Understanding Human Autonomy Teaming Through Applications
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Framework for Human Autonomy Teaming

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Commands

Automation

Vehicle

Aircraft State

System Faults

Weather & Traffic

ATC Clearances

Task Execution

Human Autonomy Teaming

Monitoring

Decision Making

Situational Assessment

Human/Machine Interface
Understanding Human Autonomy Teaming Through Applications

Cockpit Activity Planning
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Understanding Human Autonomy Teaming Through Applications

- Human/Machine Interface
- Automation
- Commands
- Vehicle

- Task Execution
- Human Autonomy Teaming
- Decision Making
- Monitoring
- Situational Assessment
- Aircraft, State
- System, Faults
- Weather & Traffic
- ATC, Clearances

Aircraft Capability Management

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Human Autonomy Teaming

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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

[Diagram showing flight path and navigational information]
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
- UX testing
  - Summer ’17 (Ground Station Agent)
Cockpit Hierarchical Activity Planning and Execution

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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
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
- ATC Approach Clearance
- Periodic monitoring

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

Flight Processes
- Approach
- Initial Approach
- Localizer Capture Process
- Glideslope Capture Process
- Flap Setting Process
- Cancel Approach Process
- Clearance Process
- Altitude Setting Process
- Airspeed Setting Process
- Speed Monitoring

Periodic Monitoring / Triggers
- Clearance Monitoring
- Airspeed Monitoring
- Altitude Monitoring
- Localizer Monitoring
- Flap Change Monitoring
- Flap Monitoring
- FMAs Monitoring

Realized Actions
- SetSpeed(VREF+5)
- SetMissedApprAlt
- (PM) CheckSpeed
- (PM) MoveFlaps
- (PM) CallOutFlaps
- (PF) ConfirmFlaps
- (PM) RequestFlaps

Translate to Hierarchy
Example Activity Plan

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

Tasks:
- Nominal
- Replanning Required
- Future Task Group (high level task)
Example Activity Plan

Nominal Replanning Required

Future Task Group (high level task)
Example Activity Plan

ARCHI 7000 ft

Clearance 270 / +3500

DUMBA 4000 ft

Clearance ILS 28R

CEPIN FAF+3 FAF+1

Arm Localizer

AXMUL 1800 ft

Loc Cap

1000 AGL 500 AGL 50 AGL

G/S Capture

Final Approach

Gear Down

Nominal

Replanning Required

Future Task Group (high level task)

Scrolls this direction

Flaps 20

Airspeed 180

Speedbrakes
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

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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Common Themes

- Focus on Operational Decision Making
- Evolution from Pilot Decision Support to Human-Autonomy Teaming
Explosion of Alert Messages

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
Current Approach to Aircraft System Alerting

Airplane System Failure

Identify urgent actions (for stable flight)
Identify a non-normal checklist (NNC) tied to a component failure

Complete NNCs, as needed

Not Prioritized

Contradictions
Redundancies

Not Organized by Flight Phase

Use “Notes” to identify operational limitations

Make decision about need to divert

No Decision Aid / Support

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
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 . . . .

- 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

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

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 Airport, Weather, NOTAMS, etc
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