Past, Present and Future of Titanium for Ground Combat Vehicles

International Titanium Association
Kissimmee, October 2010

T. James Dorsch
BAE Systems Land and Armaments
US Combat Systems, Santa Clara, CA
Outline

- BAE Systems overview
- History of Ti for military ground vehicles
- BAE Systems ground vehicle applications
- Future applications
- Welding and associated manufacturing processes
- Future trends
- Challenges and opportunities
About BAE Systems

- Global defense and aerospace company delivering a full range of products and services for air, land and naval forces, as well as advanced electronics, information technology solutions and customer support services.
- Largest European defense company.
- Fifth-largest U.S. defense company.
- Sales exceeded $34.4 billion in 2008.
- Invests over $2.3 billion annually on research and development.
- Approximately 105,000 employees worldwide.
- BAE Systems, Inc. is a U.S. company, reporting to BAE Systems, plc in the UK via a Special Security Agreement (SSA).
Executive Committee and other direct reports to the Chief Executive

Executive Committee

Ian King
Chief Executive

Grenville Hodge
MD, Corporate Responsibility

Raj Rajagopal
MD, Performance Excellence

Fiona Davies
Chief of Staff

Philip Bramwell
Group General Counsel

Alan Garwood
Group Business Development Director

Andrea Davies
Group Strategy Director

George Rose
Group Finance Director

Alastair Imrie
Group HR Director

Charlotte Lambkin
Group Communications Director

Linda Hudson
President and CEO of BAE Systems, Inc.

Nigel Whitehead
Group MD, Programmes & Support

Guy Griffiths
Group MD, International

Bob Murphy
Executive Vice President, Product Sectors

Larry Prior
Executive Vice President, Service Sectors
Organizational Structure

BAE Systems plc

Linda Hudson
President & CEO

BAE Systems Inc.

Mike Heffron
President

Electronics, Intelligence & Support

Land & Armaments

Bob Murphy
President

United States

U.S. Combat Systems

Security & Survivability Systems

United States

Global Combat Systems

United Kingdom

Global Tactical Systems

Sweden

South Africa
U.S. Combat Systems Overview

USCS is a modern, efficient, full-spectrum developer, integrator and supplier of survivable, lethal ground and naval combat platforms and advanced technologies.

- Remarkable people...
  - 7,500+ employees and 300+ contractors at 20+ locations in 16 states
  - Outstanding program management and experienced workforce

- With remarkable capabilities...
  - CMMI Level 5 software and systems engineering process
  - Physics-based models and real-time simulation capabilities
  - Rapid prototyping of complex systems
  - Lean, cost-effective production facilities

- Creating remarkable products...
  - Main supplier to the U.S. Army Heavy Brigades
  - Mine-protected wheeled vehicles
  - Naval gun and missile launcher powerhouse

- For remarkable customers.
  - Supporting nearly all U.S. military branches – the world’s best troops
7,500+ employees and 300+ contractors at 20+ locations in 16 states
Close coordination across multiple sites for rapid ramp-up and quick start to production programs
U.S. Combat Systems Locations

**York, PA**
- Lean manufacturing
- Steel, aluminum, titanium and composites fabrication
- Final assembly, integration and test
- 1,912 employees

**Santa Clara, CA**
- Combat vehicle technologies
- Future vehicle engineering
- Modeling and simulation
- SEI CMMI Level 5
  - Systems and software
- 1,306 employees

**Anniston, AL**
- Reset, upgrade, disassembly, and assembly
- Track research and production
- Commercial products
- Three Anniston locations
- 713 employees

**U.S. Combat Systems’ Other Locations**

<table>
<thead>
<tr>
<th>Location</th>
<th>Employees + Contractors (as of Oct. 30, 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fayette, PA</td>
<td>264 (+2)</td>
</tr>
<tr>
<td>Aiken, SC</td>
<td>216 (+2)</td>
</tr>
<tr>
<td>Fort Hood, TX; Ft. Benning, GA; Ft. Stewart, GA; Ft. Carson, CO</td>
<td>136 (+543)</td>
</tr>
<tr>
<td>Arlington, VA</td>
<td>40 (+1)</td>
</tr>
<tr>
<td>Orlando, FL</td>
<td>26 (+5)</td>
</tr>
<tr>
<td>Letterkenny Army Depot</td>
<td>17 (+2)</td>
</tr>
<tr>
<td>Red River Army Depot</td>
<td>9</td>
</tr>
<tr>
<td>Quantico, VA</td>
<td>5</td>
</tr>
</tbody>
</table>
U.S. Combat Systems Locations

Minneapolis, MN
- Modeling and simulation
- System integration
- Combat vehicle reliability testing
- Assembly, integration and test
- 1,019 employees

Sterling Heights, MI
- World-class engineering and design
- Combat systems integration
- Prototyping and testing
- 419 employees

Louisville, KY
- Naval gun “Center of Excellence”
- Gun fabrication and assembly
- Advanced Gun System sub-assembly production
- Spares fabrication
- 306 employees

<table>
<thead>
<tr>
<th>U.S. Combat Systems’ Other Locations</th>
<th>Employees + Contractors (as of Oct. 30, 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aberdeen, SD</td>
<td>135</td>
</tr>
<tr>
<td>Elgin, OK</td>
<td>7</td>
</tr>
<tr>
<td>Cordova, AL</td>
<td>65 (+1)</td>
</tr>
<tr>
<td>Berthoud, CO</td>
<td>149</td>
</tr>
<tr>
<td>Brea, CA</td>
<td>158</td>
</tr>
<tr>
<td>Yuma Proving Ground, AZ</td>
<td>10</td>
</tr>
<tr>
<td>Jacksonville, FL</td>
<td>8</td>
</tr>
<tr>
<td>Norfolk, VA</td>
<td>14</td>
</tr>
</tbody>
</table>
Advanced Processes: Lean Manufacturing

- Aluminum or titanium hull welding
- Ballistic composite manufacturing in place
- Flexible gantry mills for aluminum, titanium or steel
- In place and proven, technically and economically
- World class small parts, weldment manufacture
- Considerable experience with aluminum and titanium

No other combat vehicle and naval gun company has more experience in combat system structures manufacturing, or a more lean, cost-effective, flexible capability in place for future programs.
Products: Ground Combat Systems

Supporting the Warfighter – current to future

Core Competencies:
- Combat vehicle survivability
- Modeling and simulation
- Systems integration
- Rapid prototyping
- Reliability testing
- Lean manufacturing
- Field support

Current Force
- Amphibious Family of Vehicles
- Survivable Wheeled Vehicles

Future Force
- Future Combat Vehicle
- Advanced Tactical Vehicle
- High Energy Laser Technology Demonstrator
- Self Propelled Artillery Family of Vehicles
- Personnel Carrier Family
- Recovery Vehicle

Future Combat Vehicle

BAE SYSTEMS
Enhancing vehicle and crew protection and performance

Core Competencies:
- Advanced passive and active armors
- Hybrid electric propulsion
- Rapidly fielded solutions

Products: Survivability and Platform Technologies

- Transparent Armor Shields
- Reactive Armor
- Band Track
- Hybrid Electric Drive
- Mortar Stowage Kit
- Vehicle Emergency Escape Windows
- Active Protection
- Container Solutions
- Lightweight Structures and Composites
- Signature Management
1959 Watertown Arsenal Report

- Ontos T-165 Hull Ti-7%Mn
- "US Army Requirements for Titanium Alloys With Respect to Vehicular Applications"
Infantry Fighting Vehicle

1993 Fielded

• Commander’s Hatch
  - Development began in 1990 (20 years ago)
    - ~150 lb Ti-6Al-4V forging
    - Ballistically qualified
    - Specification developed for optimizing ballistic properties
    - Ballistic testing required on every 50 hatches
    - 2000 produced, no failures
    - Single melt option recently tested and added to specification

• Roof armor
  - 5/8 inch plate, unwelded
  - Developed specification – not MIL-A-46077
  - Composition optional
  - O content <0.30
  - Ballistic qualification
Lightweight Towed Howitzer

- Less than 50 years after Ontos, the 155 mm lightweight howitzer is fielded
- BAE Systems UK Global Combat Systems
- All titanium (with primary exception of barrel)
- 400 systems delivered
- In service in Afghanistan since 2006
- Replaces 17,000 pound M198
- Permits single rotor helo transport
- Welded Ti-6Al-4V plate, sheet, and castings
Tracked vehicles
Wheeled vehicles
Artillery systems
Experimental Ti Projects

- Light, Air Droppable Tank
  - Ti hatches, armor plate
- Future Self Propelled Howitzer
  - Gun mount
- Composite Vehicle
  - Selective armored areas
- 8x8 Wheeled Demonstrator
  - Primary hull structure
- Lightweight Self Propelled Howitzer
  - Several gun components
- Space Frame Demonstrator
  - Lower hull, space frame
Potential Future Ground Applications

- Future Infantry Combat Vehicle
  - Delayed
- Light Tactical Vehicle
  - Still under competition
- Amphibious Troop Transport
  - In development
- Infantry Fighting Vehicle
  - Survivability upgrades hitting upper weight limit
- Armored tracked personnel carrier family replacement
- Amphibious Personnel Carrier
  - Survivability upgrades planned

Trade studies are conducted constantly: ballistic performance, weight, space, cost
Fabrication Technologies

- Weldments
  - AWS weld code
  - Structural / armor applications
- Forming and bending
  - Opportunities if can be done cost effectively
- Machining
- Castings
  - Mechanical components
- Forgings
  - Hatches
- Shapes
  - Extrusions
  - Rolled
- Heat treating
  - Stress relieving

Learning curve for OEMs and suppliers adopting titanium in their products
New Trends in Combat Vehicle Market

- Increased armor protection required
  - Use of IEDs is increasing
  - Multi-material armor systems (metal, ceramic, composite)
- Desire lighter weight to maintain same vehicle performance
- Declining defense budget
  - Cost is an object
- Customer wants vehicles Off – the – Shelf
  - Acquisition reform
  - Competition – multiple awards with shoot outs
  - Wants it “now” (months, not years)
- Rapid development
  - “Design in” what is immediately available
- OEMs invest significant sums designing vehicles and systems to respond to RFPs
Opportunities and Challenges

- Titanium alloys will find niche applications where high strength to weight ratio or light weight armor solutions are required
- Major OEMs now have considerable experience with Ti and will continue to find appropriate applications
- Cost is a significant issue for ground combat vehicles
  - Raw material cost, plus cost of manufacturing processes such as machining and welding
- New powder metallurgy processes look interesting, but are they competitive and viable?
- Competing materials are being developed
  - Steel, aluminum, magnesium, composites
U.S. Combat Systems Commitment

We Protect Those Who Protect Us