ISLAND CITY LLC

SINGLE-FLUID-FORWARD® Integrated Vehicle Lubrication System

Introduction

The *Single-Fluid-Forward*®, Integrated Vehicle Lubrication System technology utilizes engine oil (OE) as a single lubricant and working fluid for all vehicle systems (engine, transmission, hydraulics, steering, etc.) except axles. SFF combines otherwise separate fluid reservoirs and fluids into a single integrated system, with one self-prioritized reservoir servicing multiple subsystems without redundant stand-alone sumps and filters. In addition to reducing vehicle system components, complexity, weight and cost, the SFF filters and de-aerates isolated yet shared fluid reserves, while simultaneously maintaining consistent fluid temperature (viscosity) and fluid condition in severe operating environments,

Island City, LLC, developed SFF specifically for defense vehicles that have demonstrated performance benefits on heavy, medium and light vehicle platforms. First installed on the USMC LVSR Technical Demonstrator in 1998, Island City exclusive common hydraulic system technology is described in two United States Patents 6,227,221 and 7,610,927. SFF is adaptable to all defense and commercial vehicle systems, and offers significant benefit in new and retrofit applications. The more hydraulically intensive a vehicle system, the more is gained with SFF technology. *Single-Fluid-Forward*® integrates wide-ranging vehicle principle and ancillary hydraulic/lubrication functions into a single system:

Transmission
Torque Converter
Modulated driveline clutch (Mod Clutch)
External slave and slaving (exportable hydraulic power)
Hydrostatic fully modulated braking retarder
Hydraulic powered cooling fan, 2-speed
Hydraulic powered cooling fan, modulated
Primary steering boost
Remote (rear) electronic controlled steering hydraulic supply
Secondary (emergency) steering supply
Hydraulic vehicle suspension strut charging
LHS
SRW
MHC
Arctic engine rapid warm-up and crew cab heat
Air conditioning motor drive
Exportable electric power drive
Marine (thruster) drive
Fire control hydraulic system
Integrated fire-fighting apparatus
Engine oil Top-off
Transmission fluid Top-off
Cab lift
Many others…

Key Performance Parameters

- One reservoir and one lubricant for the entire vehicle (except axles).
- Fluid level for entire vehicle checked at one gage.
- Engine top-off, transmission, retarder, LHS, steering, cooling fan, auxiliary hydraulics and others are all operated on standard engine oil utilizing one reservoir.
- Internal reservoir compartments maintain transmission/main hydraulics, primary and secondary steering system dedicated reserve volumes within the SFF reservoir.
- Synthetic lubricants (0W40) permit operation between –50°F and +125°F with a single lubricant. Synthetic lubricants further extend lubricant operating life and peak temperatures without lubricant breakdown.
- Improved oil cleanliness with no dipsticks, and filtered top-off oil.
- No electrical power or ECU is required to carry out principle functions – SFF will continue to operate indefinitely without electrical power.
- Consistent and correct operating temperature reached without regard to outside ambient temperature. All oil is maintained at optimal temperature within moments of engine start, as the main hydraulic pump is available to bring all oil systems and engine coolant rapidly to operating temperature.
- Consistent oil viscosity delivered throughout hydraulic system from shared supply reservoir.
- Oil is delivered through a single cooler - multiple *system* coolers are not required.
- Prolongs oil life as there is less deterioration with larger shared oil volume, efficient filtration, and water removal.
- Reduced total oil volume through sharing oil between systems.
- Maintains emergency reserve oil quality. Example: Emergency steering is used if the primary steering system fails – in conventional hydraulic systems emergency steering oil remains unused for extended periods to collect water, and contaminants while remaining at the ambient temperature. SFF uses this oil as part of a *shared yet isolated* oil reserve where it is continuously filtered, de-watered and heated – ready to use.

- Shared but compartmented oil. Example, if a steering failure occurs, a larger oil volume is available to maintain emergency steering boost capability – improved opportunity to get a vehicle off the road in an emergency or escape threats.
- Improves oil entrained air removal with de-aeration provisions located in the central reservoir.
- Maintains homogenous system fluid temperature through forced reservoir mixing.
- Eliminates system filters – multiple stand-alone filters are replaced with one central high performance, high capacity return-filter.
- System automatically "tops off" engine oil sump. Initial engine oil fill is performed manually, proper level is maintained automatically.
- Reduced low temperature engine starting load – no main hydraulic pump load during engine cranking.
- Improved braking – main pump employed as a hydrostatic retarder to slow vehicle motion without additional components, weight or cost.
- Reduced components and cost as compared to conventional hydraulic systems.
- Smaller target area (lower hit probability) as compared to multiple-reservoir conventional hydraulic systems.
- Configurable to common automatic transmission systems.
- Enhances transmission operation with OE as a operating fluid

A complete SFF hydraulic system is divided into five functional regions:

Shared, Multi-volume Hydraulic Reservoir

- common return filter
- filtered system fill and top-off
- common system vent
- air removal provisions
- visual level check
- dedicated reserve fluid volume(s)
- electronic level sensor

Transmission Circuit

- transmission
- torque converter (when used)
- transmission charge and scavenge pump(s)

Main Pump Circuit

- main pump compensator
- auxiliary hydraulics i.e.:
  - hydraulic slave
  - winch
  - LHS
  - engine oil top-off
  - others
- cooling fan drive circuit
- hydrostatic retarder circuit
- main pump filter
- rapid warm-up provisions

Steering Circuit

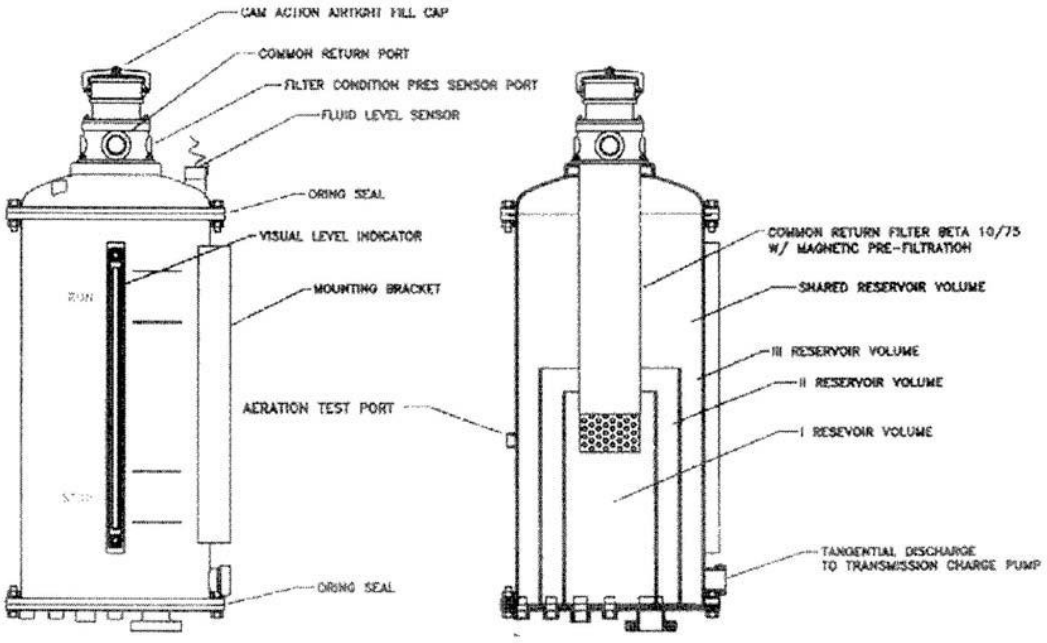
- primary steering
- secondary ground-driven steering (when required)
- engine oil top-off (alternate)

Cooling Circuit

- primary oil/water heat exchanger
- thermal bypass valve

Reservoir

The Single-Forward-Forward hydraulic system distributes fluid from a central compartmented reservoir, The USMC LVSR TD tri-reservoir containing three internal compartments is shown in Figure 1.0. The reservoir volume, shape, internal volume geometry and porting is specific to the vehicle application.



Each reservoir compartment is open to the common fluid volume yet retains a dedicated fluid reserve. Reservoir priority is cascaded from the central compartment outward. Control critical and failsafe volumes such as secondary steering draw from the centermost volume. Control critical functions such as primary steering draw from the second volume and other systems from the outer reservoir compartment. In event of fluid loss the centermost volume is first to receive any fluid returning to the reservoir, the second compartment once the first compartment is satisfied and then the third. A fluid loss from systems serviced from the 3rd (outermost) compartment has no effect on systems drawing from the 1st and 2nd levels. Fluid loss from the 2nd and 3rd levels has no effect on the systems fed from the center compartment. SFF affords the ability to survive hydraulic system losses while protecting those critical to vehicle survivability and safety.

All fluid entering the reservoir passes through a common replaceable 10 micron (absolute) BETA 10/75 filter (IAW ISO 17/14) with magnetic pre-filtration and a dearation screen. In addition any top-off oil added to the reservoir must also pass through this filter insuring freedom from top-off oil contamination. The central filter operates from inside to out – captured particles are removed when the filter is replaced. A mechanical-visual and electronic filter condition monitor alert the operator when 30% filter life remains. There are no dipsticks or readily open-able unfiltered ports to limit opportunities for contamination.

Specific reservoir dearation provisions reduce oil-entrained air. In conventionally lubricated transmissions aeration levels reach 5 to 10% by volume. The SFF reservoir demonstrated (USMC LVSR TD evaluation at NATC) oil aeration **less than 2%** with mineral base OE and **less than 1%** fluid aeration using synthetic base engine oils.

The SFF reservoir utilizes a mechanical-visual and electronic capacitance fluid level sensor to give the operator an instantaneous vehicle fluid readiness check with or without electrical power. The USMC LVSR time requirement for checking fluids other than axles without electrical power is 15 seconds using the SFF system (Ref: USMC M67854-03-R-5121 PM-MT-PRF-01).

Hydraulic Fluid, Permitted Lubricants

SFF hydraulic operating fluid and lubricant is engine oil OE (viscosity as specified for the engine) per MIL-PRF-2104G and MIL-PRF-46167. SFF is fully compatible without modification, adjustment or loss in performance with commercial synthetic base engine oils such as 0W40 synthetic motor oil. Enhanced system capabilities are available when serviced with wide temperature range synthetic motor oils – permitting vehicle operation without inter-seasonal or inter-theatre oil changes and extended lubricant life.

Filtration System

All SFF filters include electronic and visual filter condition monitors. All high pressure fluid passing through a quick disconnect fitting are provided with a downstream filter before returning to the vehicle system (i.e.: hydraulic slave quick-disconnect) All returning fluids including system top-off oil are filtered to meet the component manufacturers oil cleanliness specifications and at least to 10 Micron (absolute) before distribution from the SFF reservoir. To prevent dirt and water incursion there are no dipsticks or readily accessible unfiltered ports.

Oil Sampling

Oil sampling valves are located before the common system primary filter. Additional sample valves may be located in individual system return lines when required. Sample valves are accessible and operate without special tools or equipment.

Engine Oil Top-off

SFF is able to use engine oil (OE) as required for the engine for all fluid systems. The engine oil sump may be topped off with hydraulically clean engine oil from the vehicle hydraulic sump without operator intervention. There is absolutely no mixing between the engine oil sump and the greater SFF system. SFF serves to automatically top-off the engine sump oil level.

Integral Hydrostatic Retarder

The SFF main hydraulic pump may also serve as a braking retarder without modification or additional components. In current applications the main hydraulic pump provides up to 225 hp constant torque retardation to slow vehicle motion. During retardation the wheels rather than the engine drive the main hydraulic pump through the drive-line. An infinitely variable joystick control inside the cab gives the operator precise control over the hydrostatic retarder.

With the accelerator at 0% and the vehicle retarder turned-on the transmission torque converter automatically goes into lock-up mode. The retarder is applied in three stages: 1) with the first motion of the joystick the fan control commands full fan power to provide maximum cooling and absorb drive-line power through the fan motor. When additional retardation is requested: 2) the pressure control valve located in main pump manifold begins to modulate pump delivery pressure until maximum set pump operating pressure is reached, if the operator calls for further retardation: 3) a compensator valve located downstream from the main pump outlet dilates to increase pump flow until maximum displacement is reached. The pump now works to deliver maximum flow at maximum pressure while being driven from the drive-line. Retardation stops when accelerator is depressed, or the joystick is returned to the off-position.

As the hydrostatic retarder is working only when in lock-up the torque converter is not rejecting heat to the cooling system and no additional cooling capacity is required to cool the

braking retarder. Retarder heat is rejected through the oil cooler to the engine cooling water then cooled by the vehicle's primary heat exchanger.
The hydrostatic retarder can be used simultaneously with an engine brake or exhaust retarder. As an example the HEMTT+® 8X8 is equipped with a 225 hp hydrostatic retarder. When operated in conjunction with the 535 hp engine brake the operator controls up to 760 hp in vehicle retarding capability beyond the service brakes. Continuous duty braking retarder capacity reduces reliance on service brakes particularly on steep grades while reducing brake wear and maintenance. The hydrostatic retarder may be operated in-areas where engine brake noise is not permitted.

Integral Hydraulic System, Engine and Crew Heater

Heat rejected from the retarder is used during cold conditions to accelerate hydraulic system, engine and crew compartment warm-up. Supplemental heat rejected from the hydraulic system to the engine coolant reduces warm up time for all systems under arctic conditions. In cold environments it is often difficult to raise and maintain tactical vehicle system temperatures due to large cooling system capacities leading to oil entrained water build-up as heat is not available to drive-off accumulated moisture. SFF is available to automatically maintain system temperatures able to drive-off oil entrained water under all climatic conditions.

Transmission Circuit

The SFF system hydraulic pumps are direct driven from the transmission PTO. All pumps are driven at a direct ratio to engine speed.

Fluid passes from the outer reservoir compartment to the transmission charge pump and on to the transmission pressure regulator delivering oil to the transmission clutch circuit and torque converter combining with oil from the main pump circuit (retarder/fan/aux) and on to the system oil/engine coolant heat exchanger equipped with a thermal bypass valve to pass oil around the cooler until the system reaches operating temperature.

Fluid leaving the heat exchanger flows in two paths. The first flow maintains a supercharge pressure set by the transmission lubrication port relief valve which through the main pump filter and onto the main pump.

In the second path, fluid passes through the pressure relief valve to lubricate the transmission finally returning to the transmission sump where it is scavenged then pumped through the transmission scavenge pump onto the return filter in the SFF reservoir.

Main Pump Circuit

The main hydraulic pump performs multiple functions: 1) supplies fluid flow to the cooling fan circuit; 2) supplies fluid to all auxiliary hydraulic systems 3) operates as a vehicle braking retarder and 4) rapidly warms the hydraulic system, engine and crew compartments during cold weather start-up and operation.

Auxiliary Hydraulics

Auxiliary hydraulic systems are served from the main hydraulic pump. Self-Recovery-Winch (SRW), Load-Handling System (LHS), Material-Handling-Crane, external hydraulic slave, engine oil top-off and others are supplied from the main pump manifold. Present installations provide up to 225 hp auxiliary hydraulic power at pressures up to 6300 psi.

Hydraulic Fan

The main pump supplies the cooling fan regulated circuit to supporting single speed, two-speed or variable fan speed control via a signal from the engine ECU, transmission ECU or a stand-alone fan controller. In the event the fan control signal or electrical power is lost the fan operates at full speed. Fluid exhausted from the cooling fan hydraulic motor passes through the system heat exchanger returning to the main pump inlet and transmission lubrication inlet port.

Primary Steering Circuit

SFF steering boost hydraulic circuits are entirely independent of all other hydraulic circuits except common filtration. A fluid loss in any other hydraulic circuit will not cause fluid loss, system degradation in either the primary or secondary steering circuit. In addition the primary and secondary steering circuit functions are entirely independent utilizing a separate dedicated pump, pump drive and separate reservoir volume and reserve volume within the SFF reservoir. The primary steering circuit has a dedicated fluid reserve volume that is only accessible to the primary steering system.

Secondary Steering Circuit

The SFF steering circuit(s) meets the requirements per MIL-STD-1472 requiring the vehicle to retain positive steering control following engine or electrical power loss. The SFF secondary steering system provides steering boost in the event of engine and/or electrical power loss. Lightweight vehicles able to meet dead-engine steering requirements without hydraulic boost generally do not require secondary steering boost capability.

The SFF secondary steering boost circuit maintains a dedicated reserve fluid volume in the SFF reservoir only accessible to the secondary steering system. The transmission is equipped with a ground driven shaft - as long as the vehicle remains in motion the pump drive continues to rotate. Alternative hydraulic circuits are available to deliver oil to the secondary steering circuit if the primary boost fails. 1) A gear pump is direct coupled to a spring applied hydraulically released multi-disc clutch coupled to the transmission ground driven shaft to provide steering boost when the main steering pressure fails. The clutch piston is normally closed (engaged) but maintained open (disengaged) with primary steering boost pressure. In the event that the main boost pressure is lost the clutch engages turning the gear pump to deliver oil from the center reservoir compartment to the steering circuit. In a second application the clutch function is replaced with a variable displacement hydraulic pump

which is normally stroked during normal operation but maintained de-stroked with primary steering boost pressure. In the event main boost pressure is lost the pump strokes delivering fluid to the steering boost circuit. In both cases oil exhausted from the secondary steering system returns directly through the reservoir filter to the secondary steering dedicated reservoir volume in a closed circulation.

SFF Enhances Transmission Performance with Engine Oil

A conventional automatic transmission utilizes an oil sump and circulation system containing a relatively small volume of oil . Subsequently this oil volume is subject to high a turnover rate on the order of 6 times/minute with resulting high fluid entrained air volume typically reaching 7% to 10% by volume. Special transmission fluids designed for low foaming and other attributes enhance performance under these severe operating conditions. In a fully integrated IC SFF hydraulic system the transmission has access to the entire hydraulic system fluid volume not just the oil in the transmission sump. This gives the transmission oil a much lower turnover rate typically about 1 time/minute - greatly improving the reservoir dwell time for air removal. To provide ideal oil quality to all subsystems the SFF system entrained air levels are less than 2% by volume. A transmission integrated with Single-Fluid-Forward benefits from reduced oil degradation due to a much larger oil volume, efficient air removal and hydraulic quality filtration. A transmission operating with the SFF will have a longer operating life without specially blended fluids. In addition because it is possible to increase the temperature of the greater hydraulic system with the engine even when the transmission is not operating at temperature water does not accumulate in the transmission fluid.

Island City, LLC Single-Fluid-Forward® Applications

FIGURE 2.0: USMC 10X10 LVSR Technical Demonstrator (LVSR TD) equipped with Single-Fluid-Forward®, Twin Disc TD61-1183 transmission and Detroit 600 hp 60 Series engine undergoing testing at Quantico, VA. The SFF reservoir is visible behind the left fender. The LVSR TD was developed and assembled at the Nevada Automotive Test Center (NATC). Island City, LLC provided the principle integration engineering for the LVSR TD. The LVSR TD has undergone extensive performance and endurance testing at the NATC proving grounds. The USMC used the LVSR TD to evaluate and form the technical requirements for the LVSR program.

USMC LVSR Technical Demonstrator

The United States Marine Corps selected the Island City *Single-Fluid-Forward* ® integrated hydraulic system in conjunction with the Twin Disc TD61-1183 transmission for the United States Marine Corps developed at the Nevada Automotive Test Center, Silver Springs, Nevada. The LVSR TD SFF system supplies all lubrication requirements with a single fluid - engine oil (OE) except axle differentials including:

Transmission
Torque Converter
2-spd hydraulic cooling fan drive
Front Steering boost
Electronic Rear Steering
LHS
Engine oil Top-off
225 hp hydrostatic braking retarder
Artic engine rapid warm-up

One fluid, one fill point, one checkpoint provides for rapid PMCS without the need for tools or dipsticks. High-performance filtration delivers hydraulically clean (IAW:ISO 17/14) fluid to all systems minimizing filters and extending component life. SFF uses the same fluid for multiple tasks minimizing reservoir volume, and weight

FIGURE 2.1: ISLAND CITY 8X8 HEMTT Upgrade (HEMTT+) Advanced Technical Demonstrator equipped with Single-Fluid-Forward®, Twin Disc Model TD61-1179 transmission, CUMMINS 565 hp ISX engine and numerous upgrades presented by ADI Technologies at the 2006 Platform Systems Demonstration (PSD) at Aberdeen Proving Grounds (APG). The SFF Reservoir is located behind the left fender. The HEMTT+® was developed and assembled by ISLAND CITY, LLC. Twin Disc Corporation uses the HEMTT+® to develop and test advanced defense transmission systems.

FIGURE 2,2: USMC LVSR 10X10 (ATC/TEREX LVSR) American Truck Company/TEREX equipped with Single-Fluid-Forward®, Twin Disc Model TD61-1187 Transmission and 625 hp C18 Caterpillar engine. The SFF reservoir is visible, located above the #2R fender. The ATC/TEREX LVSR successfully completed first article testing at APG in 2005/2006.

FIGURE 2,3: South Africa MOD 8X8 (SA8X8) TATRA equipped with Single-Fluid-Forward®, and Twin Disc Model TD61-1179 transmission. The rectangular SFF reservoir is not visible - located in the center compartment. The TATRA SA8X8 successfully completed first article testing in South Africa in 2005.

FIGURE 2.4: Rectangular Single-Fluid-Forward® reservoir as applied to the TATRA South African 8X8 truck. This compact SFF reservoir is equipped with a visual site glass, capacitance based fluid level sensor.

FIGURE 2,5: Israeli MOD (IMODHETT) 8X8 TATRA equipped with Single-Fluid-Forward®, and Twin Disc Model 3600 transmission. The SFF reservoir is visible located ahead the #2L wheel behind the air cleaner. The TATRA IMODHETT successfully completed first article testing in Israel in 2006.

FIGURE 2.6: NATC CTV 4X4 included ISLAND CITY, LLC SFF in the USMC CTV development as part of JLTV program. Photographs and details of the CTV SINGLE-FLUID-FORWARD® integration are not available for publication at this time.

USMC CTV Technical Demonstrator - JLTV Prototype

The United States Marine Corps selected the Island City *Single-Fluid-Forward* ® integrated hydraulic system in conjunction with the Twin Disc TD61-1501 transmission for the USMC CTV, JLTV prototype developed at the Nevada Automotive Test Center (NATC). The JLTV SFF system supplies all lubrication requirements with a single fluid - engine oil (OE) except axle differentials including:

Transmission
Fully modulating hydraulic cooling fan drive
Steering
Hydraulic suspension
Winch
Engine oil Top-off

Future options include expanding the CTV *Single-Fluid-Forward*® systems to include the air-conditioning and export electrical power systems that are presently mechanically driven. The Twin Disc CTV transmission does not have a lubricant sump and utilizes the SFF reservoir for all fluid requirements. Eliminating the transmission sump reduces transmission size and weight for the compact CTV design. One fluid, one fill point, one check point provides for rapid PMCS without the need for tools or dipsticks. High-performance filtration delivers hydraulically clean (IAW:ISO 17/14) fluid to all systems minimizing filters and extending component life. SFF uses the same fluid for multiple tasks minimizing reservoir volume, and weight. The SFF system provides integral engine, hydraulic system and crew compartment rapid warm-up and heating without additional heaters, exhaust or equipment. -

FIGURE 2.7: FMTV+ ATD technology insertions include Single-Fluid-Forward® to supply all power-train, steering, cooling fans, auxiliary hydraulics, air-conditioning, engine oil top-off requirements from a single prioritized reservoir with a single-fluid OE.

US Army FMTV+ Advanced Technical Demonstrator

The United States Army selected the Island City *Single-Fluid-Forward* ® integrated hydraulic system in conjunction with the Twin Disc TD61-1187 transmission for the US Army developed at the Island City, LLC New Product Development Center (NPDC) Merrill, Wisconsin. The FMTV+ SFF system supplies all lubrication requirements with a single fluid - engine oil (OE) except axle differentials including:

Transmission
Torque Converter
2-spd hydraulic cooling fan drive
Steering boost
MHC
Engine oil Top-off
Air conditioning compressor
Arctic rapid warm-up and crew heater

One fluid, one fill point, one checkpoint provides for rapid PMCS without the need for tools or dipsticks. High-performance filtration delivers hydraulically clean (IAW:ISO 17/14) fluid to all systems minimizing filters and extending component life. SFF uses the same fluid for multiple tasks minimizing reservoir volume, and weight. The SFF system provides integral engine, hydraulic system and crew compartment rapid warm-up and heating without additional heaters, exhaust or equipment.

FIGURE 2.8: FMTV+ SFF reservoir located on the drivers' side behind the forward hard lift support. The reservoir is equipped with a capacitance fluid level, and indirect visual fluid level site gage.

FIGURE 2.9: USMC conceptual Marine Personnel Carrier (MPC)

USMC Marine Personnel Carrier (MPC) Technology Demonstrator

The United States Marine Corps selected Island City, LLC to supply the *SINGLE-FLUID-FORWARD*® advanced mobile hydraulic system for the MPC Technology Demonstrator developed at the Nevada Automotive Test Center (NATC) Silver Springs, Nevada .

The MPC SFF system supplies all lubrication requirements with a single fluid
- engine oil (OE) except axle differentials including:

Modulated speed hydraulic cooling fan drive
Primary Front Steering System Supply
Primary Rear Steering System Supply
Secondary Emergency Steering System Supply
Hydraulic Suspension
Braking Retarder (integrated with transmission to prevent transmission upshift on downgrades)
SRW
Engine oil Top-off
Transmission oil Top-off
Air conditioning compressor
300 hp Swim Pump with Twin Swim Motors

One fluid, one fill point, one checkpoint provides for rapid PMCS without the need for tools or dipsticks. High-performance filtration delivers hydraulically clean (IAW:ISO 17/14) fluid to all systems minimizing filters and extending component life. SFF uses the same fluid for multiple tasks minimizing reservoir volume, and fluid weight. The MPC SFF system accomplishes multiple and high-horsepower hydraulic tasks with 30 gallon reservoir volume. The reservoir design shape is specific to the MPC hull and available space claim. ALLISON transmission design forces a upshift at the transmissions operating performance limits. The SFF braking retarder is integrated with the MPC transmission control to prevent over-speed and subsequent transmission upshift to keep the vehicle safely under control when negotiating steep down-hill grades .

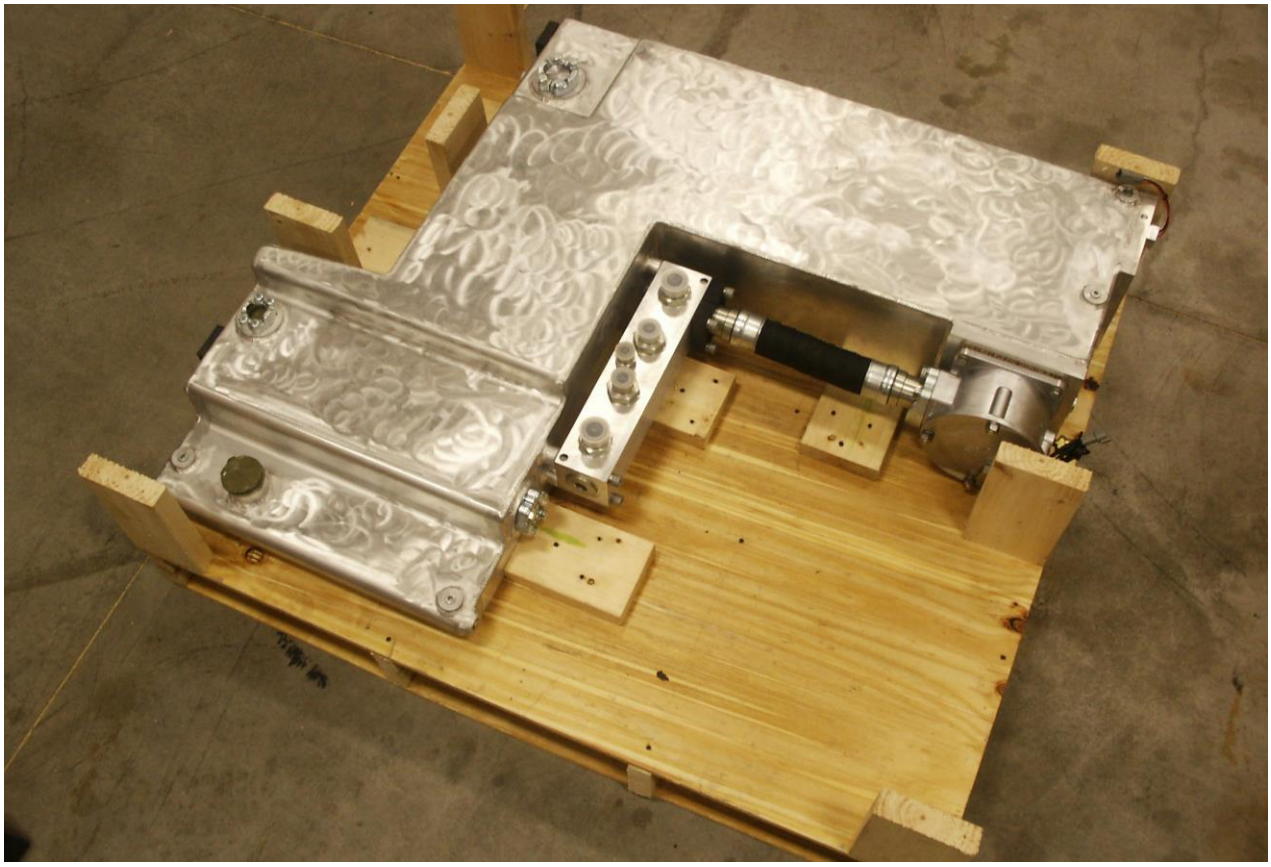


FIGURE 2.10: USMC MPC SFF hydraulic reservoir.