


U.S. ARMY RDECOM
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Mobility Demonstrator

22 August 2013

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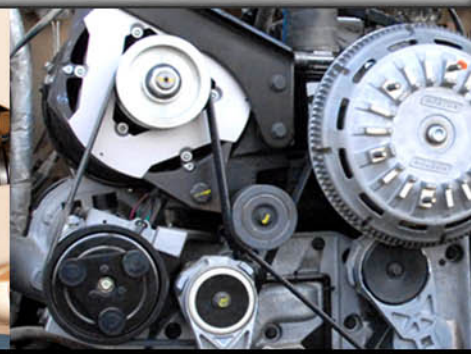
Ground Vehicle Power and Mobility



Report Documentation Page

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GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM (GVSETS), SET FOR AUG. 21-22, 2013

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Briefing Charts

15. SUBJECT TERMS

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Objective

- **Presentation of the Mobility Demonstrator effort which exercised a "paradigm shift" in TARDEC Mobility's traditional methodology / thinking regarding combat vehicle mobility design.**
- **Exercising of atypical methods to stimulate creativity.**
- **Focus on innovative / creative thought towards mobility systems.**
- **Perform a subsystem-by-subsystem evaluation of the art of the possible.**

Engineers Gone Wild !

Exercise I

- TARDEC Engineers sequestered and tasked to concept a new vehicle.
- Requirements - Futuristic, highly mobile, 40 ton weight.
- Concepts to be grounded in some reality, albeit innovative to the point of science-fiction.
- To be “safe”, engineers developed short , medium, and long-range concepts.
- Engineers found lack of defined requirements “stressful”.

Wheeled Conventional Design

Quad Tracked Vehicle

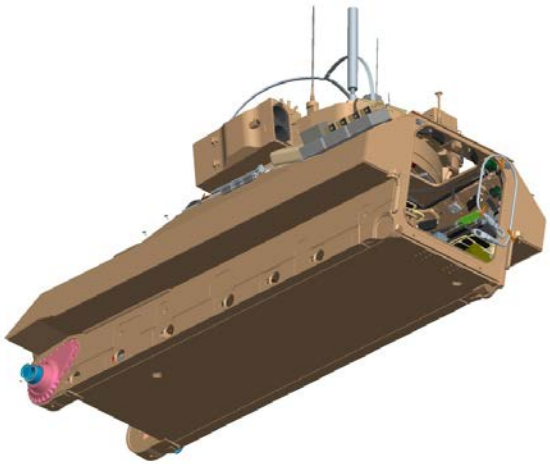
Modular/Detachable Center Pod & Scouts Vehicle

Highly Articulated Wheeled Vehicle

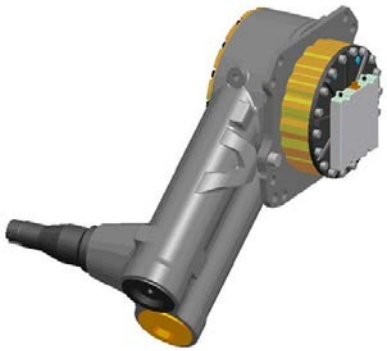
Wheels on a Bradley !

Exercise II

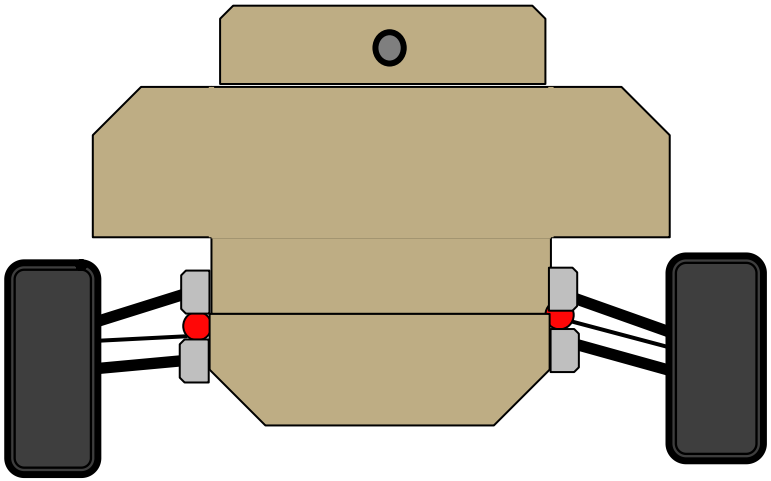
- **Mechanical Track Drive / Electric Wheeled Drive Approach**
- **Modular Mechanical Track Running Gear**
- **Modular Electric In-Hub Motor Wheels with External Hydraulic Suspension Unit (HSU) Running Gear System**
- **Both systems fit in same sponson cavity location.**

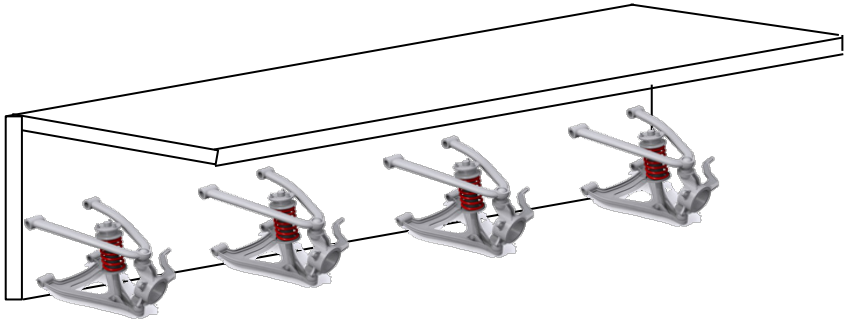


Tracked Modular Suspension



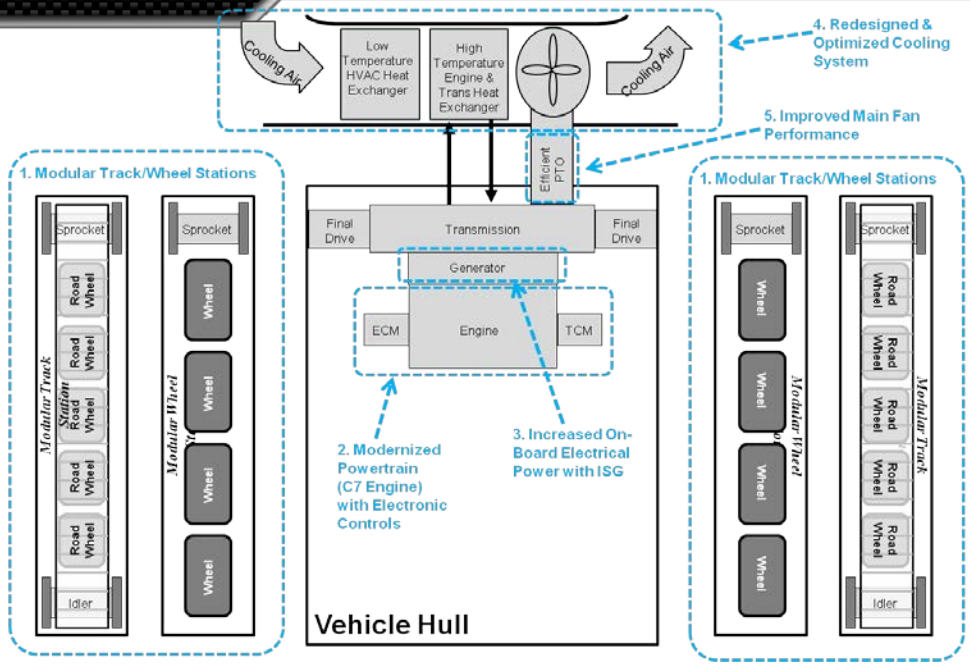
Wheeled Modular Suspension



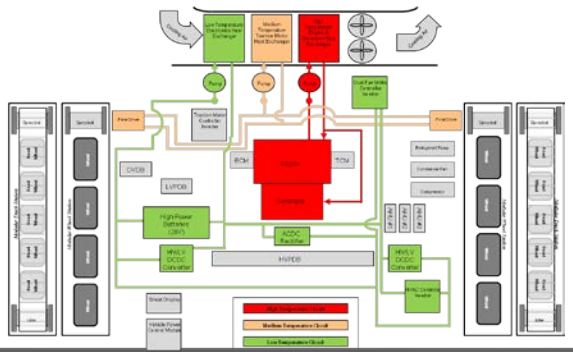


Propulsion Architecture

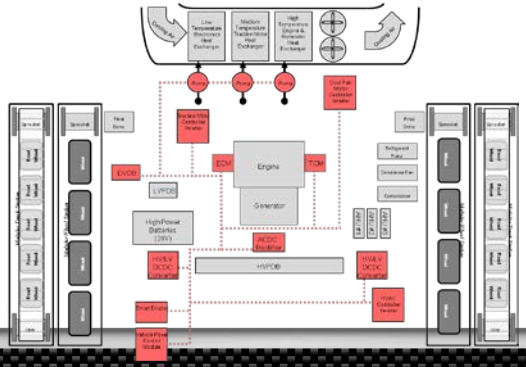
Mechanical Track Drive / Electric Wheel Drive Propulsion System



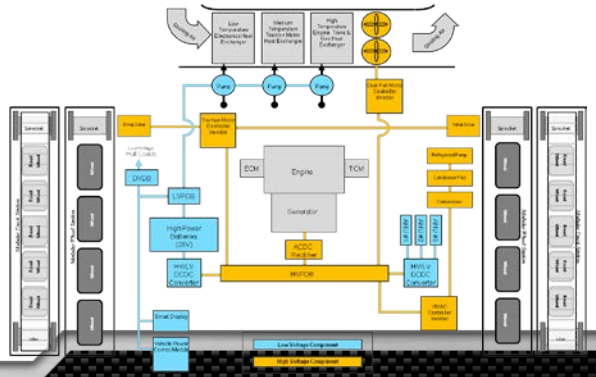
Electrical Power



Thermal Management

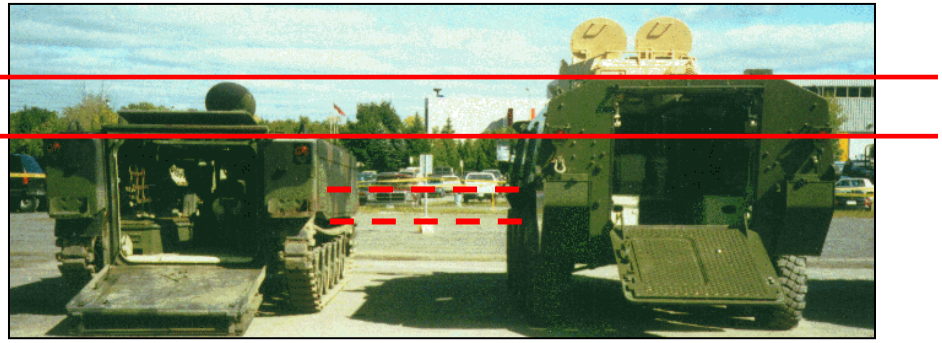


Communications and Control

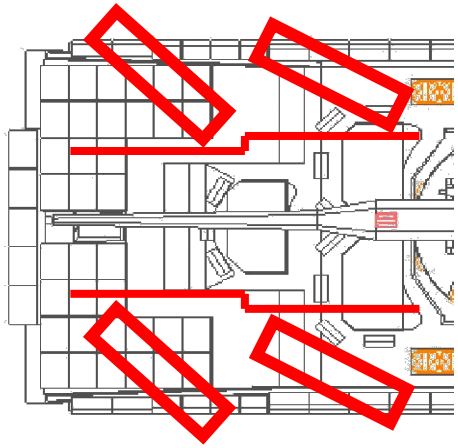


Chassis Configuration Challenges

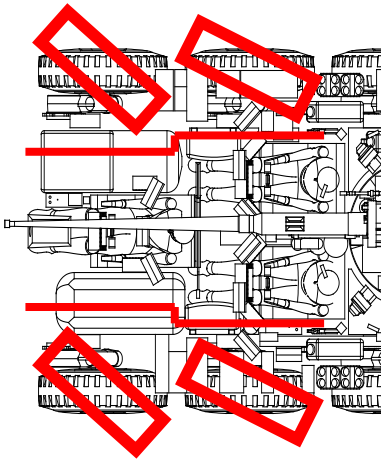
Sponsons



Vehicle Heights

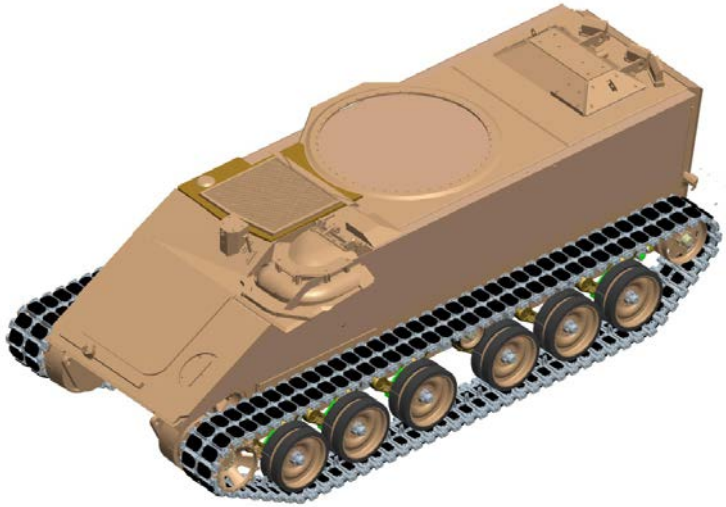


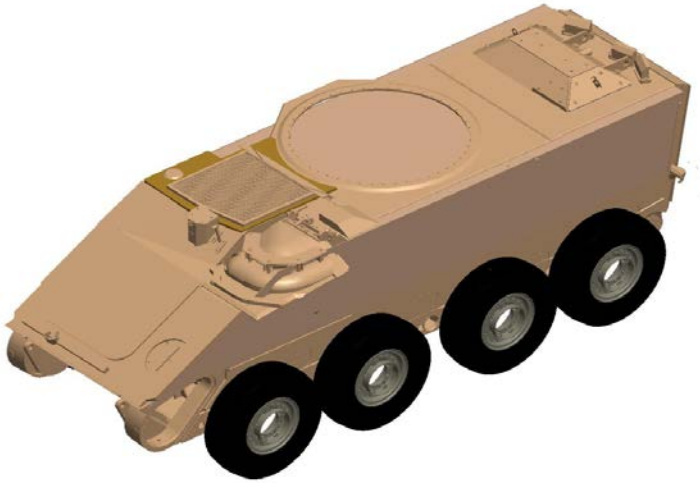
Ackerman Steering Volume Requirements



Converting tracked vehicle to wheels requires raising vehicle and / or widening vehicle wheelbase

Bradley with Sponsons Removed





College of Creative Studies - Concept Ideation
Exercise III

- 17-19 December 2012 – TARDEC Innovation Event

- Purpose: To collaborate and develop new mobility and situational awareness ideas for combat tracked and wheeled vehicles using latest Mobility Demonstrator Guidance.

- Participants:
  - 4 Chief Warrant Officers from the U.S. Army Ordnance Center and School.
  - 11 College of Creative Studies Associate Professor and Students
  - 11 TARDEC Engineers

- Concept a theoretical “Mobility Demonstrator” military vehicle with flexible / reconfigurable running gear system capable of converting between tracks and wheel modes.

- Agnostic to either wheels or tracks during the assembly process.

- Focus on future commonality of mobility components and systems.

- Maximum 40 ton weight.

- Military environment.

- Be novel, creative, anything goes.

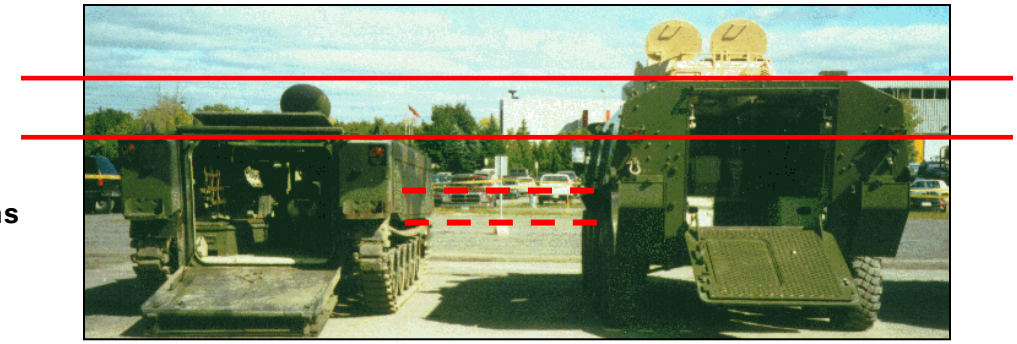
Tracked Military Vehicles

Wheeled Military Vehicles

Performance Comparisons

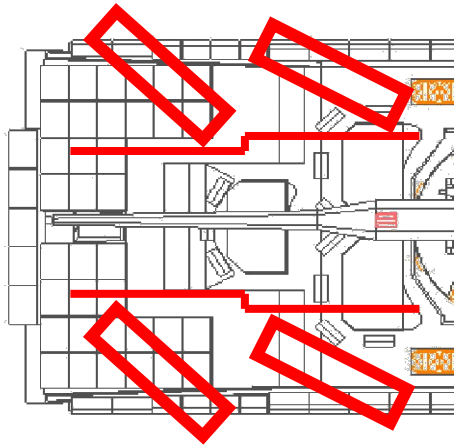
	Wheels	Tracks
Greater Vehicle Weights		X
Faster Pavement Road Speed	X	
Lower Ground Pressure		X
Greater Vertical Climb		X
Greater Trench Crossing		X

Chassis Considerations

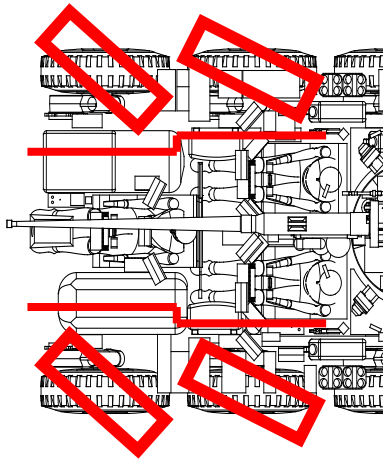


Vehicle Heights

Sponsons

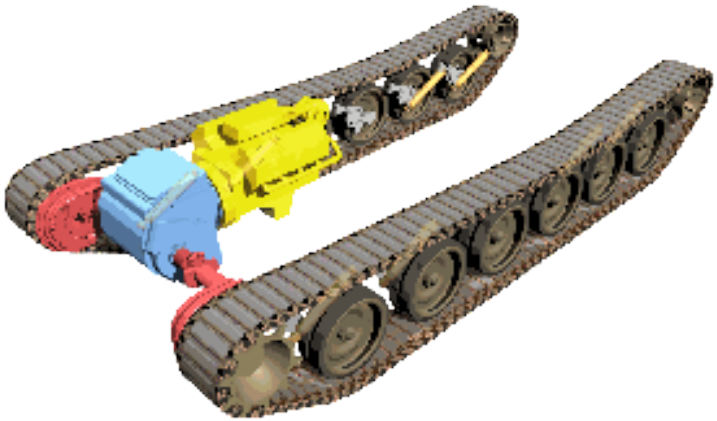


Ackerman Steering Volume Requirements



Configuration Considerations – Complexity

Tracks



Wheels

Wheeled Vehicles have a More Complicated Running Gear System, but Tracked Vehicles have a More Expensive Running Gear System

Vehicle Summary
Pros / Cons

TRACKS

ADVANTAGES:

- Higher Cross Country Speeds
- Superior Obstacle and Gap Crossing
- Increased Slope Climbing Capability
- More Compact / Lower Silhouette

DISADVANTAGES:

- Higher Production, Maintenance, and Repair Costs
- Fewer Commercial Components
- Not Efficient in Sustained Highway Travel
- More Vibration on Hard Surface

WHEELS

ADVANTAGES:

- Capable of Maintaining Higher Speeds on Roads
- More Fuel Efficient (over Hard Surfaces)
- Less Cost Per Mile of Operation (over Hard Surfaces)
- Ability to Use Commercial Components
- Reduced Production Costs (Below 20 tons)
- Lower Maintenance and Repair Costs

DISADVANTAGES:

- Less Obstacle and Gap Crossing Capability
- Requires Stockage of More Spare Parts
- Less Stable Gun Platform (Tire Flex)
- Poor Soft Soil Performance over 25 tons

We Want Both

Vehicle Width can be a Problem

NATO Troops
Afghanistan

Vehicle Length can be a Problem

NATO Troops
Afghanistan

Sometimes the Road is too Narrow

NATO Troops
Afghanistan

Sometimes the Road Fails

Sometimes the Road is Rough

NATO Troops
Afghanistan

Sometimes the Vehicles Fail

NATO Troops
Afghanistan

A lot

NATO Troops
Afghanistan

The Road may be Unstable

NATO Troops
Afghanistan

The Road may Collapse

NATO Troops
Afghanistan

The Bridge may be Unsafe

NATO Troops
Afghanistan

May not Trust the Bridge

NATO Troops
Afghanistan

May want to Swim

NATO Troops
Afghanistan

Traverse All Terrains

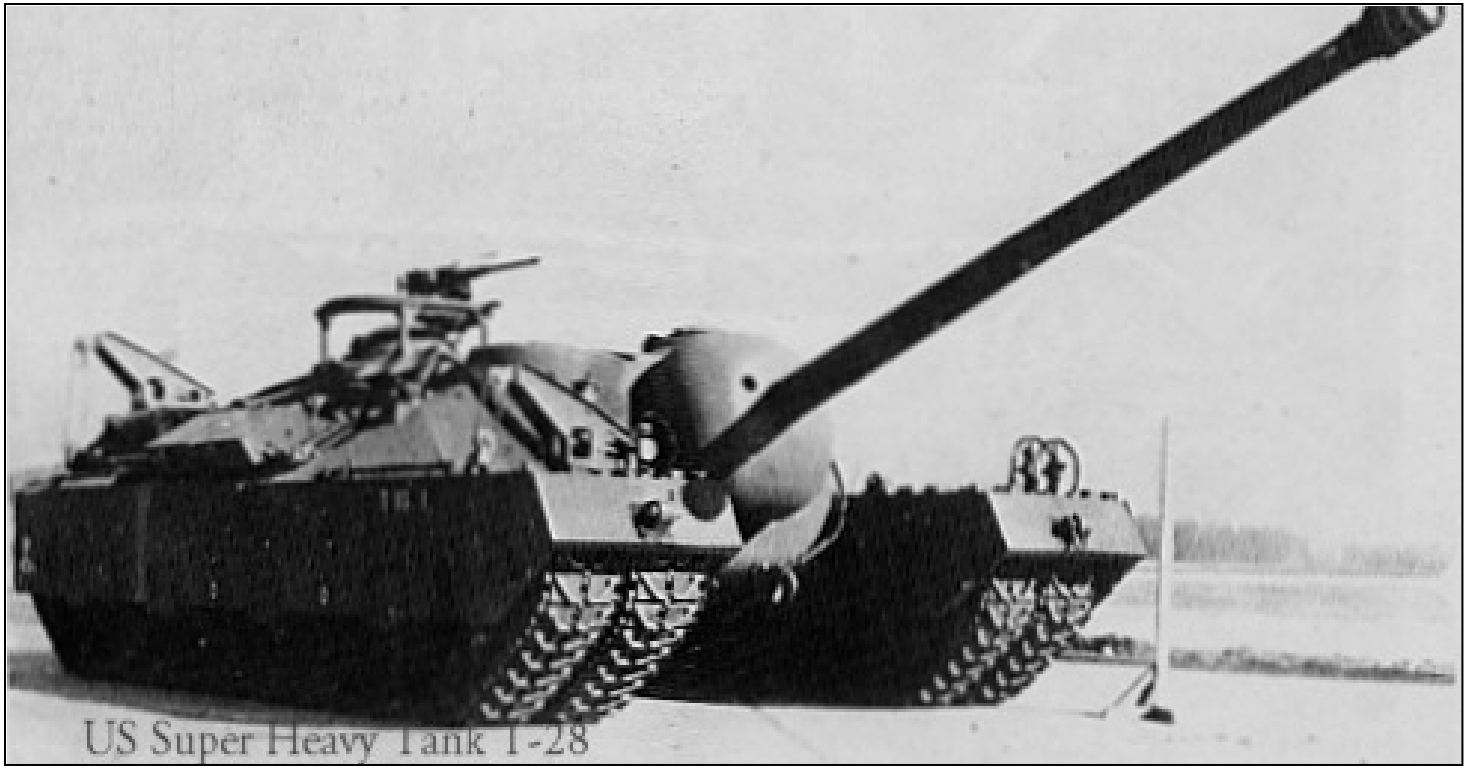
In All Climates

Mud can be an Issue for Wheels

NATO Troops
Afghanistan

Mud Can be an Issue for Tracks

Too Much of a Good Thing

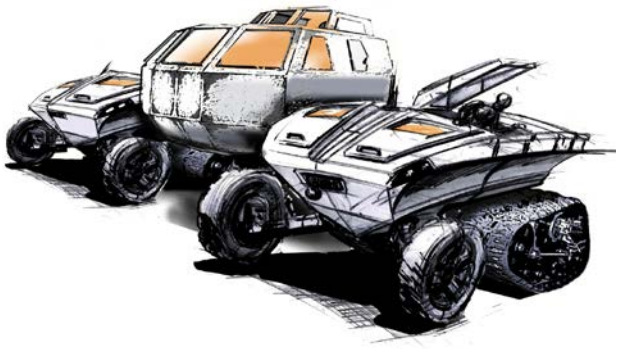


Sometimes the Driver is Wild

Sometimes Old Way still Works

NATO Troops
Afghanistan

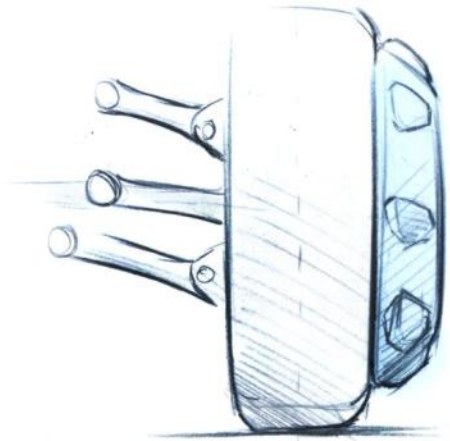
Good Luck and Be Creative

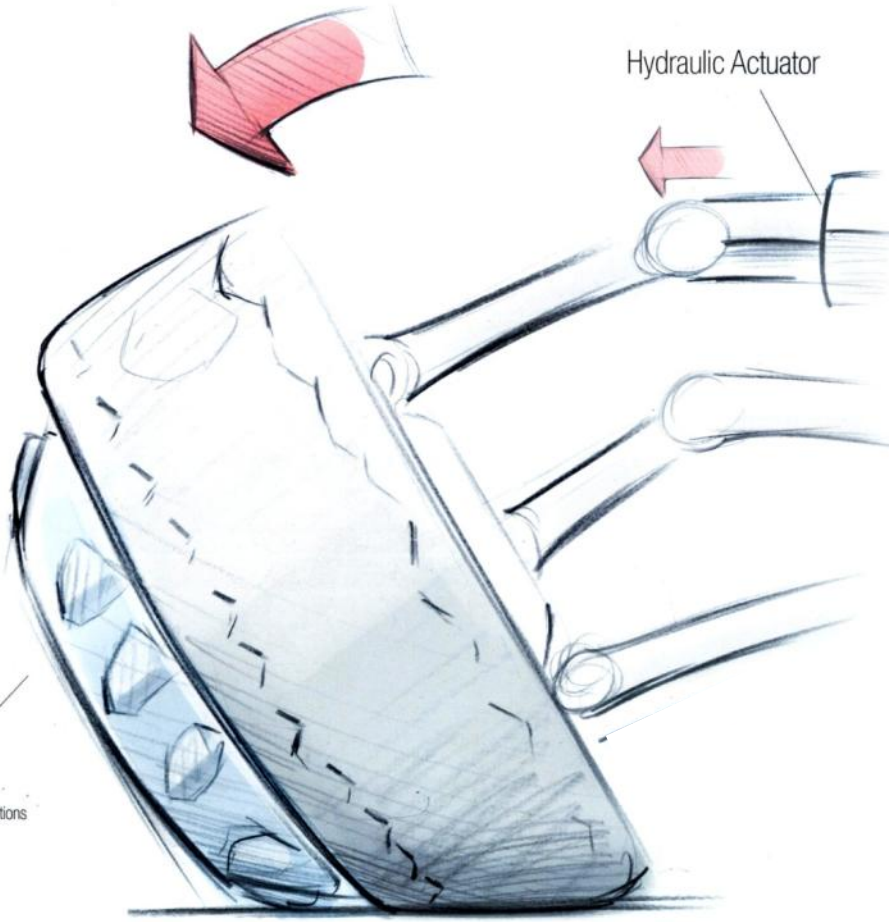


CCS - Mobility Demonstrator Ideations

Wheel Articulation

-Can be built on existing Striker platform

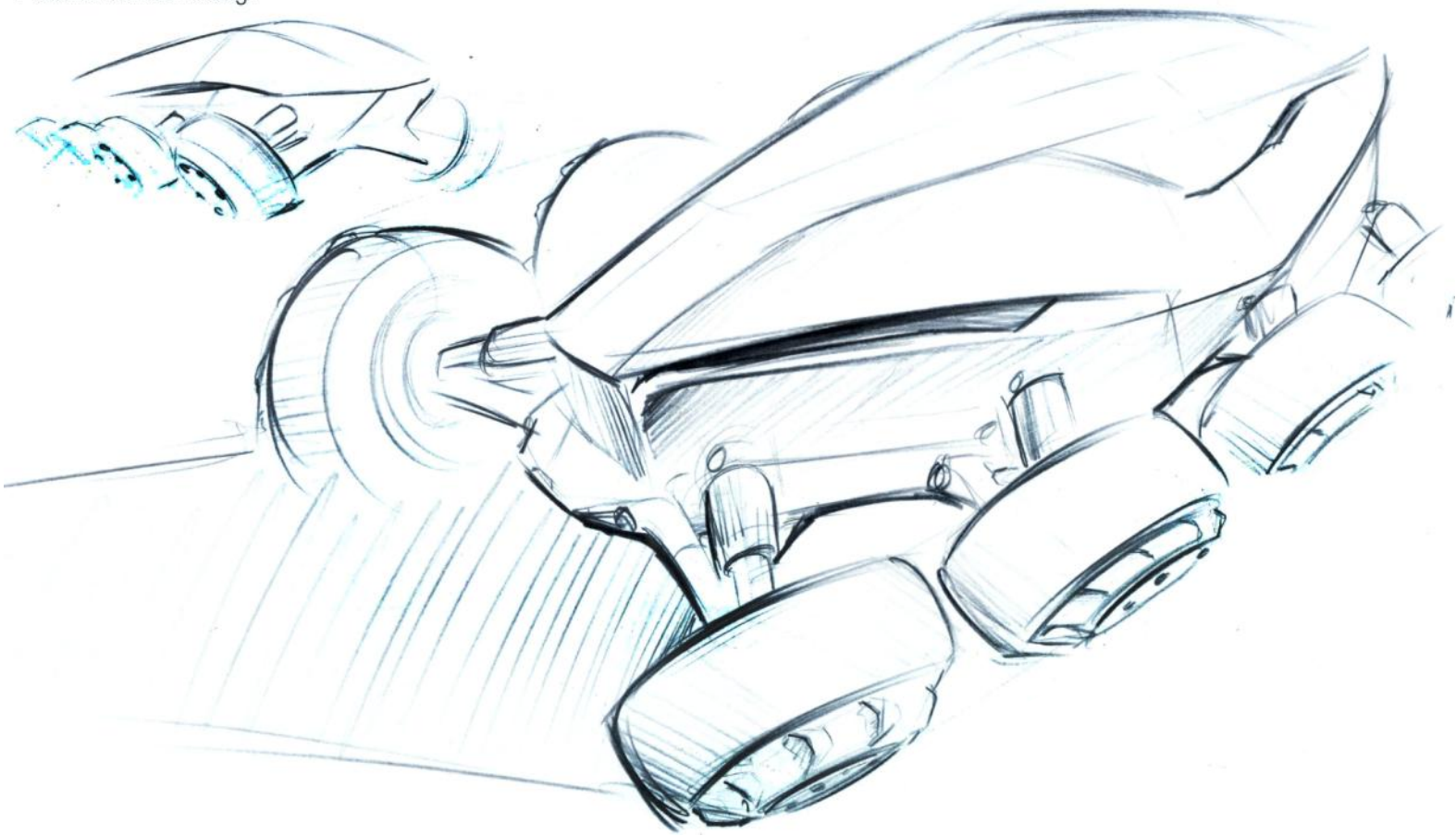




CCS - Mobility Demonstrator Ideations

Final View

-Positive Camber Design



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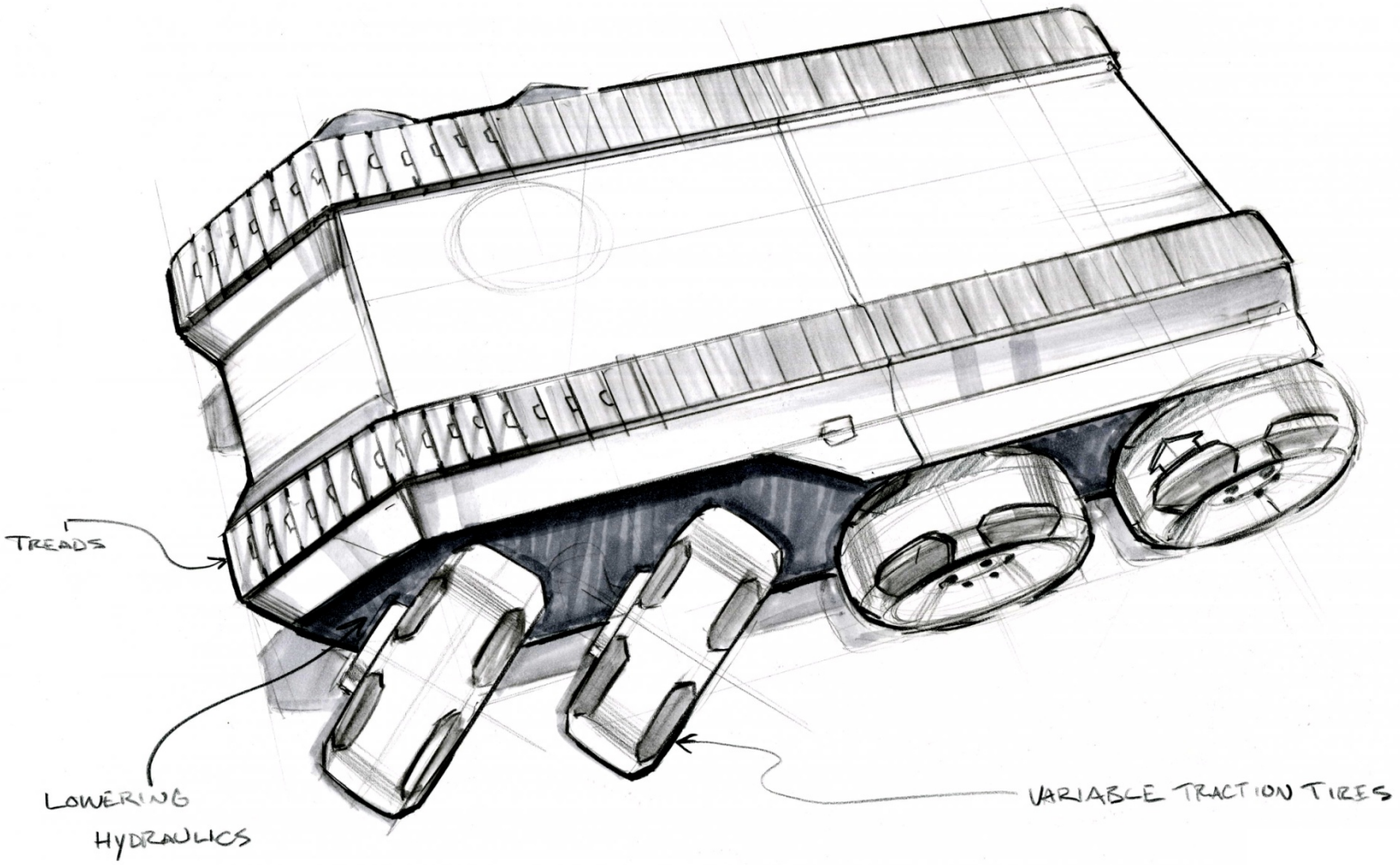

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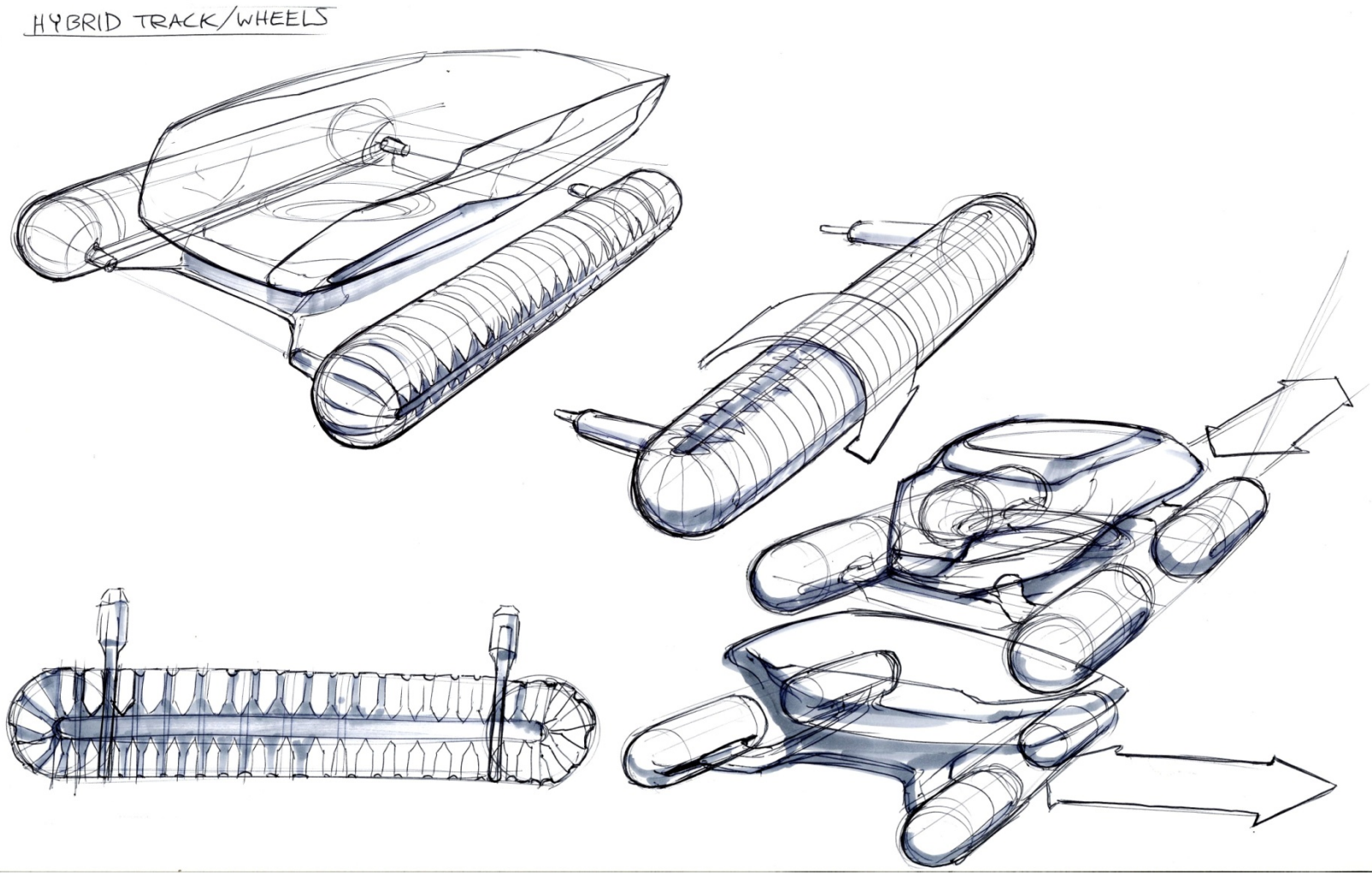

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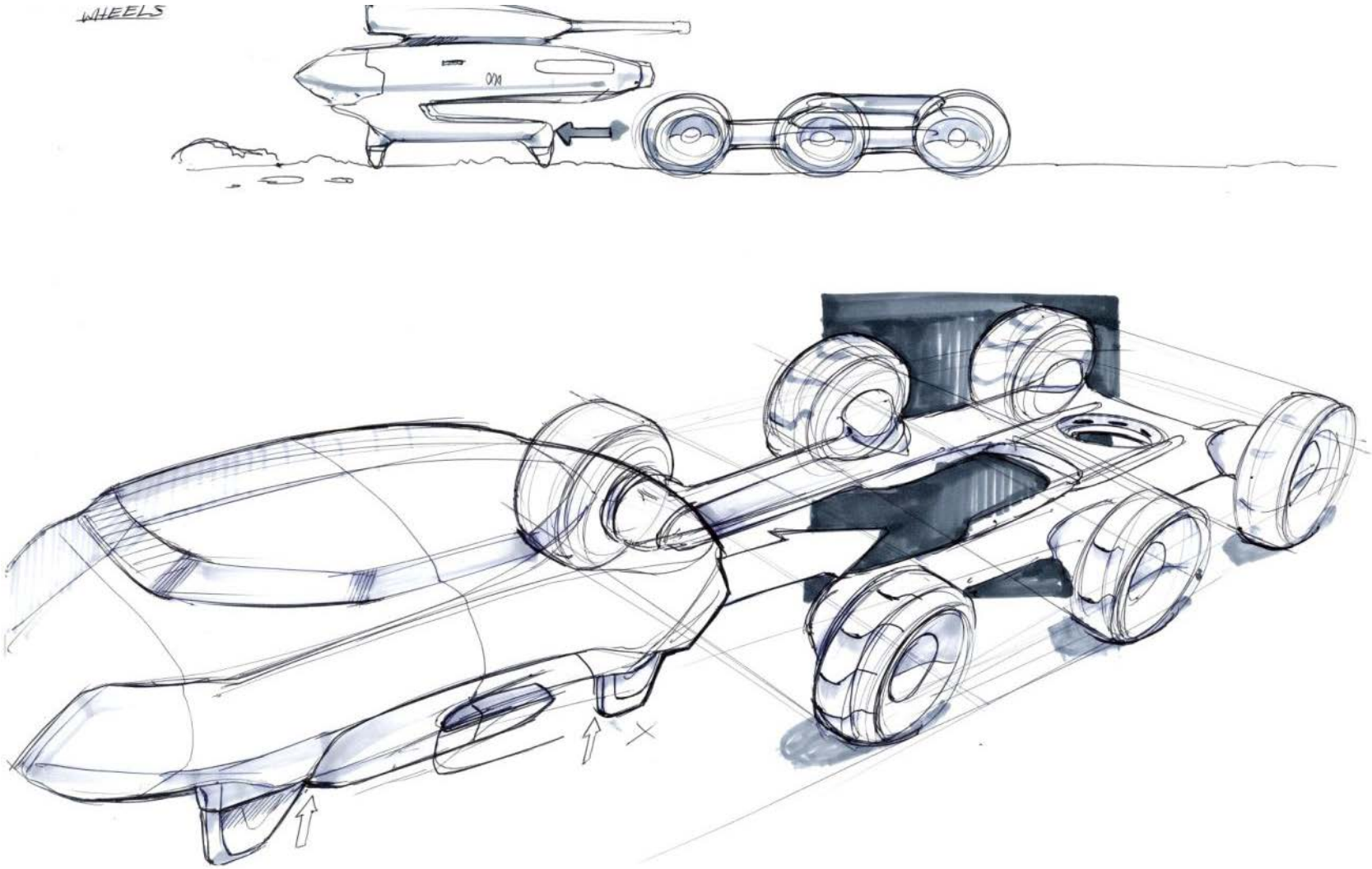

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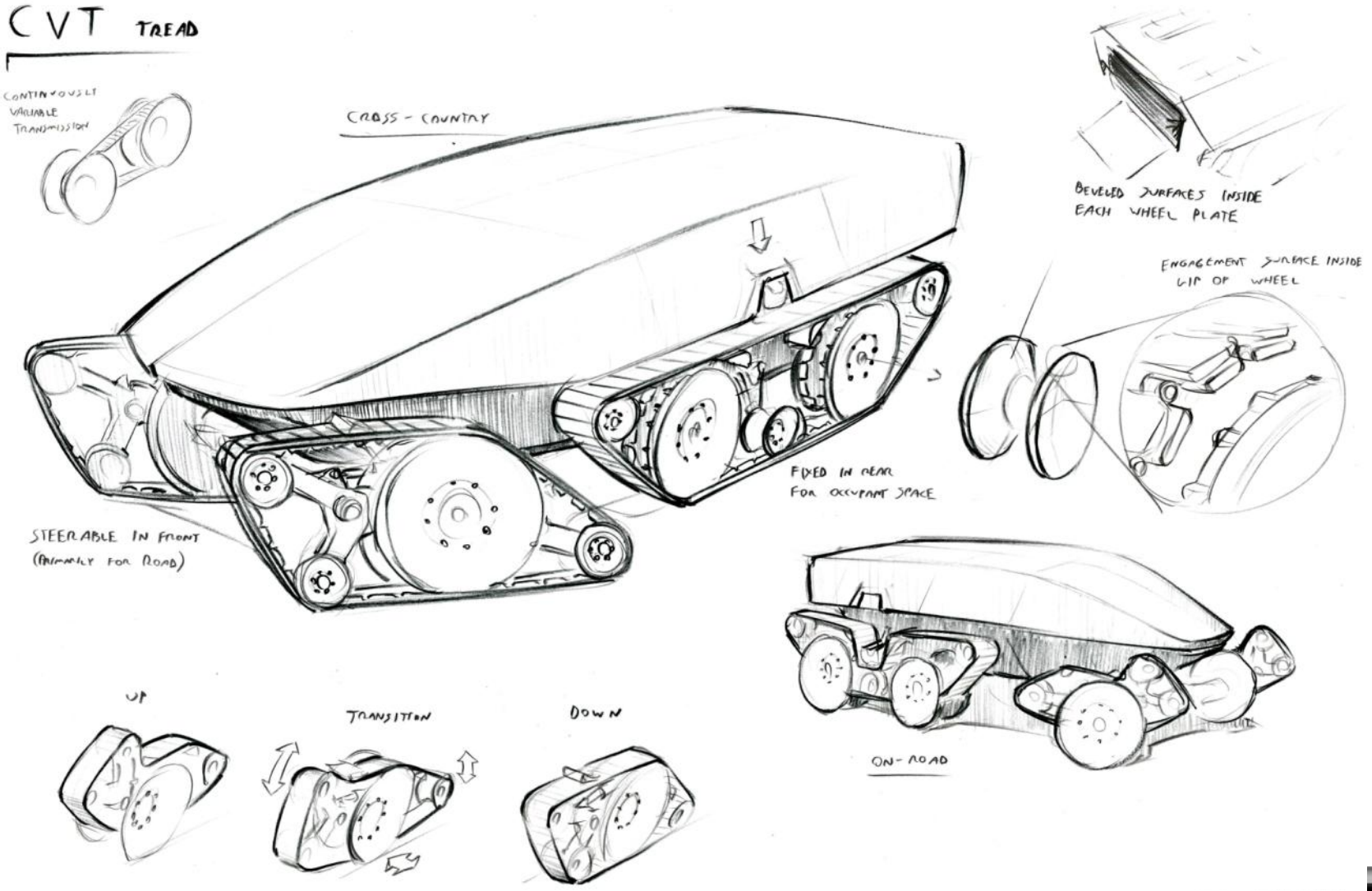

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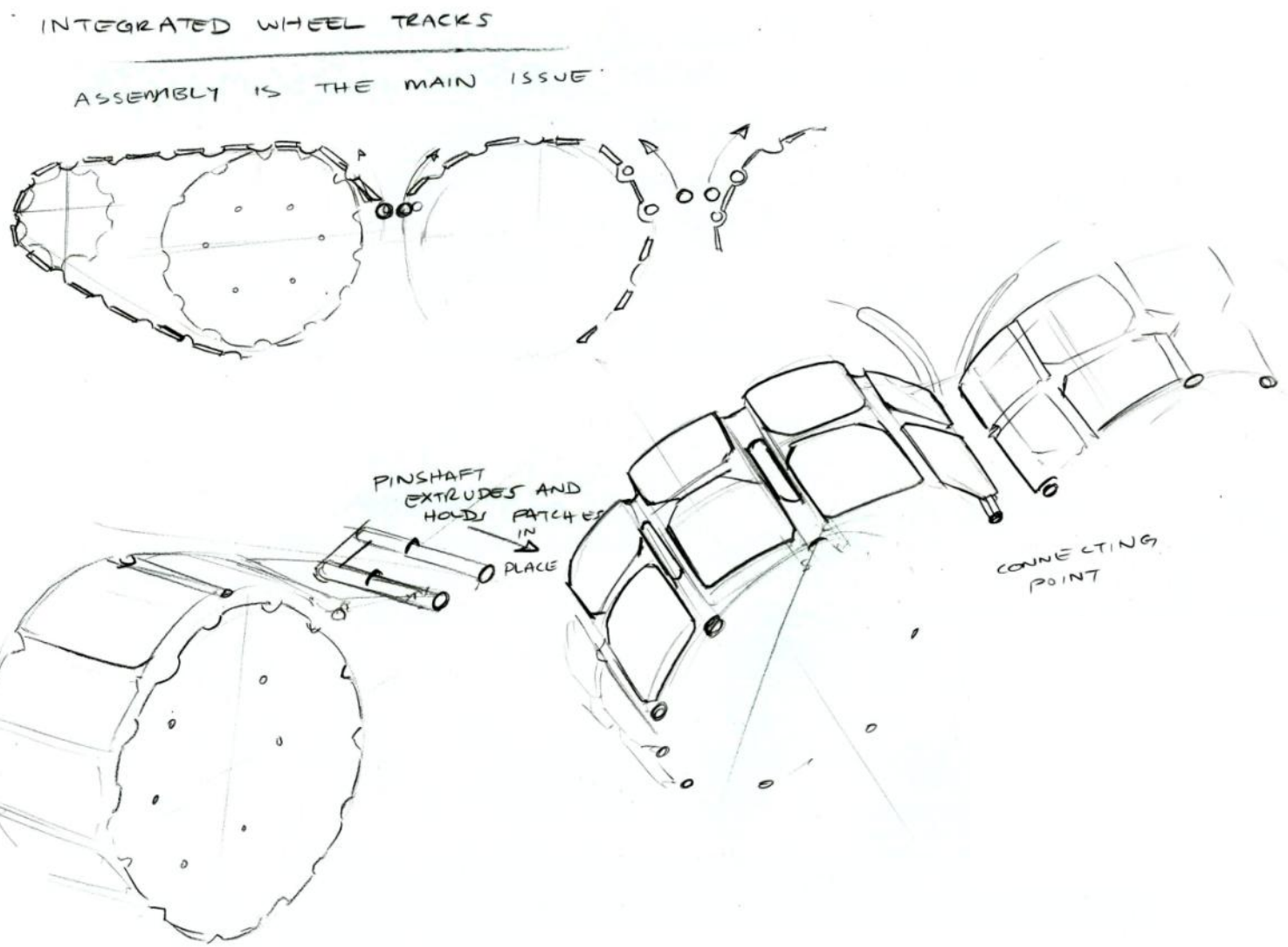

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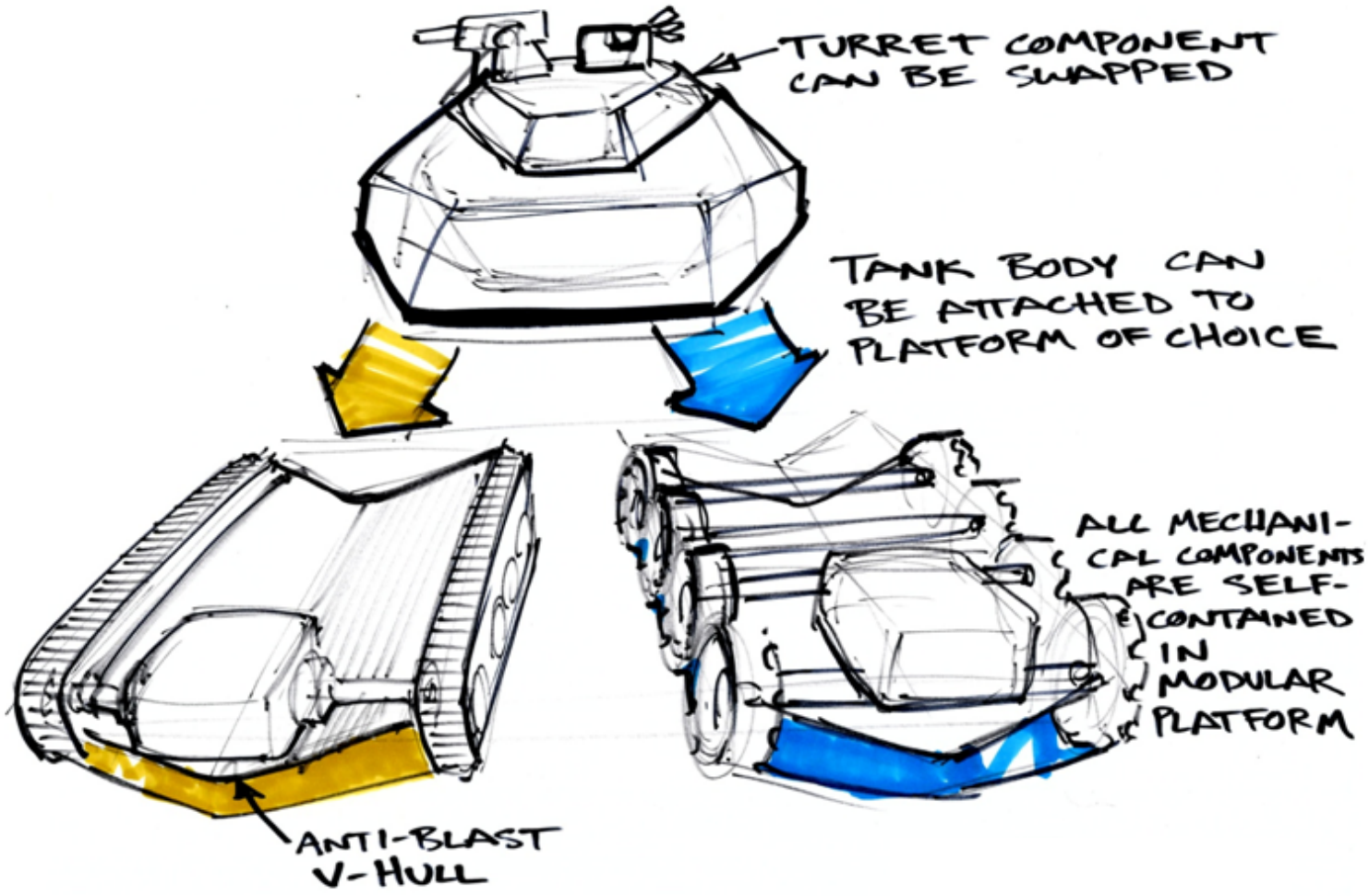
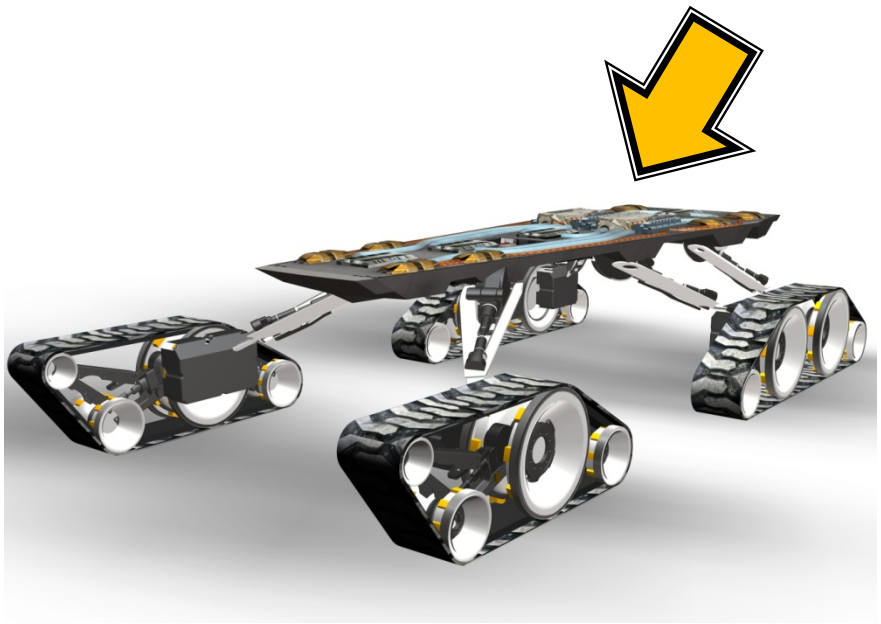
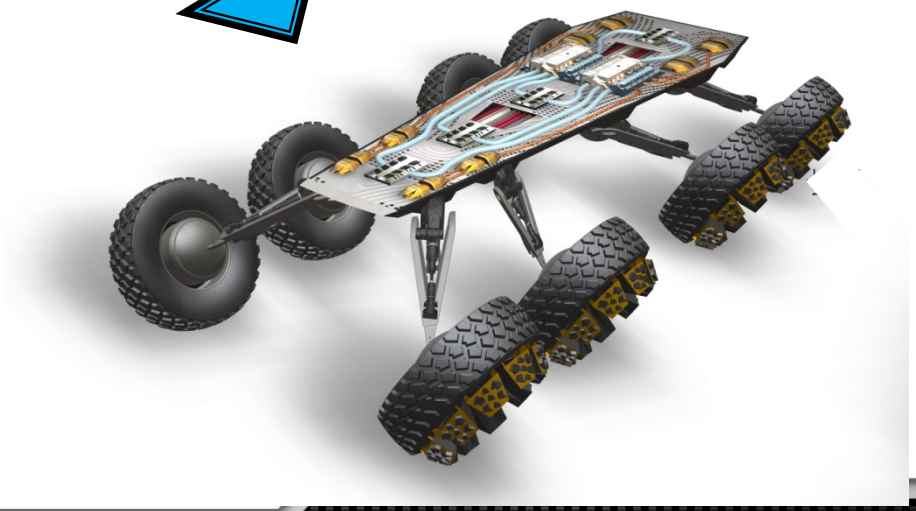


Body-On-Carrier Concept Vehicle or Modular Chassis Concept

Tracked or Wheeled Carrier can be used depending on mission

Tracked or Wheeled solution can be integrated at the Depot or Assembly Line level



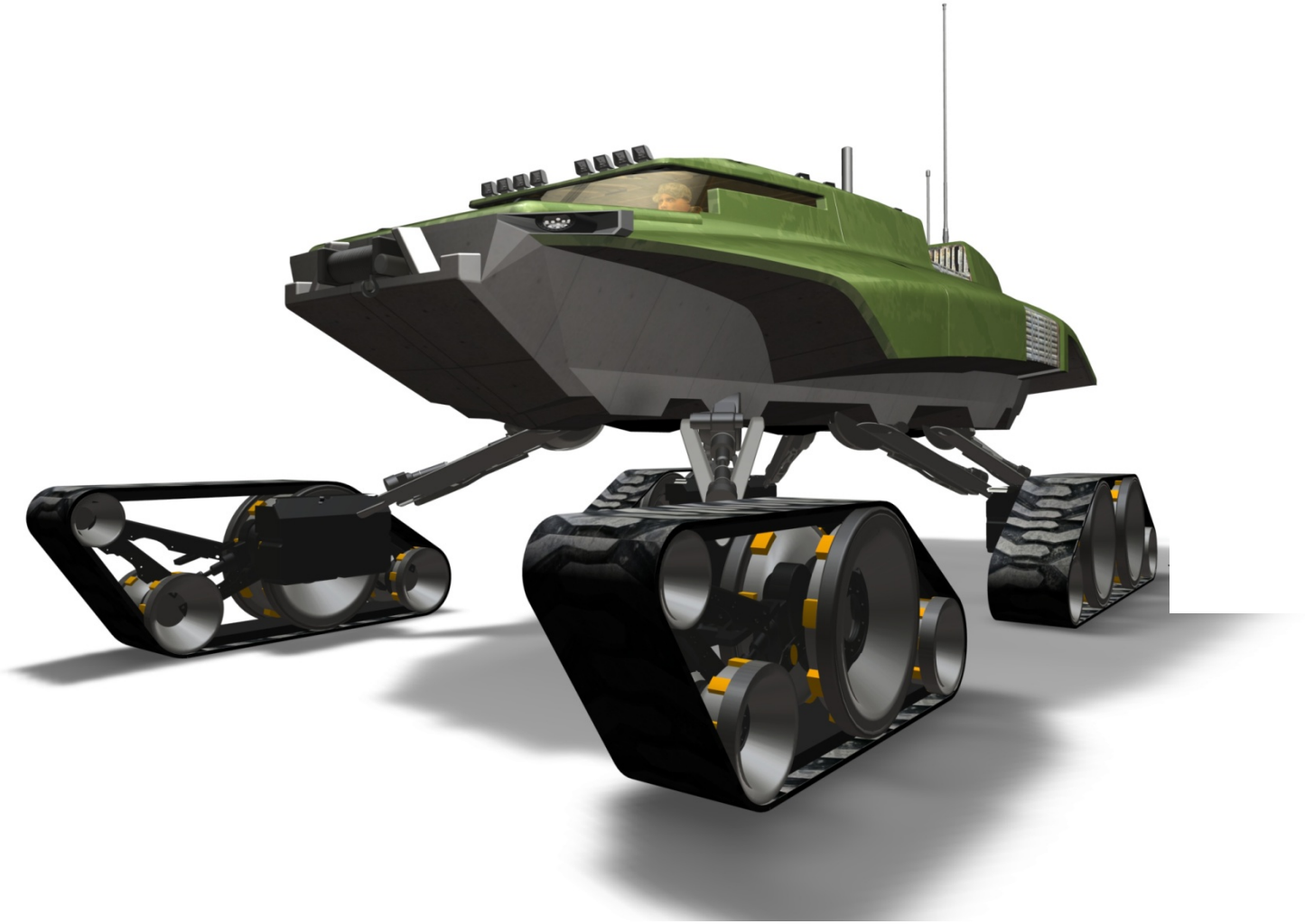


Body-On-Carrier Concept Vehicle or Modular Chassis Concept

Body-On-Carrier Concept Vehicle Wheeled Solution

Body-On-Carrier Concept Vehicle Wheeled Solution

Body-On-Carrier Concept Vehicle Tracked Solution



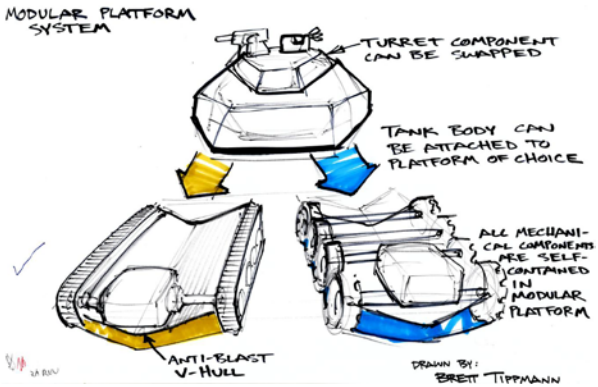
Path Forward Concepts

Exercise IV

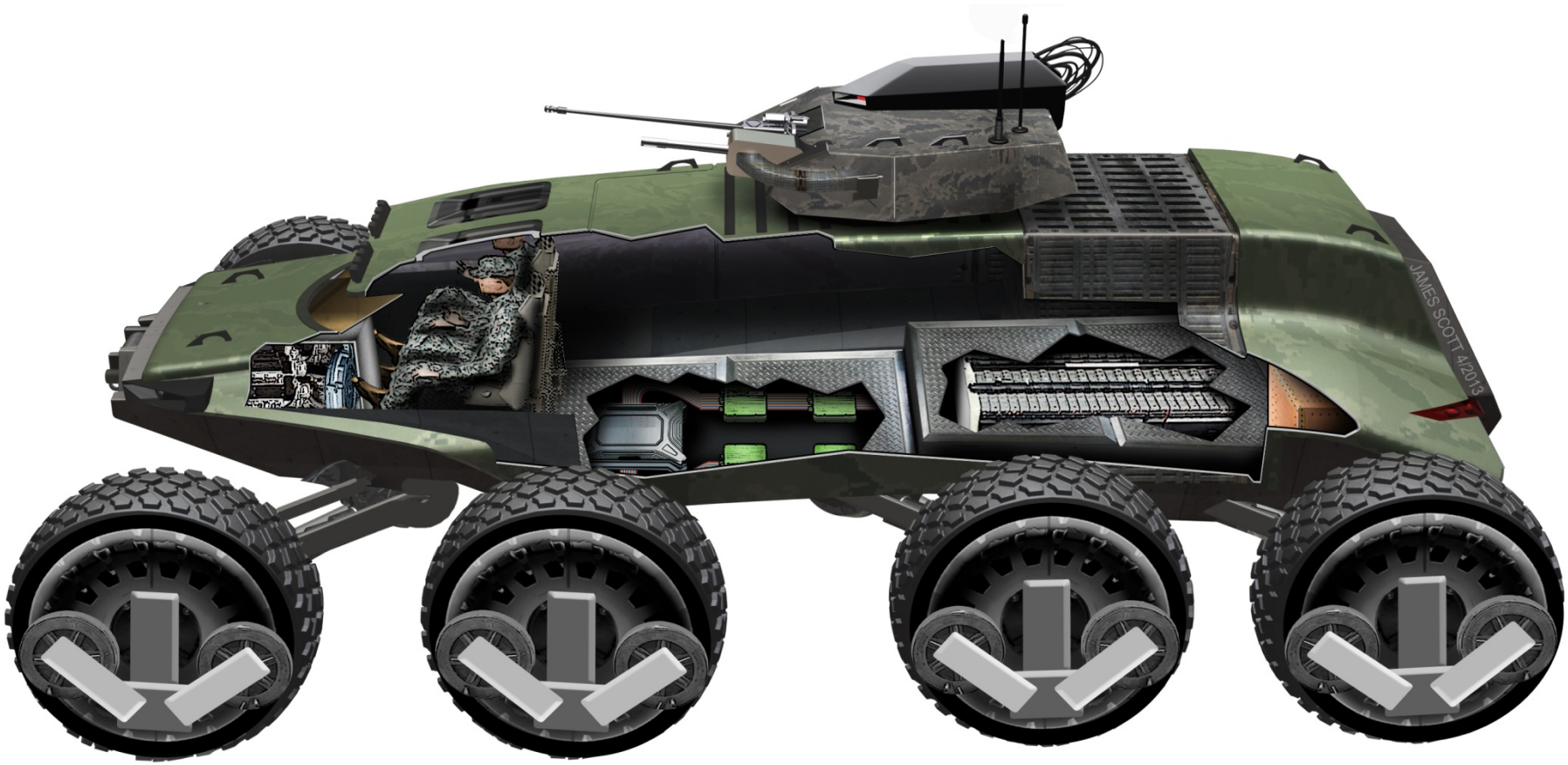
COA I – Modular Chassis

COA II – Modular Running Gear System

COA III – “Morphing” Track to Wheels System



Initial Mobility Demonstrator Concept



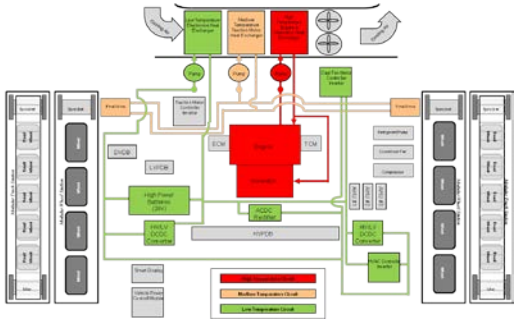
COA III – “Morphing” Track to Wheels System

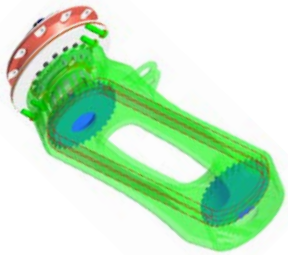
Sequestration Wheel Concept Vehicle

Sequestration Tracked Concept Vehicle

Subsystem-by-Subsystem Evaluation
Exercise V

- Wheels to Track Transformation Sub Systems
- Advanced Suspension Sub Systems
- Advanced Power Pack Sub Systems
- Advanced Thermal Management Systems
- Electrified Propulsion Systems
- Advanced Energy Storage Systems





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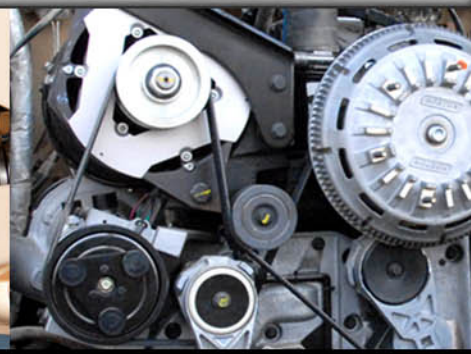
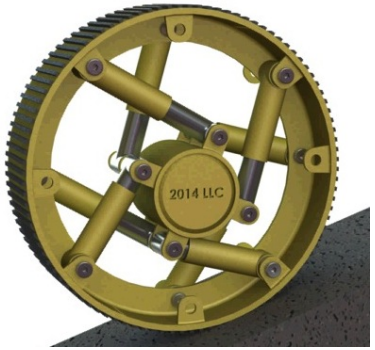
Tire To Track Transformation Sub Systems



Future Airless Wheel Technologies

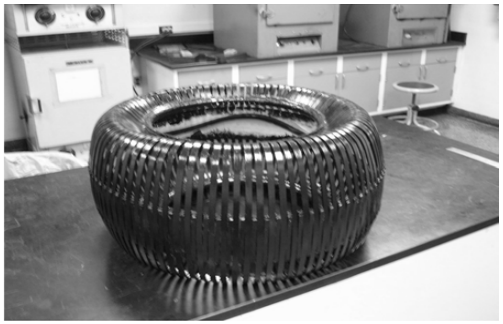
Company: Structural Dynamics Cons. Eng. Co
Technology: Shweel Tire /Shock-Wheel
Description: Rigid wheel with attached tread connected with shock absorbers between wheel and hub.



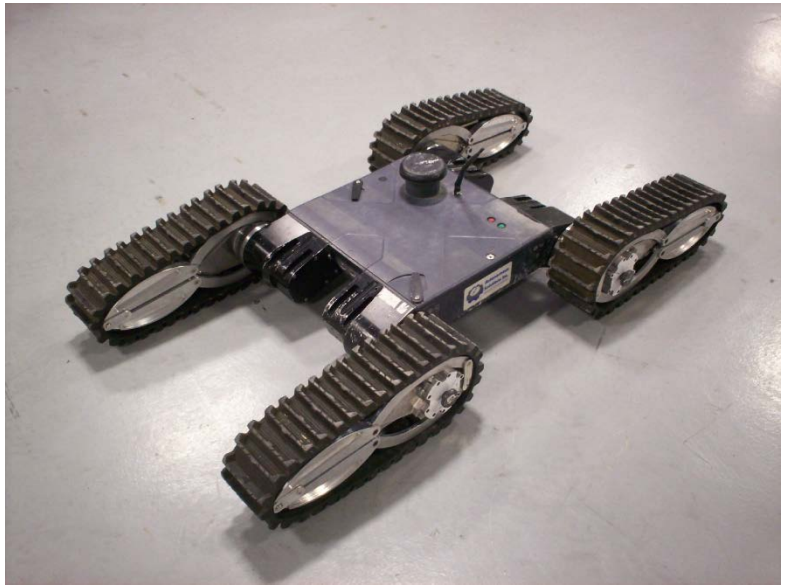
Company: Resilient Technologies (Polaris Defense)
Technology: Non-Pneumatic Tire
Description: Airless Tire/wheel with honeycombed shaped polymer supporting structure between tread and hub.

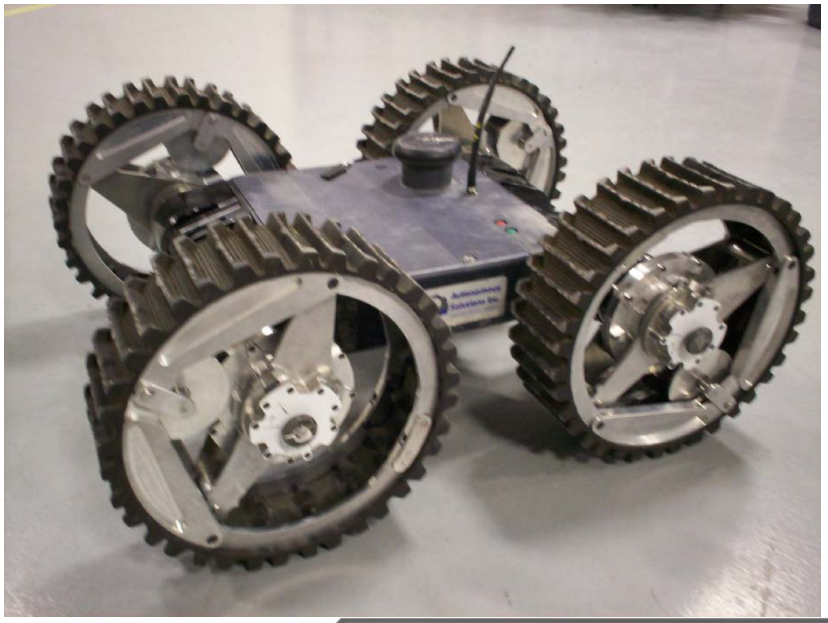
Company: Michelin
Technology: TWEEL Airless Tire
Description: Airless tire/wheel with polymer spokes between tread and hub.

Company: Scitech Industries
Technology: Airless Tire
Description: Airless tire which uses U-shaped springs made of epoxy or fiberglass to mechanically support the load



Roadrunner Tire to Tracks System

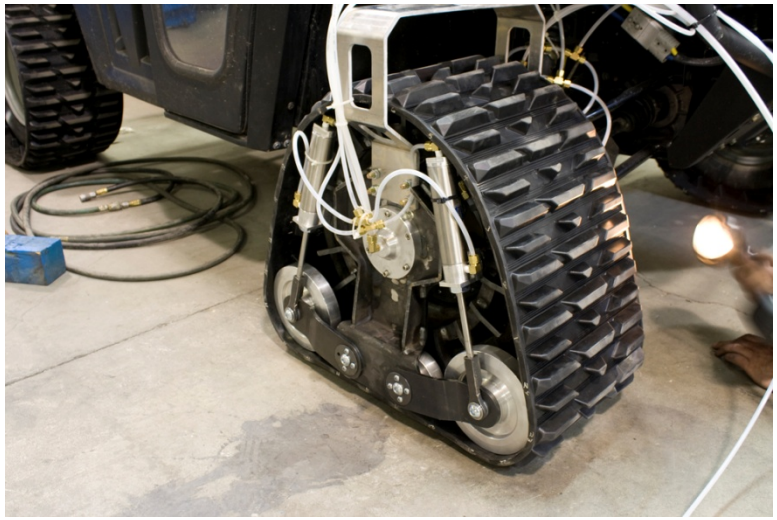




Roadrunner by Autonomous Solutions

Track –N – Go System

MATTRACKs Tire to Track Transformation System



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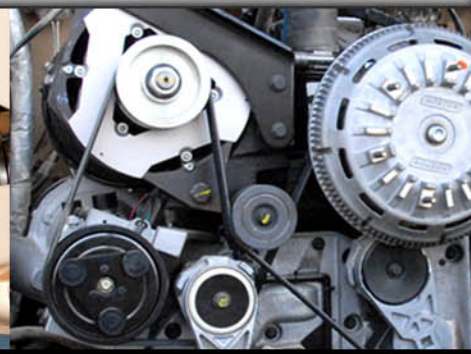
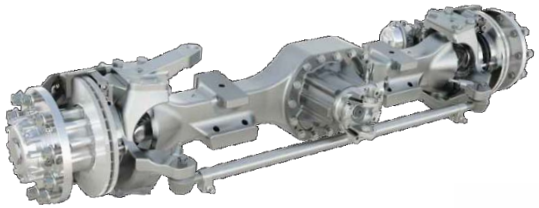
Advanced Suspension Sub Systems

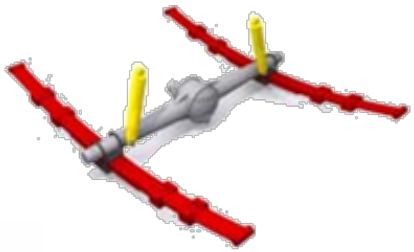


Tactical Suspension Technologies

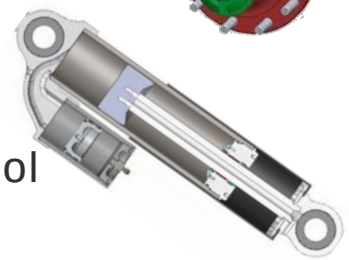
- Wheeled vehicle suspension systems continue to evolve over past 50 years:
  - Independent suspensions
  - Dependant suspension (solid axles)
  - Trailing arms
- The biggest advancement in these systems has been in controls development.
- Suspension control systems have been used to improve ride and handling.
- Controls are now being developed to improve occupant safety through ride height adjust.

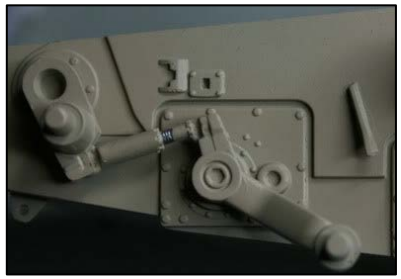


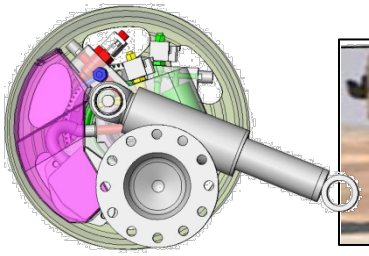


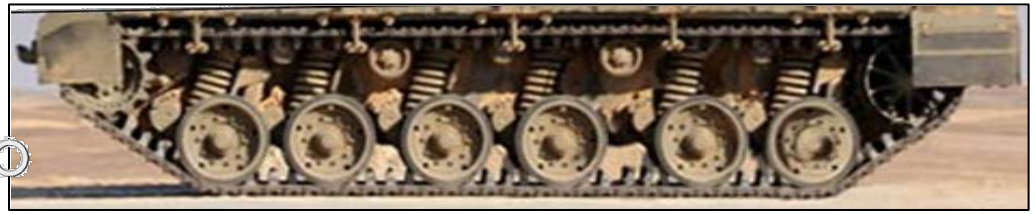
Combat Suspension Technologies

- Tracked vehicle suspensions continue to evolve over the past 70 years.
  - Trailing arm suspensions with torsion bar springs.
  - Either linear or rotary dampers
  - Simple linear track tensioners or self-adjusting track tensioners
- The biggest advancement in these systems has been pneumatic external road-arm design (external suspensions).
- There has been some research into semi-active suspension control systems to improve ride, but nothing fielded.



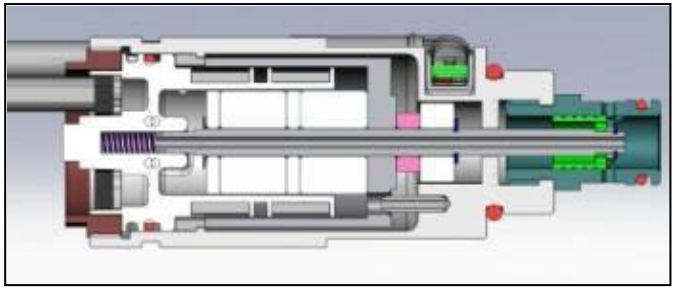




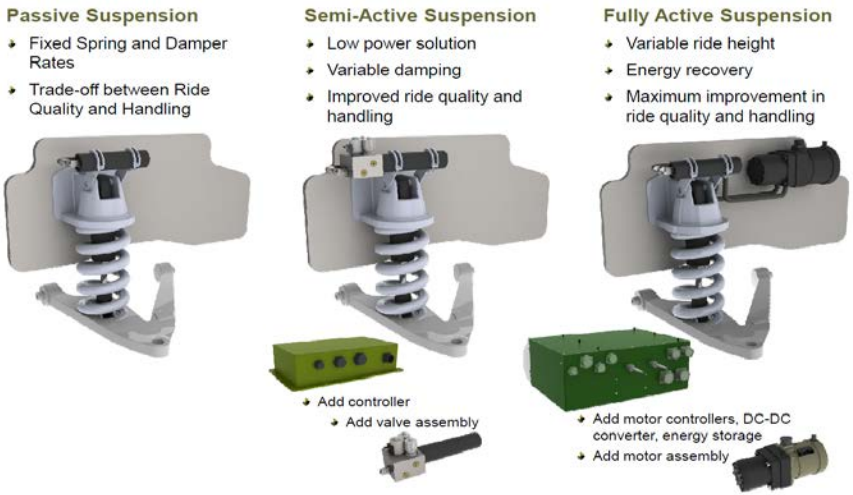


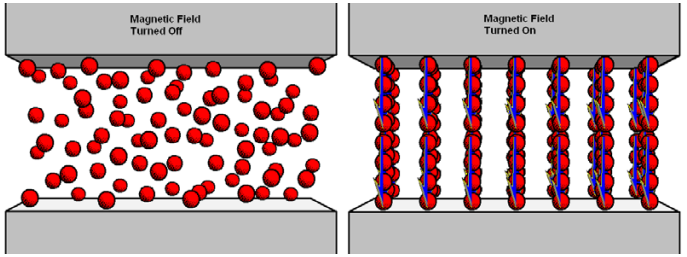
Adaptable Suspension Technologies

- Types / levels of vehicle suspension systems
  - Passive
  - Semi-Active (Dampers are controlled)
  - Fully-Active (Springs and/or dampers are controlled)



Variable Orifice
- Semi-active option -

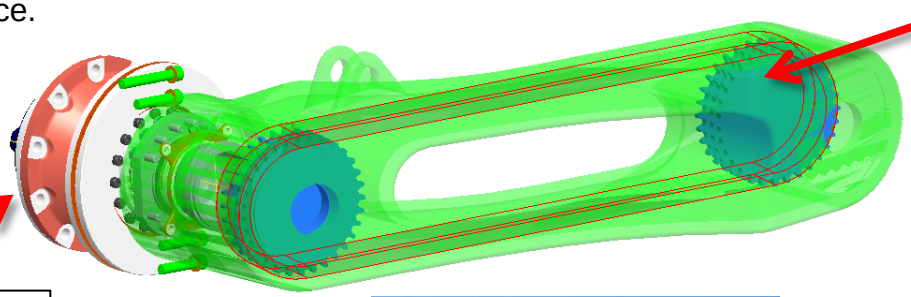


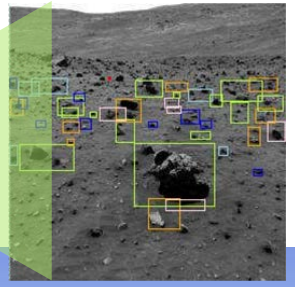


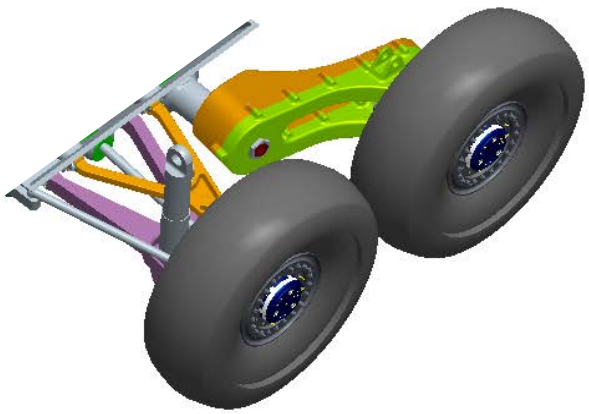
Magneto-Rheological Fluid
- Semi-active option -

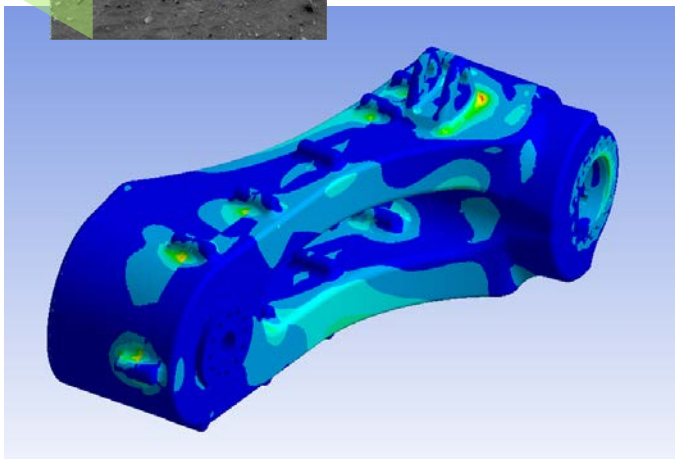
Advanced Suspension Systems

Suspension technology will evolve to become fully predictive of the terrain environment it's operating on. Controls algorithms will lead the realm of possible for vehicle performance.









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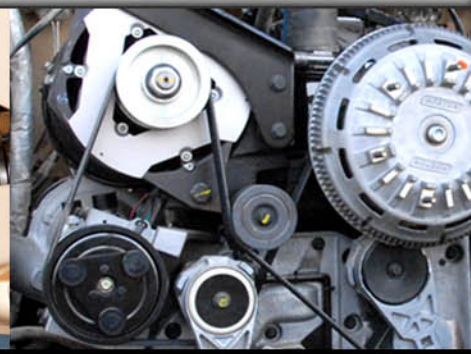
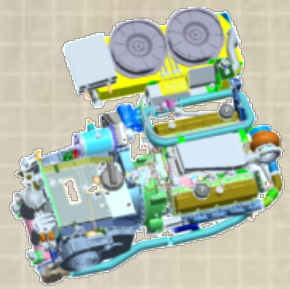
Advanced Power Pack Sub Systems

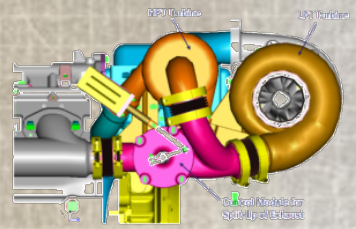


Power Plant Challenges

Challenges:
- Increase engine power density
- Decrease cooling system burden
- Decrease waste energy





Increasing Capability

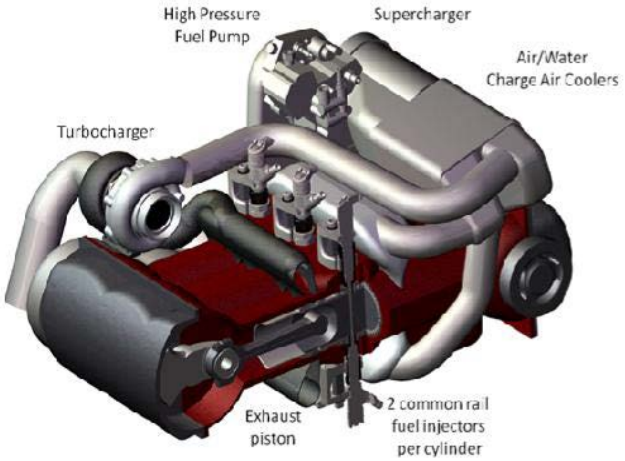
Power Density (HP/ft³): 3 → 6 → 10

Mean Engine ΔT (Deg F): 90 → 110 → 160

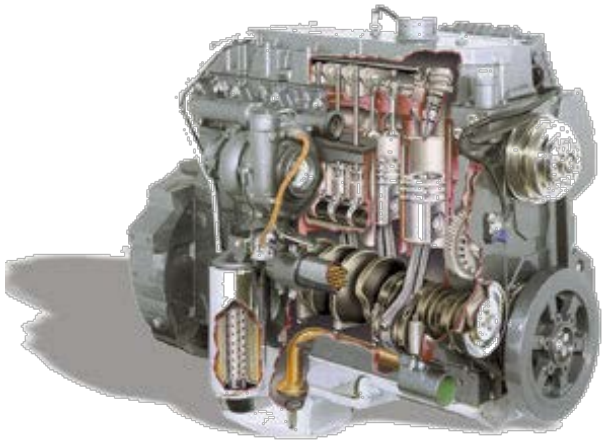
Heat Rejection (BTU/HP-min): 31 → 25 → 20

2010 2020 2030

High Power Dense Engines

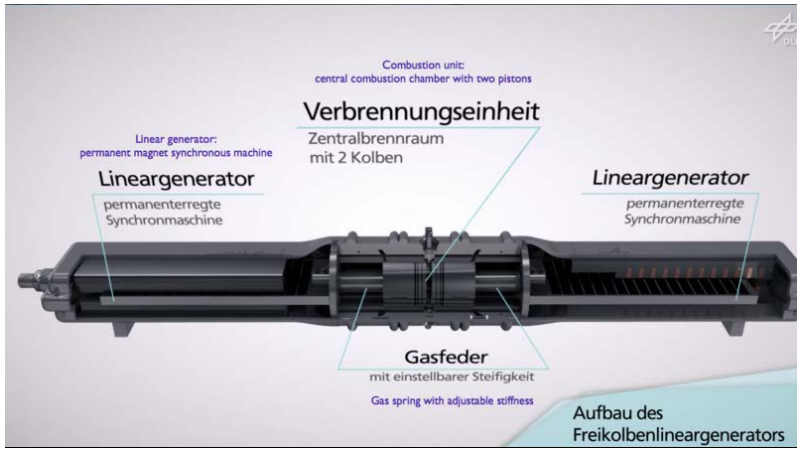


Next Generation Engine



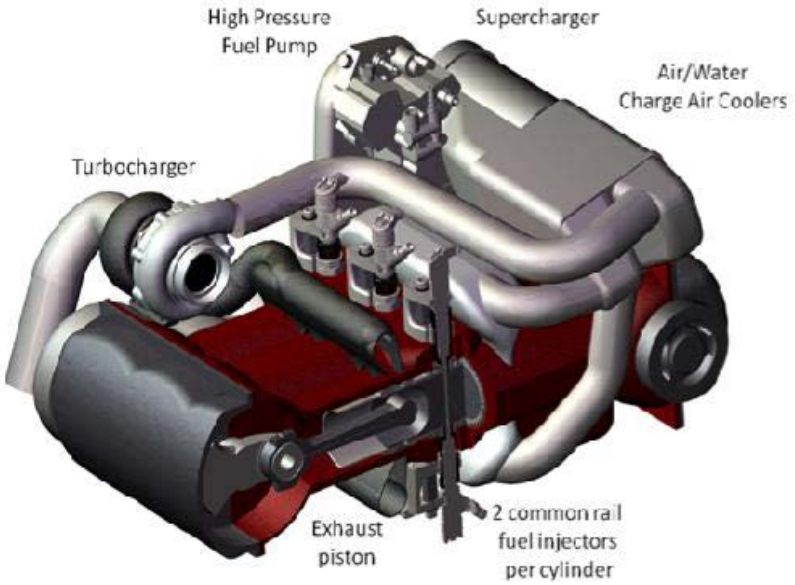
HOTHED Engine

Advanced Fuel Cells



Free-piston Linear Generator

Next Generation Combat Engine



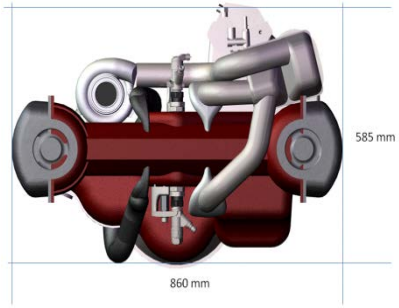


Figure 2a. Front View of 3-Cylinder Engine Concept

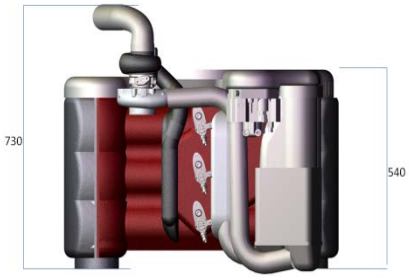


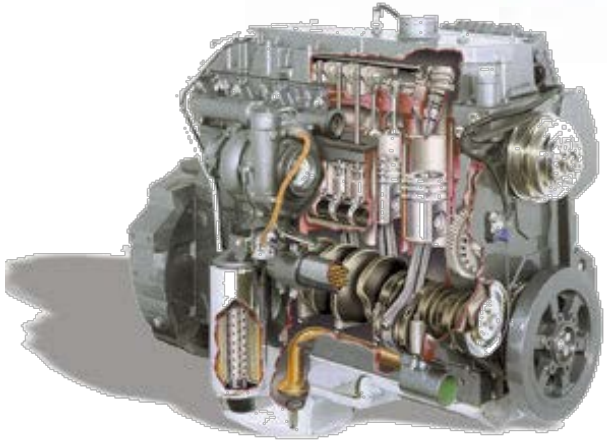
Figure 2b. Plan View of 3-Cylinder Engine Concept

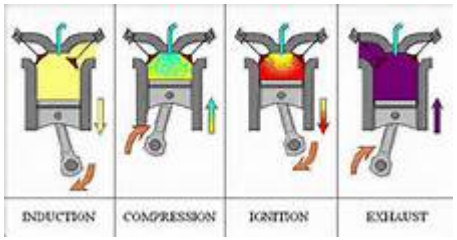
Opposed piston high output 2-stroke engine

Payoffs:

- Higher installed propulsion system power density-twice the power in same volume.
- Less volume under armor (weight save)
- Lower cooling system thermal burden with less cooling fan hp draw.
- Improve fuel economy (15-20% improvement).
- Scalable engine family building blocks with high degree of commonality with reduce logistical burden (parts & maintenance).
- Restore mobility capabilities lost due to vehicle weight gains
- Compact design to improve under hood packaging flexibility
- Scalable Engine Family Specification (competitive).

High Operating Temperature, High Density Engine (HOTHED)





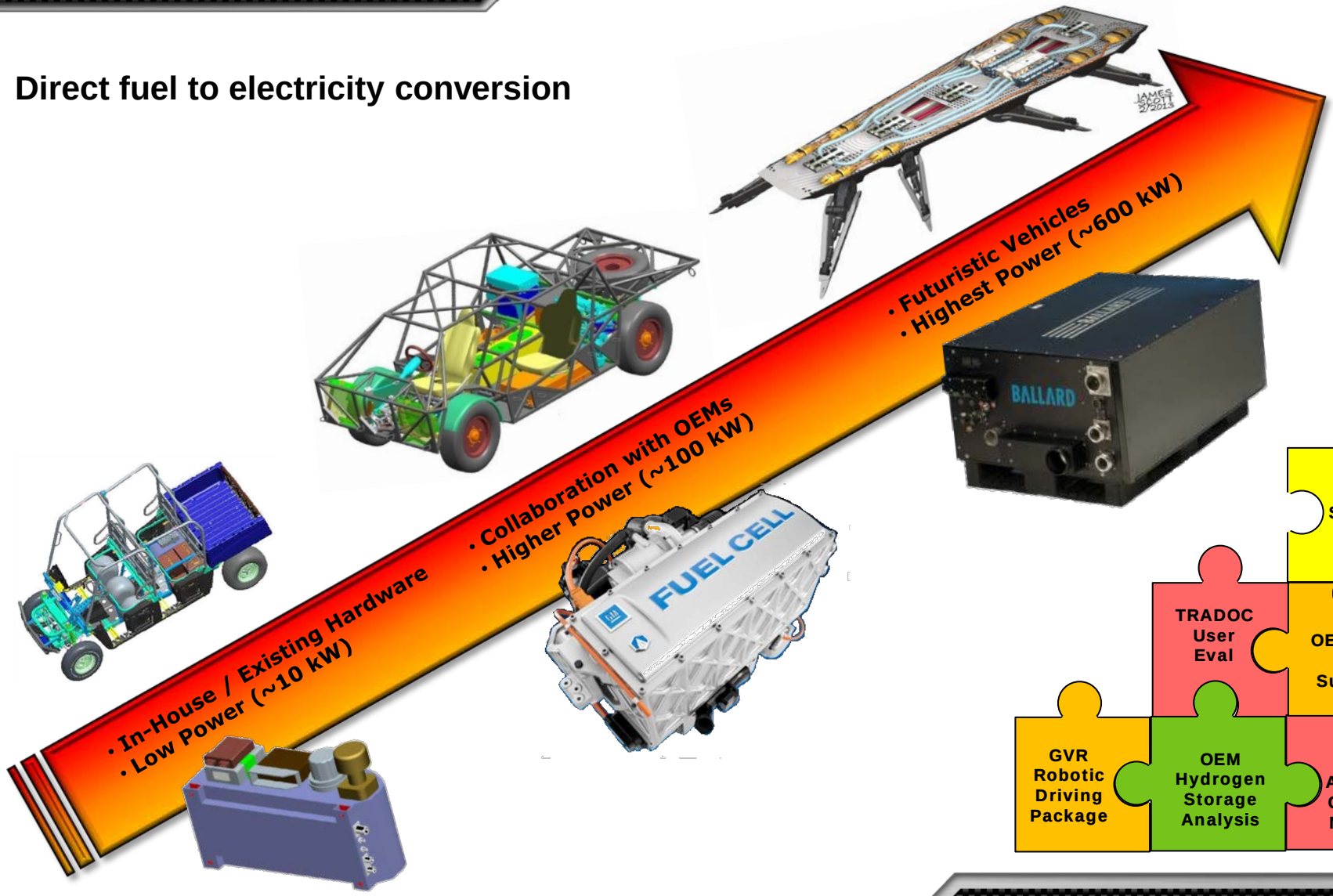
Higher operating temperature / decreased heat rejection engine.

Payoffs:

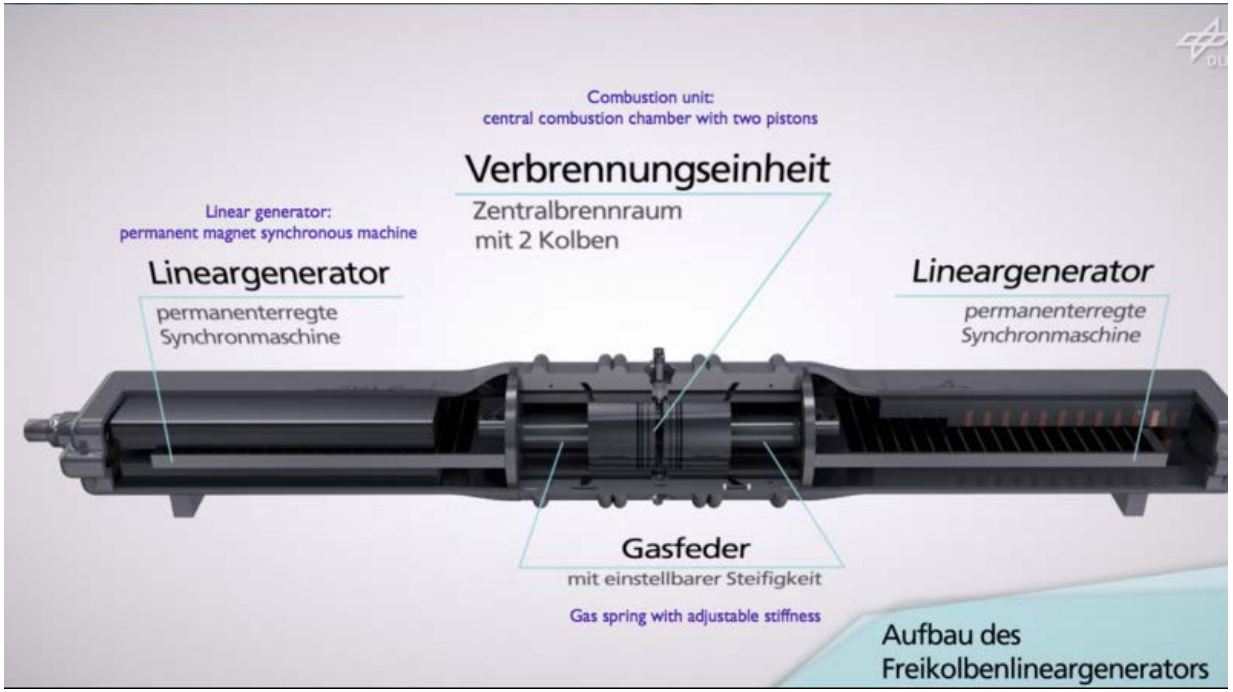
- Engine with increased installed power density for better packaging in future combat vehicles.
- Smaller thermal management system.
- Decreased engine friction for improved fuel efficiency.
- New air charging system for increased power density. Compact two-stage turbocharger systems.

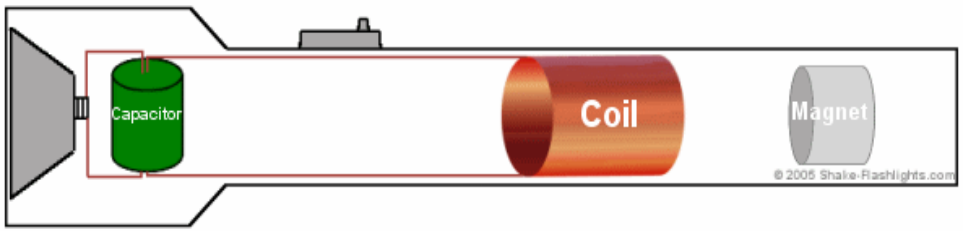
Fuel Cells

Direct fuel to electricity conversion



Free-Piston Linear Generator Concept





Faraday principle of electromagnetic energy to charge

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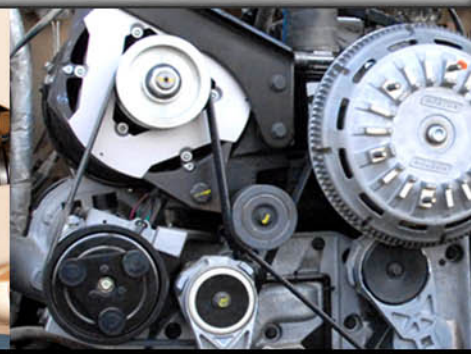
Advanced Thermal Management Sub Systems



Mechanical Drive Propulsion System Losses

1000 kW of fuel

Fuel

Engine

400 kW

Available Power Approx. 40%

350 kW

Primary Power

50 kW Loss

Driveline Losses

300 kW

Sprocket Power

50 kW

Non-Primary Power

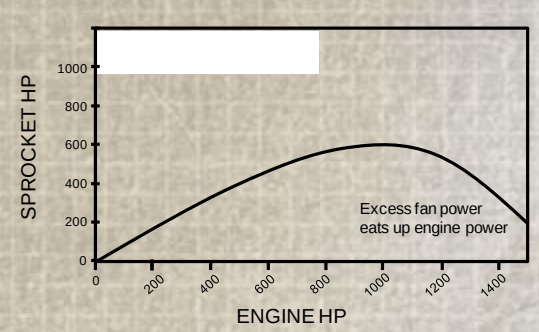
Coolant Approx 30%

300 kW

Exhaust Approx. 30%

300 kW

Fan Power



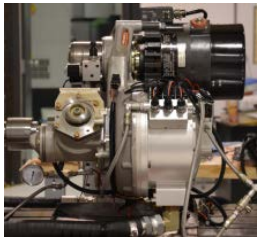
Only 30% of fuel energy available at sprocket!!

Near Term Thermal (Improve Components)

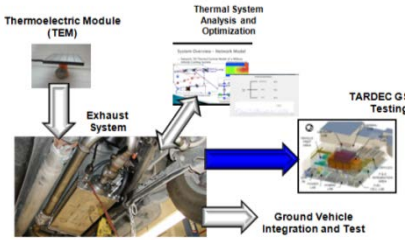
Improve Existing Component Technologies – efficient power take-off, thermoelectric generator muffler, fan geometry improvement, radiator materials.

Efficient Fans

Efficient Radiators



Geared PTO



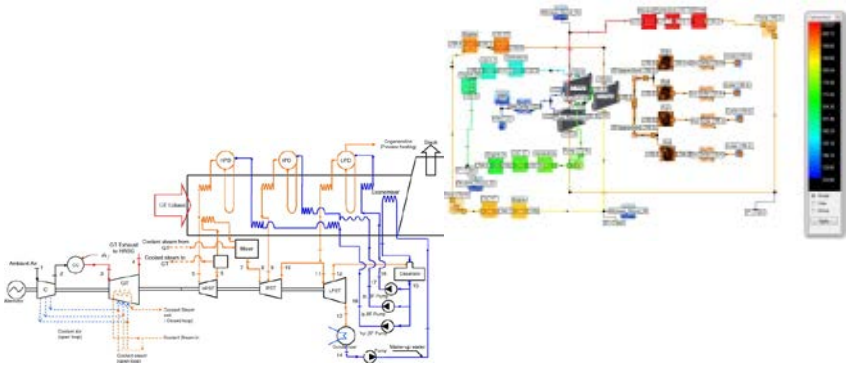
Thermoelectric Generator Muffler

Electrified Fans and Controller Hardware

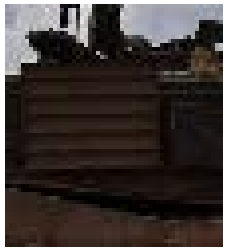
Mid Term Thermal (Systems Approach)

- **System – begin integration of thermal loops and architecture optimization, common controller implementation, heat to electrical conversion with engine off**
- **Technologies – adaptable grills, advanced waste heat recovery, solid state cooling, turbocharging /turbocompounding**

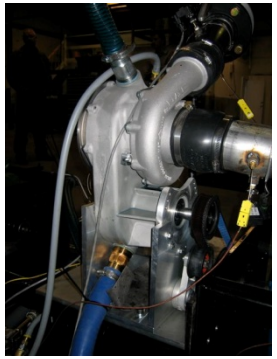
Advanced Waste Heat Recovery



Optimized Cooling Loops



Grills



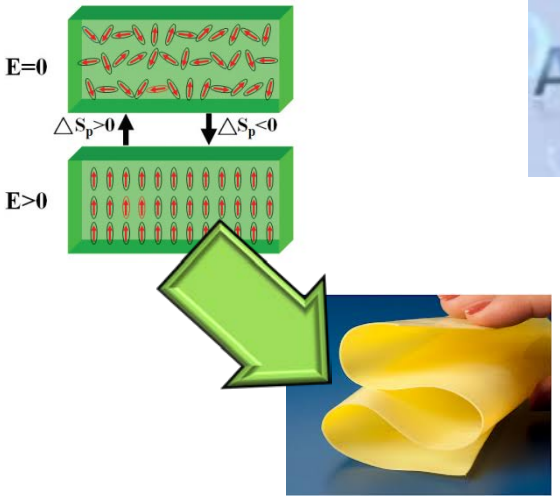
Turbocharging

Control Module

Thermoelectric Power Generation

Long Term Thermal (System-of-Systems Approach)

- System – develop components capable of handling multiple roles within thermal system
- Technologies – adaptive insulation, chemical to thermal conversion, thermal to electrical converting hoses, engine component thermal wraps, self-pumping hoses



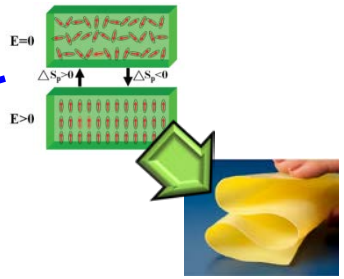
Adaptive Insulation

Chemical to Thermal Conversion

Thermal Wrap

Advanced Hoses

Future Thermal Management

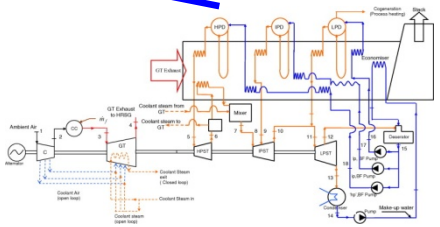


Adaptive Insulation

Thermoelectric Power Generation

Intelligent Fans/Radiators

Advanced Hoses



Optimized Cooling Loops

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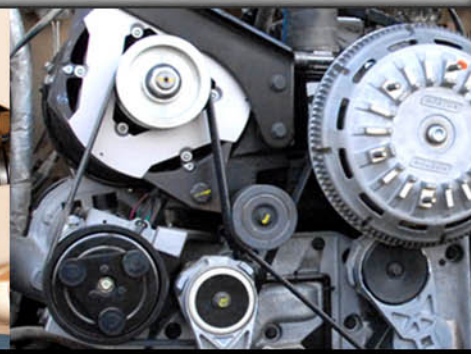
Advanced Electrified Propulsion Sub Systems



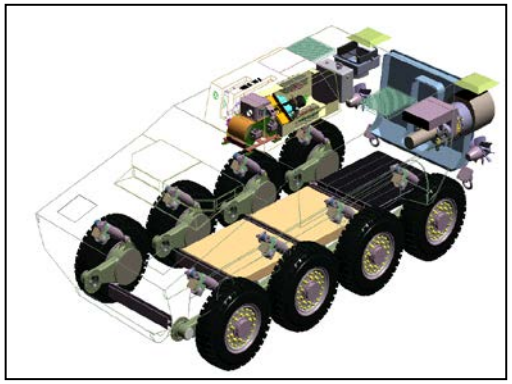



Electrified Propulsion – Why?

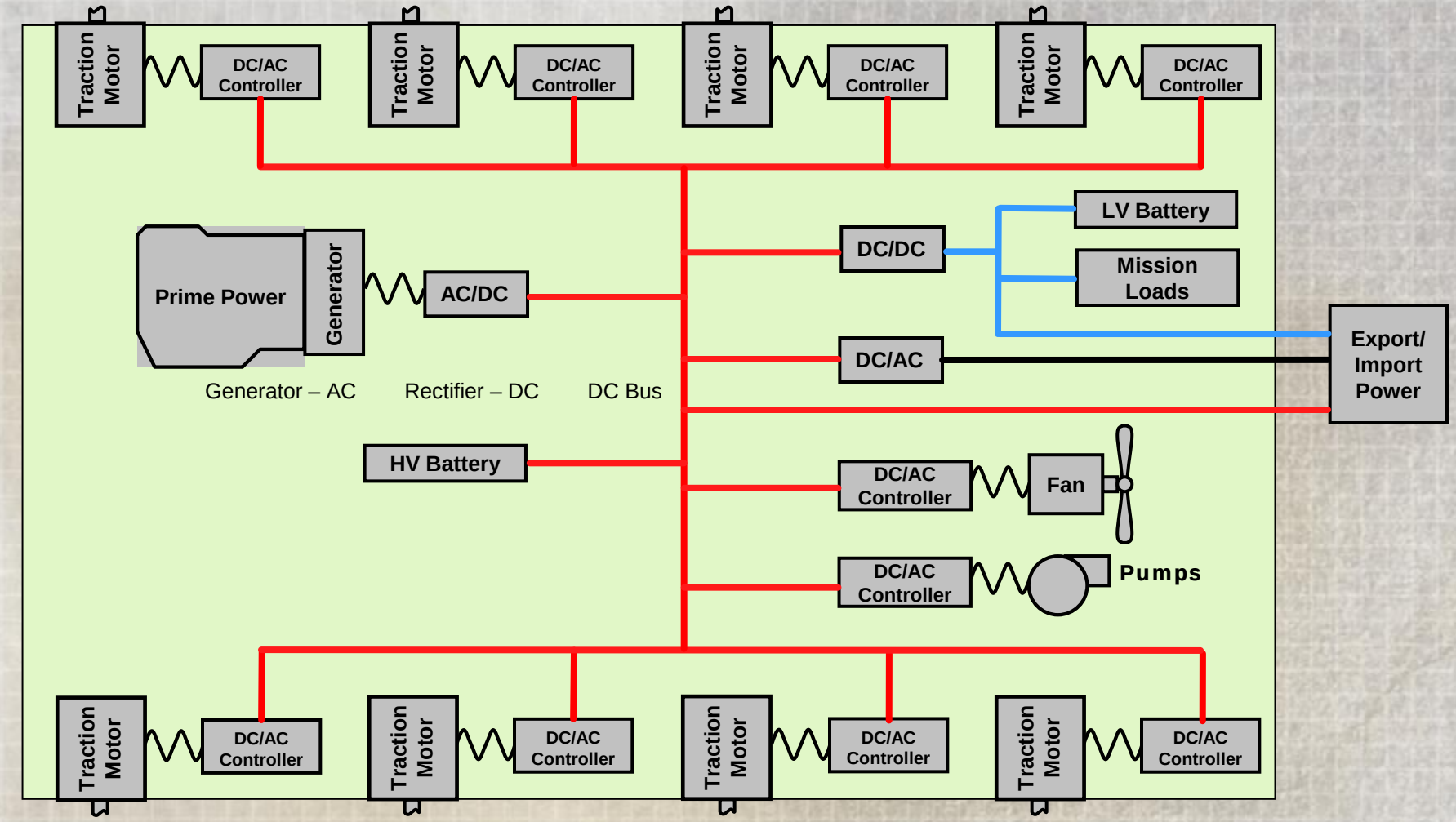
- Enables power for Future Weapons, Defense, and Communications
- Exportable Power Sharing

- Packaging Flexibility
- Enables unique powertrain architectures

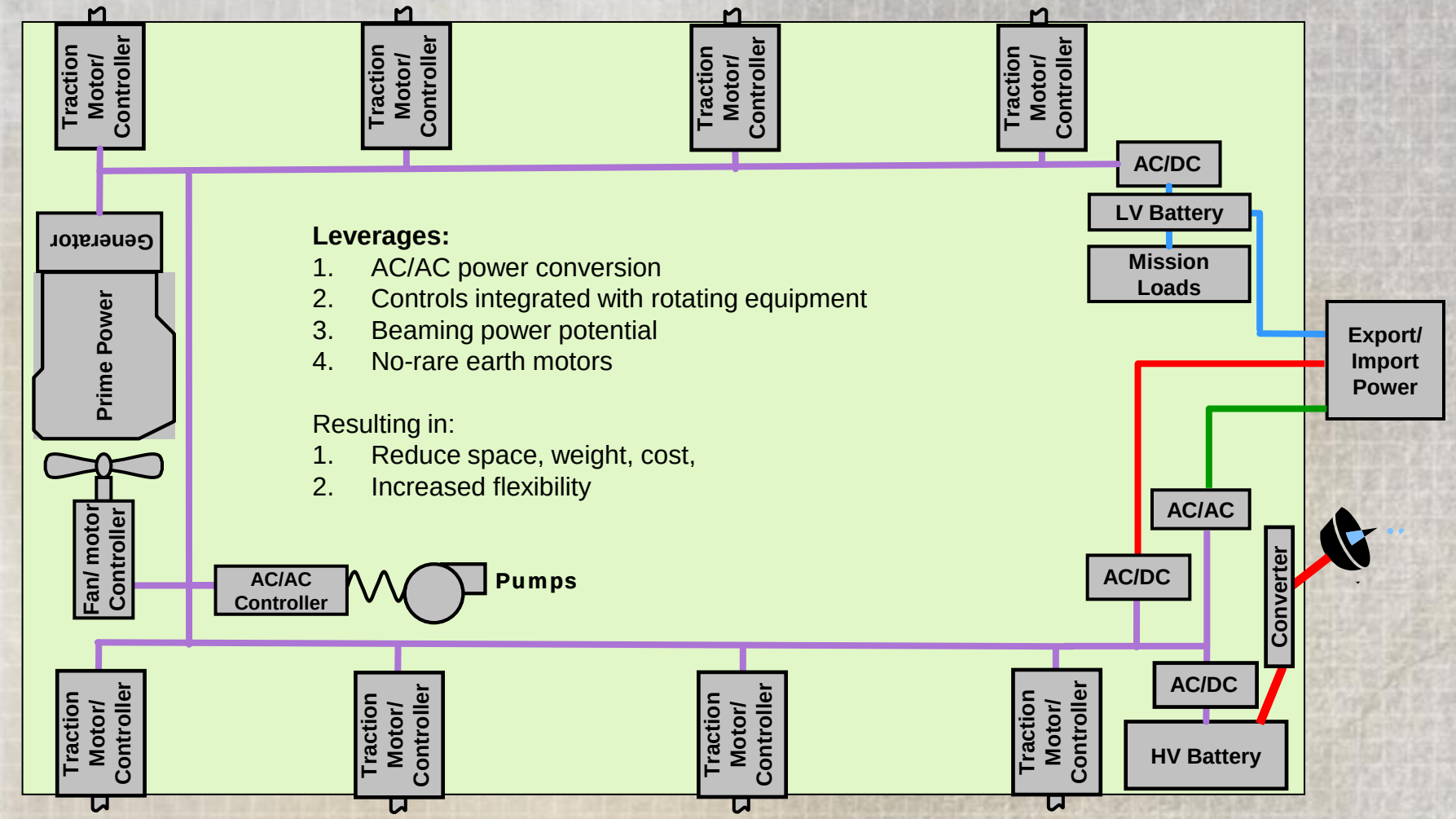
- Burst Power for Mobility
- Silent Mobility (reduced thermal and audible signature)
- Silent Watch
- Potential Improvement in Fuel Economy.



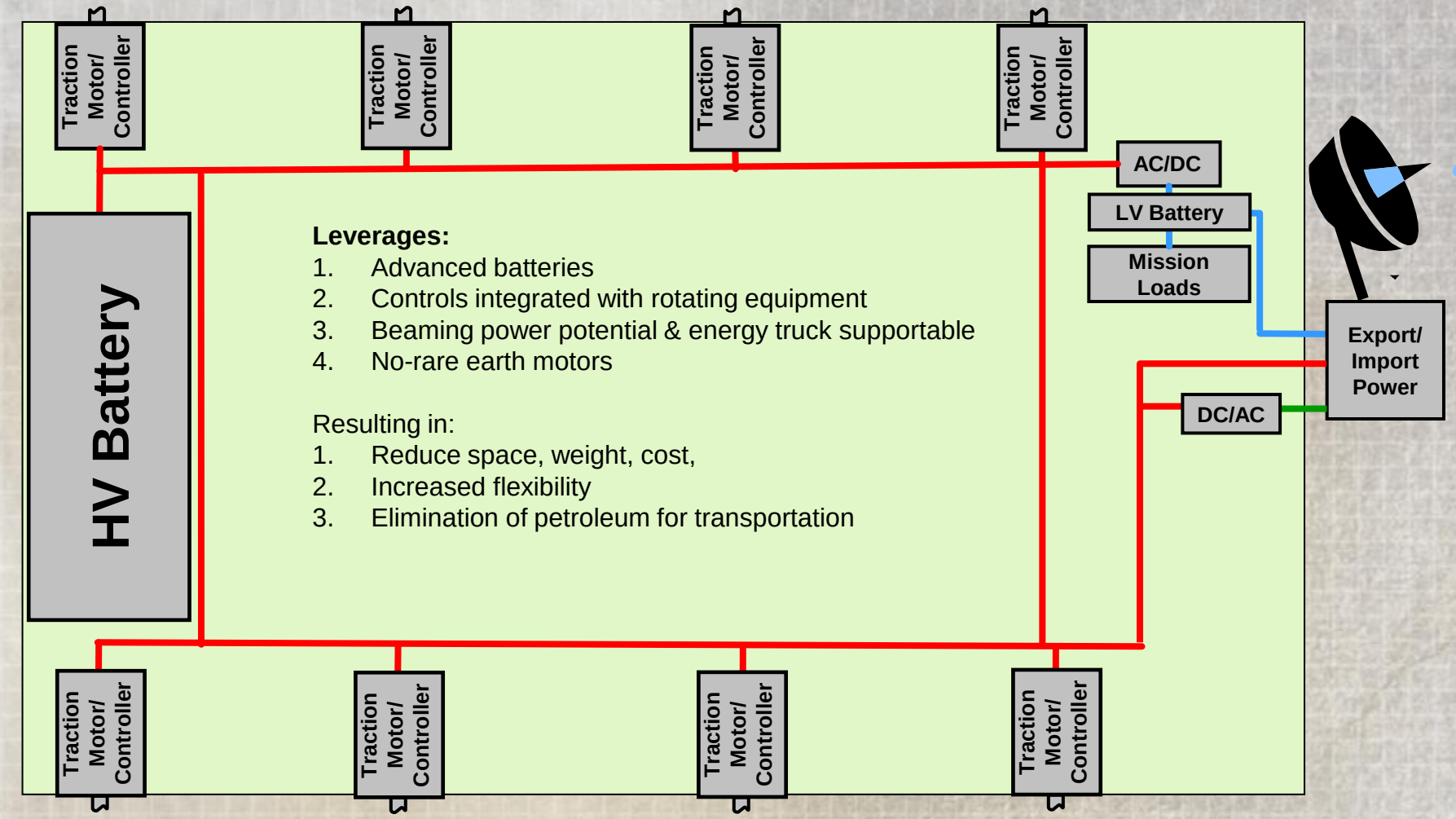
Electric Drive Architecture
Today's approach



Electric Drive Architecture
Tomorrows approach



Electric Drive Architecture
Way, way out there approach



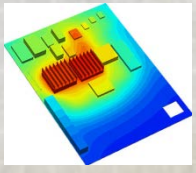
Leverages:

1. Advanced batteries
2. Controls integrated with rotating equipment
3. Beaming power potential & energy truck supportable
4. No-rare earth motors

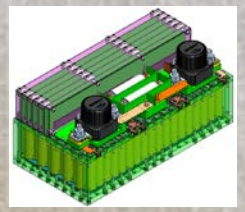
Resulting in:

1. Reduce space, weight, cost,
2. Increased flexibility
3. Elimination of petroleum for transportation

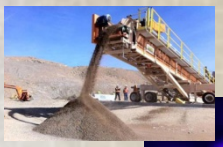
Art of the Possible – Enabling the Future



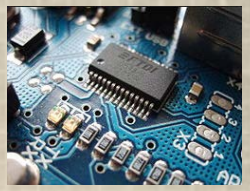
High Temperature electronics



Advanced energy storage

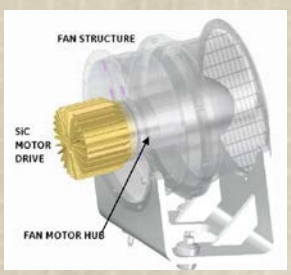


Non-Rare Earth Magnets



High Density electronics

Beam Power to vehicles to reduce logistic trail



Integrated motor controllers

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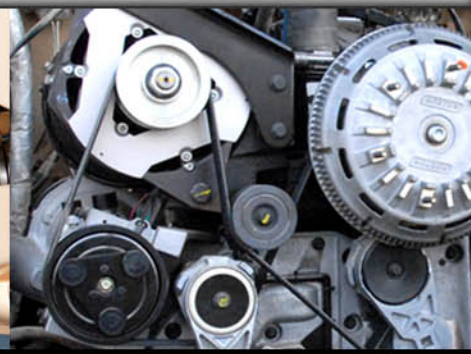
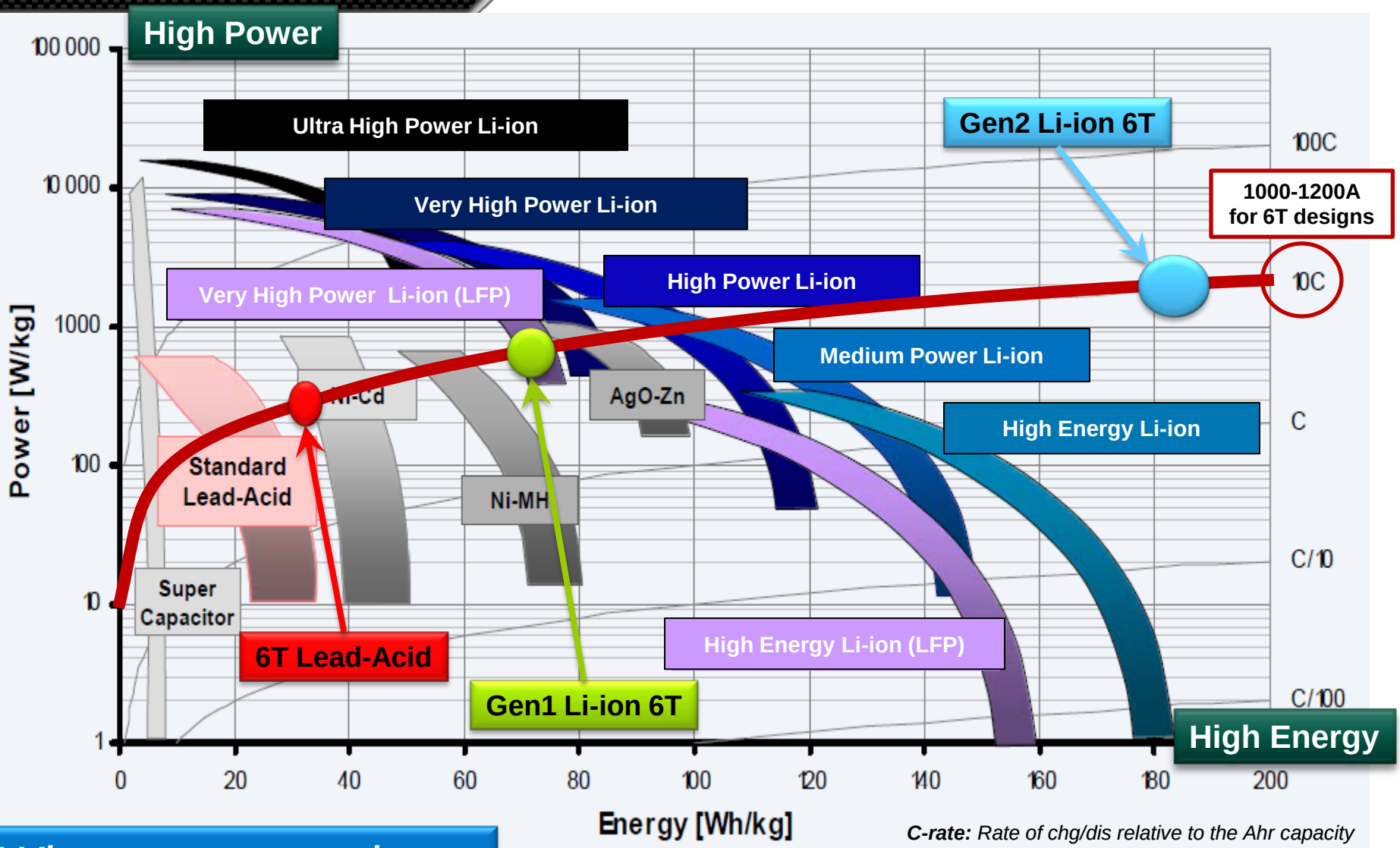
Advanced Energy Storage Sub Systems



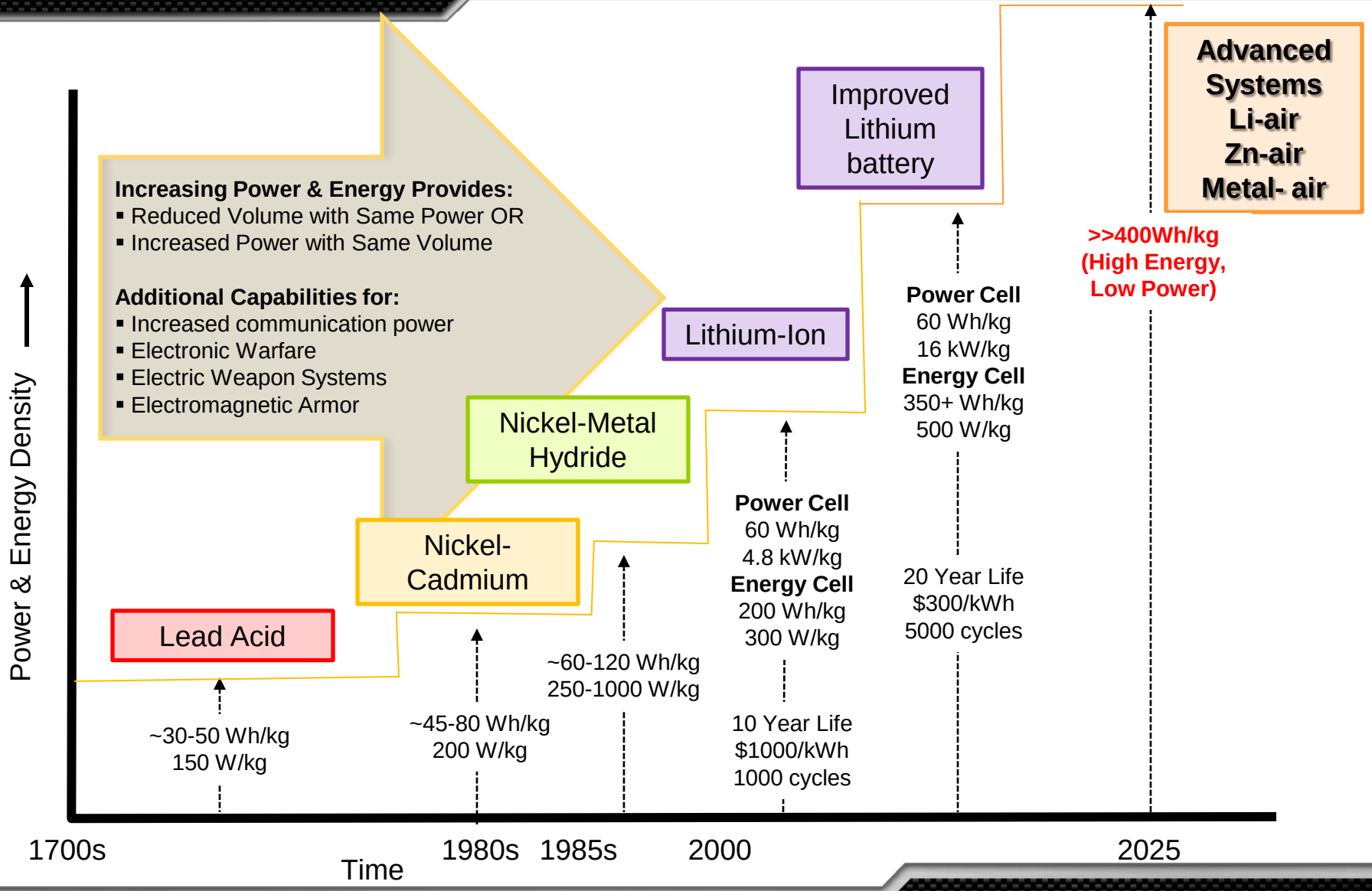
Power versus Energy



C-rate: *Rate of chg/dis relative to the Ahr capacity (1C indicates battery discharged in 1 hour)*

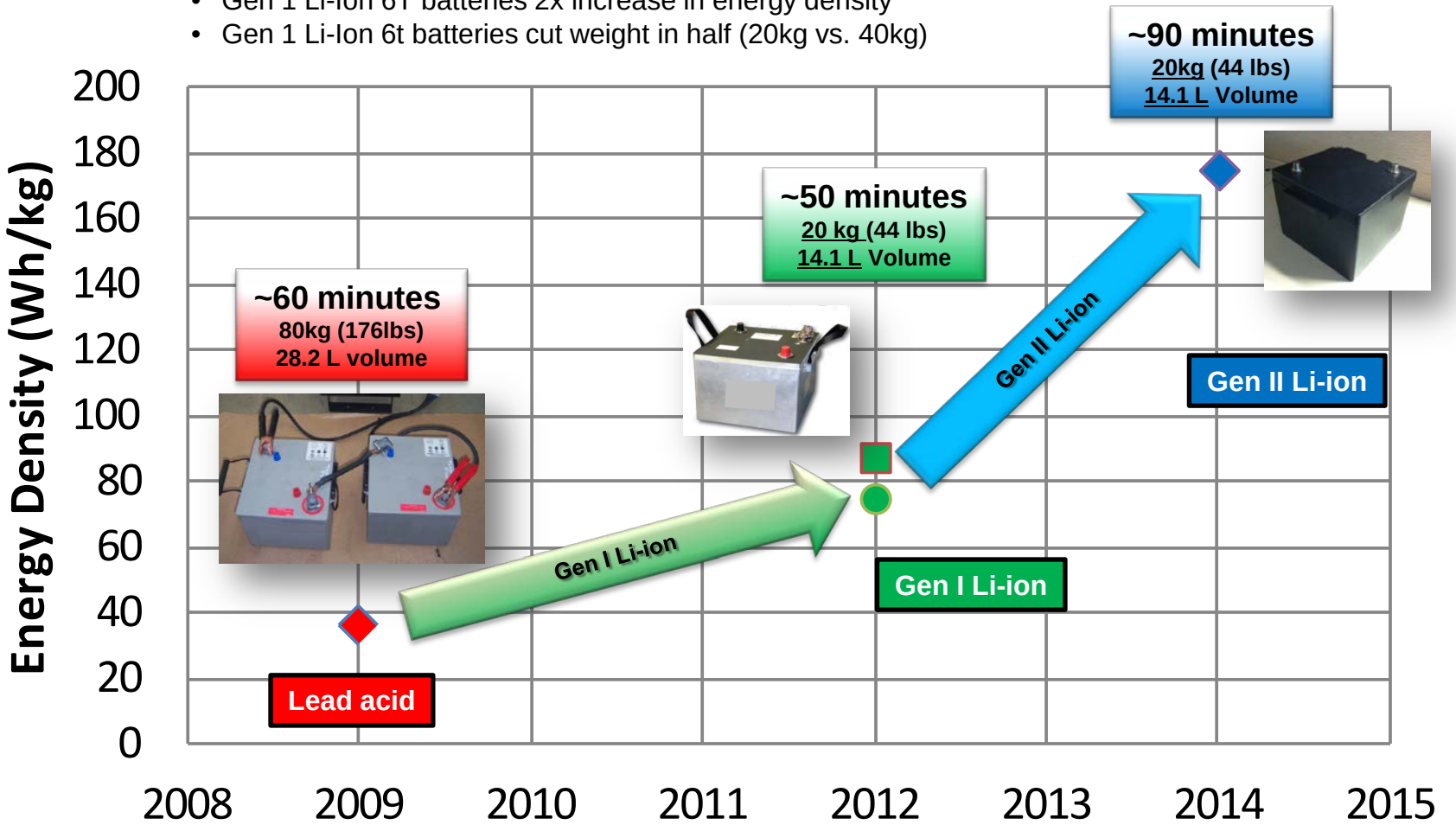
Where are we today…

Battery Roadmap

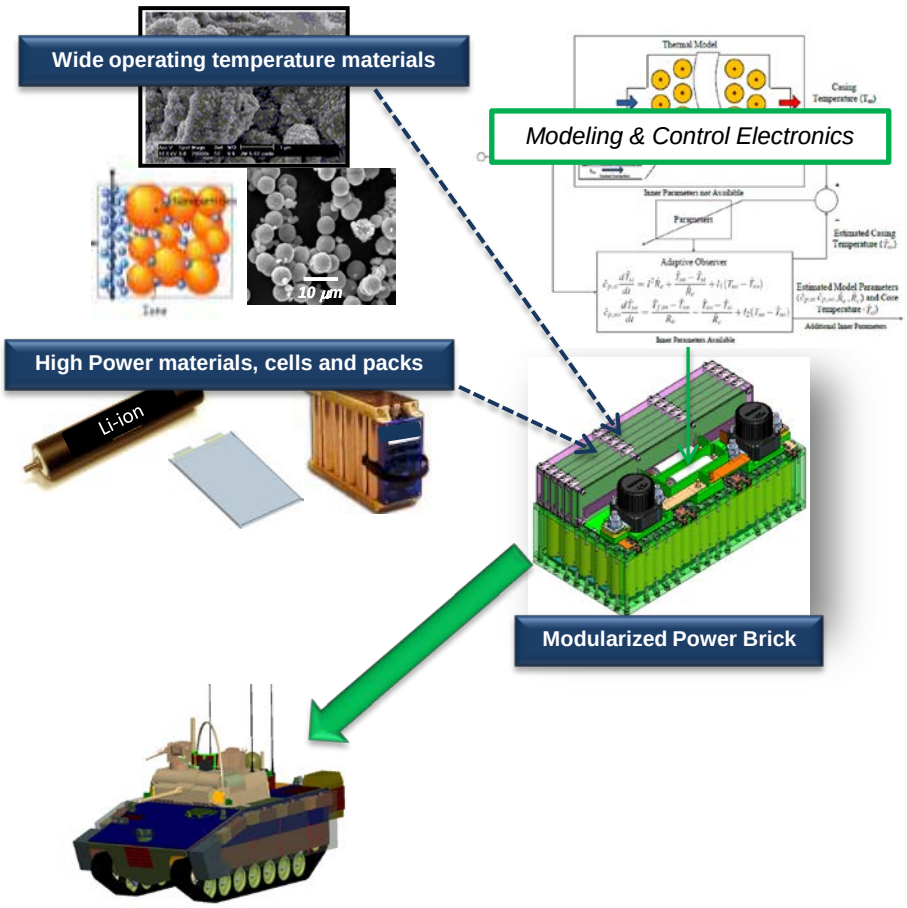


6T Li-ion Battery Development

- Gen1 Li-ion 6T batteries developed and under test
- Gen 1 Li-Ion 6T batteries 2x increase in energy density
- Gen 1 Li-Ion 6t batteries cut weight in half (20kg vs. 40kg)



High Voltage (600V) High Power Batteries



Power Brick Battery Technology

Purpose:

- To develop HV battery systems and designs that can meet military shock/vib/environmental requirements.
- To develop compact, modular 600V, high power battery that can be embedded into pulsed power applications to enable multi-use capability.
- To reduce power draw on vehicles for pulse power applications.
- To develop advanced charge control technologies to improve reliability and modularity.

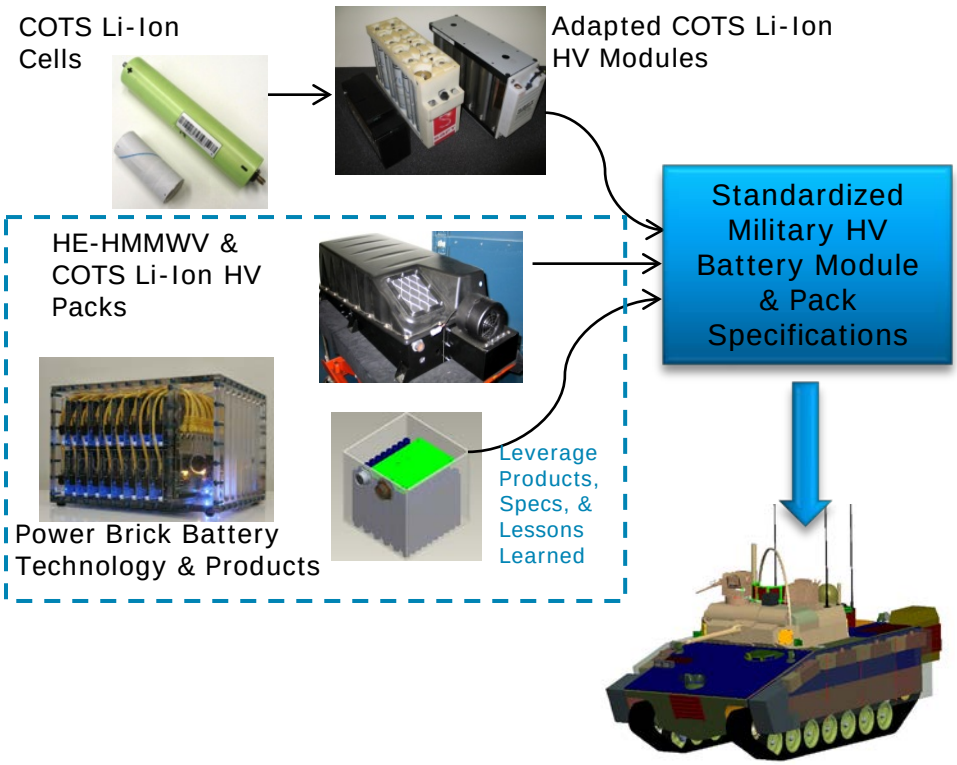
Product:

- Design concepts, standards and specifications for modularized HV batteries for vehicle applications.
- Modularized high power battery systems that can be reconfigured to support multiple high power applications, including advanced survivability, directed energy and non-lethal weapon systems.

Payoff:

- Requirements and as the basis for a standardized high voltage battery systems.
- Key enabler for pulse power applications on military vehicle platforms.
- Significant cost reduction.

High Voltage (600V) High Energy Batteries



Purpose:

To develop standardized ground-vehicle high-voltage (HV) battery system & architecture to enable increased commonality as well as reduce overall cost and associated logistics and sustainment burden in support of the Ground Combat Vehicle (GCV) and all other ground-vehicle platforms using high-voltage batteries.

- Develop standardized scalable HV battery modules capable of working in military vehicle environments
- Develop specifications and safety requirements for the HV module and HV battery systems
- Develop and demonstrate prototype HV modules in a HV pack configuration

Product(s):

- High-Voltage battery module and pack system performance specifications
- Interface control documents
- Testing and demonstration of prototype high-voltage standardized, modular battery system
- In-house HV battery testing & qualification capability

Payoff:

- Enabler for silent mobility, hybridization, and export power capabilities
- Reduced logistics and sustainment burden through increased commonality and standardization at the module & pack levels
- Increased cycle life
- Advanced electrical & communication architecture to support connection of vehicle-based high-voltage battery system to external microgrids

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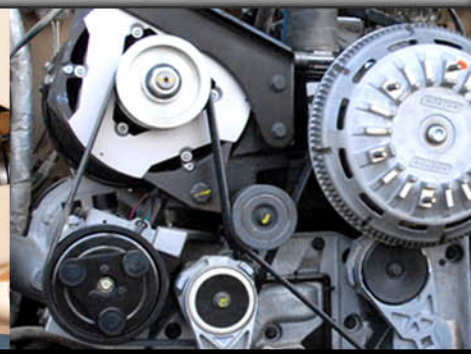
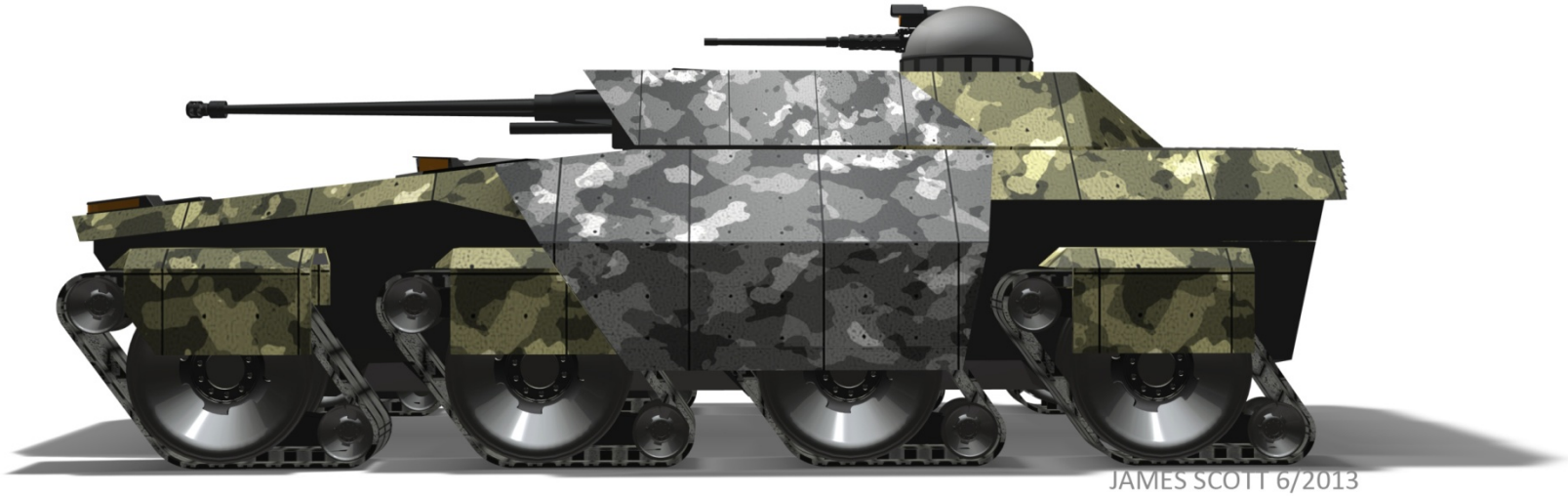
Final Mobility Demonstrator Concept
Exercise VI



Mobility Demonstrator Concept

Tracked



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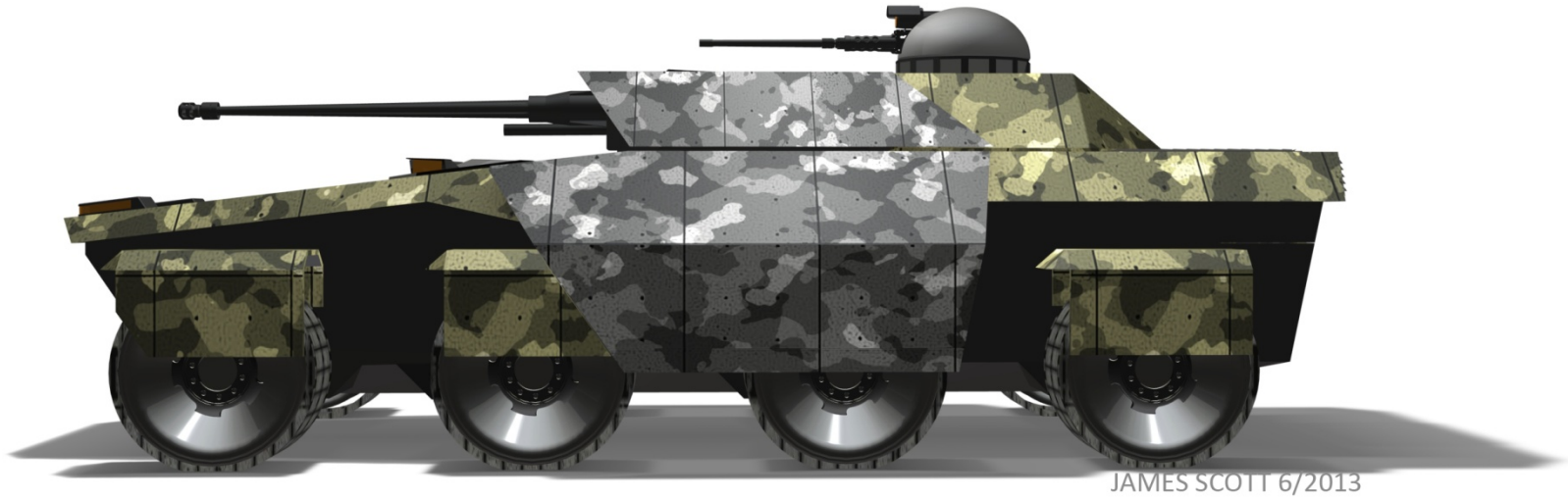

Mobility Demonstrator Concept

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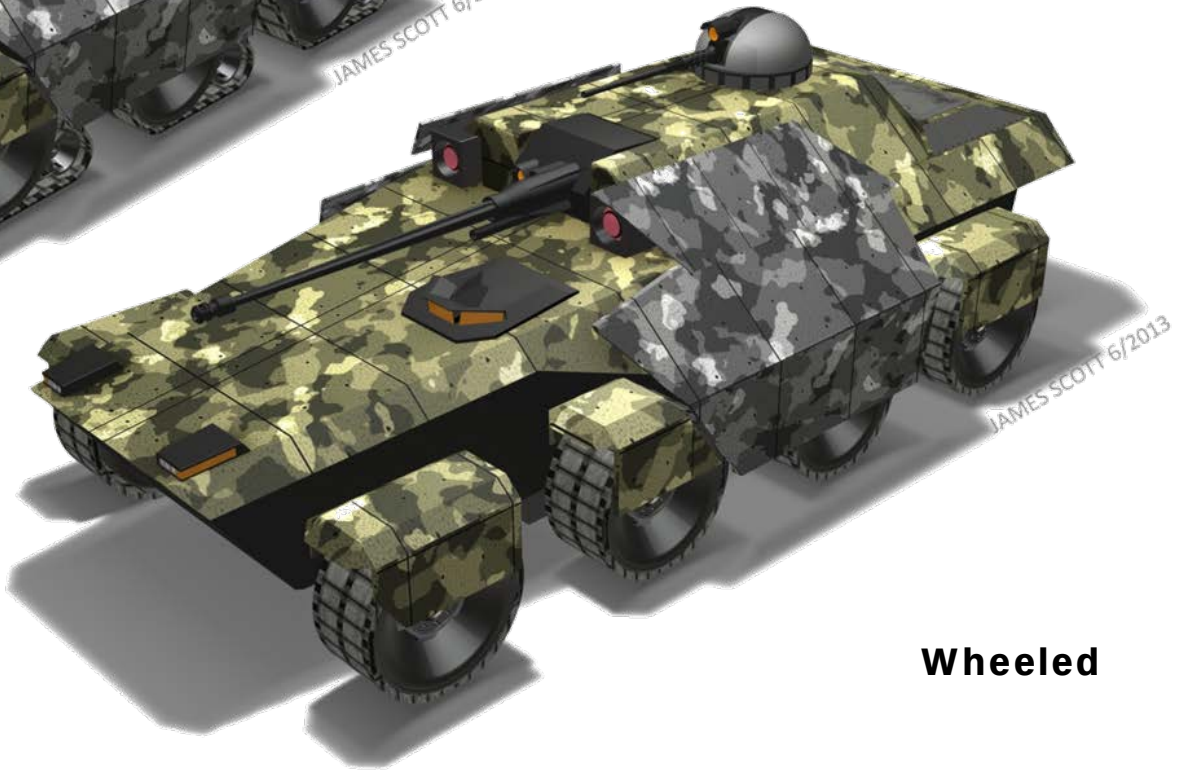

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Mobility Demonstrator Concept

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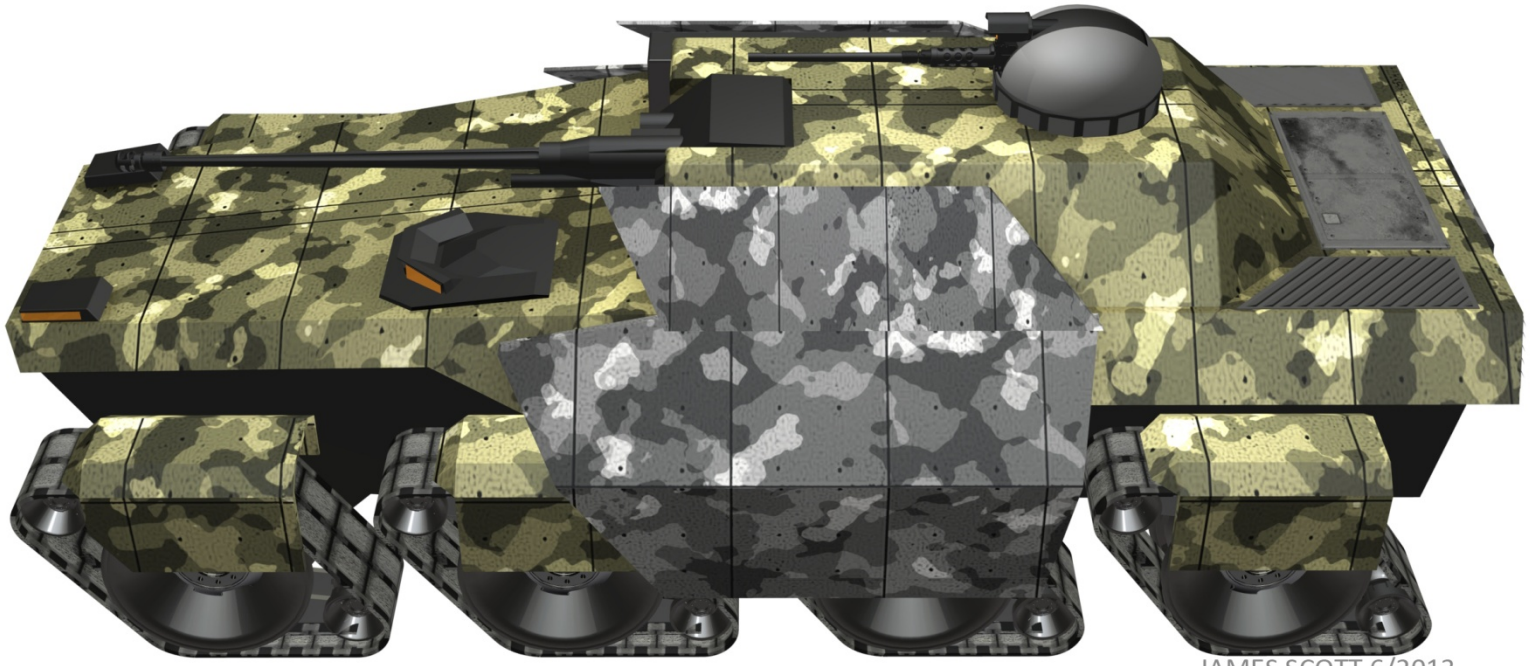
Mobility Demonstrator Concept



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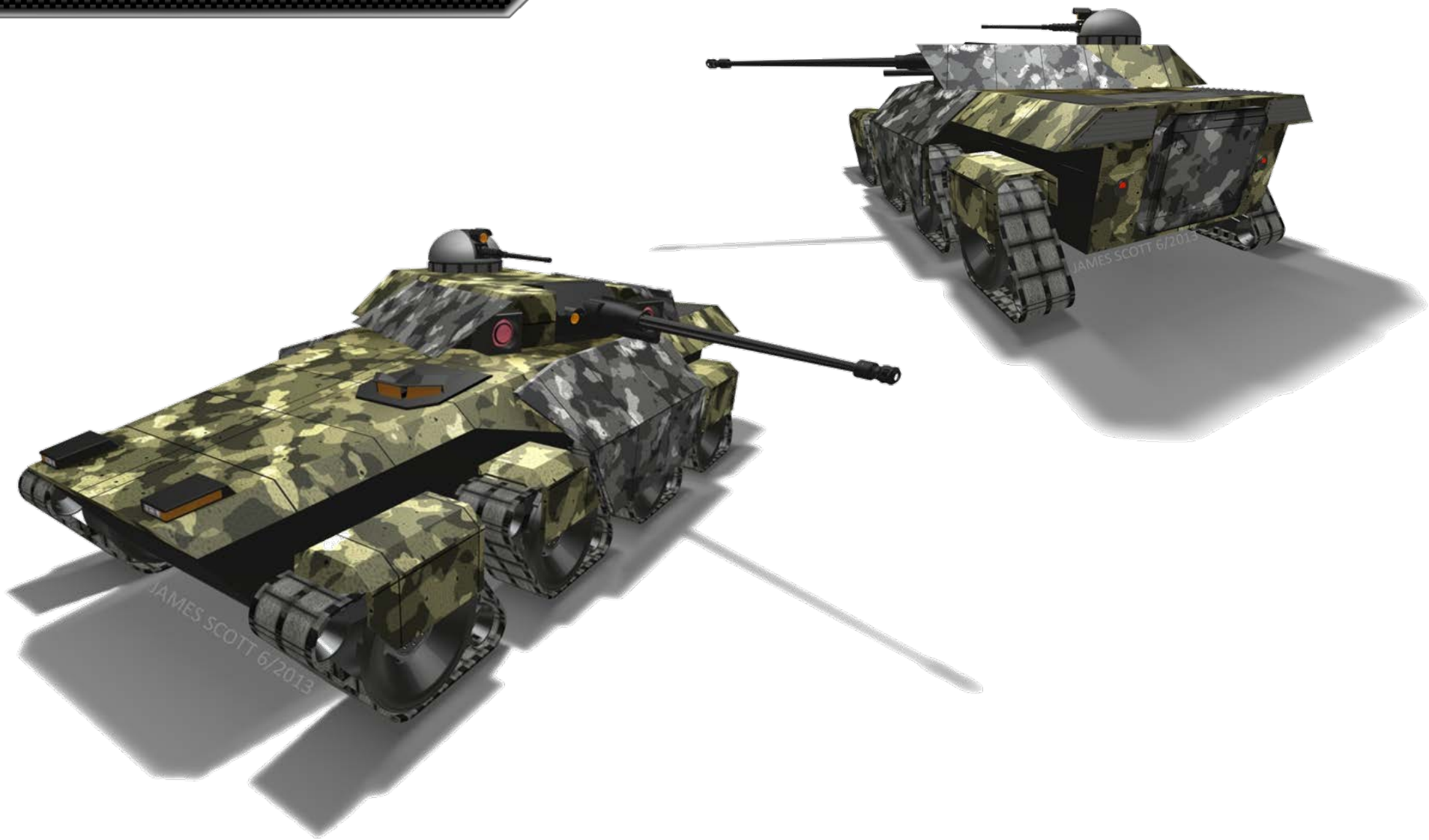
Mobility Demonstrator Concept



Mobility Demonstrator Concept

Mobility Demonstrator Concept

Conclusion