Understanding Human Autonomy Teaming Through Applications
Bimal Aponso, NASA Ames Research Center

Commands

Vehicle

Automation

Monitoring

Human Autonomy Teaming

Decision Making

Task Execution

Human/Machine, Interface

Aircraft, State

System Faults

Weather & Traffic

ATC, Clearances

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Framework for Human Autonomy Teaming

Summer Brandt
Joel Lachter
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Cockpit Activity Planning

J Benton

John Kaneshige
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Aircraft Capability Management
Randy Mumaw
Mike Feary

- Aircraft, State
- System Faults
- Weather & Traffic
- ATC, Clearances

Commands
- Automation
- Human Autonomy Teaming
- Situational Assessment
- Decision Making
- Task Execution

Human/Machine, Interface

Vehicle

Human, Machine, Interface
Human Autonomy Teaming

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February 16, 2017
Problems with Automation

• Brittle
  – Automation often operates well for a range of situations but requires human intervention to handle boundary conditions (Woods & Cook, 2006)

• Opaque
  – Automation interfaces often do not facilitate understanding or tracking of the system (Lyons, 2013)

• Miscalibrated Trust
  – Disuse and misuse of automation have lead to real-world mishaps and tragedies (Lee & See, 2004; Lyons & Stokes, 2012)

• Out–of-the-Loop Loss of Situation Awareness
  – Trade-off: automation helps manual performance and workload but recovering from automation failure is often worse (Endsley, 2016; Onnasch, Wickens, Li, Manzey, 2014)
HAT Solutions to Problems with Automation

• Brittle
  – **Negotiated decisions** puts a layer of human flexibility into system behavior

• Opaque
  – Requires that systems be designed to be **transparent**, present **rationale** and confidence
  – Communication should be in terms the operator can easily understand (**shared language**)

• Miscalibrated Trust
  – Automation **display of rationale** helps human operator know when to trust it

• Out–of-the-Loop Loss of Situation Awareness
  – Keep **operator in control**; adaptable, not adaptive automation
  – Greater interaction (e.g., **negotiation**) with automation reduces likelihood of being out of the loop
Simulated Ground Station
Autonomous Constrained Flight Planner (ACFP)

Recommended airports - rank ordered.
Adding HAT Principles to the Ground Station

With Added Transparency
Adding HAT Principles to the Ground Station
Adding HAT Principles to the Ground Station

- **Transparency**: Divert reasoning and factor weights are displayed.

- **Negotiation/Dialog**: Operators can change factor weights to match their priorities.

- **Shared Language/Communication**: Numeric output from ACFP was found to be misleading by pilots. Display now uses English categorical descriptions.
Adding HAT Principles to the Ground Station

- Human-Directed: Operator calls “Plays” to determine who does what
HAT Simulation: Tasks

• Participants, with the help of automation, monitored 30 aircraft
  – Alerted pilots when
    • Aircraft was off path or pilot failed to comply with clearances
    • Significant weather events affect aircraft trajectory
    • Pilot failed to act on EICAS alerts
  – Rerouted aircraft when
    • Weather impacted the route
    • System failures or medical events force diversions

• Ran with HAT tools and without HAT tools
HAT Simulation: Results

- Participants preferred the HAT condition overall (rated 8.5 out of 9).

- HAT displays and automation preferred for keeping up with operationally important issues (rated 8.67 out of 9)

- HAT displays and automation provided enough situational awareness to complete the task (rated 8.67 out of 9)

- HAT displays and automation reduced the workload relative to no HAT (rated 8.33 out of 9)
HAT Simulation: Results

- HAT workload reduction was marginally significant (HAT mean 1.7; No HAT mean 2.3, p = .07)
HAT Simulation: Debrief

• Transparency/Shared Language
  – “This [the recommendations table] is wonderful…. You would not find a dispatcher who would just be comfortable with making a decision without knowing why.”

• Negotiation
  – “The sliders was [sic] awesome, especially because you can customize the route…. I am able to see what the difference was between my decision and [the computer’s decision].”

• Human-Directed Plays
  – “This one was definitely awesome. Sometimes [without HAT] I even took my own decisions and forgot to look at the QRH because I was very busy, but that didn’t happen when I had the HAT.”
Where we are and planned FY17 work

- Trust repair with automated system part-task  
  **Now (Transparency Part Task)**

- Implementing HAT features on the flight deck  
  **Spring ’17 (Flight Deck)**

- Developing a software framework for creating HAT Agents
- Updating ground station re-routing tool  
  **Summer ’17 (Ground Station Agent)**
- UX testing
Cockpit Hierarchical Activity Planning and Execution

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February 16, 2017
Hierarchical Activity Planning

• Abstract idea of what will happen next
  – Abstract plans, not fully defined (instantiated) at start

• Partially ordered, conditions on tasks
  – Some tasks can be completed in any order
  – Timing is dependent on circumstances

• Precise tasks become more clear as time goes on
  – Interleaved execution and expansion
  – Clearance changes, weather, equipment failures, errors cause plan revision
  – Monitoring/projection detects failures, triggers revision
Activity Plan Components

- **Tasks**
  - Primitive
  - Non-primitive

- **Methods**
  - Method T:
    Parameters: x,y
    Subtasks: T1, T2, T3, T4
    Constraints/Limitations: T1 -> T3, C -> T3

- **Planner**
  - Expansion of tasks using methods
  - Satisfaction of constraints
Activity Plan Construction

Flight Processes

Initial Approach

Airspeed Setting Process
- Set airspeed to <airspeed>
- Verify speed setting
- Call out <airspeed>

Clearance Process
- Confirm ATC Clearance

Periodic Monitoring / Triggers

Clearance Monitoring
- Yes: ATC Approach Clearance
- Periodic monitoring: ATC Clearance
- No: Periodic airspeed check

Airspeed Monitoring
- Is airspeed within constraints?
  - Yes: Inform PF: "Check speed"
  - No: Is airspeed reasonable and within constraints?
    - Yes: Airspeed
    - No: Periodic airspeed check
Activity Plan Construction

Flight Processes

1. Approach Process
   - Request Flaps to <flaps setting>
   - Confirm flap setting at <flaps setting>
   - Move flaps to <flaps setting>
   - Call out "Flaps <flaps setting>", Speed appropriate for flaps <flaps setting>?

2. Glaideslope Capture Process
   - Call out "glaideslope captured"
   - Confirm glideslope captured

3. Localizer Capture Process
   - Call out "localizer captured"
   - Confirm localizer captured

4. Cancel Approach Process
   - Call out "glideslope captured"
   - Confirm glideslope captured

Periodic Monitoring / Triggers

1. Airspeed Monitoring
   - Is airspeed within limits?
   - Is airspeed 'reasonable'?
   - Periodic airspeed check
   - Call out <airspeed>

2. Altitude Setting Process
   - Verify speed setting
   - Communicate with ATC: "NASA123, cleared ILS to 28R, slowing to <airspeed>", Request "set altitude to <altitude>"
   - Set MCP altitude to <altitude>
   - Verify altitude

3. Localizer Monitoring
   - Is localizer captured?
   - Periodic localizer check

4. Glaideslope Monitoring
   - Is altitude within limits?
   - Is altitude 'reasonable'?
   - Periodic altitude check
   - Call out <airspeed>, Altitude within limits?

5. Allocator Monitoring
   - Is altitude within limits?
   - Is airspeed within limits?
   - Verify FMAs, "???"
   - Call out "???"

Realized Actions

- SetFlaps(LandingFlaps)
- SetMissedApprAlt
- SetSpeed(VREF+5)
- (PF) CheckSpeed
- (PM) RequestFlaps
- (PM) MoveFlaps
- (PM) CallOutFlaps
- (PF) ConfirmFlaps

Translate to Hierarchy
Example Activity Plan

- DUMBA 4000 ft
- CEPIN FAF+3 3000 ft
- AXMUL FAF+1 1800 ft
- 1000 AGL 500 AGL 50 AGL

- G/S Capture
- Final Checklist
- Arm Speed brakes
- Gear Down
- Flaps 20
- Flaps 25
- Airspeed 180
- Airspeed 135
- Stabilize Approach

Scrolls this direction
Nominal
Replanning Required
Future Task Group (high level task)

Touchdown
Example Activity Plan

- **ARCHI**: 7000 ft
- **DUMBA**: 4000 ft
- **CEPIN FAF+3 FAF+1 AXMUL**: 1800 ft

**Task Group** (high level task)

- Clearance ILS 28R
- Arm Localizer
- Localizer Capture
- G/S Capture
- Gear Down
- Flaps 5
- Flaps 20
- Airspeed 210
- Airspeed 180
- Final Approach

**Nominal**

**Replanning Required**

**Scrolls this direction**
Example Activity Plan

Scans this direction

Nominal
Replanning Required
Future Task Group (high level task)
Projection

Stochastic Sampling & Local Search

Fast Time Simulation
Monitors and Reaction

- Execution monitors check aircraft situation
- Remedial actions to repair plan
- Unplanned Contingencies

1. Set flaps 15
   Set missed approach altitude

2. Set speed 145
   Check radar altimeter

3. Capture localizer
   Capture glideslope

4. Set flaps 20
   Arm speed breaks
   Set auto breaks 3

5. Set flaps 30
   Set speed 130
   Run landing checklist

6. Anti-skid braking system indicating inoperative. Go around advised.

Testing & Integration

Flight Simulation Integration with PLEXIL
– Instrument monitoring
– Automated flight

Prototype UI Design
– Timeline view
– Gantt chart style
  • Based on location of aircraft
  • Timeline of best start times (not duration)
– Matches with trajectory vertical profile and waypoints
Aircraft Capability Management

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Michael Feary

February 16, 2017
Common Themes

- Focus on Operational Decision Making
- Evolution from Pilot Decision Support to Human-Autonomy Teaming
Qantas A380 Uncontained Engine Failure

- QF 32; Singapore to Sydney; 469 people on board
- 4 minutes after Take-off, engine no. 2 bursts, severely damaging other equipment
- 43 ECAM messages in first 60 seconds; 10 additional later
- 50 minutes to sort through the non-normal checklists (NNCs)

“It was hard to work out a list of what had failed; it was getting to be too much to follow. So we inverted our logic: Instead of worrying about what failed, I said ‘Let’s look at what’s working.’”  
A380 Captain
Airplane System Failure

Identify a non-normal checklist (NNC) tied to a component failure

Complete NNCs, as needed

Use “Notes” to identify operational limitations

Make decision about need to divert

Contradictions

Redundancies

Not Prioritized

Not Organized by Flight Phase

Current Approach to Aircraft System Alerting
What is a Capability?

Airplane System Components

- Hydraulic system
- Thrust Reverser
- Battery
- Air conditioning pack

Airplane Capabilities

- Range / Endurance
- Stopping Distance (on runway)
- Ability to perform a specific approach
- Ability to enter RVSM airspace

Airplane system components have failed

What can I do?
Where can I go?
Explicit Alerting on Capabilities

Typically, we don’t

- 787
  - 449 EICAS messages (Warning, Caution, Advisory)
  - All but 19 of them reflect physical system failures/status changes

Can I Fly?
Explicit Alerting on Capabilities

Sometimes, we do . . . .

Examples from the 787
- NO AUTOLAND
- NO LAND 3
- NAV UNABLE RNP
- STALL PROTECTION
The New Generation of Systems is Different

So are the pilots . . . .

Airplane System Integration  Pilot System Knowledge

- Airplanes have become more integrated—more shared resources, more interconnections—and failures can have effects that are difficult to anticipate or understand
- The volume and rate of crew alert and status messages can increase significantly for certain types of failures
- Non-normal procedure design for combinations of failures is challenging
- Air turnbacks or diversions occur due to confusion about severity of the failures, and impact on the mission

Both types of errors occur:
- Poor understanding of real problems
- Oversensitivity to trivial changes
Three Types of Information for the Pilot

Answering Basic Questions

- **Status of Airplane Capabilities**
  - What is working/what is not?
  - How can I restore what has been lost?

- **Operational Guidance**
  - Which limitations do I need to observe during the remainder of the mission?

- **Mission Objectives**
  - Can I still complete the planned mission?
  - If not, where else can I land?
An Alternative Approach

**Airplane System Failure**

**Time Horizon 1**
- Identify urgent actions (for stable flight)
- Present an overview of airplane capabilities (in addition to EICAS/ECAM)

**Goals:** reconfigure systems to restore as much capability as possible; understand generally what is possible

**Dynamic**
- Prioritized NNC selection

**Time Horizon 2**
- Identify operational limitations by flight phase
- Identify “Compatible” Airports within Range

**Goals:** operate with an understanding of ops limitations for remaining flight; do not “fly into” new problems

**Organized by Phase of Flight**
- Ability to Look Ahead for Limitations
- Organized with Airport, Weather, NOTAMS, etc

**Time Horizon 3**
- Decision Support for Mission Decision

**Goals:** understand where you can go and where is “best” to go; look at trade-offs; understand risks

**Integrate Airplane Capabilities with**
- Identify “Compatible” Airports within Range
Thinking about Human-Autonomy Teaming

- Initially, we pull together information relevant to mission/diversion; e.g.,
  - airplane compatibility / capability (range)
  - airport information
  - weather information

- Then, organize it in a way that flight crews can benefit, understanding how to present it to support collaborative decision making

- Finally, transition some elements to a more autonomous advisor
Planned Activities

- Develop a “framework/language” for communicating airplane capabilities
  - Pilot interviews and prototyping

- Develop a small set of failure cases

- Develop system models to simulate system failures

- Collaborate with industry (e.g. SAA with Boeing)
Thank you