Benefits of Design for Reliability and Early Test and Evaluation

John C. Paulson
Senior Director
Engineering Project Management
About General Dynamics

- Revenues: $32.7 Billion
- Employees: 95,100
- NYSE: GD
General Dynamics operates through four business groups:

- **Aerospace**
  - Gulfstream Aerospace, Jet Aviation

- **Information Systems and Technology**
  - Advanced Information Systems, C4 Systems, Information Technology, United Kingdom, Ltd.

- **Marine Systems**
  - Bath Iron Works, Electric Boat, NASSCO

- **Combat Systems**
  - Armament and Technical Products, European Land Systems, Land Systems, Ordnance and Tactical Systems
About Combat Systems

- 18,700 employees
- $8.8B sales, 2011
- Combat Systems designs, produces and modernizes:
  - Wheeled and tracked combat vehicles
  - Main battle tanks
  - Weapon and armament systems
  - Ammunition
  - Rocket and missile components
  - Axles and suspension components
Combat Systems Business Profile

Armament & Technical Products
Charlotte, North Carolina

European Land Systems
Madrid, Spain

Ordnance & Tactical Systems
St. Petersburg, Florida

Land Systems
Sterling Heights, Michigan
Stryker Family of Vehicles

- Infantry Carrier Vehicle (ICV) 130
- Commander’s Vehicle (CV) 28
- Fire Support Vehicle (FSV) 14
- Mobile Gun System (MGS) 27
- NBC Reconnaissance Vehicle (NBCRV) 3
- NBC Reconnaissance Vehicle (NBCRV) 3
- Medical Evacuation Vehicle (MEV) 16
- Engineer Squad Vehicle (ESV) 13
- Anti Tank Guided Missile (ATGM) 10
- Infantry Carrier Vehicle (ICV) 130
- Fire Support Vehicle (FSV) 14
- Mobile Gun System (MGS) 27
- NBC Reconnaissance Vehicle (NBCRV) 3
- Medical Evacuation Vehicle (MEV) 16
- Engineer Squad Vehicle (ESV) 13
- Anti Tank Guided Missile (ATGM) 10
Current Acquisition Programs

- Funding is Scarce
- O&S Costs must be driven down
- Historically, Major Weapons Programs tend to perform poorly in Operational Test
- Component/Subsystem/Qualification Testing and Engineering assets tend to be negotiated out of Contracts
Cost Benefits to Early Testing

- O&S Costs Primary Cost Driver of Programs
- O&S Costs Can be Driven down through Design for Reliability (DFR) Efforts
- Key measure where programs fall short in OT is Suitability .....reliability
- Funding for DFR and early testing saves costs later in the Program
Cost to Correct Hardware Problems by Program Phase

Cost to Correct Hardware Problem by Program Phase

DoD O&S Costs
Largest Fraction of Life Cycle Costs

**Ground Combat Systems**
- RDT&E: 1%
- Procurement: 28%
- O&S: 68%

**Rotary Wing Aircraft**
- RDT&E: 4%
- Procurement: 31%
- O&S: 65%

**Surface Ships**
- RDT&E: 1%
- Procurement: 39%
- O&S: 60%

**Fighter Aircraft**
- RDT&E: 5%
- Procurement: 29%
- O&S: 66%

**Color Key:**
- RDT&E
- Procurement
- O&S

*Source: Defense Science Board Task Force on Developmental Test & Evaluation*
Discussion

• Design for Reliability

• Benefits of Early Testing through Design of Experiments
What is DFR?

• DFR is Design for Reliability
  – Up front use of Reliability Tools to influence design
  – Infusing a mindset in the design process that promotes striving for improved Reliability
  – Produce a higher growth potential of design

• A change in attitude
  – Aggressive use of Reliability principles
  – Commitment to the DOD directive of Reliability Growth

• DFR tools:
  – Boundary Diagram
  – P-Diagram (Parameter Diagram)
  – DFMEA (Design Failure Modes Effects Analysis)
  – FTA (Fault Tree Analysis) / Prediction
  – DVP&R (Design Verification Plan and Report)

Up Front Use of Reliability Tools to change the Growth Potential of a Design
New Reliability Standard
ANSI/GEIA-STD-0009 Objectives

Objective 1: Understand Customer/User Requirements and Constraints
- Redefined System/Product Level User and Environmental Profiles
- Initial estimates of loads that assemblies will experience during life cycle
- Engineering analysis and test data identifying the system/product failure modes and distributions that will result from the life-cycle loads
- Updated reliability assessment, including results of reliability growth activities (analyses and/or testing)
- Updated System/Product -Level User and Environmental Profiles
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- Engineering analysis and test data identifying the system/product failure modes and distributions that will result from the life-cycle loads
- Updated, integrated Reliability Requirements Verification Strategy/Plan

Objective 2: Design and Redesign for Reliability
- Redefined System/Product -Level User and Environmental Profiles
- Initial estimates of loads that assemblies will experience during life cycle
- Engineering analysis and test data identifying the system/product failure modes and distributions that will result from the life-cycle loads
- Updated reliability assessment, including results of reliability growth activities (analyses and/or testing)
- Updated integrated Reliability Requirements Verification Strategy/Plan

Objective 3: Produce Reliable Systems/Products
- Updated System/Product -Level User and Environmental Profiles
- Updated estimates of loads that assemblies will experience during life cycle
- Updated reliability assessment, including results of reliability growth activities (analysis and/or testing)
- Engineering analysis and test data identifying the system/product failure modes and distributions that will result from the life-cycle loads
- Updated, integrated Reliability Requirements Verification Strategy/Plan

Objective 4: Monitor and Assess User Reliability
- Identification and analysis of all scheduled and unscheduled maintenance actions
- Reliability trends and correction action monitoring
- Establishment of timelines to determine static assessments of system/product reliability at specific reference points
- Engineering analysis and test data identifying the system/product failure modes and distributions that will result from the life-cycle loads
Top Level DFR Summary

• Major steps toward start of design and test
  – Hardware Reliability – Design for Reliability Methodology
    • Boundary Diagrams
    • Parameter Diagrams
    • Design FMEA (Failure Mode and Effect Analysis)
    • Incident Screening Team
    • Failure Prevention Review Board (FPRB)
    • Steering FPRB
  – Operational Reliability
    • Personnel/Maintainer/Operator Training
    • Manuals
  – Quality/Manufacturing
    • Vehicle Shake down
    • Process FMEA
    • Vendor/Supplier Training

Three Major Areas to Facilitate Reliability Growth Potential
Mobile Gun System – The Bunker Buster
Autoloader System

- Feed Rails
- Rammer Assembly
- 8 Round Ready Carousel
- 10 Round Replenisher
Key Factors for Successful Reliability Growth Program

• **Program Management – Integrated Team**
  – The systems, tools, and practices now in place between the US Government and General Dynamics Land Systems allowed the system’s reliability to grow (repeatable process)
  – Reliability growth requires commitments from Material Developer Team, Combat Developer, and Independent Test and Evaluation Communities (requirements, test, data, methodology, tools)

• **System Engineering – Reliability Backbone**
  – Integrates All Reliability Tasks
  – Redirects Tasks Toward a Single Objective
  – Crosses Boundaries Affecting Operational Reliability
  – Provides Program Manager Authority, Funding, and Focus on Engineering, Processes, Documentation, Training, Manufacturing, and Testing for Reliability

• **Reliability Data Analysis – Reliability Assessment**
  – FDSC – Failure Definition Scoring Criteria
  – Failure Categories
    • Inherent vs. Induced Reliability
  – Mission Profile and Life Variable
  – Data Grouping and Modeling
  – Instantaneous vs. Cumulative Reliability
MGS Idealized Growth Curve

MGS Rebaselined MEP Idealized Growth Curve
RGT Demonstrated Reliability

PreART & ART
RGT
PVT

20% RGT Threshold
RGT Demonstrated Reliability

MTBF_i = 47
T = 6757
α = 0.22

RGT Demonstrated Reliability
57 MRBSA

Input Parameters

MRBSA
Rounds Fired

20% RGT Threshold
RGT Demonstrated Reliability

Rebaselined Idealized Growth Curve
MGS - Systems Engineering Approach

- Integrates All Reliability Tasks
- Redirects Tasks Toward a Single Objective
- Crosses Boundaries Affecting Operational Reliability
- Provides Program Manager Authority, Funding, and Focus on Engineering, Processes, Documentation, Training, Manufacturing, and Testing for Reliability
- Approach Provides Metrics that can be Measured
Multi-Level Design Validation Increases Design Maturity before Test-Fix-Test

Virtual Proving Ground

Virtual Integration

Multi-Level Validation Matrix

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<th>3D CAD</th>
<th>ADAMS</th>
<th>MATLAB</th>
<th>VSA</th>
<th>FEA</th>
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SE Approach to Reliability

Increase Design Effectiveness Using Robust Design Methodology

- Modeling
- Allocation
- Prediction
- FMEA
- Parts Program
- FRACAS
- Failure Prevention & Review Board
- Verification

Manage Growth Potential

- Higher Initial MTBF
  - At Start Of Test
- Failure Prevention
- Failure Categorization
- Timely Corrective Actions

Increase Initial MTBF

Potential MTBF

Design Phase

RG/DT
Design for Reliability Management Focuses on Failure Prevention

**Requirements Review**
- Performance Requirements
- Environmental Requirements
- Reliability Requirements Definitions
- Safety Requirements
- Maintainability Requirements
- Support Requirements

**Analyses**
- FMEA and Fault Tree
- Reliability Design Tradeoff
- Design – Stress Reliability
- Safety
- Maintainability Analysis
- Parts Selection
- Manufacturing for Reliability

**Testing**
- Verification
- Validation
- Reliability Growth
- IRGT, FRACAS

**Design for Reliability**
- Failure Mode Mitigation Risk Modes
- Expanded FMEA Worksheet

**Update Status**
- Reliability Growth In Design

**Failure Prevention and Review Board**
- Identify Risk Modes
- Critical Issues
- Outputs, Results, Issues
- DART Process

**Management Systems**
- FPRB
- Interactive Reliability and Design Activity And Reviews
- Issues Resolved/Closed

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Stryker – Mobile Gun System
Failure Prevention and Resolution Implementation

- External Experts
- Failure Analysis 2X per Week
- Corrective Action 2X per Week
- PVT Retrofit Review 2X per Week
- CA Design Oversight
- FPRB Steering Committee Weekly
- FPRB Daily
- Quality Committee 2X per Week
- Prevention & Systemic Issue Committee Weekly
- Reliability Assessments and Predictions
- HYDRAULIC LEAK FOCUS TEAM
- HARNESS & ELECTRICAL FOCUS TEAM
- LRU & SIGHTS FOCUS TEAM
- INDEPENDENT (MUNRO) FOCUS TEAM
- ADDITIONAL TEAMS AS REQ'D

DECISIONS / APPROVAL

STATUS

ISSUES

STATUS

ISSUES

DECISIONS APPROVAL

ISSUES

ISSUES

DECISIONS APPROVAL

ISSUES

DECISIONS APPROVAL

STATUS

Issues

Decisions

Approvals

Status
Reliability Data Analysis

• Proper Reliability Assessment is a key for the program success at PVT

• Reliability Assessment must be discussed up front and consensus should be reached on:
  – FDSC – Failure Definition Scoring Criteria
  – Failure Categories
    • Inherent vs. Induced Reliability
  – Mission Profile and Life Variable
  – Data Grouping and Modeling
  – Instantaneous vs. Cumulative Reliability
Failure Mode Categorization Process

Inherent vs. Induced Failure

- **Failure Mode**
- **Was Vehicle Operated/Built/Maintained as Intended?**
  - Yes → **Performance Failure**
  - No → **Initial Quality?**
    - Yes → **Vendor Quality?**
      - Yes → **Adjust Process/Inspection/Control**
      - No → **Adjust Specification**
    - No → **Maintainance?**
      - Yes → **Operator Error?**
        - Yes → **Adjust Process/Inspection/Control**
        - No → **Adjust Manual/Training**
      - No → **Maintainance**
  - No → **Adjust Process/Inspection/Control**

**Performance Failure**

- Probability of Repeat?
  - >100% → **Failure Improvement**
  - <100% → **Reliability Failure**

**Initial Quality**

**Vendor Quality**

**Reliability Improvement**

**Design Improvement Feasible?**

- Yes → **Design Improvement**
- No → **Adjust Manual/Training**
Idealized Growth Curve and Observed Parametric Curve for Demonstrated Instantaneous MRBSA
How to Make Testing More Efficient

- Design of Experiments
  - Component Test
  - Subsystem Test (ALT/HALT)
  - Developmental System Test
  - Operational Test
- Involve All Stakeholders up front
  - Program Manager
  - Contractor
  - User
  - Developmental Tester
  - Operational Tester
  - Evaluator

Plan Testing as an Integrated Sequence of Events
Combine CT, DT, OT Data when it makes sense
Example – MGS Reliability Growth Test

• Redesign of Ammunition Handling System (AHS)
  – Event Driven
  – Speed still essential
  – Stay on Budget

• Involve All Stakeholders up front
  – Provided PM Stryker, DTC and AEC office space at Land Systems
    • Viewed and Reviewed Component/Subsystem Test Plans
    • Viewed Component/Subsystem and System Contractor Tests
  – Invited TRADOC System Manager, DTC, AEC to Preliminary and Critical Design Reviews (PDR, CDR)
Autoloader System

- Feed Rails
- Rammer Assembly
- 8 Round Ready Carousel
- 10 Round Replenisher
Early Testing
MGS System Integration Lab (SIL)
MGS SIL
Lessons Learned

• Understand the Requirements
• Understand How the Requirements will be Evaluated
• Fund Design for Reliability Up Front
• Include Government Testers/Evaluators while conducting Component and Subsystem Testing
• Fixing Reliability in the Design Process is Cheaper than fixing it during DT
• Fixing Reliability at the Component or Subsystem test level is cheaper than fixing it during OT.
• Make DT as much like OT as possible – Early Discovery
• Contractor and USG Data Collectors share data for early hardware fix development and implementation
• Communicate, Communicate, Communicate
ROI for Reliability RD&T

Small increases in reliability equate to great decreases in Spares Replenishment Costs

Over $13B return

$100M investment

7-year Spares Replenishment Cost

Increase Reliability R&D program as much as possible to optimize Spares Replenishment Costs

ROI for reliability R&D is > 130:1

Adding additional component testing and analysis adds up front nonrecurring cost to the program with a very high return on investment (AMSAA estimate).
Summary

- Funding Robust Systems
  Engineering Process and Design for Reliability up front will save overall program cost

- Conducting Early Tests to gain knowledge when applied fixes are more cost efficient

- Planning Tests as DOE will save Cost & Schedule while providing better end product

Success is about... execution, speed and continuous improvement