CESARONI TECHNOLOGY INCORPORATED

Lightweight Cooling Component Development (LCCD) Program

Polymeric LVS Cooling System

Design Report

24 August 1998

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14. ABSTRACT
The purpose of this analysis was to discuss the design of the new polymeric cooling components and comment on the expected performance and durability of these units over the field trial and in-service use. Cesaroni Technology Incorporated (CTI) was tasked to design and build polymeric cooling components for several Marine Corps vehicle platforms. These platforms include the High Multi-purpose Wheeled Vehicle (HMMWV), the Advanced Amphibious Assault Vehicle Propulsion System Demonstrator (AAAVPSD), the MK48 Logistics Vehicle System (LVS), and the M939 5-ton truck.

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1.0 INTRODUCTION

The goal of the Lightweight Cooling Component Development (LCCD) program is to further improve commercial and military mission capabilities and life cycle costs through the integration of lightweight polymeric heat exchangers. The perceived advantages of this technology are increased corrosion and fouling resistance, reduced weight, improved reliability and reduced life cycle cost.

The United States Marine Corps is interested in the development of lightweight and non-corroding cooling components to replace OEM components used in existing Marine Corps vehicles. Cesaroni Technology Incorporated (CTI) was asked to design and build polymeric cooling components for several Marine Corps vehicle platforms. These platforms include the High Mobility Multipurpose Wheeled Vehicle (HMMWV), the Advanced Amphibious Assault Vehicle Propulsion System Demonstrator (AAAV PSD), the Helo-Transportable Multi-Mission Platform (HTMMP), the Mk 48 Logistics Vehicle System (LVS) and the M939 5-Ton Truck.

The LVS is a large, articulated, high mobility vehicle used for carrying large mission essential equipment. (figure 1) It has suffered from severe corrosion problems in the area of the engine radiator and the oil coolers. These units have corroded rapidly, necessitating frequent and costly replacements. It is felt that by replacing these easily corroded units with polymeric ones that the system life cycle cost can be reduced through diminished requirements for maintenance and replacement. The significantly reduced weight of the polymeric system will also facilitate installation and maintenance work.

One polymeric system has been built for the LVS and was done based upon the information available at that time. This system was installed in a vehicle and performance data was gathered during field testing in July of 1996. (figure 2) That data was then analysed and a revised design has been produced based upon the lessons learned during the field testing of this unit, as well as modifications made to adapt to the revisions currently being made to the LVS platform. There have also been improvements made in the area of polymeric heat exchanger manufacturing technology that will be incorporated into this prototype build. The revised cooling system will now be built and subjected to more thorough testing by the Marine Corps.

The purpose of this report is to detail the design of the new polymeric cooling components and comment on the expected performance and durability of these units over the field trial and in-service use.

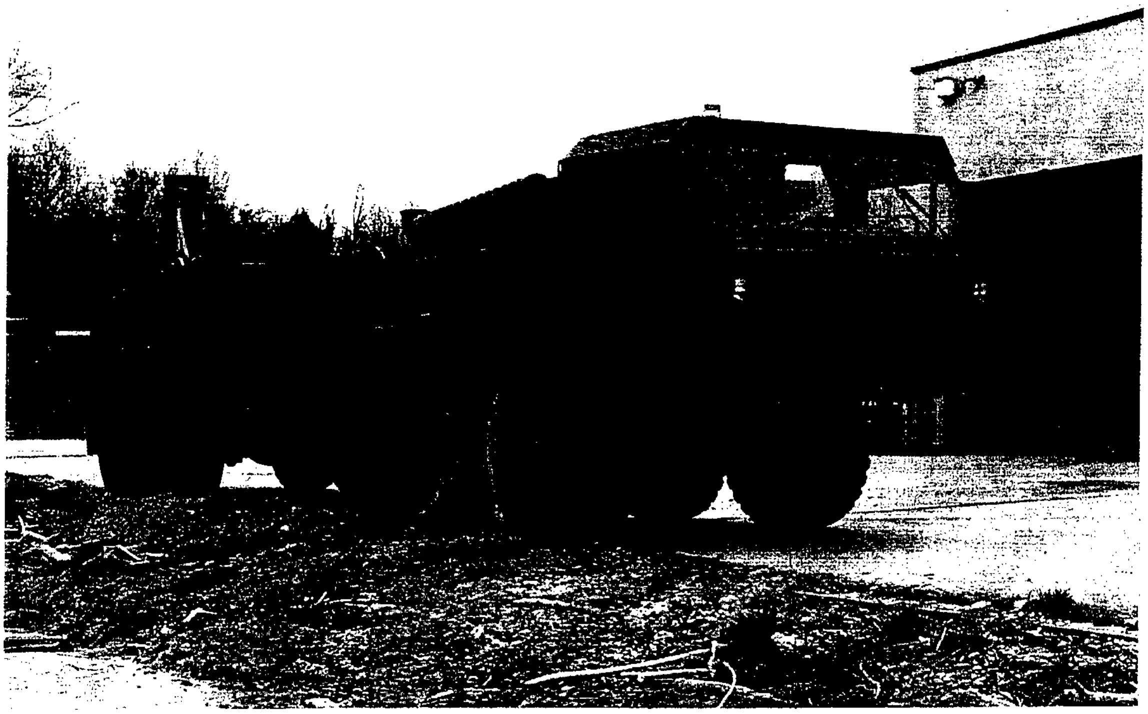


Figure 1 - Mk48 Logistics Vehicle System

Figure 2 - LVS Field Trial

2.0 THE FIRST GENERATION POLYMERIC LVS COOLING SYSTEM

The first generation polymeric LVS cooling components are the largest units constructed to date. There are three polymeric components to the cooling system; a radiator, a transmission oil cooler, and a hydraulic oil cooler. The three units replaced the incumbent metal units in the same location and volume.

2.1 Radiator

The nylon core LVS radiator was the largest high performance polymeric heat exchanger constructed to date. Among the major developments included in the design of this radiator were single piece end tanks and spacer-free self stacking panels. The radiator built for the LVS was a single pass, air cooled plate type heat exchanger. The overall dimensions of the nylon core LVS radiator were the same as those of the metal unit.

The radiator core was constructed of thermoformed panels of nylon film. These panels were then bonded to form a full radiator core. The panels were mounted vertically and were inherently self-spacing. The core was removable from the frame and end tanks, and could be replaced in the event of major damage. The core was rugged, impact resistant and non-corroding. It is field repairable with the use of an epoxy patch kit.

The performance of the polymeric unit was very good as far as heat rejection was concerned. Both lab and field trials indicated that the polymeric radiator would reject more heat than the metal unit for a given air flow rate. The air side pressure drop through the core of the polymeric radiator was, however, significantly higher than that of the metal unit. This was an area that was to be addressed in the second generation radiator. The liquid side pressure drop of the polymeric radiator was lower than that of the metal radiator.

The end tanks of the radiator were constructed of 3/16" Q6 aluminium. One tank incorporated the system expansion tank. The basic geometry of the end tanks was the same as the existing radiator so as to facilitate a one for one changeout of exchangers for testing purposes. The header tanks were not constructed of plastic on this prototype for several reasons. The main reason is that the cost of making an injection mould for one end tank was prohibitively expensive. Other methods of constructing the end tanks from nylon were also considered, including roto-moulding and stereo-lithography. Roto-moulding facilities were not available to construct the tanks in the time period required and stereo lithography has not yet evolved to where a reliable end tank could be constructed. Plastic welding technology at present does not allow the welding of nylon sheet material, though the equipment manufacturers hope to have the capability in future equipment models. Once production scale quantities of nylon radiators of a given geometry are to be produced, an injection-moulded nylon end tank is certainly readily producible. Injection moulded end tanks are currently in widespread automotive use. The use of aluminium in the construction of the end tanks had no bearing on the performance of the radiator.

The fittings on the tank matched those on the drawing provided by the manufacturer of the metal radiator with a couple of exceptions. Two secondary fittings had been omitted on the tank. These were compensated for during the field trial and this oversight will be fixed for the second generation radiator.

The filler neck was a standard automotive filler neck. It was welded to the header tank. The radiator cap was a standard 16 psi relief truck radiator cap. There were no problems found with either the rad cap or the filler neck. The radiator took a long time to fill, due to some internal differences between the prototype tank and the production one. This was also identified as a point to be corrected in the second generation system.

Attachment of the core to the end tanks was accomplished through an adapter plate. This plate was recessed to allow the core to fit into its center. The core was held in place with stainless steel toe clamps around the perimeter of the core. An O-ring was used to make a seal between the adapter plate and the core. The adapter plate was bolted directly to the header tanks. A rubber gasket was used between the tanks and the adapter plates to provide a water tight seal.

The radiator frame was also constructed of aluminium on this prototype. This was done so as to allow a consistent appearance with the aluminium end tanks. Nylon frames have been used on exchangers before and would be part of production volume units. Again, the use of an aluminium frame did not affect the heat transfer performance in any way.

The nylon that was used to make the panels expands when it is heated. The radiator frame was designed to compensate for this expansion. The two side frames were spring loaded and kept the panels taught as they expanded and contracted with changes in temperature. (see figure 3) Work is currently underway by Dupont Canada to improve the dimensional stability of the nylon and eventually eliminate the requirement for a special tensioning frame.

The nylon core radiator weighed 180 lbs. when dry. This represents a 70 % weight saving in comparison to the metal radiator currently used on the LVS. The introduction of a polymeric frame and end tanks will further reduce the weight of this component.

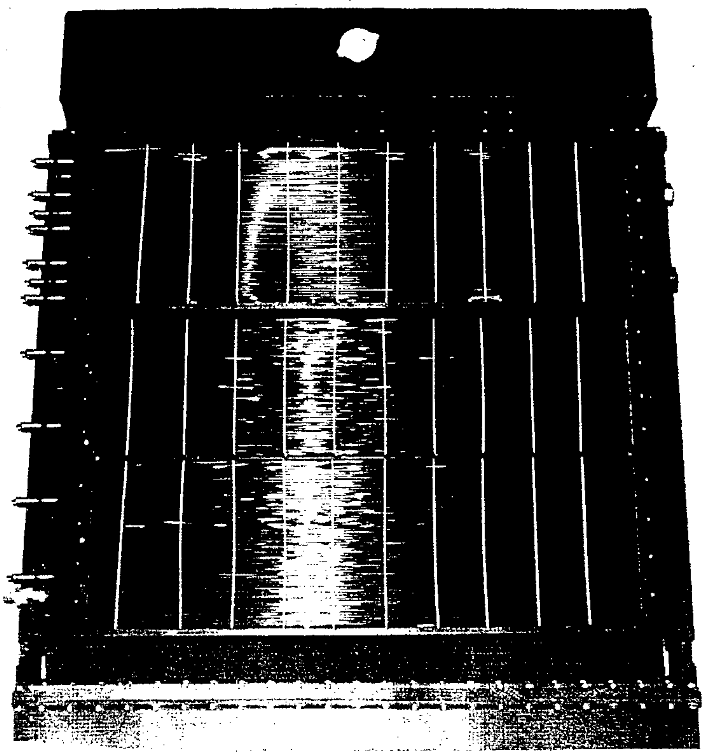


Fig. 3 Nylon LVS Cooling System

2.2 Transmission Oil Cooler

The polymeric LVS transmission oil cooler was a tube style exchanger, with a core composed of a bank of thin walled nylon tubes bonded to an aluminium end tank. This exchanger was configured as a three pass unit. The transmission oil cooler mounted on top of the radiator in the same location as the current metal exchanger. It had been pressure tested to 200 psi, 33% higher than the highest expected system pressure, according to the vehicle manufacturer.

2.3 Hydraulic Oil Cooler

The polymeric LVS hydraulic oil cooler was a tube style exchanger, with a core composed of a bank of thin walled nylon tubes bonded to an aluminium end tank. This exchanger was configured as a single pass unit. The hydraulic oil cooler mounted on top of the transmission oil cooler, in the same location as the current metal exchanger. It had been pressure tested to 500 psi, again, above the highest expected system pressure.

3.0 Design Improvements for the Second Generation

3.1 Radiator

The design of the radiator has changed significantly since the original LVS build. The most significant changes were made to the core of the radiator. The panel design has changed to allow for a reduced air side pressure drop, while still allowing for improved heat transfer performance. This has been done through improved water flow channel design, and improvements in CTI's ability to manufacture panels with small diameter, shaped flow channels. Liquid side pressure drop should also be reduced, in comparison to the first prototype and the metal radiator.

The tanks have been redesigned from the original metal units. Most of the redesign was done to correct errors made in the first set of tanks. This includes, the addition of the missing two fittings and changes to the internals of the tanks to allow for faster filling of the radiator.

The tanks will also be constructed of a new material. They will be fabricated with a composite material. This is more representative of the weight of an all polymeric tank. It will be significantly lighter than the aluminium tank that was fitted on the original prototype.

The bonding of the panels and joining of the panels has also changed since the original prototype. The panel inserts will now be welded together directly. There will be no adhesive between them. This technique provides for a more reliable bond and is significantly more consistent for production. We also have reduced the volume of the inserts, thus further reducing the weight of the structure.

We have also demonstrated a new tank bonding method for use with nylon components. This method could replace the tank to adapter plate joint. This would reduce the weight of the unit significantly, since this would eliminate the 100 sets of nuts and bolts that currently join the tank to the adapter plate on both the metal unit and the original prototype. This technique will not however be used for the second generation radiator tanks, since the tanks will not be made from nylon for this particular unit. The technique will however be used for the oil cooler end tanks.

The frames of the radiator will also be constructed of a composite material. This will provide significant strength, while reducing the weight of the overall package. The frames will also be pre-drilled for mounting on the rad supports to speed installation on the vehicle.

3.2 Oil Coolers

The tanks of the hydraulic and transmission oil coolers will be fully polymeric. These tanks will be hermetically sealed and will be a significant improvement over the previous aluminium tanks. There will be no possibility of leakage with the new tank geometry and weight will be reduced significantly from the previous prototype.

The tubes will be welded directly to the tube sheet for both of these prototypes. This technology has been developed by CTI since the last prototype was built. This will further improve the reliability and weight of the oil coolers.

The frames will be polymeric for the oil cooler prototypes. This is an improvement over the aluminium frames used in the original prototype. The tensioning arrangement for the tubes has been redesigned such that it will not interfere with the placement of the hoses in the vehicle. Development work is still underway at DuPont to eliminate the requirement for tensioning of the tubes and some progress has been made. The amount of tensioning required has been reduced through improvements in materials. The need for tensioning has not been eliminated however.

4.0 Durability

Several durability tests have been conducted on both nylon heat exchangers and nylon heat exchanger components over the past several years. The following is a brief synopsis of these tests and the results:

4.1 Pressure Capability

The radiator panels have the lowest pressure capability of all of the polymeric cooling components. These panels are pneumatically tested to 100 psi immediately after fabrication. Peak operating pressure is approximately 40 psi. This should cause no problem during normal operation in the vehicle, since there is a 15 psi rad cap on the prototype radiator. The production version has a rad cap relief pressure that is below 15 psi.

The tubes used in the construction of the oil coolers have been tested to over 1200 psi without a burst failure. This significantly exceeds the maximum expected operating pressure of both the transmission oil cooler and the hydraulic oil cooler. The pressure capability of the weld between the tubes and a tube sheet has also been hydrostatically tested several times at CTI's laboratory. In all cases, the tubes failed prior to the tube to tubesheet bond.

4.2 Pressure Cycling & Vibration Testing

Both panel and tube heat exchangers have undergone pressure cycling tests at CTI and at external test facilities. These exchangers have also passed commercial automotive (simultaneous) pressure cycle and vibration tests.

4.3 Temperature

The radiator and oil coolers are constructed of 6,6 nylon. The polymer used, does have flame retardant additives and will not burn. It will however, melt. This nylon has a melt temperature of 491°F (255°C). If the polymer is brought into contact with something above this temperature, then it will melt. Instantaneous exposure to a flame will not cause significant damage to the cooling components. However, if subjected to a flame for more than a couple of seconds, the polymer will melt. Similarly, a cigarette will not instantaneously damage the nylon. It will slowly deform the material (lowering its pressure capability), until it eventually melts a hole in the area of contact.

The nylon used will not become brittle at temperatures well below freezing. Field tests with the U.S. Army National Guard in Caribou, Maine demonstrated the ability of the material to retain its pliability while operating in temperatures of –50°F.

4.4 Temperature Cycling & Thermal Shock

The DuPont nylon used to construct these cooling components is not sensitive to temperature cycling or thermal shock over the operating range of the LVS cooling components. Both film panel and tube style exchangers have been temperature cycle tested as well as subjected to significant thermal shock, with no ill effects.

4.5 Impact Resistance

The cooling system components on the LVS are mounted underneath a protective grille, which insulates the components from significant impact. The radiator is however, resistant to significant impact, as are the oil coolers. There are no fins to dent or bend and the units return to their original shape after impact, unlike a metal radiator.

4.6 Erosion

The LVS cooling system components may be subjected to long term exposure to severe environments, including sandy areas. It is quite likely that at some point these units will be subjected to abrasion by sand, both from environmental sources and sand driven through the cooling components by the vehicle main cooling fan. While there is no "standard" test for exposure to environmental sand, we have subjected several nylon film panels to high velocity sand in a commercial sandblasting cabinet. The panels lost some of their glossy finish over time, but suffered no significant damage.

4.7 Corrosion

Nylon, being a polymer, does not corrode. Nylon heat exchangers have been exposed to highly corrosive environments during a three-year test at the LaQue Centre for Corrosion Technology. To nobody's surprise, the heat exchangers tested suffered no ill effects or corrosion after three years of exposure to sun, and a very humid, salt air environment.

4.8 Exposure to Ultraviolet Light

CTI uses a modified nylon 6,6 in the construction of its nylon polymeric heat exchangers. This polymer contains additives that stabilise the polymer and stop it from degrading under exposure to ultraviolet light. The longest running demonstration of this was the three year field trial at the LaQue Centre for Corrosion Technology. This was a three-year trial that indicated that there was no significant effect after three years of exposure to direct sunlight.

4.9 Chemical Compatibility

There is a very long list of chemicals and substances that have been tested for compatibility with the nylon that is used in the construction of these heat exchangers. Rather than go through the complete list, we will focus on those substances that are expected to come into contact with these units. Transmission oils, such as ESSO Dexron III, have been tested for compatibility with the nylons used to construct these heat exchangers. They have been demonstrated not to harm nylon, even after long term exposure at high temperatures.

Pure ethylene glycol at high temperatures will degrade nylon over a long period of time. Water and water/ethylene glycol solutions do not harm the nylons used in these units. Therefore, the radiator should not be run with 100% ethylene glycol. Solutions as rich as 90% ethylene glycol and 10% water will have no impact on the strength of the nylon in the radiator. Propylene glycol will not harm the nylon cooling components.

4.10 Reparability

Polymeric heat exchangers can be repaired, should they become damaged for some reason. The repair process has been demonstrated several times and is applicable to both tube and panel style heat exchangers. The exchanger can usually be repaired in situ. The repair process does not normally effect the pressure capability of the exchanger. The performance is generally unaffected as well.

5.0 Anticipated Performance

The original polymeric LVS cooling components performed very well in heat transfer tests. They did however, suffer from a very high air side pressure drop. Since that time, considerable work has been done to reduce the air side pressure drop without having a negative impact on heat transfer. This work was conducted using several calorimeter tested prototypes as well as finite element computational fluid dynamics. The result of this development work is that we now have a panel geometry with both improved heat transfer and improved air side pressure drop. This panel geometry has been built and tested in automotive radiator size prototypes. These prototypes have been tested both by CTI and by independent test labs. The panel to be used for the LVS will be the same basic design, with the exception that the panels will be wider (therefore more flow channels per panel), and the pitch between the panels will be widened slightly.

The following graphs indicate the performance of the metal radiator, the performance of the original polymeric prototype and the anticipated performance of the second-generation polymeric prototype.

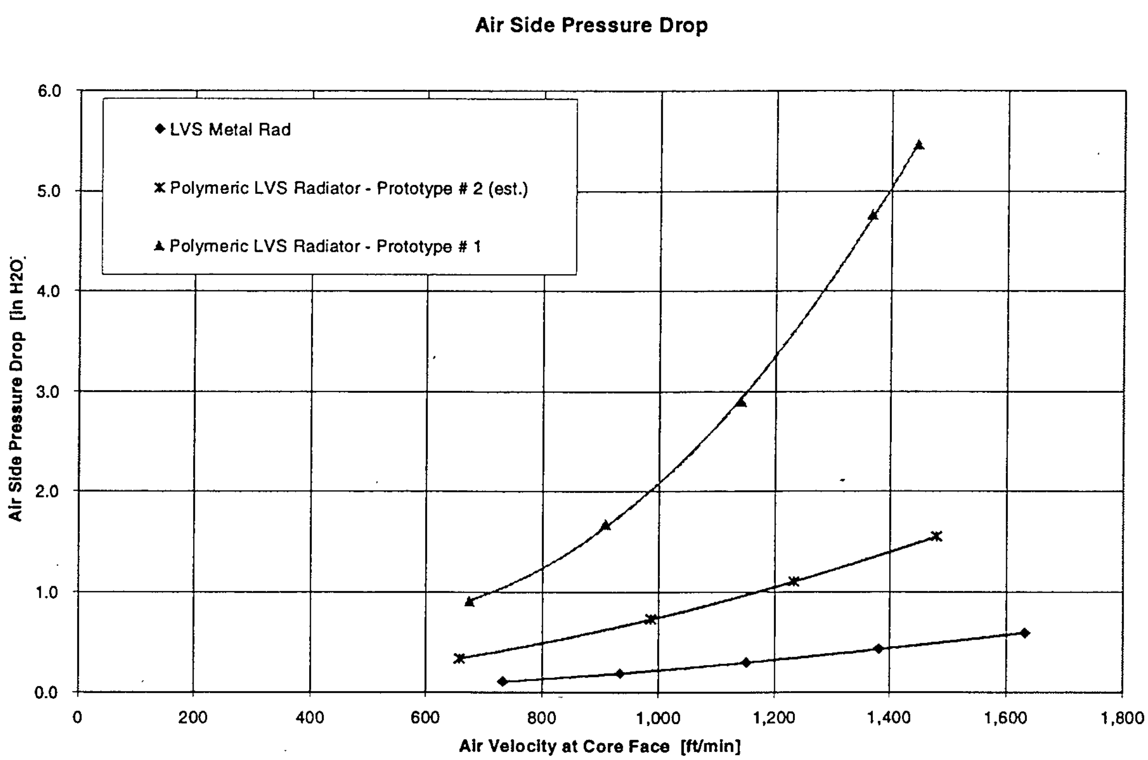


Figure 4 – Radiator Air Side Pressure Drop

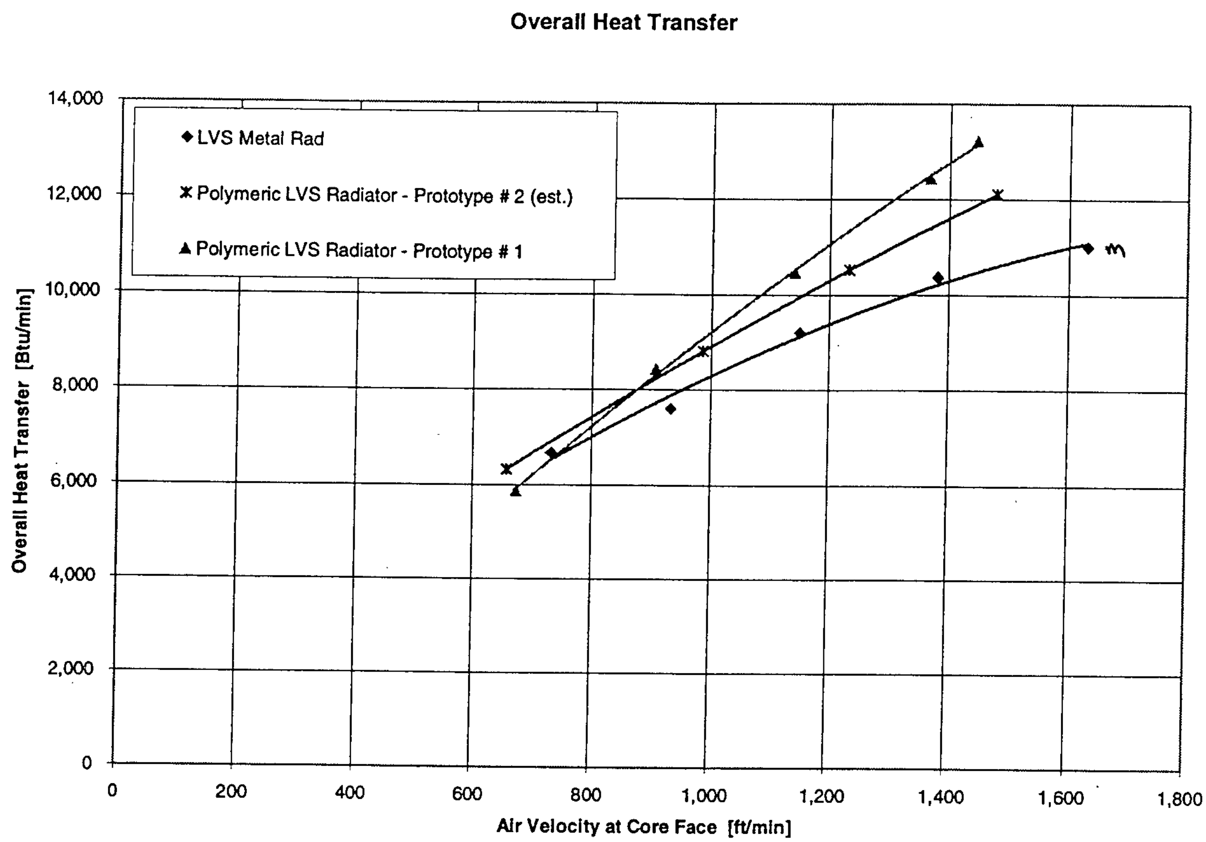


Figure 5 – Radiator Heat Transfer

The reduced air side pressure drop, coupled with an increased cooling capacity, will provide additional main engine cooling capacity for the modifications currently being made to the LVS platform.

The original oil coolers also had a high air side pressure drop, while demonstrating significant heat transfer. Improvements in tube welding technology have led to more freedom in the tube patterns usable for liquid to air oil coolers. This will allow us to use a tube pattern that is better suited to the performance requirements of the LVS oil cooler applications.

The following graphs indicate the anticipated performance of the LVS oil coolers.

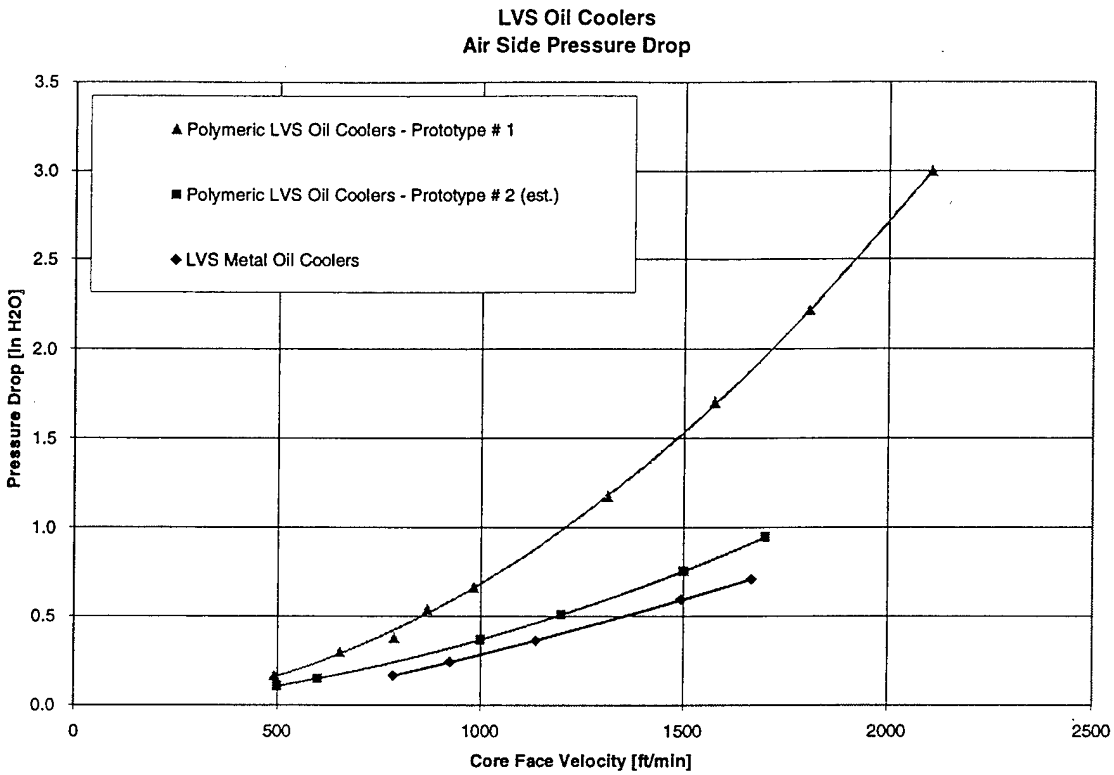


Figure 6 – Oil Cooler Air Side Pressure Drop

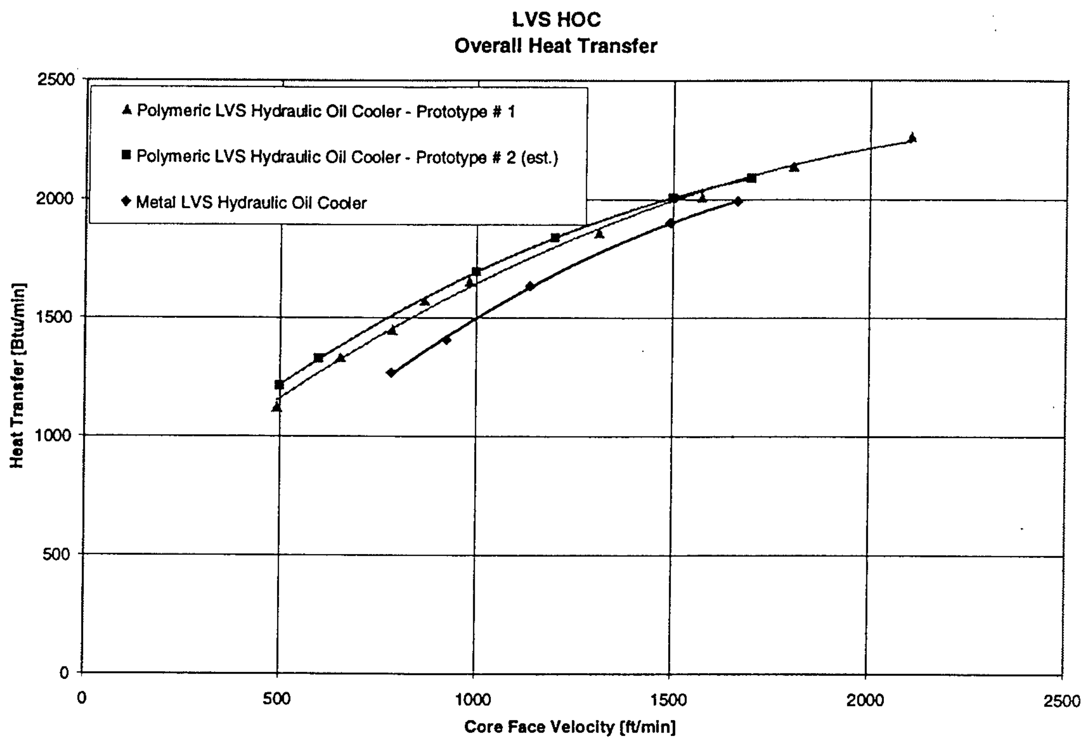


Figure 7 – Hydraulic Oil Cooler Heat Transfer

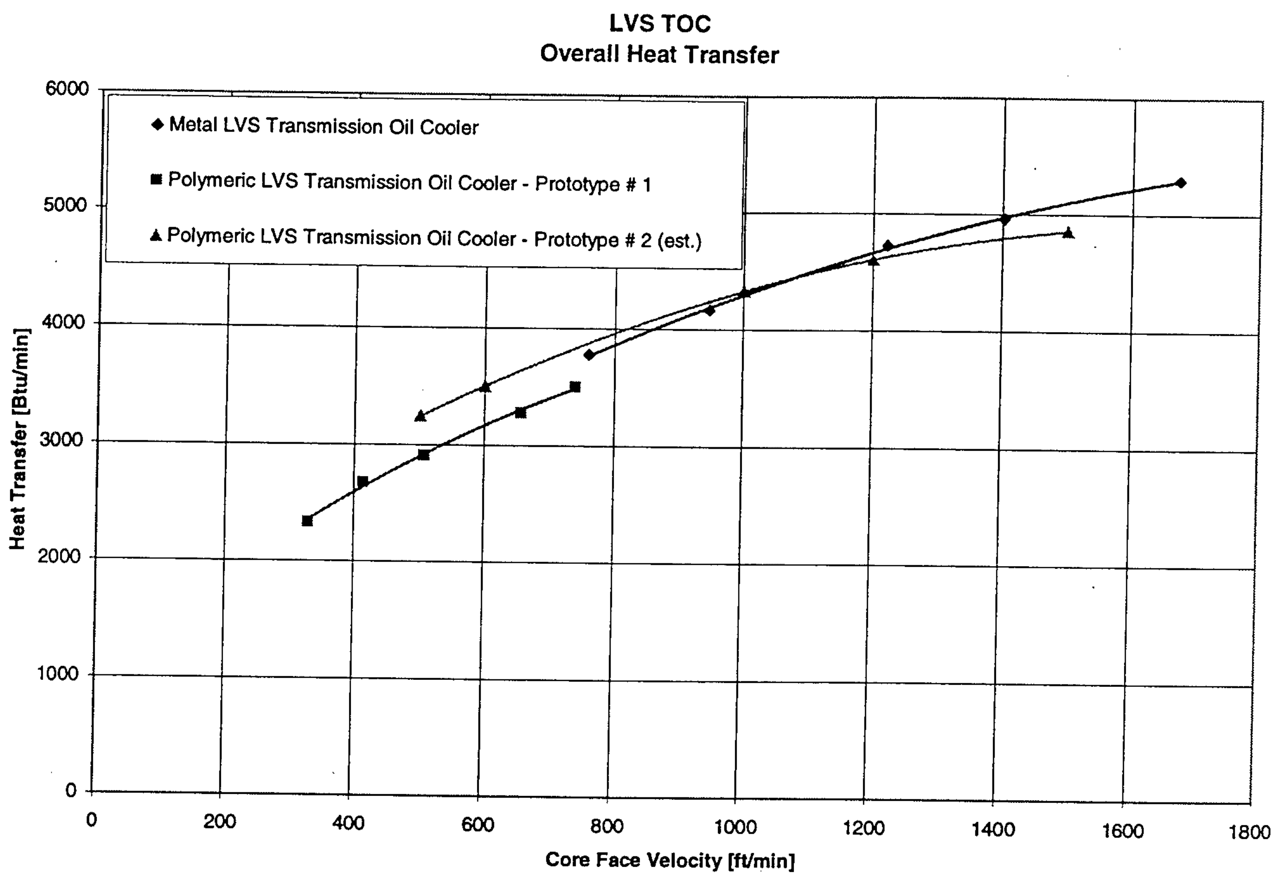


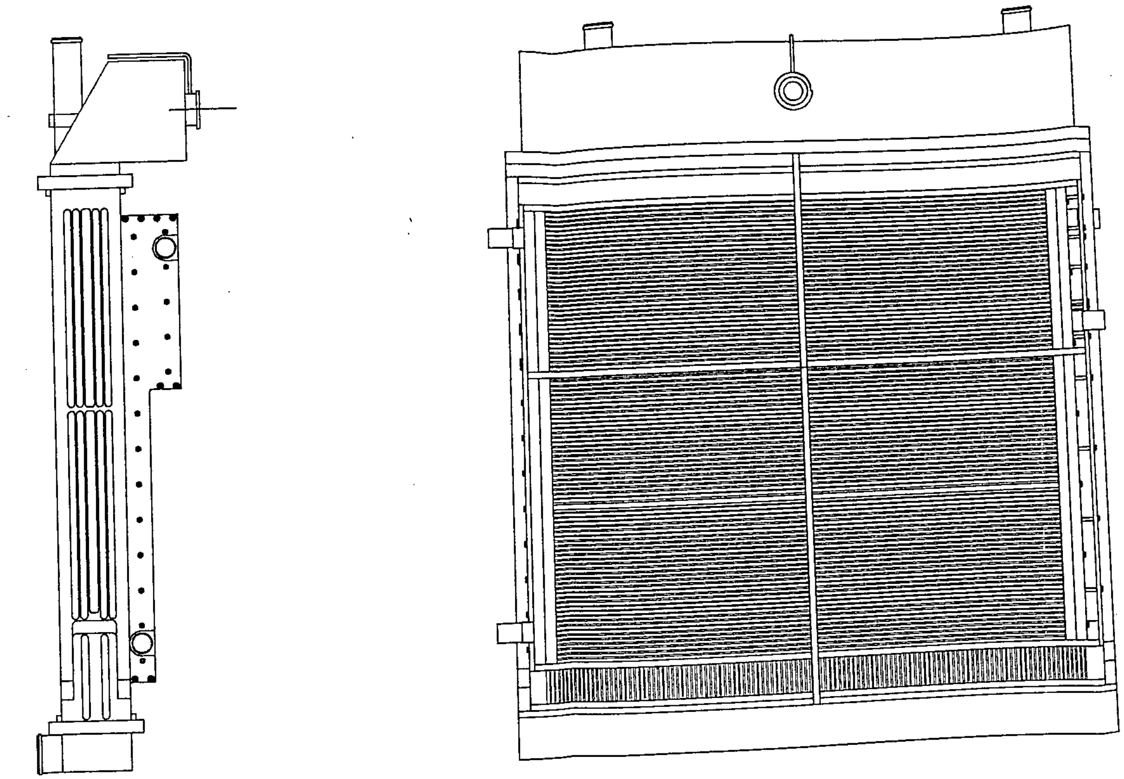
Figure 8 - Transmission Oil Cooler Heat Transfer

6.0 Conclusions and Path Forward

The next generation polymeric LVS cooling components promise to demonstrate significant improvements in both performance and reliability. These units will offer the benefits of light weight, corrosion free heat exchangers, without the drawbacks associated with metal fin tube heat exchangers.

These components will be built and then installed on the LVS vehicle. They will then be field and performance tested on the vehicle. This should further demonstrate the suitability of polymeric cooling components for use in military vehicles.

7.0 LVS Cooling Component Overall System Drawings



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TITLE: LVS HEAT EXCHANGER DIAGRAM

SHEET: 1 OF 4

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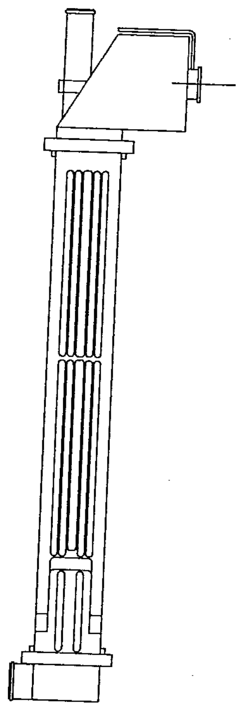

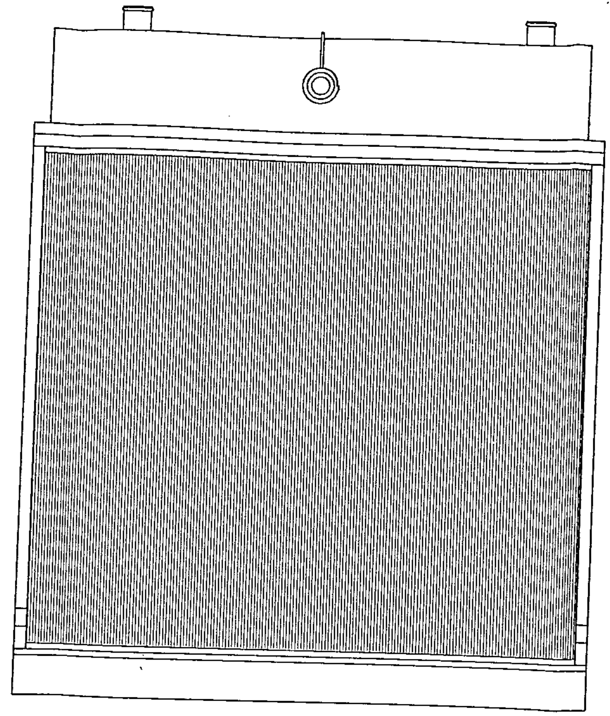

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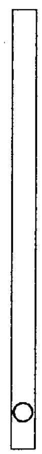

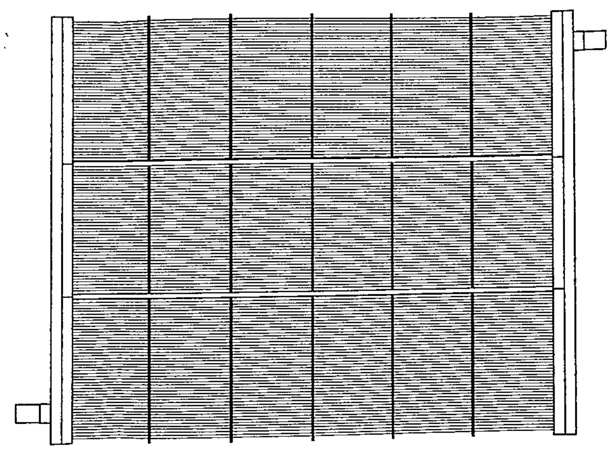

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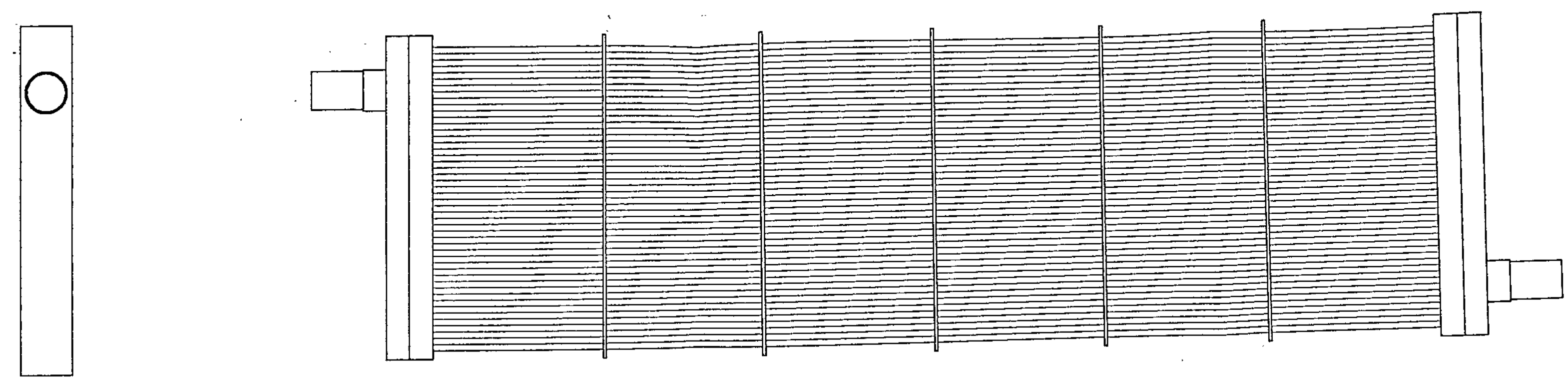

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