Lean SE Approach
Global Hawk Case Study

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Agenda

- Global Hawk Background
- Global Hawk Program Problems
  - Cost & Schedule Overruns
  - Poor Technical Performance & Quality
- Root Causes of Program Problems
  - Inadequate Acquisition Regulations
  - Government & Contractor Lack of Scruples
  - Inadequate Government Oversight
  - Lack of Risk Management
  - Unhealthy UAV Pilot Practices
- Proposed Solution Using Effective Systems Engineering
  - Project Goal
  - SpaceX Approach
  - Lean
  - Top Level Requirements
  - Architecting
  - Ethics
  - Improved Pilot Employment Practices
  - Risk Management
- Conclusion
- Lessons Learned
Global Hawk Background

System Components

Air Vehicle
- Components: Airframe, sensors, flight control & navigation
- Objective: Surveillance capabilities

Common Ground Segment (CGS)
- Components: Launch and Recovery Element (LRE) & Mission Control Element
- Objective: Launch and recover the air vehicle, monitor onboard systems, perform operational control and sensor processing, and mission payload control

CGS = MCE & LRE

Global Hawk Background

Concept of Operations (CONOPS)

- Multiple communications systems
- Surveillance
- Reconnaissance
- Communications relay for over 32 hours
- All-weather capabilities

Global Hawk Background

Top Level Requirements

Requirement
- $10M Unit Flyaway Price (UFP) – this was the only requirement!
- ZERO technical requirements

Other performance objectives labeled as “goals”
- Quick reaction capability
- Medium altitude endurance
- Full satisfaction of the Mission Need Statement

Performance Objectives changed throughout technology demonstration phase

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>December '94</th>
<th>December '99</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Station Loiter (hours)</td>
<td>24</td>
<td>Same</td>
</tr>
<tr>
<td>Operating Radius (miles)</td>
<td>2000 – 3000</td>
<td>3000</td>
</tr>
<tr>
<td>Loiter Altitude (ft msl)</td>
<td>60,000 – 65,000</td>
<td>&gt;60,000</td>
</tr>
<tr>
<td>True Air Speed (knots)</td>
<td>300 – 375</td>
<td>300 – 350</td>
</tr>
<tr>
<td>Takeoff Weight (lb)</td>
<td>15,000 – 27,000</td>
<td>25,600</td>
</tr>
<tr>
<td>Survivability Measures</td>
<td>Threat Warning, ECM, Decoys</td>
<td>Same</td>
</tr>
<tr>
<td>Sensor Payload</td>
<td>SAR, GMTI and EO/IR</td>
<td>Same</td>
</tr>
<tr>
<td>Sensor Payload Weight (lb)</td>
<td>1000 – 1500</td>
<td>1800</td>
</tr>
</tbody>
</table>

- Began in 1994; plan for completion in December 1999
Global Hawk Program Problems

- Cost & Schedule Overruns
- Poor Technical Performance & Quality
- Regulatory Breach
Global Hawk Program Problems

Cost & Schedule Overruns

2004 Government Accountability Office (GAO) report:
- Total cost estimates increased by almost $900 million
- Threefold increase in development costs (larger air vehicle)
- Total acquisition cost increased 44 percent

Schedule Overruns
- Advanced Concept Technology Development phase total schedule delay 15 months
- Engineering and Manufacturing Development & Production phases experienced periodic delays for administrative tasks
- Joint Program Office (JPO) constantly changed schedule & funding availability
Global Hawk Program Problems

Poor Technical Performance & Quality

Poor Performance

- March 1999 loss of Air Vehicle 2 (AV–2) (crash)
- December 2001 loss of AV–5 (structural failure)
- July 2002 loss of AV–4 (fuel nozzle and engine failure)
- Reduced quantity of vehicles due to budget overruns
- Contractor faced SW development & integration problems

2006 Nunn–McCurdy Breach

- >25% Cost growth; Pentagon must re-certify
- Causes
  - Unstable requirements
  - Cost & schedule overruns
  - Insufficient testing
  - Inadequate formal engineering reviews

Root Causes of Program Problems

- Inadequate Acquisition Regulations
- Government & Contractor Lack of Scruples
- Inadequate Government Oversight
- Lack of Risk Management
- Unhealthy UAV Pilot Employment Practices

Root Causes of Program Problems

Inadequate Acquisition Regulations

Acquisition Reform Period

- Adequate acquisition typically follows Federal Acquisition Regulations (FARs): Uniform policies and procedures
  - Encourage planning
  - Verify certification of contractors
  - Defense Contract Audit Agency audits
  - Competition in Contracting Act
    - More competition = lower prices
  - Truth in Negotiations Act
    - Allows government access to contractor cost data
- Global Hawk followed inadequate regulation: Section 845 Other Transactions Authority (OTA)
  - Release contractor from FARs compliance
  - Use of commercial auditor – possibility for corrupt incentives
  - Almost no government oversight
  - Gave contractor complete control over configuration

Cost Plus Program

- Little incentive for contractor to minimize costs
- Unhappy taxpayer
Root Causes of Program Problems

Government & Contractor Lack of Scruples

Air Force desire to field the system as quickly as possible
- Agile Acquisition Initiative
- Shortened program schedule, concurrent design and development
  - No feasible way to meet the new schedule constraints
  - Contractor proceeded with benefit of cost plus

Contractor paid no attention to activities that would affect cost and schedule
- Once requirements were created, they were constantly changing
  - Larger air vehicle, software complexity

 Tradable requirements
- Unit Flyaway Price (UFP) amount not based on actual analysis
- UFP ended up being thrown out to preserve capability
- Sole cost requirement not an effective acquisition strategy
  - Design to Cost (DTC): Cost as a design parameter; emphasizes cost, sometimes over quality or capabilities
  - Cost as an Independent Variable (CAIV): Other variables react to cost
Root Causes of Program Problems

Inadequate Government Oversight

Integrated Master Schedule (IMS)

- Contractor used multiple IMSs
- Subcontracted efforts were not included on schedules
- Schedules were not updated consistently, different technologies

Inadequate test procedures

- Contractor as test lead (Government role was inadequate)
- Insufficient test resources available at subcontractor level
- Hardware and software changes not tested at subcontractor level

First instance of Air Vehicle Specifications in August 2003

- Result of an Air Force requirement not previously enforced
- Once enforced, specifications were written to match current capabilities

Root Causes of Program Problems

Lack of Risk Management

Insufficient funding & schedule

- Air Force shortened schedule: Concurrent development & production
  - Required investment in half of larger Air Vehicles prior to configuration validation
  - Funding was insufficient to support this strategy
- Program goals unattainable

Proceeding with open risks

- Undefined requirements

Root Causes of Program Problems

Unhealthy Unmanned Air Vehicle (UAV) Pilot Practices

- UAV pilots able to live near home in US, but severely overworked due to low staff
- Pilots suffer from psychological strain due to dissociation from remote traumatizing actions ¹²
- UAV pilots scorned by Air Force colleagues as fighting a "coward's war" ⁸
- High turnover of drone pilots
  - Air Force has begun offering massive incentives (increasing pay by up to $1,500 per month for 6 year commitment) ²

http://theaviationist.com/2013/09/06/nobody-wants-to-fly-drones/
Proposed Solution Using the Best Available SE

Project Goal

Design a hypothetical program solution in accordance with best available Systems Engineering practices, exemplified by SpaceX and Lean Strategies

Global Hawk
- Inefficient
- Wasteful
- Poor quality
- Wasted taxpayer funds

Lean Methods/SpaceX
- Efficient
- Cost effective
- Efficient use of taxpayer funds

http://www.fundchat.org/2013/10/15/finding-room-for-improvement-in-your-major-giving-program/
Proposed Solution Using the Best Available SE

SpaceX

- Colocation of the program; all in one building
- Flat Organization: CEO, 7 VPs, Everyone else
  - Superb communication; no chain of command
- About 1/10th number of staff (technical and non-technical) compared to traditional operations
- "Responsible engineer" – Responsibility for the entire lifecycle and all aspects of a given item, full coordination with all stakeholders across all disciplines
- World-class technology
- Prioritize cost, time and quality
- High internal motivation
  - Private company, everyone owns stock
  - All profits invested

Proposed Solution Using the Best Available SE

SpaceX: Requirements Management

Requirements management
- Limited top level requirements
- Concerned with payload interfaces

Traditional SE Vee
- Mission assurance requires perfect requirements from the beginning
- Time consuming

SpaceX SE Vee
- Mission assurance supported by rapid testing and optimization

User requirements are tracked and verified but everything below these requirements is constantly traded and optimized during the design phase.

Possible to trade key parameters between subsystems to optimize results because designers not separated by contract-subcontract bounds.
Proposed Solution Using the Best Available SE
SpaceX: In-house Development & Testing

Vertical Integration
- Escape traditional cost structure
- Minimal allocation and management of requirements
- Rapid requirements changes
- Vastly lower complexity in communication, contracts negotiation
- Supports rapid optimization
- Hyper-efficient in-house development

Testing
- Design testable system
- Test what you fly
- Test rigorously, at multiple levels of integration, including right before service
- Highly efficient test infrastructure
  - 3D printing: Design–Build–Test

Proposed Solution Using the Best Available SE
SpaceX: Learning through Experience

SpaceX learns through experience rather than attempting to anticipate all possible system interactions

- Traditional Developments Use Single Cycle to Product—This Mandates Heavy Systems Engineering to Protect the Design-Build-Test Investment

- Trial and error
- Design-build-test at low cost
  - Fast prototyping
  - Enabled by colocation, vertical integration, flat organization

SpaceX relies on rapid design-build test cycles to inform design by experience

Documentation and process becomes more formal as systems move into later cycles
Final qualification, first flight and production

© Space Exploration Technologies Corp.

Proposed Solution Using the Best Available SE

SpaceX: Culture

Traditional Department of Defense Contractor

- 95% of time dedicated to bureaucracy
  - Interface Control Documents (ICDs)
  - Lengthy meetings
  - Contracts renegotiation
  - Requirements allocation
- 5% of time dedicated to engineering

SpaceX

- Engineering replaces bureaucracy
- 100% of time dedicated to engineering & optimization
- Learn by experience
- Small staff = Communication
- Responsibility, Accountability, Authority (RAA): Responsible Engineer

Proposed Solution Using the Best Available SE

Lean Enablers

Lean Thinking

- Elimination of waste
- Promotion of value

Lean Enablers

- Best practices of Lean Thinking
- The majority of the 326 Lean Enablers for Managing Engineering Programs could be applied to this case study and solution
- This is beyond the scope of this presentation
- Therefore, I will discuss a few select enablers that I believe are most relevant to this solution...

Oehmen, J., & Oppenheim, B. (2012)
Proposed Solution Using the Best Available SE

Lean

Large Scale Engineering Programs

- Great technological and innovative potential, great challenges

Challenges in Managing Engineering Programs (Global Hawk)

1. Firefighting – reactive program execution
2. Unstable, unclear and incomplete requirements
3. Insufficient alignment of the enterprise
4. Locally optimized processes that are not integrated across the entire enterprise
5. Unclear roles, responsibilities and accountability
6. Mismanagement of program culture
7. Insufficient program planning
8. Improper metrics
9. Lack of proactive program risk management
10. Poor program acquisition and contracting practices

Results

- Enormous cost and schedule overruns, massive waste of resources, people, time, money
Proposed Solution Using the Best Available SE

Lean Enablers

1.1. Build a program culture based on respect for people
   - Firefighting, mismanagement of program culture
   - Attack problem, not people

2.6. Actively minimize the bureaucratic, regulatory, and compliance burden on the program and subprojects
   - Enterprise alignment
   - All steps are truly value added
     - Value stream mapping

4.2. Ensure clear responsibility, accountability and authority (RAA) throughout the program from initial requirement definition to final delivery
   - Unclear roles, responsibilities and accountability
   - Accountability throughout program life cycle; upstream activities contribute to downstream issues
Proposed Solution Using the Best Available SE

Lean Enablers

4.5. Pursue collaborative and inclusive decision making that resolves the root causes of issues

- Process integration
- Track changing assumptions
- Clear, streamlined process for critical decision making; promote consensus

6.6. Proactively manage uncertainty and risk to maximize program benefits

- Firefighting, risk management
- Transparent uncertainties
- Risk management results to support critical decisions
- Regularly monitor and review risks
Proposed Solution Using the Best Available SE
Stable, Verifiable Top Level Requirements

Primary Requirements

- Survivability
- Capability
- Cost

<table>
<thead>
<tr>
<th>AIR FORCE’S OPTIONS</th>
<th>U-2 Dragon Lady</th>
<th>Global Hawk UAV</th>
<th>Avenger UAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST</td>
<td>Classified</td>
<td>$65.8 million</td>
<td>$15 million</td>
</tr>
<tr>
<td>PAYLOAD</td>
<td>5,000 pounds</td>
<td>3,000 pounds</td>
<td>6,500 pounds</td>
</tr>
<tr>
<td>SPEED</td>
<td>475 mph</td>
<td>357 mph</td>
<td>460 mph</td>
</tr>
<tr>
<td>ENDURANCE</td>
<td>10 hours</td>
<td>35 hours</td>
<td>20 hours</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>70,000 feet</td>
<td>60,000 feet</td>
<td>53,000 feet</td>
</tr>
</tbody>
</table>

http://www.nationaldefensemagazine.org/archive/2012/May/Pages/U-2, GlobalHawkAdvocatesSquareOffInBudgetBattle.aspx
Proposed Solution Using the Best Available SE Architecting

My interpretation of Department of Defense Architecture Frameworks for UAV Program

- Operational View 1 (OV–1): High-Level Operational Concept Graphic
- OV–2: Operational Node Connectivity Description
- OV–3: Operational Resource Flow Matrix
- OV–4: Organizational Relationships Chart
- Systems View 1 (SV–1): Systems Interface Description

Proposed Solution Using the Best Available SE Architecting

OV-1: High-Level Operational Concept Graphic

- Mission
- Operations
- Players
- Scope

UAV

- Air Vehicle
- Sensors
- Communication Systems

Navy Broad Area Maritime Surveillance (BAMS) UAV
http://defence.pk/threads/u-s-unmanned-aerial-systems.261495/
Proposed Solution Using the Best Available SE Architecting

OV-2: Operational Node Connectivity Diagram
- Operational concepts
- Capability requirements
- Resources & activities

UAV
- Nodes:
  - Components
  - Organizations
- Needlines:
  - Information: threat, position, system status, weather

Proposed Solution Using the Best Available SE Architecting

OV-3: Operational Resource Flow Matrix

- Resource transfers required for operational activity
- Nature of information (what is transmitted)
- Nature of transfer (to and from whom the information is transmitted)

<table>
<thead>
<tr>
<th>Needline</th>
<th>Information Exchanged</th>
<th>Nature of Information</th>
<th>Producer</th>
<th>Consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AV Position</td>
<td>Coordinates</td>
<td>GPS, AV Sensors</td>
<td>Com satellite, CGS</td>
</tr>
<tr>
<td>B</td>
<td>Target Image</td>
<td>Imaging</td>
<td>EO/IR Sensor</td>
<td>Com satellite, CGS</td>
</tr>
<tr>
<td>C</td>
<td>Weather Image</td>
<td>Imaging</td>
<td>EO/IR Sensor</td>
<td>CGS</td>
</tr>
<tr>
<td>D</td>
<td>Threat Detection</td>
<td>Imaging</td>
<td>EO/IR Sensor</td>
<td>Com satellite, CGS</td>
</tr>
<tr>
<td>E</td>
<td>Fuel status</td>
<td>Lbs</td>
<td>AV Software</td>
<td>CGS</td>
</tr>
</tbody>
</table>
Proposed Solution Using the Best Available SE Architecting

OV-4: Organizational Relationships

Chart

- Role-based
  - Command structure
  - Human roles
- Actual
  - Identify stakeholders
  - Relationships between organizations

UAV

- Role-based
  - Flat structure (like SpaceX)
- Actual
  - Minimal subcontractors, minimal users
Proposed Solution Using the Best Available SE Architecting

SV-1: Systems Interface Description

- Interaction between systems
- Subsystems

UAV

- AV subsystems
- Surface component subsystems
- Who communicates with whom

Proposed Solution Using the Best Available SE Ethics

International Council on Systems Engineering (INCOSE) Code of Ethics

- Fundamental Principles
  - Honest and impartial
  - Highest level of integrity

- Fundamental Duties to Society and Public Infrastructure
  - Guard the public interest
  - Accept responsibility for actions; be open to ethical scrutiny
  - Manage risk using knowledge granted by the “system viewpoint” and understanding systemic interfaces

- Rules of Practice
  - Treat all constituents fairly
  - Provide diligent and competent services to the best of your ability

http://www.incose.org/about/leadershiporganization/codeofethics
Proposed Solution Using the Best Available SE

Ethics
Require Defense Contract Audit Agency (DCAA) audits
- Honest and impartial
- Highest level of integrity
- Accept responsibility for actions; be open to ethical scrutiny

No more cost-plus
- Guard the public interest

Mandatory Government involvement in critical reviews
- Accept responsibility for actions
- Manage risk, understand systemic interfaces

http://www.acqnotes.com/acqnote/tasks/major-reviews-overview
Proposed Solution Using the Best Available SE
Improved UAV Pilot Employment Practices

- Adequate mental health counseling
  - Must be delivered in a timely manner
  - Improve or avoid U.S. Department of Veterans Affairs
- Adequate pay
- Reasonable schedule, adequate time off

Proposed Solution Using the Best Available SE
Risk Management

Identification
- Identify problems early (easier to mitigate)
- Don’t kick the can down the road (test & operation phases = expensive fixes)
- Risk categories
  - Reliability, Safety, Cost, Schedule
  - Lean: Cultural acceptance

Analysis
- Likelihood
- Impact

Mitigation Planning
- Approach unfavorable consequence
- What, When, Who, How Much
Proposed Solution Using the Best Available SE

Risk Management

1. Contractor rejects Lean/SpaceX approach
2. Government rejects Lean/SpaceX approach

<table>
<thead>
<tr>
<th>Level</th>
<th>Likelihood</th>
<th>Probability of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not Likely</td>
<td>10%</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>30%</td>
</tr>
<tr>
<td>3</td>
<td>Likely</td>
<td>50%</td>
</tr>
<tr>
<td>4</td>
<td>Highly Likely</td>
<td>70%</td>
</tr>
<tr>
<td>5</td>
<td>Near Certainty</td>
<td>90%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimal or no consequence</td>
</tr>
<tr>
<td>2</td>
<td>Minor reduction in performance</td>
</tr>
<tr>
<td>3</td>
<td>Moderate reduction in performance</td>
</tr>
<tr>
<td>4</td>
<td>Significant degradation in performance</td>
</tr>
<tr>
<td>5</td>
<td>Jeopardize program success</td>
</tr>
</tbody>
</table>
### Proposed Solution Using the Best Available SE Risk Management

**Before Risk Mitigation**

<table>
<thead>
<tr>
<th>Risk Identifier</th>
<th>Risk</th>
<th>Likelihood</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Contractor rejects Lean</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>#2</td>
<td>Government rejects Lean</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**After Risk Mitigation**

<table>
<thead>
<tr>
<th>Risk Identifier</th>
<th>Risk</th>
<th>Likelihood</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Contractor rejects Lean</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>#2</td>
<td>Government rejects Lean</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Color Coding for Likelihood and Impact**

- **Likelihood:**
  - Green: 1
  - Yellow: 2
  - Orange: 3
  - Red: 4
  - Pink: 5

- **Impact:**
  - Yellow: 1
  - Orange: 2
  - Red: 3
  - Pink: 4
  - Purple: 5
Proposed Solution Using the Best Available SE Risk Management

Risk Mitigation Options
- Avoid risk eliminating root cause
- Control cause or consequence
- Continue on with risk unresolved

Solution
- Eliminate root cause: Persuade government to work exclusively with organizations that practice Lean (like SpaceX)

How? Radical solution...
- Create short, concise video about massive waste in DoD projects (like Global Hawk)
  - Include Lean proposals and comparison with SpaceX practices
- Use Social Media to share video with millions of users
- Include instructions for contacting Secretary of Defense, Congress to demand change
Proposed Solution Using the Best Available SE
Risk Management

If persuasion is not successful...

- Call Musk and ask for help

Proposed Solution Using the Best Available SE

Summary

- Lean SpaceX model
  - High risk in DoD environment, highly unlikely to be accepted
  - Many government & private organizations and individuals are content with current bureaucratic practices
  - High resistance to change
  - SpaceX method must be considered by those interested in efficiency and change
Conclusion

- Global Hawk program was horribly executed
- Huge failures from Government and contractor
- Program had great potential and capabilities were needed by DoD
- Time & money wasted

- I have presented best possible procedures and principles for improved program execution
- Unfortunately, it is highly unlikely that the proposed solution would be received and adopted by Government or contractors
Lessons Learned

- Lean is an enormous improvement to traditional Systems Engineering practices
- Many defense contractors suffer from sickness of wasteful culture
- Change must be internal and prevalent at all levels of the organization
- I will take what I have learned and see for myself...
Sources

Thank you.