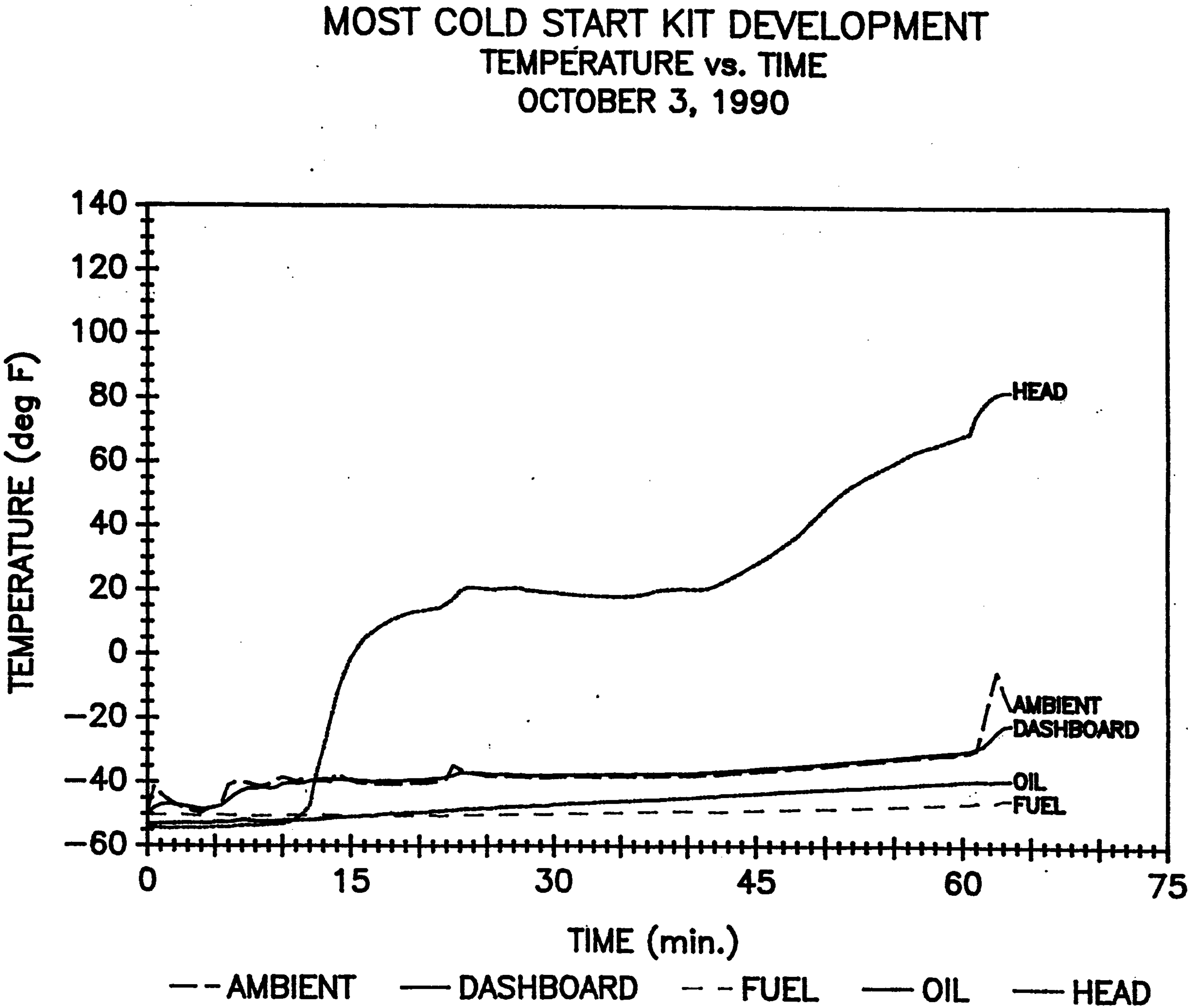

Figure 19 Graph of vehicle and ambient temperature data from cold room cold start at -50°F. Heated intake manifold for 1.0 minute along with other cold start kit methods.

Fuels - May reach cloud point (crystallization), especially diesel fuels. Attempt to use higher octane or jet fuels. These should have as low an amount of parafins as possible. Non-gelling and non-icing additives should be used if possible.

Lubricants - May start to crystallize. Use synthetic oils and grease, except in the engine. Use napthanic instead of parafinic based lubricants. Preheat if possible.

Bearings - Lubricants in bearings may start to crystallize. Use synthetic, silicone or diester based lubricants if possible. Use bearings with matched materials to reduce the affects of thermal expansion.

Belts and Tracks - Belts and tracks may become stiff and may crack in severe cold environments. The strength of the rubber composite material decreases at very cold temperatures. Relieve tension when not operating. Remove and install belt while warm. Lift track off of the ground when not in use and spin track with load off of the track before a load is put on the track. Attempt to use low temperature belting and track.

Clutches and Brakes - Plates may freeze. Material may become embrittled or reach its glass transition temperature. Use synthetic, silicone or teflon based lubricants.

Chains - May become stiff. May break before stretching. Use synthetic, silicone or teflon based lubricants.

Push-Pull type Cables - These would include the choke, throttle and brake cables. Use synthetic, silicone or teflon based lubricants.

Conclusions and Recommendations

The series of tests conducted during this project resulted in the determination of what is needed in order to start the MOST vehicle in severe cold conditions. The cold room does not allow for any types of vehicle movement and therefore tests with the drive belt and the track could not be accomplished. The ambient temperatures at KRC are not as severe as in Alaska and other Northern parts of the world. Some simple tests were run where the vehicles were left outside after operating all day in snow. Some of the snow had melted and was left in the undercarriage overnight and subjected to subzero temperatures. Each time the vehicle started easily and moved relatively easily, although at first the track was stiff until it moved a short distance.

From this study several conclusions can be made:

1.) Below -35^{0}F the behavior of the MOST vehicle changes drastically. All parts become very difficult to move and as the temperature dropped to -50^{0}F damage appeared possible to some moving parts.

2.) Cold starting a two stroke engine in severe cold environments requires as much fuel in the cylinder as possible at full choke, in other words a very rich mixture. Also, at the very minimum, some form of heat must be applied to the intake manifold.

3.) Adding gas to the oil reservoir or a lean oil-gas mixture in the fuel tank for engines without oil injection is required for good oil flow to the cylinders. A new 2-stroke oil is now available that is advertised to flow well down to temperatures as low as -45^{0}F. This oil was not tested in the KRC cold room because it arrived after the testing was completed but a photograph of this oil brand is shown in Figure 20.

4.) Special low temperature lubricants are available for severe cold and arctic environments. These are synthetic lubricants with silicone or ester base materials. A photograph of a typical low temperature lubricant that is available from snowmobile dealers is shown in Figure 21.

5.) Ether doesn't work very well at severely cold temperatures because there is no good way of getting it directly into the cylinders with restricted inflow such as in a full choke situation. Ether may easily damage a 2-stroke engine and should not be used if at all possible.

6.) The addition of a primer pump is critical to starting an engine in severe cold temperatures.

7.) Warm spark plugs (near body temperature) are helpful when starting in severe cold environments.

8.) The rubber-composite drive belt and track became very stiff in severe cold environments. The belt could be kept close to the SF personnel's bodies to keep them warm until the vehicle is started. The track end of the machine could be lifted off of the ground and spun by accelerating the engine before moving in order to break it free and prevent damage.

Figure 20 Photograph of two-stroke injection oil which is advertised to flow well down to -45^{0}F.

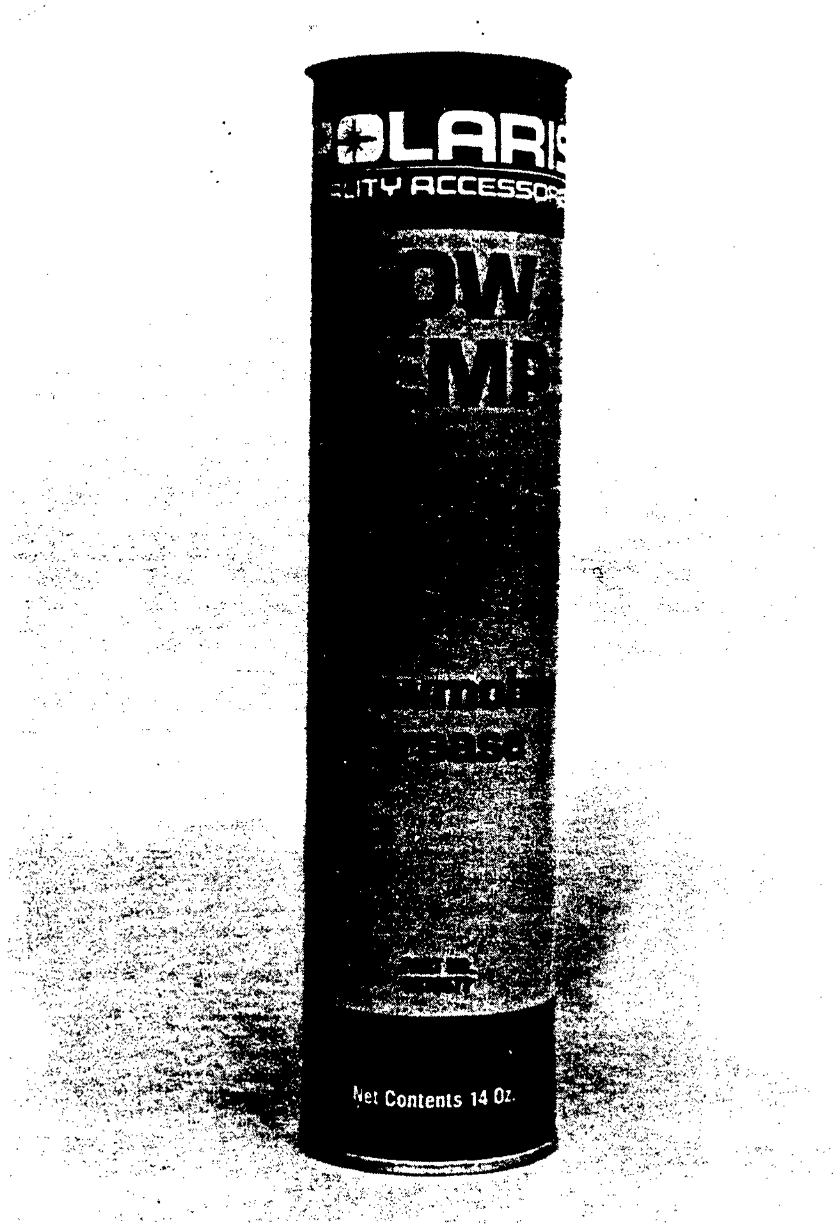

Figure 21 Photograph of a typical low temperature lubricant commonly available from most snowmobile dealers.

9.) Hotter burning plugs were never used in combination with the successful method of heating the intake manifold with a torch, adding gas to the cylinders and pumping the primer continuously. They may possibly allow the engine to warm up faster. But hotter plugs may also damage the engine if used for a long period of time at high speeds and loads.

10.) The best method of cold starting the engine in severe cold temperatures is by heating the intake manifold with a propane torch for a minimum of one minute, adding 15 ml of straight gasoline to each cylinder, installing new, warm (body temperature) standard spark plugs just before starting and pumping the primer continuously while pulling the starter rope. Figure 22 shows the successful kit (except for the primer pump) that was used in the KRC cold room.

11.) With the current primer pump installation the primer will be difficult to operate by one person while pull starting. A different location of the primer pump installation is recommended.

From the tests conducted during this project the following recommendation for successful cold starting may be made.

1.) For a successful cold start in severe cold conditions SF personnel should have at least two sets of new spark plugs, small (15 ml) packets or bottles of straight gasoline and a miniature propane torch with electronic ignition for lighting. The MOST vehicle should be purchased with a primer pump kit on the vehicle or installed after the vehicle is purchased. These items are the key ingredients to a successful cold start. See Figure 22.

2.) Along with the above mentioned items, SF personnel should mix about 4 ounces of gas with the injection oil and carry isopropyl alcohol (Heet) fuel deicer. No more than 6 ounces should be used per tank full of fuel. Note that methyl alcohol is not recommended for this application as past studies have indicated seal damage from the use of methyl alcohol. A photograph of a typical iso-heet isopropyl alcohol is shown in Figure 23.

3.) When performing a mission in severe cold environments the SF should prepare machines using special low temperature greases and lubricants.

Figure 22 Photograph of successful cold start kit components except for the primer pump on the vehicle.

Figure 23 Photograph of a typical iso-heet isopropyl alcohol.

4.) When on a mission requiring the MOST vehicle to be parked (cold soaked) for extended periods, SF personnel should carry or sleep with fuel packets, spark plugs, drive belt and a miniature propane torch near their body to keep these items somewhat warm.

5.) For faster cold starts and engine warm-up periods the intake manifold, engine block and even the exhaust manifold should be heated for as long as possible. External heat will help the engine warm up faster once it has started allowing quicker returns from missions.

6.) In the cold room study the snowmobile was allowed to idle after a successful start. In a real life situation the SF personnel should be able to increase engine speed using the throttle (revving) and thereby warm up the machine faster.

7.) If the machine will be used in very snowy conditions a small thermal blanket may be used to cover the engine compartment under the cowling while it is cached. This will prevent snow from being sucked into the engine when starting as well as avoid snow getting into the drive belt causing slippage.

8.) Before the start of a mission in severe cold conditions SF personnel should prepare the machine with lightweight chain case oils, and spray the clutch parts with a teflon lubricant. A low temperature grease such as those sold by most snowmobile manufacturers should be used on all grease fittings on the MOST vehicle prior to beginning the mission.

9.) After traveling to a specific location where the MOST vehicle will be cached, the operator should remove the final drive belt while it is still warm and plyable. After starting the engine, upon returning to the cached vehicle, and allowing it to warm up, the engine can be shut down and the belt can be reinstalled.

Assuming that the engine and MOST vehicle are not damaged, the author feels confident that by using the cold start kit and procedures described in this report, the SF personnel will be successful at starting the vehicle at temperatures as low as -50^{0}F 99 percent of the time. This is based on the fact that there were no failed starts at -50^{0}F using the cold start kit and procedures. The SF personnel may have to conduct the procedure more than once but the engine will start, which is better than not starting at all. The following description proves the value and justification of using this kit and procedures. In a separate test at KRC the Flextrac MPV, with a Yamaha 340 engine, could not start at temperatures below -40^{0}F using standard procedures. The engine did not have a primer pump. In place of using the primer pump, the operator pumped the throttle continuously while at full choke, and using the cold start kit and procedures was successful at starting the Flextrac MPV at -50^{0}F.

The Appendix to this report contains a manual with techniques and guidelines using off-the-shelf equipment for cold starting and operating the MOST in a severe cold environment.

Reference

1. Walsh, M.R. and Morse, J.S., "Preliminary Design Guide For Arctic Equipment", CRREL Special Report 89-13, May 1989.

APPENDIX A

Technical Manual For MOST System Operation In Severe Cold Environments

Introduction

The following pages contain a technical type of manual for SF personnel to use as a guideline for preparing and using the MOST System on a mission in a severe cold environment. The following instructions consist of describing Vehicle Preparation, Preparation at the Cache Site and the Cold Start Procedure.

Vehicle Preparation

Before beginning a mission where severe cold temperatures are expected the MOST vehicle should be prepared such that it is in new or almost new condition. Any worn belts should be replaced, all fittings should be lubricated, all cables lubricated, chain tensions adjusted, skis and slides checked for wear and any springs or shock absorbers should be checked to make sure they are in proper working condition. All bolts, nuts and fittings should be checked for tightness per vehicle operator's manual.

In preparation for the mission, SF personnel should perform the following tasks:

1.) Install a new drive belt on the machine and pack a spare drive belt for the mission.

2.) Lubricate all grease fittings with the special low temperature grease.

3.) Fill all gear boxes and chain case compartments with special low temperature gear lubricants.

4.) Fill fuel tank with highest octane fuel available or fuel specified in owners manual. Pour approximately 6 ounces of isopropyl gas line deicer into fuel tank to prevent carburetor icing. Pack extra containers of isopropyl gas line deicer for the mission, assuming 6 ounces per tank full of gasoline. The amount required during the mission will depend on the length of the mission.

5.) Disassemble recoil starter unit and clean out lubricant. Put in low temperature lubricant on recoil assembly. Reassemble recoil assembly and install on the engine.

6.) Mix approximately five percent gasoline with the 2-stroke oil for the MOST vehicle engine. It is better to mix this before oil is put into oil reservoir. Additional containers of premixed oil and gasoline should be carried with the machine, the amount dependent on the expected mileage of the mission.

7.) Lubricate choke, throttle and brake cables with special low temperature lubricants to prevent cable malfunction due to ice build-up.

8.) Prepare Cold Start Kit for mission. The quantities will be dependent on mission mileage and the expected number of vehicle cold starts. This kit should contain the following items:

   a.) A miniature propane torch with electronic ignition.
   b.) Small packets or squeeze bottles of pure gasoline. Minimum of 4 at 15 ml each.
   c.) A minimum of at least 2 spare sets of standard spark plugs for the vehicle's engine.
   d.) A thermal blanket to cover the engine at the cache site.
   e.) The standard tool kit for the MOST vehicle.

<u>Preparation At The Cache Site</u>

Once the SF personnel have reached the cache site there are a few procedures that will make operation easier when they are ready to return from the mission.

1.) After parking vehicle attempt to lift and support rear of vehicle such that the entire track is off of the ground. With engine running accelerate to spin track to remove snow chunks that may have accumulated in the track undercarriage.

2.) Immediately after turning engine off remove final drive belt while it is still warm and plyable.

3.) Open hood to engine compartment and cover engine, especially air intake with thermal blanket to prevent snow from coming in air intake compartment and keep engine warm. Care must be taken not to allow the blanket to burn.

4.) Close hood to engine. Fill fuel tank and add isopropyl gas line deicer to prevent ice formation in fuel tank and lines. Fill oil reservoir.

5.) Camouflage MOST system as required.

<u>Cold Starting Procedure</u>

When returning from mission SF personnel should perform the following procedure for cold starting the MOST vehicle.

1.) Prepare vehicle by removing thermal blanket from underneath engine compartment hood.

2.) If possible, the driver should keep the spare spark plugs, propane torch and final drive belt next to his/her body for several hours (3-6) to warm these items.

3.) Remove spark plugs from engine.

4.) Light propane torch and heat intake manifold for a minimum of one minute.

5.) Turn off propane torch and add one packet or bottle of fuel to each cylinder.

6.) Install new, warm spark plugs.

7.) While pumping primer continuously and choke set to full, attempt to pull start engine. The engine should fire within two or three pulls and start soon afterward.

8.) If machine does not start within 20 pulls, remove spark plugs, reheat manifold, add another packet of fuel to each cylinder and insert another set of new warm spark plugs.

9.) If the vehicle is not equipped with a primer pump the throttle can be pumped at full choke in place of the primer. It may take longer to start the engine in this case.

10.) Once the engine has started, accelerate with throttle slowly to warm up the engine and also to spin the track free. Gradually diminish the choke setting while keeping the engine running smoothly.

11.) Lower rear end of vehicle to ground and return from mission.

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