Unmanned Aircraft System (UAS) vs. Manned Aircraft System (MAS): A Military Aircraft Study

Ignacio Serrano

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Dr. Karen Miller
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Should Unmanned Aircraft take over the role for a traditional Manned Aircraft for certain missions?

- The project’s goal is to show how systems engineering (SE) can provide a basis for this decision.

- This unique project will enable a greater understanding of SE by performing a top down trade study comparison of the U-2 vs. Global Hawk from a systems engineering standpoint.

- The above two systems were chosen as they are the only current situation in which a UAS and MAS performs the same mission.
Outline of SE Processes

Project Goal – to show how the following SE processes can contribute to future decision-making of unmanned vs. manned aircraft

- Ethical Issues
- Mission Objective and Stakeholders
- Architectural Views
- Requirements Analysis and Allocation
- Technology Readiness Assessments & Designed Solutions
- Project Cost and Schedule Monitoring
- Lean and Quality
- Integration, Verification, and Validation
- System Trade Study
- Lifecycle Management
- Conclusion and Lessons Learned
ISR Mission Specific Ethical Issues

Many ethical issues about ISR aircraft are of concern:

- Violation of privacy rights
  - High altitude reconnaissance is generally accepted by the public as it promotes safety for U.S. population and military personnel.
  - Reconnaissance is typically over less densely populated areas.
- However, low altitude reconnaissance by remotely piloted aircraft (a.k.a Drones) do not have general public acceptance as the aircraft can be visibly seen following or watching people. The concern is that most drones are used for monetary purposes of gathering and selling information or the likeness of a person.
 Autonomous Aircraft Ethical Issues

- Use of autonomous aircraft raises other ethical concerns:
  - Public may not accept a computer making decisions that affects people's lives and want a human in the loop to make the final decisions.
  - People can accept a person making a judgment call based on information presented, applying human emotion.
  - Therefore, limiting UAV autonomy to gathering, processing, and disseminating scenarios for action.
- SE has the responsibility for increased autonomy requirements flow down.
- SE can work with the software engineers to design in a code of ethics for a rule-based approach for this level of increased autonomy.
Mission Objective
Provide High Altitude near real-time data collection and transmission of imagery, and signals intelligence anywhere in the world, in all weather conditions, day or night.

System Stakeholders
- Ground Troops
- Air Force Squadrons
- Pilots
- Ground Support Crew
- Mission Planners
- Decision Makers
- Intelligence Analysts
- Mission Control Crew
- Satellite Operators
- Contractors
High Altitude ISR Mission
High Level Operational Concept View (OV-1)
Operational Resource Flow Description (OV-2)

Node A: Mission Planning
- Need Mission Reqs/Targets
- Need Flight Path Program

Activity 1: Plan Mission

Node B: Launch & Recovery
- Need Health System Status
- Need to Command & Control Aircraft

Activity 2: Launch and Recover Aircraft

Node C: Aircraft Command & Control
- Need Command to Transmit
- Need to Command & Control Payload

Activity 3: Send and Receive Commands
Activity 4: Monitor System Health
Activity 5: Control Aircraft & Payloads

Node D: Gather Intelligence
- Need Intel Data
- Need to Command & Control Payload

Activity 6: Gather Image, Signals/Communications Data

Node E: Transmit Intelligence
- Need Data to Process
- Need Data to Transmit

Activity 7: Transmit Data to Ground

Node F: Process & Disseminate Intelligence Data
- Need Processed Data to Transmit
- Need Processed Data to Make Decisions

Activity 8: Process Data for dissemination to Users

External Conflicts Mission Needs
- Need Processed Data to Make Decisions
- Need Mission Reqs/Targets
Top Level ISR Aircraft Mission Requirements

- The system shall perform High Altitude Intelligence gathering
- The system shall perform Imagery Intelligence gathering
- The system shall perform Communications Intelligence
- The system shall perform Electronics Intelligence
- The system shall perform in all weather conditions, day & night
- The system shall transmit data back to ground stations in near real time
- The system shall perform continuous surveillance
  - U-2: Medium endurance = 10-12 hours on patrol
  - Global Hawk: Long Endurance > 24 hours on patrol
Requirements Allocation to Aircraft Subsystems

Systems Interface Description (SV-1)

- Aircraft
  - System
    - Subsystems
      - Airframe
      - Flight & Navigational
        - C2
      - Comms
      - Ground Segment
      - Sensor Payloads

Subsystems

Elements/Components

- Wing
- Center Fuselage/Center Body
- Tail (Control Surfaces)
- Engine (Propulsion)
- Electrical Power
- Environmental Control System
- Fuel System
- Landing Gear
- Nose Gear
- Flight Computer
- Flight Software
- GPS
- Inertial Sensors
- Magnetic Compasses
- Air data sensors
- Avionics
- Auto Pilot
- Data Bus
- Wiring Harnesses
- Cockpit Instrumentation
- Antennas
- Modems
- Amplifiers
- Transmitters/Transponders
- Data links (Airborne/SATCOM)
- Launch/Recovery
- Ground support Equipment
- Mission Planning/Control
- Health Status Monitoring
- Ground Crew
- Antenna
- Ground Control Computer
- STE
- Data Links
- Drive Motors
- Gimbals
- IR Sensor
- Electro-Optical Sensor
- SAR
- SIGINT/ASIP Sensor
- HR Camera

Superscripts tie back to Activity Nodes on OV-2
U-2 Technology Readiness Assessment: Design Alternatives

- Instead of a new design chose a proven XF-104 fuselage (>TRL-6).
- Designed a new long high-aspect, lower thickness ratio wing (at Least TRL-5).
- Camera A was an improved USAF K-38 camera requiring a new Mylar based Kodak film (at least TRL-5).
- Camera B started as a concept that later developed a 36-inch focal length camera prototype (at least TRL-3).
- Signals Intel payload was to be miniaturized version of current existing design (at least TRL-4).

TRL levels determined by using NASA TRL Calculator
Global Hawk Technology Readiness Assessment: Design Considerations

- Global Hawk was DARPA Initiative to demonstrate the technology of an unmanned High Altitude Long Endurance (HALE) system prior to Engineering, Manufacturing and Development.

- USAF needed to prove that the entire system, in particular the software was > TRL6.

- Most important subsystems to interface with was the technology needed to launch, control and recover the aircraft from the ground stations.

- Global Hawk Imagery and Signals intelligence sensor technologies were already developed and needed to be modified for the use of the Global Hawk (> TRL-7)
Comparison of Design Solutions

<table>
<thead>
<tr>
<th>U-2</th>
<th>Global Hawk</th>
</tr>
</thead>
<tbody>
<tr>
<td>105 ft. (32 m)</td>
<td>130.9 ft. (40 m)</td>
</tr>
<tr>
<td>63 ft. (19 m)</td>
<td>47.6 ft. (14.5 m)</td>
</tr>
</tbody>
</table>

**U-2**
- **Range**: 7,000 mi. (11,265 km) plus
- **Approx. speed**: 410 mph (660 kph) plus
- **Ceiling**: 70,000 ft. (21,336 m) plus
- **Payload**: 5,000 lb. (2,268 kg)
- **Endurance**: 10-12 hours
- **Cost per plane**: Classified
- **First flight**: 1955

**Global Hawk**
- **10,000 mi. (16,093 km)**
- **350 mph (563 kph)**
- **60,000 ft. (18,280 m)**
- **3,000 lb. (1,361 kg)**
- **28 hours plus**
- **$176 million, estimated**

Images from:
U-2 Designed Payload Solutions

Advanced Synthetic Aperture Radar for all weather, day/night, imagery

Electro-Optical camera for special signature imagery

Optical Bar Panoramic Film Camera

High resolution Film camera for targeting and battle damage

Comm. & Electronic intelligence payloads

Dorsal Faring with antennas to transmit intelligence data

Image From: http://www.spyflight.co.uk/images/JPGS%5CLockheed%20U-2%5Cu-2r%20equip%202.jpg
Enhanced Integrated Sensor Suite (EISS) includes all weather synthetic aperture radar for ground moving targets, high resolution electro-optical digital camera, and a third-generation infrared sensor.

**SAR:** The synthetic aperture radar (SAR) gimbaled antenna can scan from either side of the aircraft to obtain one-foot resolution spot images and three-foot resolution images in wide area search mode.

**EO/IR:** Electro-optical (EO) and infrared (IR) sensors operate through shared reflective optics.

Images From:
https://aerospaceblog.files.wordpress.com/2010/08/35661.jpg
Northrop Grumman 2012 Brochure Q4-HALE Enterprise
Currently both programs have a project plan outlining detailed tasks with both cost and schedule.

**U-2**

- Developed in the 1950’s without these plans, and monthly progress reports were kept short with little government oversight.
- Initial U-2 completed under budget by $2 million within 17 months due to Skunk Works environment.

**Global Hawk**

- Used earned value and risk management principles to monitor cost and schedule but it initially overran cost and schedule with its unrealistic unit fly away price of $10 million.
- SE is needed in upfront planning to help understand and flow down the requirements for all detail tasks, clearly defining the SOW to allow for the most accurate system cost and schedule estimates.
Global Hawk was a "Lean Now" prototype program from the Lean Aerospace's Initiative utilizing 35 Lean events with the following major accomplishments:

<table>
<thead>
<tr>
<th>Supplier Focused Events</th>
<th>Cycle Time Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Raytheon</td>
<td>• Alpha Contracting</td>
</tr>
<tr>
<td>• $49M Savings for ISS Deliveries</td>
<td>• 28% Initial Reduction of 99 M-days</td>
</tr>
<tr>
<td>• Increased Units from 3 to 6 per Year</td>
<td>• Change Process</td>
</tr>
<tr>
<td>• L-3 Communications</td>
<td>• 63% Reduction from 95 to 35 Days</td>
</tr>
<tr>
<td>• $33.8M Savings for AICS/GICS</td>
<td>• Production Delivery Cycle</td>
</tr>
<tr>
<td>Deliveries</td>
<td>• 38% Reduction per Schedule BL-10</td>
</tr>
<tr>
<td>• Aurora</td>
<td>• Supplier Delivery Reductions Documented</td>
</tr>
<tr>
<td>• Aft Fuselage 42 Day Cycle Time Gain</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td></td>
</tr>
</tbody>
</table>

**Enterprise Value Stream Mapping**

- Completed Tier I Enterprise VSM – Feb. 03
- Updated Tier II Production VSM – May 03
- Supplier VSM's for Raytheon, L-3, Aurora
- Eng. Development VSM – Aug. 03
- Process Level Value Stream Maps
  - Alpha Contracting
  - Change Process

**Significant Goals Achieved**

- Completed 10 Major Events
- Enterprise Collaboration SPO/NG/Suppliers
- Continuous Improvement VSM’s In Place
- 97% Award Fee Customer Rating for Affordability Supported by Lean Now Events
- Additional $5M Opportunity Savings for Identified Production Productivity Initiatives
- Joint SPO / NG LESAT Completed
Kelly Johnson was a dynamic, strong leader, who enabled his small quickly moving team to make their own decisions without the bureaucracy of the larger corporation

- The following lean enablers could be applied to the Skunk Works Environment:
  - 1.2.1 Create a shared vision which draws out and inspires the best in people
  - 1.3.3 Allow certain amount of “failure” in a controlled environment at lower levels, so people can take risk and grow by experience
  - 4.7 Use efficient and effective communication and coordination with the program team
  - 4.7.5 Promote a flat organization to simple and speed up communication
Quality Consideration Comparisons

U-2

- U-2 was manufactured by a small team of engineers working with technicians; therefore quality was built in, allowing quick remediation of problems.
- U-2 reused many proven designs to reduce variability.

Global Hawk

- Global Hawk stressed reliability primarily in their propulsion, power, and flight control electronics. SE ensured proper flow down to the various subsystems.
- SE and customer required robust quality which led to heavy qualification testing and final inspection.
- Global Hawk like most current aircraft programs uses on-going quality management systems to indicate any trends in quality. If negative trends persist they implement a root cause corrective action plan to resolve quality problems.
Integration, Verification, and Validation

- Global Hawk and U-2 used traditional aircraft integration, verification and validation techniques:
  - Ground integration of subsystems for interface and functional checkout.
  - Verification through model analysis and through functional and qualification testing:
    - Static and Fatigue testing
    - Environmental Stress Screening
    - EMI/EMC testing
  - Flight Testing to verify and validate systems meet operating requirements.
  - Military Scenarios or Utility demonstrations to validate right system was built.

- Global Hawk and later versions of the U-2 used System Integration Laboratories (SIL) extensively to integrate new subsystems with the software in a lab to verify and validate prior to flight test.

- In comparison to the U-2 the Global Hawk had extensive software validation in the SIL to ensure autonomous flight. In addition, the ground support system validation for command and control of the aircraft and payloads.
Military Utility Demonstrations for Validation of Systems

- Air Force Operational Test & Evaluation performs Military Utility Assessments using real operational scenarios to validate that the system and its payloads performed mission critical needs.
- Validated military utility for Imagery and Signals payload sensors using Air Force intelligence analysts to evaluate operational intelligence value per the following Essential Elements of Information (EEI) rating scale:

<table>
<thead>
<tr>
<th>FOM Score</th>
<th>FOM Definitions</th>
<th>Operational Intelligence Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No mission EEI content could be resolved</td>
<td>No Intelligence Value</td>
</tr>
<tr>
<td>1</td>
<td>Minimal (≤ 50%) mission EEI content could be resolved</td>
<td>Minimal Intelligence Value</td>
</tr>
<tr>
<td>2</td>
<td>Most (51-99%) mission EEI content could be resolved</td>
<td>High Intelligence Value</td>
</tr>
<tr>
<td>3</td>
<td>All (100%) mission EEI content could be resolved</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3 from Pentagon OT&E RQ-4B 2011 Report
Paraphrasing Maj. Gen Shanahan, head of Air Force’s ISR comments “ISR must be focused on Anti-Access/Area Denial (A2/AD), with emphasis for proactive processing, exploitation and dissemination of intelligence.”

In conjunction with Maj. Gen Shanahan comments above and the FY2013 DoD Unmanned Systems Integrated Roadmap for ISR aircraft developed the following unique set of future requirements:

- The system shall survive in enemy areas of denial
- The system shall have cyber resilient communications
- The system shall be modular and interoperable
- The system shall automate data exploitation & dissemination
Technology to Improve Air-to-Ground Communications: 100 Gb/s RF Backbone DARPA Initiative

- ISR aircraft will have a fiber-optics-equivalent RF backbone by developing a point-to-point link using modulation & spatial multiplexing.
- This unique technology currently at TRL-2 (concept formulation) and moving to proof of concept stage.

<table>
<thead>
<tr>
<th>Phase 1: System Design</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
<th>FY16</th>
<th>FY17</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA-1 mmWave High-Order Modulation</td>
<td>Multiple Performers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA-2 mmWave Spatial Multiplexing</td>
<td>Multiple Performers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA-3 Related Experimental Studies</td>
<td>Multiple Performers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase 2: Prototype Integration</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype Build</td>
<td>Pointing, Acquisition and Tracking</td>
<td>Mountain-to-Ground Demonstration</td>
<td>1 or 2 Performers</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase 3: System Demonstration</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Upgrade</td>
<td>Integration onto Platform</td>
<td>Two Flight Tests (Test-fix-test)</td>
<td>1 or 2 Performers</td>
<td></td>
</tr>
</tbody>
</table>

Will have the greatest Impact to ISR Missions

# System Trade Study for Optimal Solution based on Weighted Criteria from Requirements (1-Lowest, 5-Highest)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>U-2S</th>
<th>Weighted Total</th>
<th>Global Hawk</th>
<th>Weighted Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Altitude-Wide Area Coverage</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Provide Precise Imagery Intel</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Stable Image Sensors</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Thermal Emission Imagery</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Classify Ground Targets Special Signatures</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Total Payload Capacity</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Track Ground Moving Targets</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Intercept Communications Intel</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Process and download Comm. Intel</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Collect Electronic Intel</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Process and download Elec. Intel</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Fly in all weather conditions</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Track ground targets through cloud</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Persistence Surveillance</td>
<td>5</td>
<td>3</td>
<td>15</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Full motion video</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Provide Real Time Data</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Situational Awareness: Sense and Avoid</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Aircraft Survivability</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

**Current Requirements Criteria Subtotal** 325 302

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>U-2S</th>
<th>Weighted Total</th>
<th>Global Hawk</th>
<th>Weighted Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly in Contested Airspace</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>More resilient communications</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Greater processing automation and performance</td>
<td>5</td>
<td>3</td>
<td>15</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Increased Modularity</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Increased Interoperability</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Perform in a family of systems</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Insertion of new sensor &amp; SIGINT tech</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>

**Future Requirements Criteria Subtotal** 95 132

**Total** 420 434
70% of all life cycle costs are in the operation and support (O&S) phases. Therefore, SE must carefully develop & flow down requirements for O&S.

- Global Hawk & U-2 are both in the O&S phases.
- U-2 majority of O&S is based around the Pilot's environmental control system (i.e. pressurized suit & chambers), pilot training, and recurring operating cost for maintenance.
- Global Hawk majority of O&S cost is for the MCE, LRE systems and crew.
- SE must drive reliability, maintainability in addition to Commercial Off the Shelf requirements.
Operation and Support Break Even Cost Analysis

➢ One of the Key Performance Parameters for judging Lifecycle Cost is “Cost Per Flight Hour”
   • U-2 $32,000 per flight hour\(^1\)
   • Global Hawk $14,876 per flight hour\(^2\)

➢ U-2 acquisition cost is complete, so lifecycle cost must take into account the acquisition cost of Global Hawk.
   ➢ As an example, 2014 Contract award for Republic of Korea for 4 Global Hawks = $657,400,000\(^3\) which is $164,350,000 per aircraft.

➢ $17,124 is the difference per flight hour, so it would take 9,597 hours for the Global Hawk to break even with the U-2.
   ➢ In other words, hypothetically if one Global Hawk flew three 24hr missions per week (72 hours per week) it would take 2.5 years for it to break even with the U-2.

\(^1\)Why the Air Force wants to keep Global Hawks and retire U-2s”. 2014 March 5
\(^3\) "US Approves Sale of Global Hawks to South Korea” 17 December 2014. Stars and Stripes.
Conclusions

- The most optimal solution for the current and future needs for the lowest operational cost is the Global Hawk.
- Autonomous UAVs to be developed to replace traditional manned aircraft will cost the same for development and production.
- To make UAVs more economical SE must drive requirements throughout entire lifecycle to reduce O&S costs.
- Trade-studies must be performed to understand the overall implication of how the proposed unmanned system will perform in comparison to its manned counterpart (e.g. long endurance, speed, survivability, payload complexities, cost, etc...).
Lessons Learned

- Need to think of the future demands and needs of the system in conjunction with the overall lifecycle costs for true affordability.
- Clear direction is needed to alleviate public concerns about unmanned aircraft.
- This unique project can be used as a guide for future trade studies comparing other missions and subsystems.
- A top down systems engineering approach must be used to make the best decisions.
Questions?