2015 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER & MOBILITY (P&M) TECHNICAL SESSION
AUGUST 4-6, 2015 - NOVI, MICHIGAN

SCALABILITY AND MODULARITY FOR CROSS DRIVE TRANSMISSIONS ACROSS A FAMILY OF ADVANCED COMBAT VEHICLE WEIGHT CLASSES

S. Arnie Johnson
L-3 Combat Propulsion Systems, Muskegon, MI

Gerald Dyck, P. Eng.
Kinetics Drive Solutions Inc.
Langley BC, Canada

Michael Mushroe
L-3 Combat Propulsion Systems, Muskegon, MI

Kyle Jackson
Kinetics Drive Solutions Inc.
Langley BC, Canada

ABSTRACT
L-3 Combat Propulsion Systems (L-3CPS) and Kinetics Drive Solutions (Kinetics) have teamed together to present this paper that discusses infinitely variable transmission technologies with high gear ratio & efficient steering systems for cross-drive transmissions across a family of combat vehicles. Traditionally, cross-drive transmissions for tracked vehicles are very rigid systems, which are tailored for a specific application or vehicle weight class. This becomes a problem throughout the vehicle's lifecycle, as vehicle weights continue to grow when armor and other systems are added to protect and support the war-fighter. Increased weight leads to degraded vehicle mobility performance. To regain the vehicle mobility performance more power is needed at the vehicle sprockets. Traditionally this is accomplished by increasing the engine power of the propulsion system, which requires an increased transmission size for higher input and output torques, resulting in increased losses and decreased power to sprocket. This traditional approach incurs significant hardware and potential design costs when there is a need to upgrade a tracked vehicle's power pack.

L-3CPS and Kinetics believe there is a better way. A Hydro-Mechanical Infinitely Variable Transmission (HMIVT) closely integrated with electronic generator(s) and motor(s) that is packaged in a modular architecture that has the ability to adapt to a number of vehicle classes and weights is proposed. To address the challenge a systems engineering approach will yield a propulsion system having better power density (sprocket power / propulsion system volume) than traditional propulsion systems. A high efficiency HMIVT core will be used as the basis for the scalable and the modular configuration, allowing the engine to operate within its most efficient operating band while having the ability to adapt to changing vehicle weights and applications.
The paper will discuss a building block concept for both current and future vehicle power classes from 750hp thru 1500hp. Benefits to this approach include; Open Architecture, Improved acceleration, Dynamic Braking, Scalability, Redundancy, Drive by Wire, Upgradability, and Future Growth/Optimization.

INTRODUCTION

The rigid power packs that are currently used in tracked vehicles worldwide provide the required mobility performance when the vehicle is introduced to the market. However, most, if not all, tracked vehicles continue to grow in weight over the vehicle's lifecycle. This weight growth is due to many factors that benefit the warfighter, most commonly upgraded armor and the introduction of electrical components to accommodate the vehicle's increased electrical demands. This additional weight has a negative effect on vehicle mobility, requiring additional power at the sprockets in order to regain this mobility. Increasing the power and torque output of the engine requires a transmission upgrade, along with other power pack systems. This is a costly exercise from both hardware and engineering perspectives when required across a fleet of vehicles.

A solution must be developed to accommodate this increased vehicle weight more effectively and efficiently, as all signs point to climbing vehicle weights continuing to present themselves as a challenge in the future.

The partnership between L-3 and Kinetics has uncovered this solution through leveraging their existing technologies and expertise. By combining an Infinitely Variable Transmission (IVT) architecture with a parallel electrical system, a solution is realized that is both scalable and efficient, providing an optimal response to the existing problem with climbing vehicle weights.

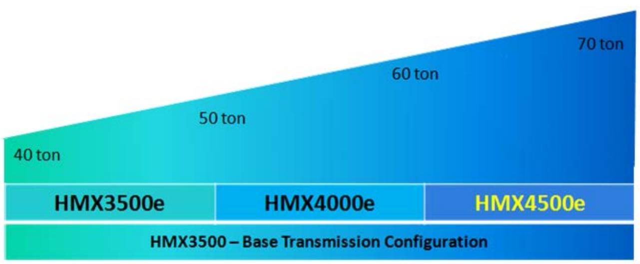

Figure 1: Weight Class Capabilities

This solution will also enable a single transmission system that has the ability to be applied to an entire operator fleet, having the adaptable nature to suit a wide range of vehicle classes, as illustrated in Figure 1. The basis for the transmission design is the existing HMX3000 transmission, which has recently been included in the AAV Survivability Upgrade. Based on this existing architecture, the core to this scalable transmission solution will be the HMX3500, a hydro-mechanical cross-drive transmission with an input rating of 3500Nm. The transmission naming follows the same nomenclature as we progress up through the models, with an "e" added to signify a system that incorporates electrical components.

Transmission	Vehicle Weight	Vehicle Power
HMX3000	30 to 40 tons	Up to 800hp
HMX3500e	40 to 50 tons	Up to 1,000hp
HMX4000e	50 to 60 tons	Up to 1,250hp
HMX4500e	60 to 70 tons	Up to 1,500hp

Figure 2: HMX Transmission Family Capbilities

The above table, Figure 2, shows the application of transmission across vehicle class (vehicle class when used in this text refers to both the vehicle weight and power as described in the above table). This transmission family can accommodate a number of vehicle classes, with the scalable transmission system providing a solution for many vehicle classes.

A scalable transmission will provide significant benefits, both operationally and financially to a fleet operator, however these advantages and features must be balanced against the overall target of reducing vehicle size and weight, while maintaining mission capable mobility. The fundamental purpose of this concept is to provide the future forces with a transmission configuration that has the following characteristics:

- High Power Density: A high power density (high efficiency & small volume) transmission that enables a high power density propulsion system is crucial to the future modernized vehicle fleet. Current tracked vehicle power packs use a large amount of the useful vehicle space. The large footprint required of current power packs results in platforms that are undesirably large causing increased vehicle size, weight, and reduced mobility and protection.
- Lower Cooling System Burden: Transmissions currently in use in the military fleet reject approximately 20-40% of the propulsion power as heat into the vehicle cooling system. This is a highly undesirable feature in a combat vehicle as it forces larger cooling system volumes (with resultant problems as identified above) and because of the protective nature of combat vehicles, cooling air must be provided by a forced air flow system, and the increase heat burden requires cooling fan systems that are very significant in both size and power requirements.
- Improved Fuel Economy: Reducing fuel requirements has two significant benefits to tracked vehicle operators: Less on board vehicle fuel required to complete mission requirements. An HMIVT is more efficient than other transmission technologies and allows the engine to run more

efficiently, which will require less fuel on board to complete the mission. This reduction of on board vehicle fuel will reduce vehicle size and weight. As the in-theatre transportation of fuel is both an expensive and dangerous operation, minimizing fuel requirements is of great benefit to the user.

HISTORY

In the last 5 years L-3 Magnet Motors GmbH (L3 MM) and L-3 CPS have teamed to develop Integrated Starter Generator (ISG), a 160kW ISG coupled with L3 CPS's HMPT800 Hydro-mechanical transmission (Figure 3). L-3 MM and L-3 CPS have been supporting many R&D initiatives with the US Government's research facilities. L-3 MM and L-3 CPS developments also include the core high voltage components utilizing power electronic/inverter technologies for complete vehicle solutions for extremely high-density 600VDC systems.

Figure 3: 75kW ISG System for Light Military Vehicle Applications

Kinetics Drive Solutions, established in 1991, is a multi-disciplinary engineering company in the field of design and development of intelligent drive solutions for heavy and medium duty defense and commercial applications. Over the past 15 years, Kinetics has developed a family of cross-drive transmissions for tracked military applications, the HMX series that includes the HMX1100, HMX1300 (not shown), HMX1600, and the HMX3000 [Figure 4].

Figure 4: HMX Family of Transmissions

These transmissions combine the efficiency of several fixed mechanical gear ratios with the variable output of integrated pump motor (IPM) units to create an IVT. The IPM's make use of commercially available bent axis hydraulics that have very low leakage and high efficiency compared to the hydraulic pump-motor units in currently fielded hydro-mechanical cross drive transmissions. IVT's continuously adjust ratios in response to load changes.

ADVANTAGES OF IVTs

Crucial to this solution is the core transmission around which the scalable architecture is built. The IVT architecture provides the required flexibility and operation required for this modular system. IVTs incorporate drive technology that is founded in the basic principle of decoupling the engine and transmission speed, allowing for independent operation and management of the engine and transmission to provide a highly fuel efficient system. This technology was developed to achieve a transmission that combines the advantages of infinite control and the efficiency of direct gear drives. The Hydro-Mechanical IVT (HMIVT) with hydrostatic drive and mechanically geared system ultimately enables the engine and transmission to operate at their maximum efficiency while still meeting the desires of the operator regarding vehicle function including vehicle speed and torque demands.

The cost and performance benefits of these transmissions have made them attractive and they continue to improve upon and offer significant advantages over competing alternative transmission technologies such as Dual Clutch Transmissions (DCT) and Automatic (Hydrokinetic) Transmissions (AT).

The trend for both AT and DCT transmissions in recent years has been to increase the number of gears ratios to enable the engine to operate at its most efficient point by using the additional gears to maintain a narrower RPM range. An example of this trend is the Binary Transmission (BT) architectures which have implemented upwards of 32 to 64 discrete gear ratios. While the DCT manages these shifts better than the AT and BT, the shift points still create a power interruption, creating transients for the engine that reduce fuel economy and affect vehicle operation. One main negative effect on vehicle performance is the reduced acceleration of the vehicle, as the power interruptions experienced with AT, BT, and DCT transmissions create a torque disruption which limits vehicle acceleration. Additionally the increase in gear ratios has the effect of increased system weight and drag losses.

When comparing the HMIVT to the AT, BT, and DCT it is clear that an HMIVT has significant advantages in heavy duty applications as it relates to overall system performance, efficiency, and ease of use as shown in Figure 5.

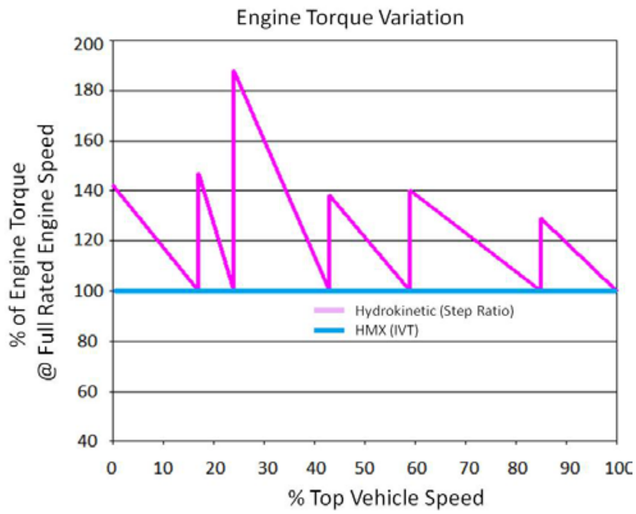

Figure 5: Engine Torque Effects

The HMIVT reduces torques spikes on the engine and driveline, which reduces wear and tear on components and can reduce system sizing, while promoting longer engine life. It produces significant torque that is de-coupled from the engine torque, and is instead a function of the transmissions hydraulic variator. This provides the benefits of the torque converter's torque multiplication, without the associated increases in heat rejection. Also allowing the HMIVT transmission to maintain its superior performance characteristics independent of the engine it is coupled with. Characteristics that AT, BT, and DCT transmissions are unable to do efficiently.

The HMIVT's speed ratio, the ratio between input and output shaft speeds, is infinitely variable. This allows the engine speed to be completely independent of the transmission's output speed. This is accomplished through continuous manipulation of the HMIVTs parallel hydraulic and mechanical power paths.

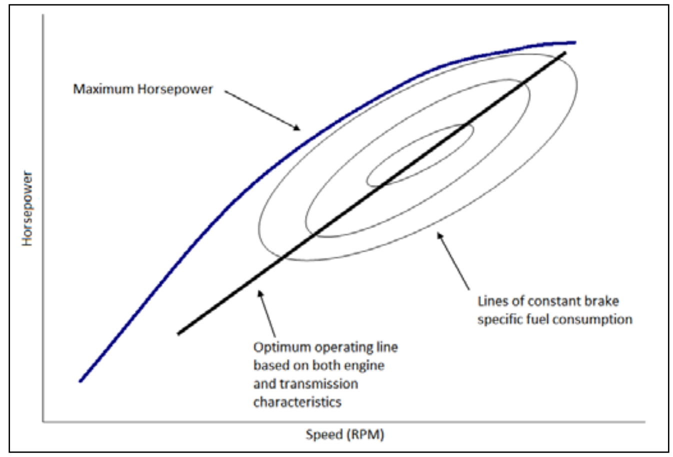

Figure 6: Engine Operating Curve

Figure 6 shows an example of a typical internal combustion engine (ICE) efficiency map. All ICEs have a characteristic efficiency map that show constant power curves and minimum fuel consumption contours on an engine torque versus speed plot, higher efficiency converging to the center of these curves. The infinitely variable nature of the HMIVT allows the engine to operate on the peak efficiency curve (with consideration for torque reserve for dynamic response needs) for any power demand. As the engine's optimal operating point is changing based operating conditions, the transmission ratio adjusts constantly to follow this curve while seamlessly maintaining the driver's speed/acceleration demand. This well defined operation and simplicity of the HMIVT is not possible with an AT, BT, or DCT.

The HMIVT power paths also allow for synchronized shift between ranges, eliminating engine RPM changes and transient point which negatively affect fuel economy. The ability of the HMIVT transmission to vary its ratio across each range, and to perform these non-interrupted shifts enables the engine to operate at its optimal operating point at all times, even during range shifts, provides efficiency and vehicle control unmatched by AT, BT, and DCT transmissions.

HMIVT transmissions have the added ability to self govern the input power and torque that pass through the transmission. This is accomplished by using the hydraulic power path of the transmission to limit the input power by monitoring system pressure and reducing hydraulic component displacements when required. The HMIVT transmission does not rely on any communication with the engine, or any special torque cells or sensors to limit the engine torque that is passed through the transmission.

The ability of self governing input torque, which is simple in an HMIVT, is not possible in discrete ratio transmissions such as AT, BT, or DCT.

SYSTEM DESIGN

The team has leveraged L-3 CPS' experience on a number of prototype programs using permanent magnet (PM) rotating machine technologies, motors, generators, and starters.

The scalable transmission solution is based on the concepts included in Kinetics' previously designed HMX transmissions, while making improvements to develop a transmission that incorporates the most modern drive technologies. Building off the HMX3000 transmission design architecture as a conceptual base, transmission components will be redesigned in order to accommodate the increased power and torque requirements, as well as including a 3rd range to provide the optimal balance between transmission performance and power density.

This section will discuss both the HMX3500e and HMX4500e transmission configurations. There is no description of the HMX4000e systems in this text, as it is a system that is identical to the HMX4500e transmission, only with smaller capacity electronic components. Systems above the HMX4500e are also possible with this architecture simply by upgrading the size or number of electric motors and generators.

HMX3500e Architecture

Design efforts will begin with the development of this core transmission, called the HMX3500e, which will serve as the base for all transmissions with power capacity over 1,000hp, and which will provide a standalone transmission that can be used with vehicles 40 tons and above.

By moving to a 3-range transmission architecture, it will allow the HMX3500e transmission to provide leap-ahead performance capabilities when compared to the current cross drive transmissions on the market. First, it will enable true synchronous shifting. This uninterrupted shift provides true infinite control of transmission through its entire operating range, vastly surpassing traditional AT's, BT's, and DCT's ability to keep engine RPM constant while shifting between ranges. Second, the addition of the 3rd range enables the transmission to meet the modern, more aggressive torque and speed requirements that are required for fighting vehicles of the future.

The HMX3500e transmission will provide the same hydro-mechanical power split as previous HMX transmissions, using a gear set at the input to split power between the hydraulic and mechanical power paths. The addition of this 3rd range requires a change in the gear set architecture that is used to connect the two parallel power paths and provide power to the outputs as shown in Figure 7

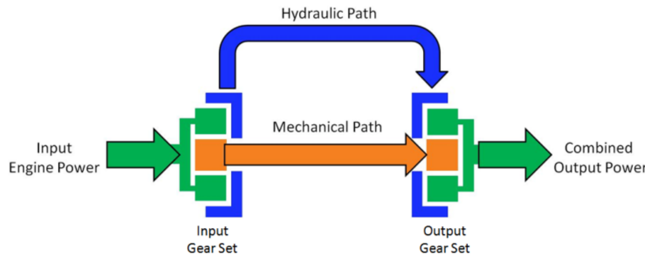

Figure 7: HMX3500e Power Paths

The hydraulic branch of the HMX3500e will make use of an Integrated Pump Motor (IPM) hydraulic variator, similar to the variator in the HMX3000 transmission. The hydraulic components of the IPM will continue to use readily available COTS hydraulic components, packaged in a custom arrangement to provide a compact power dense assembly. The IPMs will run in a dry-sump environment for increased efficiency by eliminating windage losses of standard hydraulic components. By varying the displacement of these pumps and motors, the transmission control system determines division of power between two parallel paths.

HMX3500e Braking

The HMX3500e will include a hydraulically engaged multi-disk braking system that will provide dynamic stopping power to meet modern service braking requirements. Park brake holding capabilities on grade will be accomplished by using the same multi-disk brake system, using a spring applied method for a system safety benefit. This braking system will be integrated into modular assemblies at each transmission output. This will allow for a simple exchange of these modular units to accommodate larger or smaller brakes for varying vehicle weights. Allowing the brake system to be tailored for all vehicle weights will provide space, weight and efficiency gains. Kinetics has extensive experience in brake design from experience during the development and validation of the HMX3000 transmission and its brake system, including meeting the aggressive International Test Operating Procedure (ITOP) 2-2-267(1) standard for braking.

HMX3500e Steering

In order to manage steering in a tracked vehicle, the relative speeds of the left and right hand outputs must be varied with respect to each other. The HMX3500e incorporates a planetary gear set at each output with a hydrostatic drive system (Kinetics' designed IPM) to introduce steering.

The steering system offers regenerative, high-precision steering, with a quick response time and negligible drift characteristics.

Pivot mode of operation sets the IVT ratio to geared neutral, allowing maximum power to be directed to the steering system. Once pivot mode is selected, the direction of the steering yoke rotation will determine the direction of vehicle pivot. The speed of the pivot maneuver is based on engine speed and steering yoke position.

HMX4500e Architecture

The HMX4500e is based on the HMX3500e transmission core, providing all the benefits of a HMIVT, and with the addition of electrical machines, provides a TRI-power system that includes 3 power paths: hydraulic, mechanical, and electrical, as shown in Figure 8, to provide a highly flexible, modern, and intelligent solution for the future.

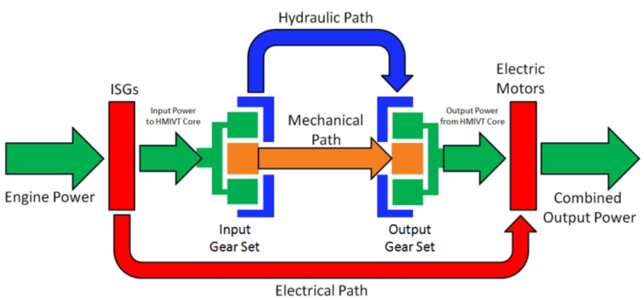

Figure 8: HMX4500e Power Paths

This maintains the self-governing nature of HMIVT's and will allow the engine to be oversized in power for alternate functions. This allows export power to be delivered to the electric machines for additional torque and power demands when increasing the vehicle's weight and power class. This also provides the ability to couple the transmission to high power engines to power electrically driven auxiliaries weapons, or protection systems for example.

This ability to manage the transmission's input torque is key to providing a modular transmission architecture.

The electrical machines will provide the performance increase from the base HMX3500e to meet the mobility requirements for larger vehicle classes, and will be integrated in the most efficient method as it relates to service, upgrade, operation and packaging. By utilizing the electrical machines as the additional power beyond 1,000hp, the amount of power that passes through the transmission core is limited. This allows the core transmission to be sized appropriately, and as previously stated will provide a core transmission that is suitable for standalone operation in applications up to 1,000hp and 50 tons. Since the HMX4500e will utilize external electric motors to provide power beyond 1,000hp, the HMX3500e will maintain its efficiency for these lower horsepower applications as core transmission components are only required to be sized for 1,000hp, ensuring parasitic losses due to oversized components are eliminated.

The electrical motors will be located at the transmission outputs, and will interface with the modular brake assemblies and their housings. This will allow the electric motors to provide torque directly to the output shafts of the hydro-mechanical core, with minimal impact to transmission control strategy. The electrical motors will be powered by input mounted generators as shown in Figure 9, which illustrates the combination of the electrical machines with the HMX3500e core. The IVT attributes of the HMX3500e core enable the additive torque capability of the electric motors unlike other transmission architectures such as AT, BT, and DCT. The combination of HMX3500e and electrical motors combine to augment an open transmission architecture called HMX4500e that enhances all IVT attributes and benefits. The generators that are used to power the HMX output-mounted electric motors will be driven prior to the transmission input, or on the PTO, and will be mounted to allow for easy service, as well to add and remove as the vehicle weight increases or decreases.

HMX4500e Braking

The modular brake assemblies from the HMX3500e will be adapted to provide dynamic braking capabilities and static park brake holding capabilities for larger vehicle classes. Dynamic braking capabilities will be augmented with the inclusion of a hydraulic retarder in order to preserve brake life and increase performance. While the HMX4500e transmission includes electrical machines to provide mobility, they do not perform any vehicle braking functions ensuring that any electrical failure will not compromise vehicle braking. Modular brakes could be downsized to take advantage of dynamic braking using the electrical system if desired and safety accepted.

Most 1500hp vehicle classes require a transverse or L-shaped configuration, which will require a transfer arm to connect the engine and transmission. To take advantage of this integrated architecture, the gear train of the transfer arm which is traditionally used only to connect engine and transmission, will be used to direct mount accessories or auxiliary components. This arrangement will provide efficient and reliable performance through the seamless blending of mechanical, hydraulic, and electrical power that leverages both Kinetics and L-3's past experiences to provide a transmission that is both capable and easily implemented in existing vehicles, while having the ability to grow and adapt to future vehicle technologies.

OPERATING MODES

The scalable architecture of the system described here lends itself to a number of operating modes, providing significant flexibility to the user. The following schematics are an illustration of the HMX4500e modes of operation.

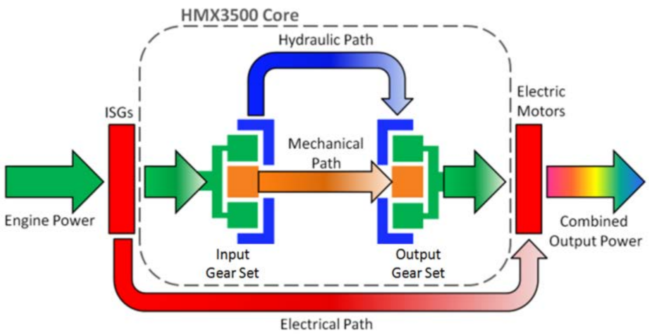

Figure 9: Normal Operation

During normal operation all power paths will be used by blending the power and torque available from all branches. The blending of power will be determined by the transmission control system to leverage the power path that provides the best efficiency for a given operating point. For events where maximum performance is required, the transmission control system will blend power to achieve the maximum performance.

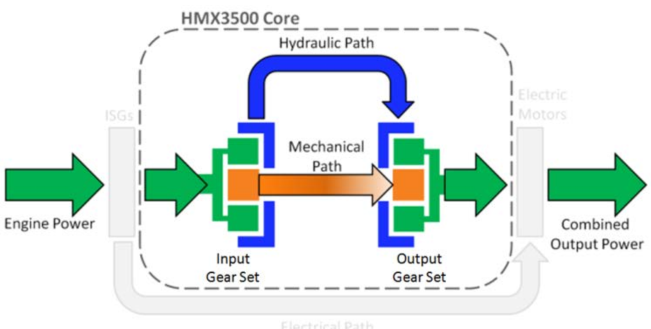

Figure 10: Operation on 65% Grade

Figure 10 shows operating up to a 65 ton vehicle on the 65% grade can be achieved by the HMX3500e core alone. This ensures the best system efficiency as the HMX3500e core provides higher efficiency than the electric motors low speed, high torque operating regimes.

The self-governing nature of the HMX3500e core allows for vehicle mobility to be maintained in the event of a failure of the electrical system.

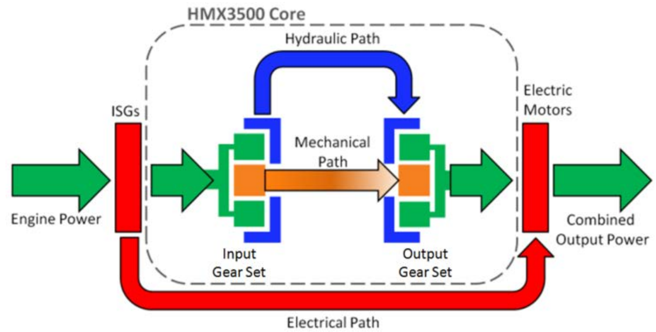

Figure 11: Maximum Tractive Effort

In order to achieve the full 1.0 TE/GVW tractive effort for a 65 ton vehicle all power paths will be used. The HMX3500e core will provide the majority of the torque through its hydraulic path for this operating point, but the electric motors will be required in order to provide the additional torque required to hit the aggressive 1.0TE/GVW requirement (Figure 11).

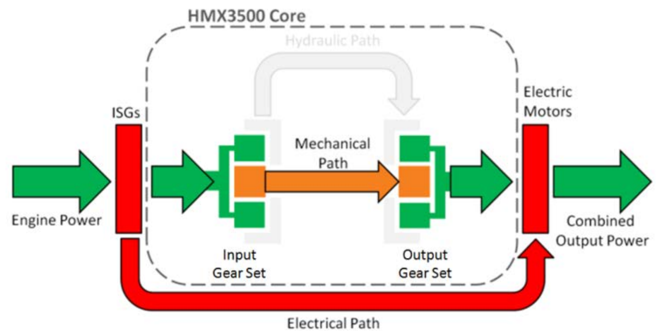

Figure 12: Top Speed Operation

At top speed the HMX3500e core is operating in full mechanical mode for the highest efficiency. The electrical motors will add their power and torque to achieve the required top speed. This allows for high transmission and system efficiency by using the electric motors in their most efficient operating range (Figure 12).

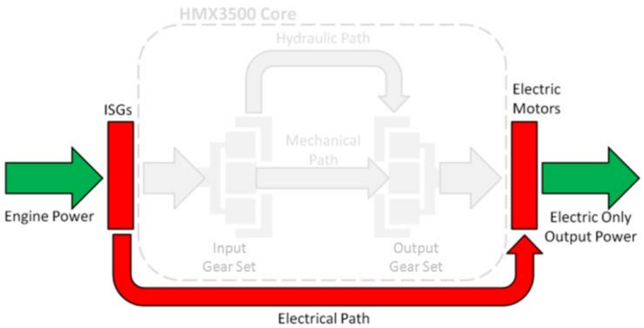

Figure 13: Electric Motor Operation

The HMX4500e has the ability to operate using only the electric motors for propulsion if desired (Figure 13), and also demonstrates the operating mode can be maintained in the event of a failure of the HMX3500e transmission core.

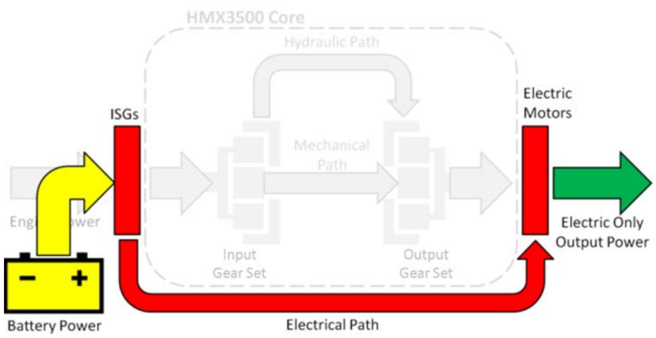

Figure 14: Future Silent Mode Operation

In the future, if onboard electrical storage were introduced to the vehicle, the transmission system would allow for the vehicle to be propelled solely by electric power for maneuvering in a workshop environment where engine emissions are unwanted. Silent mode operation would also leverage this operating mode. The size of the battery pack would determine the vehicle's distance range in this mode (Figure 14).

During braking events the HMX4500e will use both the hydraulic retarder and friction brakes to stop the vehicle (Figure 15). The hydraulic retarder will provide the means to keep the friction brake system sizing to a minimum by absorbing the majority of kinetic energy during dynamic braking events at high speeds.

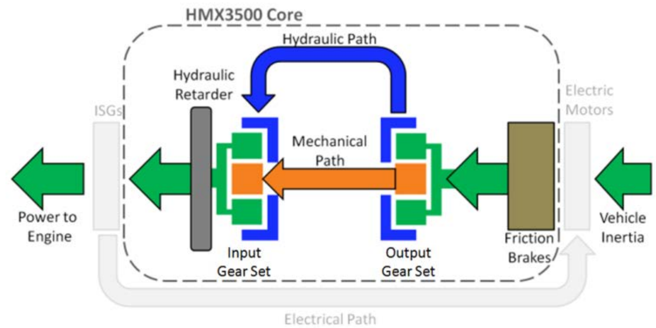

Figure 15: Normal Braking Operation

Safety improvements can enable electric motors to provide braking capabilities. Braking energy can be used to charge the batteries if desired. This may allow for reduction in size of the transmission friction brakes and hydraulic retarder. One concept is shown in Figure 16.

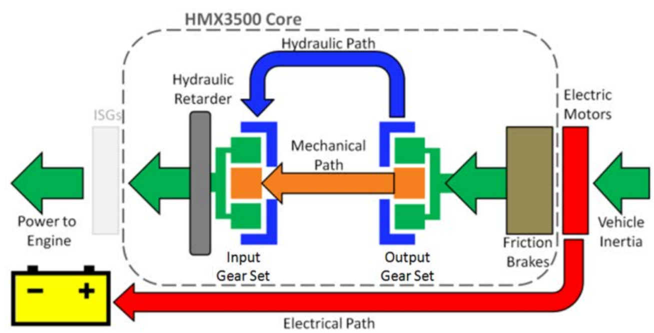

Figure 16: Future Braking Operation

SYSTEM PERFORMANCE

The scalable transmission architecture proposed in this paper provides mobility to meet modern tracked vehicle targets providing significant advantages to vehicle operators. Vehicle tractive effort requirements have consistently increased over the years as new operational capabilities are uncovered from experiences encountered in the field. This requires increased transmission output torque that must be balanced with aggressive top speed targets. The scalable concept described here meets and exceeds these modern requirements. Figure 17 shows that the core transmission exceeds 1.0 TE/GVW for vehicles up to 55 tons, while the transmission coupled with the electrical system can produce 1.0 TE/GVW for vehicles over 65 tons.

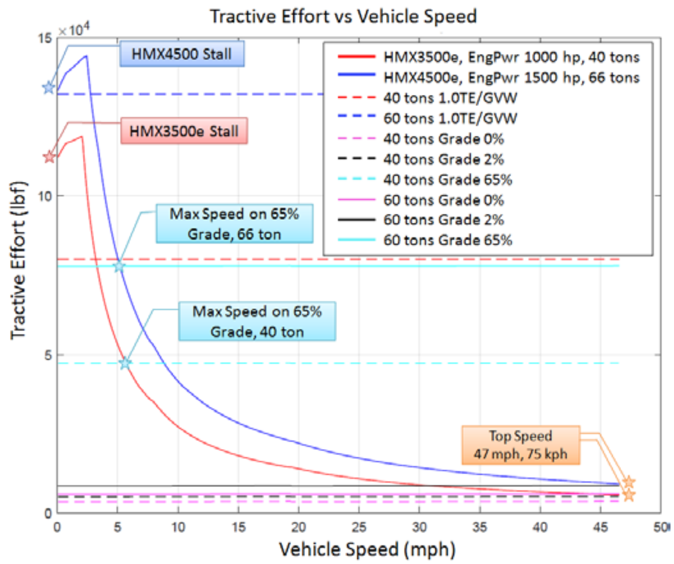

Figure 17: Tractive Effort

These tractive effort capabilities are realized while not having a negative effect on top vehicle speed, achieving a top speed of 47 mph (75 kph). Since the transmission has inherent equal performance in forward and reverse, maximum speed capabilities are also possible in reverse.

The scalable transmission also provides exceptional efficiency as demonstrated in Figure 18. The efficiency is shown for all three ranges of the transmission. The first and second range efficiency will be optimized using only the core HMIVT, while the third range efficiency is optimized using as much electrical propulsion as possible. This approach uses each power path where most and efficient and provides a system with the highest efficiency and fuel economy. This efficiency curve is shown at a full continuous mobility power level, and exceeds the efficiency of currently fielded legacy HMIVT and AT transmissions which are also shown. *[<u>NOTE</u>: The curves representing both the HMIVT and AT solutions are combinations of historical evidence, and are not meant to represent any single transmission, or any manufacturers released data]*.

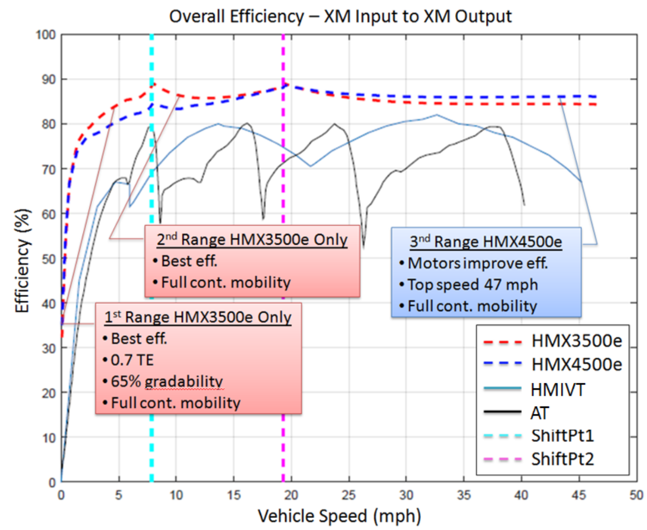

Figure 3: Efficiency

Both the core HMX3500 transmission and scaled HMX4500e transmission for larger vehicle classes provide exceptional acceleration. Figure 19 shows the acceleration characteristics of the HMX3500e and HMX4500e to 30 mph (48 kph) for the stated vehicle weights and power classes. The HMX4500e achieves this speed in 15.6 seconds, while the HMX3500e meets this speed in 14.7 seconds for 65 and 40 ton vehicles, respectively.

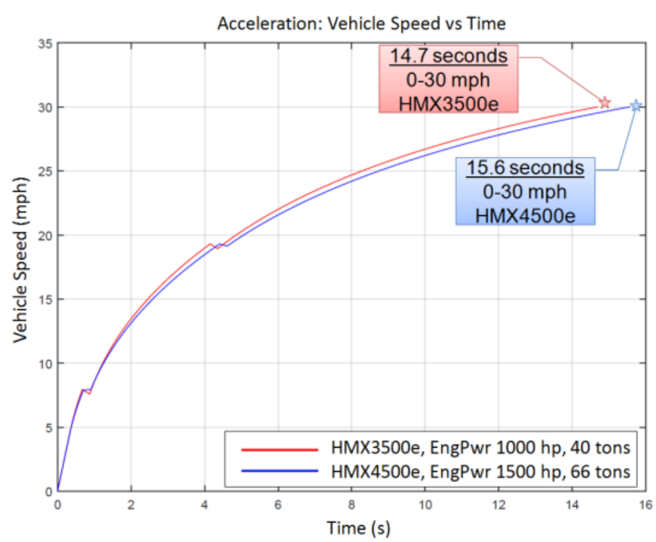

Figure 4: Acceleration

The transmission steering system provides an intuitive automotive like steering system for the operator, reducing the training required for operators. The steering system is infinitely variable, providing a smooth and predictable steering response, unlike transmissions which make use of binary or geared steering systems. This steering system, working with the transmission control system, also has the ability to increase engine power to respond to steering power demands, without a need for the driver to intervene.

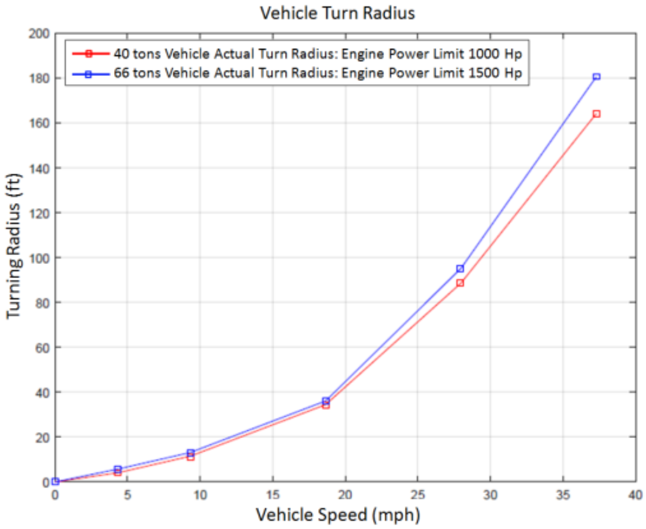

Figure 5: Steering Radius vs Speed

The fully regenerative steering system provides exceptional performance, with pivot capabilities in the 10 second range and steering radius capabilities shown as a function of vehicle speed in Figure 20. This system continues to provide full steering capabilities in the event of engine/vehicle electrical failure, ensuring the safety of both operators and occupants.

The brakes of this transmission system, for safety reasons, also maintain their full capabilities in the event of engine or vehicle electrical failure. With all transmissions having the ability to provide a stopping force up to 0.53 g from a top speed of 47 mph. All transmissions will be capable of stopping and holding the vehicle on 65% slope both forward and in reverse with service and parking brake systems.

IMMEDIATE BENEFITS

1.) Performance, Size, Weight and Scalability: Both the HMX3500e and The HMX 4500e provide exceptional tractive effort and mobility (top speed and acceleration) performance. Competing transmission technologies cannot meet both these requirements simultaneously without a large number of discrete gear ratios and a resulting large heavy transmission. Only the transmission architecture developed jointly by L-3 and Kinetics allows a transmission designed for a 40 ton application to be scaled for a 65 ton or heavier application.
2.) Built-in Powertrain Redundancy: Vehicle mobility is maintained regardless of core transmission failure, or electrical systems failure. Since there are two distinct power paths operation can be maintained in the event of failure of either system, with the operational power path providing limited mobility. These redundant power paths provide better limp home capability and eliminate towing for certain failure conditions.
3.) Drive-by-Wire: The driver's controls are electronically controlled. Therefore, the scalable transmission system is inherently drive-by-wire. It has flexibility for driver station location on vehicle and even remote control operations. Operational safety is achieved by redundant systems. Steering has both electrical and hydraulic systems. Braking is hydraulic with dual emergency fail safe, parking brake system.
4.) Ease of Upgrade: By designing the modular components of the transmission to be externally mounted, the transmission offers simple upgradeability. Climbing vehicle weights are accounted for by upgrading the externally mounted electrical components, or added if using the HMX3500e. This provides significant benefit as it relates to costs of upgrading tracked vehicle power packs.
5.) Logistical Benefits: With the HMX4500e making use of an HMX3500e core, both transmissions share common parts and subsystems. Transmission components could be shared across the fleet, even for vehicles in different weight classes, reducing supply chain costs.
6.) Service: The electrical systems are mounted external to the transmission, they can be serviced easily.

FUTURE BENEFITS

1.) Open Architecture: Provides possible battery only or hybrid architectures for propulsion power source alternatives for future needs.
2.) Improved Acceleration: Acceleration can be improved if hybrid batteries were added for propulsion power systems. The HMX4500e open architecture will take advantage of these batteries when they are available.
3.) Dynamic Braking: This can include resistive braking, regenerative braking, mechanical and

combinations thereof, depending on the application architecture. The HMX4500e open architecture will support all combinations.

4.) Silent Operation: If/when onboard energy storage is introduced into vehicles, this transmission will be able to perform silent mode operation as the electrical systems are already in place.

5.) Vehicle Power-to-Grid: The incorporation of generators and electric motors into this scaled transmission solution provide a simple means of delivering electrical power to a grid, or to support any electrical needs when the vehicle is stationary.

6.) Future Growth/Optimization: Electrical machines for this proposal are leveraged from prior projects and as such, future optimizations can be had by adjusting the permanent magnet machines for this application. In addition, new materials and improved magnetic materials

INTELLECTUAL PROPERTY

L-3 CPS and Kinetics have filed for intellectual property rights surrounding this novel concept.