



BALANCE OF PERFORMANCE PARAMETERS FOR SURVIVABILITY AND MOBILITY IN THE DEMONSTRATOR FOR NOVEL DESIGN (DFND) VEHICLE CONCEPTS

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Balance of Performance Parameters for Survivability and Mobility in the Demonstrator for Novel Design (DFND) Vehicle Concepts

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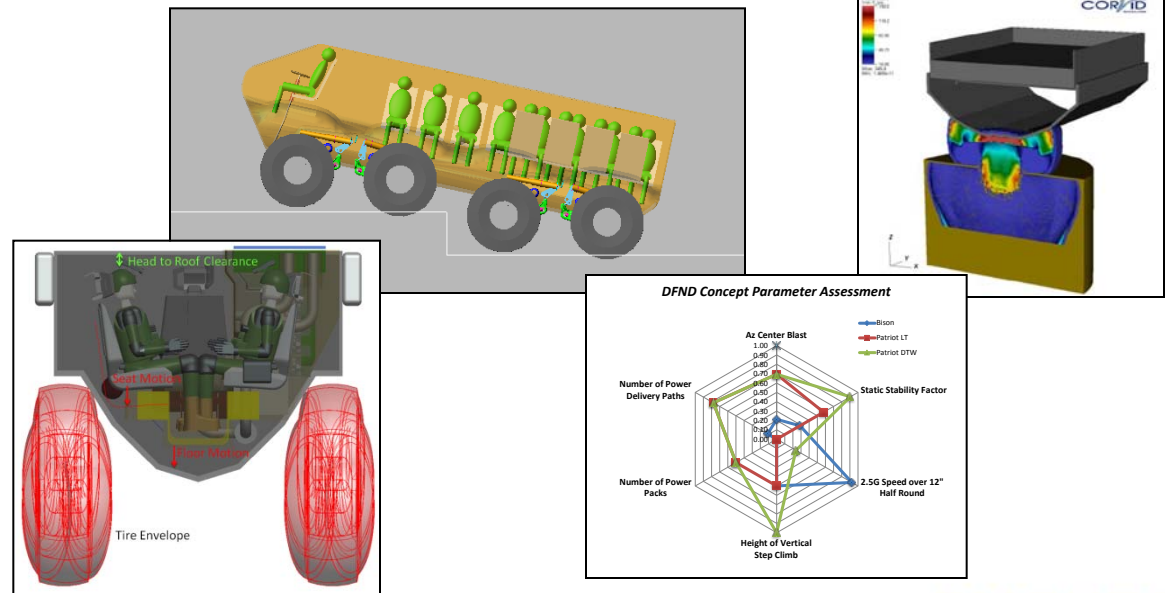
TARDEC Ground Systems Survivability
Warren, MI

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- Introduction
- DFND Project Overview
- Requirements
- Trade Study Process
- Simulations
- Trade Study Results
- Conclusion



DFND Project Overview



- TARDEC sponsored effort to develop novel vehicle concepts for a medium combat vehicle
- Primary objectives - maximize force protection, vehicle mobility, and vehicle survivability
- Apply Pratt & Miller Engineering professional motorsports lean product development process
- Develop vehicle concepts on a compressed timeline
- Occupant-centric design approach
- 3 man crew with 10 dismounts
- Weight of 40,000 lb. – 60,000 lb.
- 8 wheels



Force Protection Requirements



- Subset of requirements used for concept development and description of the process
- Force protection requirements defined as minimizing the vertical acceleration into the hull
- Threat focus - Underbelly blast
- No threshold or objective targets specified in requirements
- Range set for trade study based on simulation results

Requirement	Threshold	Objective
Underbelly Blast Hull Mass Vertical Acceleration	Not specified – set at 200 g	Not specified – set at 140 g

Mobility Requirements



- Mobility requirements included ride events, handling maneuvers, and obstacles
- An example of each included in this study
- Threshold and objective targets set

Requirement	Threshold	Objective
Static Stability Factor	Not specified – set at 0.6	Not specified – set at 0.9
12” Half Round	Not specified – set at no more than 2.5g at 12 MPH	Not specified – set at no more than 2.5g at 20 MPH
Vertical Step Climb	24”	36”

Vehicle Survivability Requirements



- Vehicle survivability defined as the ability of the vehicle to move after an underbelly blast event
- No threshold or objective targets specified in requirements
- Range set for trade study based on packaging results

Requirement	Threshold	Objective
Number of Power Packs	Not specified – set at 1	Not specified – set at 3
Number of Power Delivery Paths	Not specified – set at 1	Not specified – set at 10

Competing Requirements

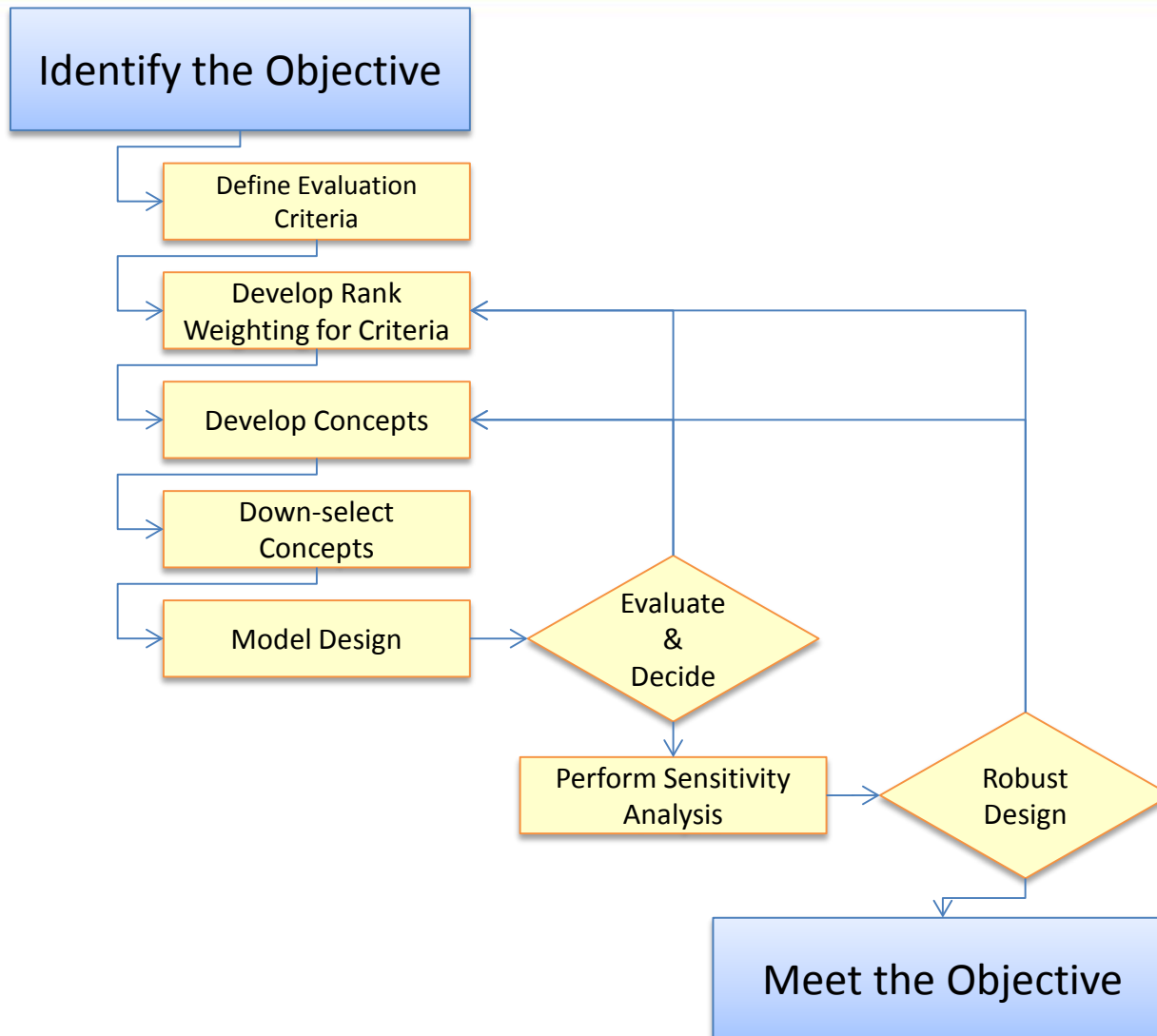


- Primary design parameters identified
- Competing nature requires a process to balance performance

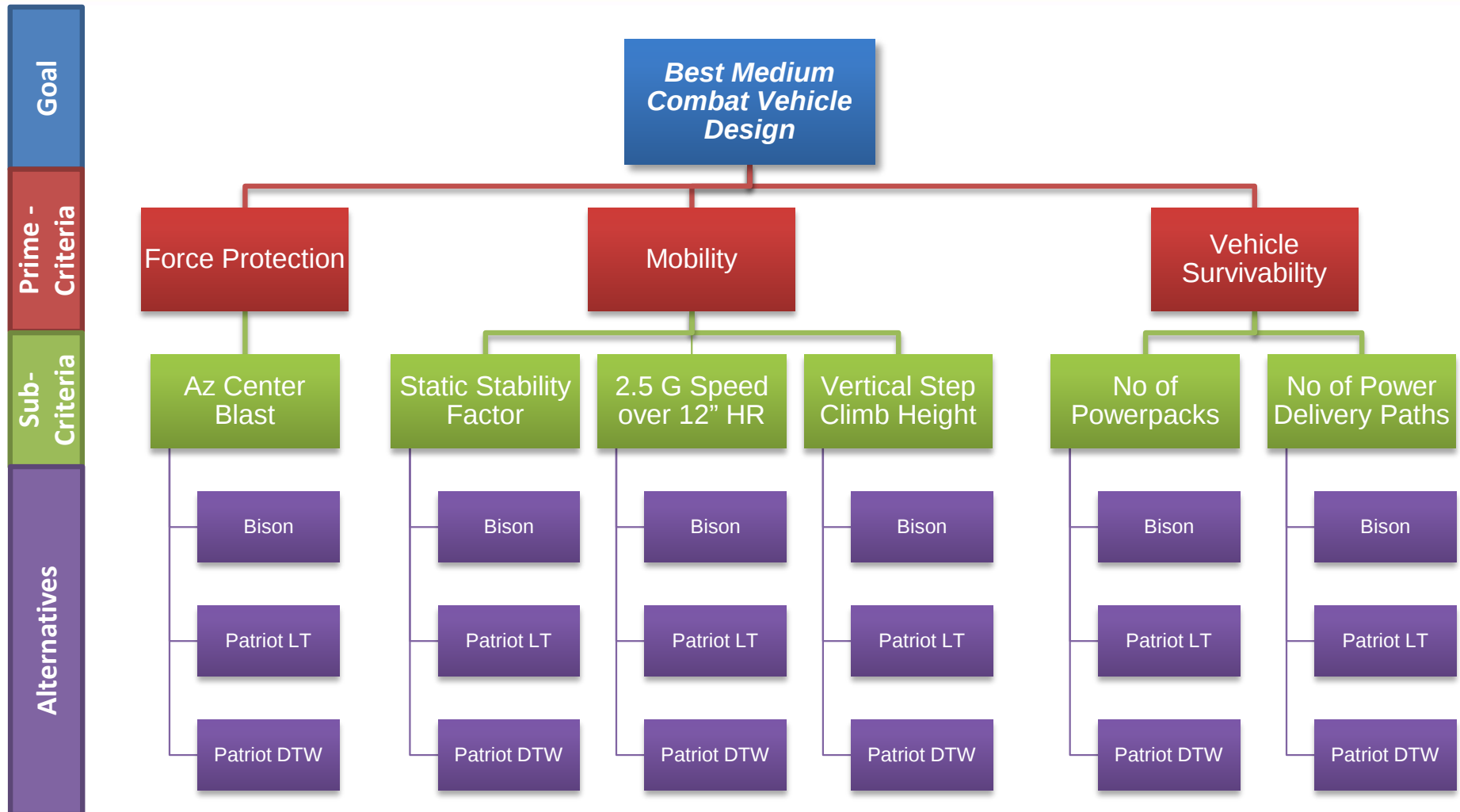
Parameter	Description
CG Height	Vertical distance from the ground to the vehicle center of gravity
Track Width	Cross vehicle width between wheel centerlines
Stand-off Height	Vertical distance from the ground to the lowest structural member of the hull
Wheel Travel in Jounce	Vertical suspension travel in jounce (compression of suspension)
Power Pack	Drive power source
Driveline	Components that transmit power from the power pack to the wheels

	Force Protection	Vehicle Mobility	Vehicle Survivability
Higher CG height	+	-	+
Wider Track Width		+	
Higher Stand-off Height	+	-	+
More Wheel Travel in Jounce		+	
Higher Number of Power Packs			+
Higher Number of Power Delivery Paths		+	+

Trade Study Process



DFND Trade Hierarchy



Analytical Hierarchy Process

- Analytical Hierarchy Process (AHP) to set the weighting factors for each criteria [2] by making pair-wise comparisons according to Scale of Relative Importance

Scale of Relative Importance		
Intensity of Importance	Definition	Explanation
1	Equal Importance	Two parameters contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one over the other
5	Strong Importance	Experience and judgment strongly favor one over the other
7	Very Strong Importance	One objective is favored very strongly over the other; its dominance is demonstrated in practice
9	Extreme Importance	The evidence favoring one objective over the other is of the highest possible order of affirmation
Intensities of 2,4,6,8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for objectives that are very close in importance.		

LEVEL 1 CRITERIA - Global Weighting

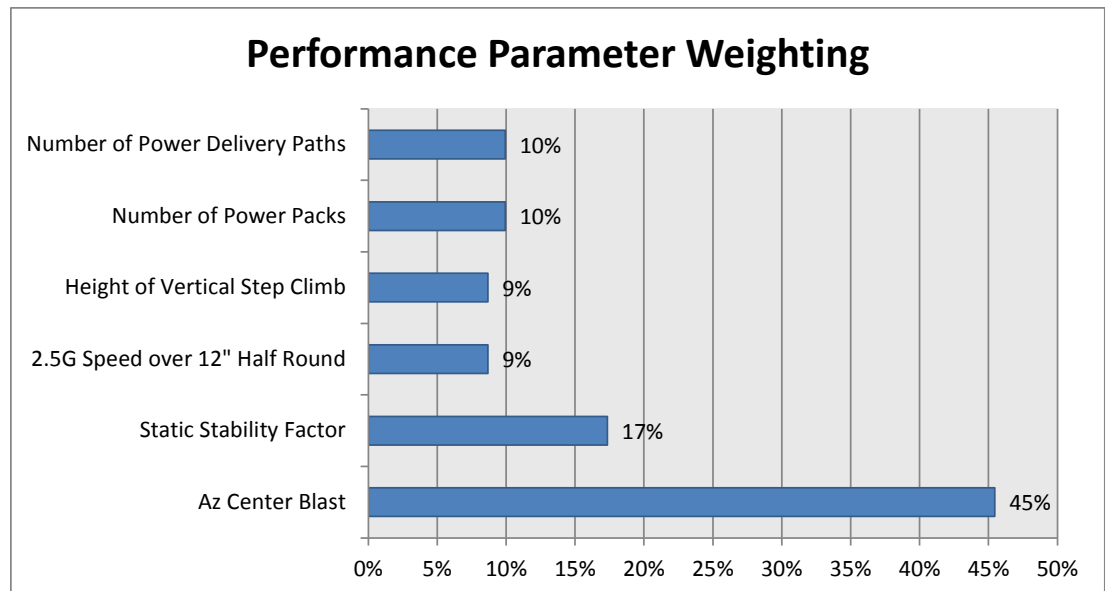
	Force Protection	Mobility	Survivability	Nth root of Product	Global Weighting
Force Protection	1	1.5	2	1.44	45%
Mobility	0.67	1	2	1.10	35%
Survivability	0.50	0.50	1	0.63	20%

[2] International Council on Systems Engineering, "A 'What To' Guide for All SE Practitioners", INCOSE-TP-2003-016-02, page 265, 2006.

Analytical Hierarchy Process

- Process duplicated for each of the sub-level criteria to create local weighting for every design objective
- Global weighting calculated as:
$$GWF_{(\text{level } n)} = LWF_{(\text{level } n)} * LWF_{(\text{level } n-1)}$$

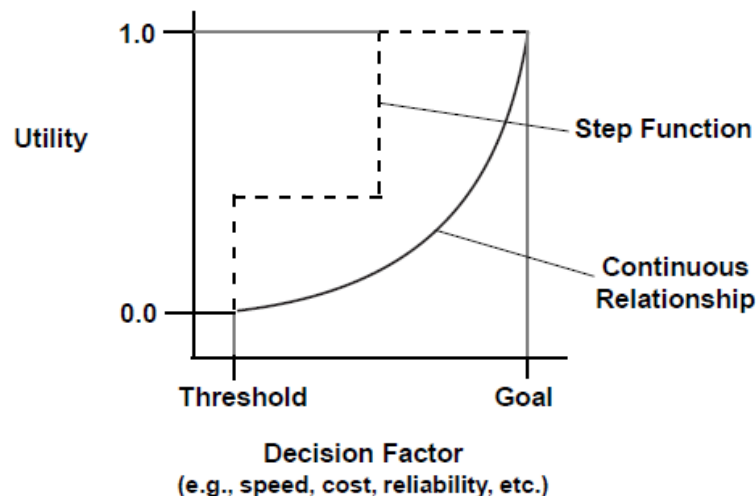
Where:
LWF(level n) = local weighting factor of the child sub-level n criteria
LWF(level n-1) = local weighting factor of the parent level n-1 criteria
- Rank importance of all criteria evaluated and confirmed



Analytical Hierarchy Process



- Design parameters normalized through Utility Functions [3]
- Metrics from force protection, mobility, and vehicle survivability generated from model based simulation and utility curves generated to normalize them from 0 to 1
- Sum of the products of the parameter weighting factors and normalized measures are evaluated to generate a score



Trade Study Matrix

Requirements	Weighting	OPTIONS		
		CONCEPT 1	CONCEPT 2	CONCEPT 3
Payload	0.05	0.5	1.0	0.7
Maneuverability	0.10	0.7	0.8	0.9
Weight	0.10	1.0	0.7	1.0
Mobility	0.25	0.8	0.9	0.3
Occupant Survivability	0.30	0.6	1.0	0.7
Vehicle Survivability	0.20	0.5	0.8	1.0
Total	100%	✗ 0.68	✓ 0.89	✗ 0.71

[3] Defense Acquisition University Press, "Systems Engineering Fundamentals", Version 3.1, page 115, 2006.

Concept Simulation

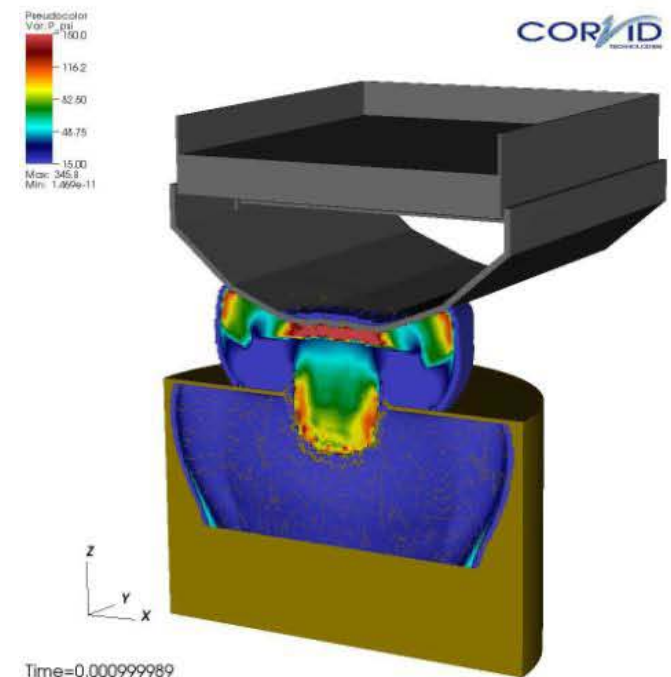


- Novel concepts developed using systems engineering process
- Design parameters specified for three vehicle concepts
- Simulations performed for blast, mobility, and vehicle packaging

Design Parameter	Bison	Patriot LT	Patriot DTW
CG Height	68.5"	60.8"	60.8"
Track Width	94"	94"	106"
Stand-off Height	20.5"	26"	26"
Wheel Travel in Jounce	8"	8"	12"
Power pack	Single	Dual	Dual
Driveline	Conventional	Electric hub motors	Electric hub motors



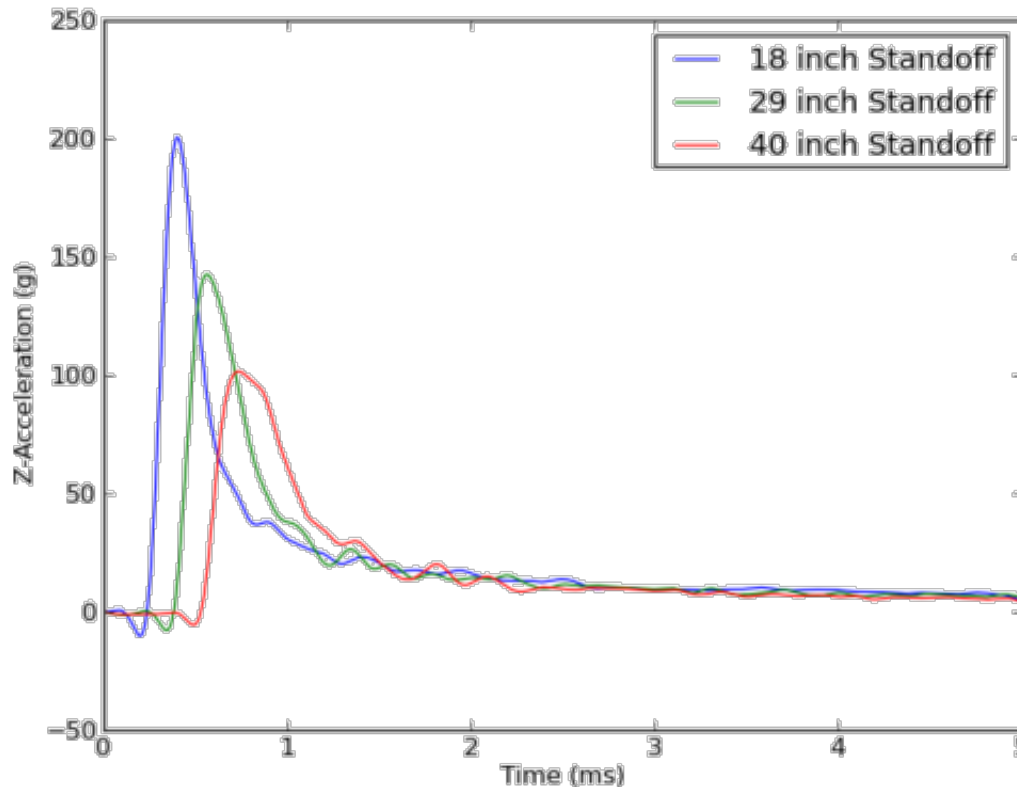
- Blast simulations performed using Velodyne - a proprietary software package developed by the Corvid Technologies
- Velodyne is a fully coupled, multi-physics, hydro-structural solver used to simulate complex high strain rate events
- Stand-off height comparisons at 18", 29", and 40" completed using a simplified hull structure
- Consistent charge size and soil depth
- The vehicle mass was set to match the status of the sprung hull mass system not including the tires, wheels, and wheel end assembly mass



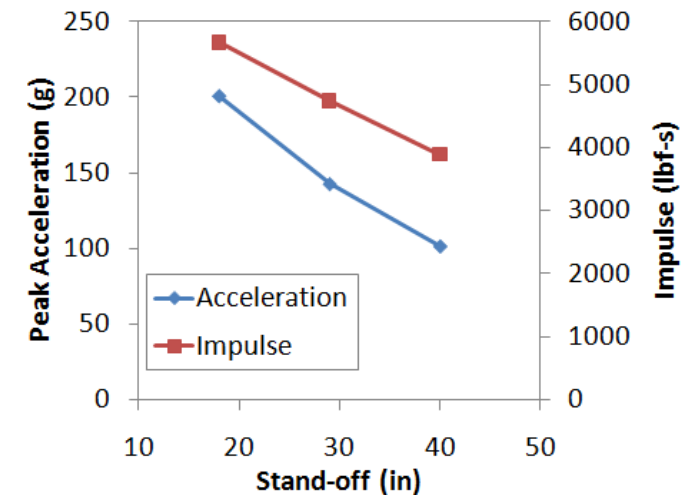
Blast Simulation

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MODELING AND SIMULATION, TESTING AND VALIDATION



- Vertical acceleration performance approximated for concepts based on stand-off height



	Bison	Patriot LT	Patriot DTW
Az for center blast	187 g	158 g	158 g



- Three events used to rank concepts – SSF, half round, step climb
- Used MSC.ADAMS multi-body simulation software to build concept vehicle models

1. Static stability factor [6]

$$SSF = T / (2H)$$

where:

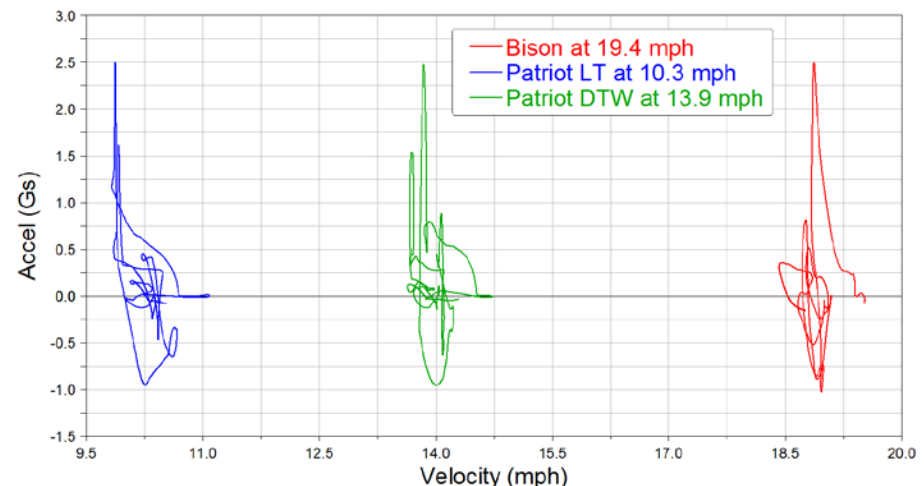
T = track width

H = CG height

	Bison	Patriot LT	Patriot DTW
Track Width	94"	94"	106"
CG Height	68.5"	60.8"	60.8"
Static Stability Factor	0.69	0.77	0.87

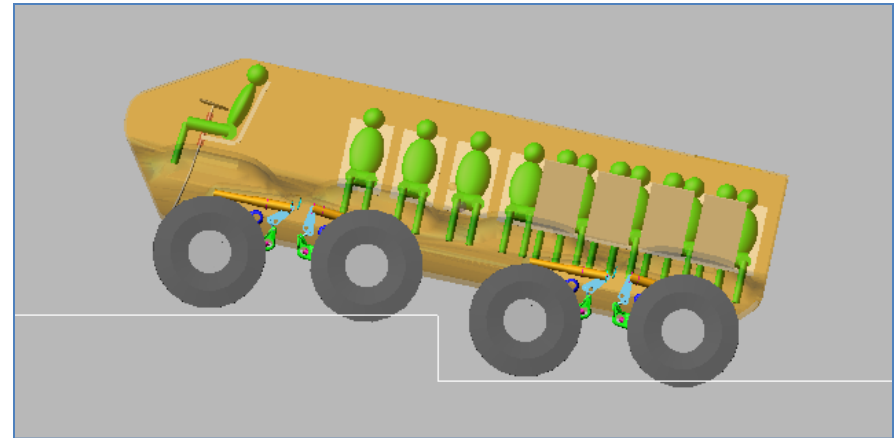
2. Determined highest speed to not exceed 2.5g vertical acceleration at driver position over a 12" half round event

12" Half Round - Driver Vertical Acceleration



[6] M. Walz, "Trends in the Static Stability Factor of Passenger Cars, Light Trucks, and Vans", NHTSA Technical Report DOT HS 809 868, page 2, 2005.

3. Vertical step climb simulated to determine the maximum height that each concept was capable of climbing

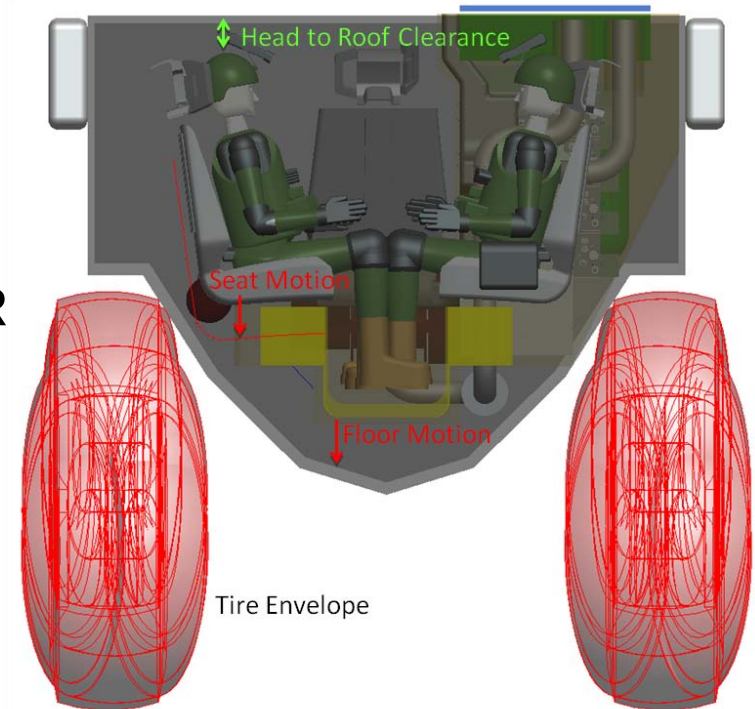


- Mobility simulation results for each concept summarized below and used in trade study

	Bison	Patriot LT	Patriot DTW
Static Stability Factor	0.69	0.77	0.87
2.5g Speed over 12" Half Round	19.4 MPH	10.3 MPH	13.9 MPH
Height of Vertical Step Climb	30"	30"	36"

Packaging

- Primary packaging related parameters – center of gravity (CG) height, number of power packs, and number of power delivery paths.
- Parametric Technology's Pro/ENGINEER computer aided design (CAD) software
- Soldier-centric packaging starting with occupant and balancing suspension travel, stand-off height, and CG height
- Vehicle survivability evaluated for each concept with redundancy as an enabler



	Bison	Patriot LT	Patriot DTW
Center of Gravity Height	68.5"	60.8"	60.8"
Number of power packs	1	2	2
Number of power delivery paths	2	8	8

Trade Study Results



DFND Concept Performance Parameter Trade Matrix

Performance Parameter	Weighting	Concepts		
		Bison	Patriot LT	Patriot DTW
Az Center Blast	45%	0.21	0.69	0.69
Static Stability Factor	17%	0.29	0.58	0.91
2.5G Speed over 12" Half Round	9%	0.93	0.00	0.24
Height of Vertical Step Climb	9%	0.50	0.50	1.00
Number of Power Packs	10%	0.00	0.50	0.50
Number of Power Delivery Paths	10%	0.11	0.78	0.78
Total	100%	 0.281	 0.585	 0.706

Conclusion

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MODELING AND SIMULATION, TESTING AND VALIDATION

- Modeling and simulation for blast, mobility, and packaging used to generate and develop DFND concepts
- Trade study process established to apply weightings and normalize data
- M&S results used to populate trade study parameters
- Simplified example shown to rank vehicle concepts
- Patriot DTW determined to be the leading concept
- Process facilitates decision making based on holistic systems engineering

DFND Concept Parameter Assessment

