Utility of Automation Function
Transparency and Usability in Supervisory Control

Dave Kaber
“Unmanned” Systems Research

- Recently completed multi-year project with NASA on unmanned systems interface design and human workload (NNX16AB23A)

- Primary human-automation interaction (HAI) research need in “unmanned” systems is to manage operator workload in monitoring and control of automation...

- Specific research tasks to address need:
  - Identify workload “drivers”
  - Identify workload “mediators”
  - Develop model of operator workload
  - Develop systematic and objective interface usability analysis tool
    - Accounting for range of unmanned system interface design principles
  - Experimental analysis of how interface design deviations from standards/guidelines may increase workload, reduce knowledge of system states and performance, etc.

Focus of present study
Progress on Workload Modeling

- Developed **new conceptual framework of cognitive workload in unmanned systems**:  
  - Identified classes of workload drivers  
  - Identified mitigators in complex systems (e.g., automation, interfaces, teamwork)  
  - Considered “overload”, “underload” and mode transition events for classifying drivers and controls.

- Surveyed existing UAV, UUV and UGV technologies to domain constraints on system operation and associated workload issues

<table>
<thead>
<tr>
<th>Workload Drivers Range</th>
<th>UAV</th>
<th>UGV</th>
<th>UUV</th>
<th>Workload Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Clear visibility / Visual Meteorological Conditions Day light Patchy fog, clouds</td>
<td>Clear visibility, No precipitation, Day light, absence of shadows, obstructions Fog glare, shadows, sunset/sunrise</td>
<td>Clear water Shallow water</td>
<td>Negligible</td>
</tr>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Instrument Meteorological Conditions Fog/cloud, Darkness, Particulates, rain, hail,</td>
<td>Fog, Darkness, Brightness, Dust / particulates, rain, hail, Positive obstacles (obstruct line of sight - Buildings, boulders, vegetation) Negative Obstacles (holes, ditches, cliffs, canyons, Graded/sloped terrain,</td>
<td>Darkness, Turbidity</td>
<td>Temporary spike</td>
</tr>
<tr>
<td>Complexity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>High altitude, Over water / Oceanic Unpopulated (air</td>
<td>Arid, barren, desert terrain Stable surface</td>
<td>Submerged, Oceanic</td>
<td>Increase</td>
</tr>
</tbody>
</table>

*Created taxonomy of drivers and mediators with projection of impacts on performance*
Progress on Interface Analysis Tool

- Developed unmanned aerial vehicle (UAV) interface evaluation tool

  (Zhang et al., 2016; IEEE SMC Conf.)

- Conducted survey of UAV usability analysis literature (e.g., Fuchs et al., 2014; Fong & Thorpe, 2001).

- Identified existing ergonomics guidelines for supervisory control interfaces (GEDIS; Ponsa et al., 2007; Lorite et al., 2013).

- Conducted comprehensive survey of existing guidelines relevant to UAV systems (HFDS; NASA-STD-3000; NORSOK; NUREG 0700; UAS_GCS_HMI).

- Integrated supervisory control and UAV interface guidelines in new enhanced usability analysis method (see next slide):
  - Tool applied to interface prototypes to identify deviation of functional and usability features from “optimal” design, based on guidelines/standards.
New UAV Interface Evaluation (“M-GEDIS”) Tool

- Nine interface evaluation worksheets (addressing major design features)
- Analyst identifies conformance / non-conformance with criteria.
  - ~300 criteria requiring novice ~2.5 hrs. to apply
  - View videos of operator use of interfaces.
- Workbook calculates percentage of “non-conformance” across all functional and usability features of interface.
- Thresholds for design acceptance or remediation identified in literature.
  - e.g., Lorite et al. (2013) → 80% of supervisory control display guidelines met = no further revision.
Outstanding Issues with Interface Evaluation Tool

- Some existing design guidelines conflict with each other (e.g., which controls should be located in primary visual field)
- No detailed standardized process for translation of design guidelines to actual interface features
- Guidelines are organized according to major design features of systems (e.g., “maps and navigation”, “alarms”) but not according to human performance issues / criteria:
  - Promote vigilance and system state awareness
  - Reduce workload
  - Promote task processing speed and accuracy (Which guidelines should be applied and when?)
- Little data exists on relative impact of specific design concepts / guidelines on performance and operator workload
  - Which guidelines are most impactful for certain human responses?
Objectives of Present Study

(Extension of work for NASA.)

1. Identify interface design concept targeted at human performance issues…with associated design principles
2. Translate specific design principles to actual unmanned system interface design features
3. Assess relative utility of application of design principles on human performance outcomes in supervisory control of “unmanned” system:
   – Operator workload
   – Operator dynamic system knowledge
   – Operator task performance
4. Identify which design principles should be used, and when, for greatest impact on workload, etc.
Concept of “Automation Transparency”

- Literature search on UAV interface design guidelines revealed design concept ("transparency"; Chen et al., 2014) for ameliorating “pitfalls” of automation in complex human systems...
  - “Clumsy automation” design increasing monitoring workload beyond nominal task workload (Wiener & Currie, 1980)
  - “Strong and silent automation” absent of feedback and leading to mode awareness issues for operators (Sarter & Woods, 1994)

- Definition of automation transparency...
  - Quality of interface to afford users with comprehension of automation states, current performance information, “reasoning”, and intentions / future plans (Chen et al., 2014)
Some General Principles of Transparency

- Degani et al. (1999) – automation should alert operators of different modes of operation and “decisions” in real-time
- Lyons (2013) – automation should provide rationales for courses of action; human should know why system is doing what
- DeVisser et al. (2014) – automation interface display cues should instill operator trust in system and support appropriate trust calibration by…
  - e.g., presenting uncertainty information on system states and highlighting automation errors (Masalonis & Parasuraman, 2003)

- Observation:
  - Design principles organized around specific construct (transparency) and directed at specific human performance issues (loss of “situation awareness” (SA), vigilance decrements, miscalibration of trust)
Principles Translated to Design Guidelines

• Kilgore & Voshell (2014):
  – Ensure perceptual accessibility of task critical info
    • Present key system variables; use visual coding of map features
  – Present information in context; e.g., system parameter values should be presented against frame/range of expected or nominal values
  – Manage user attention by highlighting critical system process info (and de-emphasize less critical info)

• Selkowitz et al. (2017):
  – Use metaphor-based presentation of info (similar to info in context)
  – Use integrated displays – multiple pieces of info in single graphic (e.g., icon, glyph)
  – Use pre-attentive cueing of stimuli - shading, color, or size coding to promote effortless and quick processing
    (Their experiments revealed features to improve SA and trust with no additional workload “cost”.)
Present Study Method

1. Translated transparency design guidelines to specific UAV supervisory control interface feature manipulations

2. Prototyped multiple interfaces representing different degrees of conformance with concept of transparency

3. Conducted UAV control experiment to assess utility of concept and design guidelines for supporting operator performance, system awareness, and workload.

   - Simulation study similar to mission rehearsal
   - Surveillance operation with common vehicle control tasks:
     - Object coordinate identification
     - Target distance estimation
     - Monitoring system status parameters
     - Prioritizing in-flight warnings and alarms
     - Resolving warnings and alarms
   - Operators executed “scheme of maneuver” (SOM; sequence of actions) with different interface designs and task event rates
Interface is “Automation Presentation”

- Started with ArduPilot Mission Planner (MP) interface – commercially available UAV ground control station (GCS) interface
- Designed and prototyped three variations on MP
- Three human factors experts evaluated each design for conformance with Molich & Nielsen’s (1991) usability heuristics
  - Preliminary validation of transparency manipulations – Application of transparency principles led to differences in usability.

**Baseline Interface**
- Represented current GCS technology
- Maintained most original MP features
- Some automation interface features added for certain control tasks
- Usability heuristics: 67% satisfaction

**Degraded Interface**
- Variation on baseline interface
- Removed some automation interface features relevant to task performance
- Usability heuristics: 22% satisfaction

**Enhanced Interface**
- Variation on baseline interface
- Translated and implemented principles of automation transparency (more later)
- Usability heuristics: 100% satisfaction
Common Components

- PFD, ND (map), flight parameter indicators, MCDU (flight path planning), alarm management controls,

13
Baseline vs. Enhanced

[Some differences or how to promote transparency]

- Added features to reveal automation capabilities
- Added pre-attentive cueing of stimuli
- Aimed at facilitating task performance and improving operator system and mission awareness

<table>
<thead>
<tr>
<th>UAV Control Task</th>
<th>Interface Component</th>
<th>Transparency Principle</th>
<th>Baseline Interface</th>
<th>Enhanced Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine coordinates; Estimate distance</td>
<td>Target location</td>
<td>Automation assistance</td>
<td>Guidelines and major coordinate markings presented on navigation display. No direct target interaction through interface.</td>
<td>Guidelines and major coordinate markings presented. “Coordinate” and “Distance” shortcut tools available to assist user.</td>
</tr>
<tr>
<td>Determine mission completion status</td>
<td>Waypoint identification</td>
<td>Pre-attentive cueing</td>
<td>Waypoints are numbered. Traditional waypoint-style icons are used for reveal against display background.</td>
<td>Waypoints are numbered. Traditional waypoint-style icons are used for reveal against display background. Waypoint color changes after UAV flies past.</td>
</tr>
</tbody>
</table>

Baseline Interface

Enhanced Interface

Coordinates and Distance tool

- Color coded WPs (as progress indicators)
- Automatic distance estimation (LP – WP24)

Outlined AOI

Shaded AOI

Automatic coordinates reading
Promoting Transparency

<table>
<thead>
<tr>
<th>UAV Control Task</th>
<th>Interface Component</th>
<th>Transparency Principle</th>
<th>Baseline Interface</th>
<th>Enhanced Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locate menu options</td>
<td>Control Action selection</td>
<td>Information in context</td>
<td>Menu items are presented in single list, grouped by function.</td>
<td>Menu items are presented in hierarchical sub-menu structure for each UAV function.</td>
</tr>
</tbody>
</table>

Features support effective use of automation
Promoting Transparency

- **Baseline interface** – operators must compare system state with nominal range and identify deviations.
- **Enhanced** – parameter deviations are automatically highlighted.

### Baseline Interface

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Parameter Value</th>
<th>Normal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Speed (knots)</td>
<td>50.00</td>
<td>[45, 55]</td>
</tr>
<tr>
<td>Dist Traveled (m)</td>
<td>5700</td>
<td></td>
</tr>
<tr>
<td>Ground Course (deg)</td>
<td>155</td>
<td>[40, 90]</td>
</tr>
<tr>
<td>Altitude (ft)</td>
<td>35</td>
<td>[0, 100]</td>
</tr>
<tr>
<td>Bat Remaining (%)</td>
<td>61</td>
<td>[20, 100]</td>
</tr>
<tr>
<td>Ground Speed (mph)</td>
<td>5.1</td>
<td>[0, 10]</td>
</tr>
</tbody>
</table>

### Enhanced Interface

- System status parameters are displayed along with acceptable parameter ranges. Alert icons appear when parameters exceed acceptable ranges.

### Features

- **Parameter name**
- **Normal range**
- **Parameter value**
- **Automatic detection and warning for abnormal status**

Features reveal automation capabilities for user
Enhanced Interface

UAV Control Task | Interface Component | Transparency Principle | Baseline Interface | Enhanced Interface
--- | --- | --- | --- | ---
Fix alarm; Prioritize alarm | Alarm presentation | Pre-attentive cueing | Messages provide basic information on priority, indicate cause of alarms, and suggest solution. | Messages provide priority information by color-coding, indicate cause of alarms, and highlight suggested solution with color and icon.

Promoting Transparency

- Enhanced interface - automation identifies system alarm/warning (SA-Transparency (T) Level 1; Chen et al., 2014); automation identifies associated system parameter deviation and prioritizes all current warnings (SAT Level 2); automation projects and identifies control solution for operator (SAT Level 3).

Features reveal automation capabilities for user
Degraded vs. Baseline Interface

- Need to also show absence of transparency leads to increases in workload and degradations in awareness and performance.
- Differences were in ND (waypoint and AOI presentation), map action menu layout, system parameter warnings, prioritize alarm display and fix alarm menu.
## Degraded Transparency

- **Removed some automation presentation features**
- **Reduced information context**
- **Reduced visual cueing**
- **Control tasks were made more complex**

### Degraded Interface vs Baseline Interface

<table>
<thead>
<tr>
<th>UAV Control Task</th>
<th>Interface Component</th>
<th>Transparency Principle Violation</th>
<th>Degraded</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count targets</td>
<td>Area of Interest identification</td>
<td>Automated assistance</td>
<td>No display filtering of AOIs available.</td>
<td>A shortcut button provides a patterned-line filter (i.e., dotted margin) to identify AOIs</td>
</tr>
<tr>
<td>Determine coordinates; Estimate distance</td>
<td>Target location</td>
<td>Pre-attentive cueing</td>
<td>No map guidelines on nav display. Users cannot interact with targets in navigation display through interface controls.</td>
<td>Guidelines and major coordinate markings are presented on nav display. No direct target interaction through interface controls.</td>
</tr>
<tr>
<td>Determine mission completion status</td>
<td>Waypoint identification</td>
<td>Pre-attentive cueing and automated assistance</td>
<td>Waypoints not numbered and colored similar to ND background (grey color).</td>
<td>Waypoints are numbered. Traditional waypoint-style icons are used for reveal against display background.</td>
</tr>
</tbody>
</table>

**Degraded Interface**

- **No AOI or gridlines**
- **WPs not numbered or colored**

**Baseline Interface**

- **Colored and numbered WPs**
- **Outlined AOI**
- **Gridlines for assisting visual alignment**

**Removal of features conceals automation capabilities**
Degraded Transparency

- Functional organization of menu items provides context for operator search for options.

<table>
<thead>
<tr>
<th>UAV Control Task</th>
<th>Interface Component</th>
<th>Transparency Principle Violation</th>
<th>Degraded</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locate menu options</td>
<td>Control Action selection</td>
<td>No information context</td>
<td>Menu items are presented in single list in random order</td>
<td>Menu items are presented in single list and grouped by function.</td>
</tr>
</tbody>
</table>

**Degraded Interface**

- Menu items in random order

**Baseline Interface**

- Logical grouped menu items

*Removal of features inhibits effective use of automation.*
Degraded Transparency

- No nominal parameter ranges in degraded interface (requires use of memory)

<table>
<thead>
<tr>
<th>UAV Control Task</th>
<th>Interface Component</th>
<th>Transparency Principle Violation</th>
<th>Degraded</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor system status</td>
<td>System Status Parameter Presentation</td>
<td>No information context</td>
<td>Only system status parameters are displayed.</td>
<td>System status parameters are displayed along with acceptable parameter ranges.</td>
</tr>
</tbody>
</table>

Removal of features conceals automation capabilities
### Degraded Transparency

- **Degraded interface** required operators to recall priorities of various alarms from memory.

- **Baseline** provided basic classification of alarms (alert, warning, advisory).

#### Degraded vs. Baseline Interface

<table>
<thead>
<tr>
<th>UAV Control Task</th>
<th>Interface Component</th>
<th>Transparency Principle Violation</th>
<th>Degraded</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fix alarm; Prioritize alarm</td>
<td>Alarm presentation</td>
<td>Lack of critical information</td>
<td>Alarms only indicate failure state and do not indicate cause. No priority information.</td>
<td>Messages provides basic information on priority, indicate cause of alarms, and solution.</td>
</tr>
</tbody>
</table>

**Removal of features conceals automation capabilities**
Experiment Design

- **Independent variables:**
  - **Interface design** variation – Enhanced (E), baseline (B), degraded (D)
  - **Vehicle speed / event rate** – Fast (F; 5.5 min./trial) and slow (S; 8.5 min.)
    - Fast = 1.5 * slow speed; high demand
  - **Mixed-factor design:**
    - Interface variation = between-subject; speed = within-subject
    - Each participant completed 4 trials with 1 interface
      - 2 vehicle speeds by 2 different mission maps for replications

- **Dependent variables:**
  - Performance – control task time and accuracy (degree of input deviation from truth; e.g., target coordinates, distance to WP)
  - Dynamic Knowledge Query (DKQ) response accuracy
    - Tested operator knowledge of UAV states and mission status
    - Accuracy = # correct responses / total responses
  - Cognitive workload – NASA-TLX (task load Index) overall score
    - Higher rating = Higher workload
Participants and Training

- **48 subjects** (23 female, 25 male) from NC State and surrounding community (Raleigh, NC)
- Age: $24.8 \pm 3.9$
- 20/20 or corrected vision and no color-impairment
- Familiarity with computers but **no prior UAV supervisory control experience** (to prevent “negative transfer” effects in interface use)

- **Training:**
  - **Familiarization with control interface** (i.e., functions and locations of features)
  - **Familiarization with mission scenarios** (flight trajectories, SOMs)
  - **Performed simplified mission** with action commands and knowledge queries
    (Repeated training mission until successful in all tasks and correct answers to all queries.)
  - **Ranked TLX demand components** based on training experience
Testing and Hypotheses

• Trial content:
  – Briefing on mission scenario and scheme of maneuver (by Army captain with experience in writing over 800 SOMs for UAV missions)
  – Action commands presented auditorily (digital audio system)
  – DKQs presented by experimenter
  – Responses to queries and parameter warning callouts recorded by experimenter
  – UAV flew flight path at fixed speed (fast or slow)
  – TLX demand ratings at end of trials
  – 2-min. rest between trials

• Enhanced interface expected to produce:
  – Greatest task accuracy (H1)
  – Shortest task times (H2)
  – Highest dynamic knowledge (H3)
  – Lowest cognitive workload (H4)

• High speed expected to degrade performance, dynamic knowledge and workload (H5)

• Differences among interfaces expected to be greatest under high demand condition (fast speed; H6)
Performance Results

- **Interface design significant for all DVs (task time and accuracy)**
  - Trends generally as hypothesized (H1-2)
  - E & B > D or E > B & D for accuracy and time (for most responses)

- **Vehicle speed / event rate significant for specific tasks:**
  - Distance estimation time (p=0.0157)
  - Fixing alarm time (p=0.0446)
  - Trend was as hypothesized (H5) – worse performance at high speed

- **No interaction effect**
  - Counter to expectation (H5); fast speed was “manageable” for subjects
Dynamic Knowledge Accuracy

- **Example (real-time) queries (no freezes):**
  - Significant effect of interface design with trend as expected (H3)
    - $E > B > D$
  - No effect of speed or interaction; counter to expectations (H5-6)

<table>
<thead>
<tr>
<th>Effect</th>
<th>F-Statistic</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>F(2,45) = 16.43</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Speed</td>
<td>F(1,45) = 1.04</td>
<td>0.3133</td>
</tr>
<tr>
<td>Interface*Speed</td>
<td>F(2,45) = 2.03</td>
<td>0.1431</td>
</tr>
</tbody>
</table>

(Note: A few missing data points due to equipment or recording issues.)

<table>
<thead>
<tr>
<th>Enhanced</th>
<th>Baseline</th>
<th>Degraded</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="chart.png" alt="" /></td>
<td><img src="chart.png" alt="" /></td>
<td><img src="chart.png" alt="" /></td>
</tr>
</tbody>
</table>

Higher is better
Workload Results

- **NASA TLX:**
  - Overall score – rank weighted sum of demand ratings for trial
  - Demand component ratings
  - Significant interface design and speed effects; trends generally as expected (H4-5)
    - E < B & D; S < F
  - Marginal interaction effect with trend as expected (H6); At fast speed (high event rate), E << B < D

<table>
<thead>
<tr>
<th>Effect</th>
<th>F-Statistic</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>F(2,45) = 3.88</td>
<td>0.0278</td>
</tr>
<tr>
<td>Speed</td>
<td>F(1, 45) = 17.83</td>
<td>0.0001</td>
</tr>
<tr>
<td>Interface*Speed</td>
<td>F(2,45) = 2.70</td>
<td>0.0778</td>
</tr>
</tbody>
</table>
Discussion

• UAV control performance:
  – Differences in task accuracy primarily between baseline and degraded interfaces:
    • Absence of info context (functional grouping) and pre-attentive cueing of stimuli (color, shape) compromised transparency and response accuracy
    • Addition of auto features in enhanced interface did not improve (coordinate or warning detection) accuracy
  – Differences in time primarily between enhanced and baseline interfaces:
    • Information analysis automation features expedited performance (coordinate identification, warning detection, fix alarm)
    • Pre-attentive cueing of alarm types reduced search time
    • Pre-attentive cueing of alarm fixes reduced reading time

Take-home Message #1
• Implementing “transparency” principles, including (1) providing information context and (2) pre-attentive cueing of task stimuli may primarily influence task performance accuracy
• Implementing “transparency” principle of providing automation features may primarily influence task time.
More Discussion

• Dynamic knowledge of UAV status and mission:
  – Enhanced interface supported increased user awareness
    • Pre-attentive cueing of stimuli (map features, parameter deviations, alarm priorities, alarm fixes) increased accuracy of responses to queries
    • Information context (provided by hierarchical, functional grouping of menu items) increased system awareness
  – Degraded interface reduced user awareness of UAV environment and subsystem states due to…
    • Lack of pre-attentive cues (e.g., waypoint numbering and color coding)
    • Absence of (information acquisition) automation features (e.g., AOI filters)
      (Participants frequently referred to printed mission materials or used memory & guessing.)

Take-home Message #2:
• Implementing “transparency” principles of (1) pre-attentive cueing of task stimuli, (2) providing information context and (3) revealing automation (info acquisition) features can improve system user dynamic knowledge.
Final Discussion

• Operator workload responses and manipulation:
  – **Enhanced interface features revealing auto capabilities** (e.g., distance tool) **lead to reduction in perceived workload** relative to baseline interface
    • Baseline and degraded remained comparable in absence of enhanced automation features
    • Substantial workload reductions occur when auto features are made accessible to address user info processing needs (Kaber et al., 2005)
  – Speed manipulation / **task event rate influenced perceptions of workload and some task times** (distance estimation, alarm fix) but not all
    • Fast speed may not have been sufficiently demanding to influence **performance in certain control tasks** (coordinate identification, warning detection, alarm prioritization)
  – **Enhanced interface was most effective for moderating operator workload perceptions under high demand conditions**

*Take-home Message #3:*
• Prior work only showed principles of “transparency” may promote performance with no additional workload cost.
• Present study showed enhanced transparency interface can reduce perceived workload.
Conclusions

• Results were consistent with some other studies:
  – Mercado et al. (2016) – agent transparency increased operator performance, trust and perceived usability
  – Wright et al. (2016) – agent reasoning transparency improved human performance [and reduced automation bias in decision making]

• Novelty of present work:
  – Automation aids were “perfect” (no reliability issues), participants “trusted” aids, and we observed effect of implementing principles of “automation transparency” without confound of auto reliability issues
  – Identified utility of transparency in automation presentation in terms of several types of responses (performance, dynamic knowledge and workload)
Applications and Limitations

• “Transparency” may be useful concept for motivating and organizing automation interface design principles to support specific human performance outcomes
  – Pre-attentive cueing and information context increases accuracy
  – Automation assistance reduces task time and workload

• Interface prototypes not fully interactive; some functions disabled:
  – Users could not make inadvertent control activations like real UAV operators in actual mission execution
  – Participants were aware “total system failure” was not possible
  – Only investigated three interface designs (based on MP GCS)
  – Need to investigate other GCS concepts (e.g., military technologies)

• Only examined performance of common control tasks under nominal conditions
  – Need to study “transparent” interface use under off-nominal conditions
Future Research

- Have **developed cognitive performance models of generic UAV control tasks** (using GOMSL (executable cognitive task modeling language)).
- Models **provide basis for deriving workload responses** (cognitive operation counts/durations, longest sequences, WM chunks)
- **Models** have been validated against actual performance responses (time).
- Plan to **use models to assess application of M-GEDIS-UAV tool and principles of transparency for managing workload responses**.
  - Are tool and principles predictive of UAV operation workload outcomes?
Acknowledgement and Questions

• Thanks to CPT David Feltner, Mr. James Shirley, and Dr. Isabel (Wenjuan) Zhang for assistance in all aspects of this research.

For additional information or questions, please send email to: dbkaber@ncsu.edu