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

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Introduction

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

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Warren, MI

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DFND Chief Engineer
Pratt & Miller Engineering and Fabrication, Inc.
New Hudson, MI

- 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

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Threshold</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underbelly Blast Hull</td>
<td>Not specified – set at 200 g</td>
<td>Not specified – set at 140 g</td>
</tr>
<tr>
<td>Mass Vertical Acceleration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mobility Requirements

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

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Threshold</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Stability Factor</td>
<td>Not specified – set at 0.6</td>
<td>Not specified – set at 0.9</td>
</tr>
<tr>
<td>12” Half Round</td>
<td>Not specified – set at no more than 2.5g at 12 MPH</td>
<td>Not specified – set at no more than 2.5g at 20 MPH</td>
</tr>
<tr>
<td>Vertical Step Climb</td>
<td>24”</td>
<td>36”</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Threshold</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Power Packs</td>
<td>Not specified – set at 1</td>
<td>Not specified – set at 3</td>
</tr>
<tr>
<td>Number of Power Delivery Paths</td>
<td>Not specified – set at 1</td>
<td>Not specified – set at 10</td>
</tr>
</tbody>
</table>
Competing Requirements

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Force Protection</th>
<th>Vehicle Mobility</th>
<th>Vehicle Survivability</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG Height</td>
<td>Vertical distance from the ground to the vehicle center of gravity</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Track Width</td>
<td>Cross vehicle width between wheel centerlines</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Stand-off Height</td>
<td>Vertical distance from the ground to the lowest structural member of the hull</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Wheel Travel in Jounce</td>
<td>Vertical suspension travel in jounce (compression of suspension)</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Power Pack</td>
<td>Drive power source</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Driveline</td>
<td>Components that transmit power from the power pack to the wheels</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
Trade Study Process

Identify the Objective

- Define Evaluation Criteria
- Develop Rank Weighting for Criteria
- Develop Concepts
- Down-select Concepts
- Model Design

Evaluate & Decide

- Perform Sensitivity Analysis

Robust Design

Meet the Objective

Meet the Objective

8 August 2011
DFND Trade Heirarchy

Best Medium Combat Vehicle Design

Force Protection
- Az Center Blast
  - Bison
  - Patriot LT
  - Patriot DTW

Mobility
- Static Stability Factor
  - Bison
- 2.5 G Speed over 12" HR
  - Bison
- Vertical Step Climb Height
  - Bison

Vehicle Survivability
- No of Powerpacks
  - Bison
- No of Power Delivery Paths
  - Bison

Goal
Prime - Criteria
Sub-Criteria
Alternatives
Analytical Hierarchy Process

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

**LEVEL 1 CRITERIA - Global Weighting**

<table>
<thead>
<tr>
<th></th>
<th>Force Protection</th>
<th>Mobility</th>
<th>Survivability</th>
<th>Nth root of Product</th>
<th>Global Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force Protection</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>1.44</td>
<td>45%</td>
</tr>
<tr>
<td>Mobility</td>
<td>0.67</td>
<td>1</td>
<td>2</td>
<td>1.10</td>
<td>35%</td>
</tr>
<tr>
<td>Survivability</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
<td>0.63</td>
<td>20%</td>
</tr>
</tbody>
</table>

**Scale of Relative Importance**

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal Importance</td>
<td>Two parameters contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Importance</td>
<td>Experience and judgment slightly favor one over the other</td>
</tr>
<tr>
<td>5</td>
<td>Strong Importance</td>
<td>Experience and judgment strongly favor one over the other</td>
</tr>
<tr>
<td>7</td>
<td>Very Strong Importance</td>
<td>One objective is favored very strongly over the other; its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme Importance</td>
<td>The evidence favoring one objective over the other is of the highest possible order of affirmation</td>
</tr>
</tbody>
</table>

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.

Analytical Hierarchy Process

• Process duplicated for each of the sub-level criteria to create local weighting for every design objective

• Global weighting calculated as:
  \[ GWF_{(level \ n)} = LWF_{(level \ n)} \times LWF_{(level \ n-1)} \]
  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

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Weighting</th>
<th>CONCEPT 1</th>
<th>CONCEPT 2</th>
<th>CONCEPT 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>0.05</td>
<td>0.5</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>0.10</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Weight</td>
<td>0.10</td>
<td>1.0</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Mobility</td>
<td>0.25</td>
<td>0.8</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Occupant Survivability</td>
<td>0.30</td>
<td>0.6</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Vehicle Survivability</td>
<td>0.20</td>
<td>0.5</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td><strong>0.68</strong></td>
<td><strong>0.89</strong></td>
<td><strong>0.71</strong></td>
</tr>
</tbody>
</table>

Concept Simulation

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

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Bison</th>
<th>Patriot LT</th>
<th>Patriot DTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG Height</td>
<td>68.5”</td>
<td>60.8”</td>
<td>60.8”</td>
</tr>
<tr>
<td>Track Width</td>
<td>94”</td>
<td>94”</td>
<td>106”</td>
</tr>
<tr>
<td>Stand-off Height</td>
<td>20.5”</td>
<td>26”</td>
<td>26”</td>
</tr>
<tr>
<td>Wheel Travel in Jounce</td>
<td>8”</td>
<td>8”</td>
<td>12”</td>
</tr>
<tr>
<td>Power pack</td>
<td>Single</td>
<td>Dual</td>
<td>Dual</td>
</tr>
<tr>
<td>Driveline</td>
<td>Conventional</td>
<td>Electric hub motors</td>
<td>Electric hub motors</td>
</tr>
</tbody>
</table>
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
- Vertical acceleration performance approximated for concepts based on stand-off height

<table>
<thead>
<tr>
<th></th>
<th>Bison</th>
<th>Patriot LT</th>
<th>Patriot DTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Az for center blast</td>
<td>187 g</td>
<td>158 g</td>
<td>158 g</td>
</tr>
</tbody>
</table>
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 \([6]\)

\[
SSF = \frac{T}{2H}
\]

where:

- \(T\) = track width
- \(H\) = CG height

<table>
<thead>
<tr>
<th></th>
<th>Bison</th>
<th>Patriot LT</th>
<th>Patriot DTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track Width</td>
<td>94”</td>
<td>94”</td>
<td>106”</td>
</tr>
<tr>
<td>CG Height</td>
<td>68.5”</td>
<td>60.8”</td>
<td>60.8”</td>
</tr>
<tr>
<td>Static Stability Factor</td>
<td>0.69</td>
<td>0.77</td>
<td>0.87</td>
</tr>
</tbody>
</table>

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

---

Mobility Simulation

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

<table>
<thead>
<tr>
<th></th>
<th>Bison</th>
<th>Patriot LT</th>
<th>Patriot DTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Stability Factor</td>
<td>0.69</td>
<td>0.77</td>
<td>0.87</td>
</tr>
<tr>
<td>2.5g Speed over 12” Half Round</td>
<td>19.4 MPH</td>
<td>10.3 MPH</td>
<td>13.9 MPH</td>
</tr>
<tr>
<td>Height of Vertical Step Climb</td>
<td>30”</td>
<td>30”</td>
<td>36”</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th></th>
<th>Bison</th>
<th>Patriot LT</th>
<th>Patriot DTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of Gravity Height</td>
<td>68.5”</td>
<td>60.8”</td>
<td>60.8”</td>
</tr>
<tr>
<td>Number of power packs</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Number of power delivery paths</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>
### DFND Concept Performance Parameter Trade Matrix

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>Weighting</th>
<th>Concepts</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Az Center Blast</td>
<td>45%</td>
<td>0.21</td>
<td>0.69</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Static Stability Factor</td>
<td>17%</td>
<td>0.29</td>
<td>0.58</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>2.5G Speed over 12&quot; Half Round</td>
<td>9%</td>
<td>0.93</td>
<td>0.00</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Height of Vertical Step Climb</td>
<td>9%</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Number of Power Packs</td>
<td>10%</td>
<td>0.00</td>
<td>0.50</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Number of Power Delivery Paths</td>
<td>10%</td>
<td>0.11</td>
<td>0.78</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>0.281</strong></td>
<td><strong>0.585</strong></td>
<td><strong>0.706</strong></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

- 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