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

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Framework for Human Autonomy Teaming

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Understanding Human Autonomy Teaming Through Applications

Human/Machine Interface

Commands

Automation

Human Autonomy Teaming

Task Execution

Monitoring

Decision Making

Situational Assessment

System Faults

Weather & Traffic

ATC, Clearances

Aircraft State

Cockpit Activity Planning

J Benton

John Kaneshige
Understanding Human Autonomy Teaming Through Applications

- Human/Machine, Interface
- Automation
- Commands
- Human Autonomy Teaming
- Decision Making
- Task Execution
- Situational Assessment
- Monitoring
- Vehicle
- Aircraft, State
- Aircraft Capability Management
- Randy Mumaw
- Mike Feary
- System Faults
- Weather & Traffic
- ATC, Clearances
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

The runway crosswind conditions are marginal for landing. The runway width, the length, the speed because of the crosswind components, and the surface are acceptable for landing.
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

Task Abstractions

Flight (from, to)

- FileFPlan(from, to, alt)
- ObtainClearance
- Taxi(rwyo)
- Fly(from, to)
- Taxi(gate)
- Shutdown

- Takeoff(rwyo)
- Climb
- Cruise
- Descend
- Approach
- Land(rwyo)
- GoAround
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

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
- ATC Clearance

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

Flight Processes

Approach

Cancel Approach Process

SetSpeed(VREF+5)

SetMissedApprAlt

→... →

CaptureGideslope

SetFlaps(LandingFlaps)

Realized Actions

(PF) RequestFlaps

(PM) CheckSpeed

(PM) MoveFlaps

(PM) CallOutFlaps

(PF) ConfirmFlaps

Periodic Monitoring / Triggers

Clearance Process

ATC: "NASA123 clear for ILS approach to RWY 28R speed <airspeed> to descend via MODESTO 5"

Clearance Monitoring

Airspeed Monitoring

Inform PF: "Check speed"

Airspeed Setting Process

Is airspeed within limits?

No

Set airspeed to <airspeed>

Is airspeed 'reasonable'?

No

Periodic airspeed check

Call out <airspeed>

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

Localizer Capture Process

Call out "localizer captured"

Confirm localizer captured

Flap Setting Process

Request Flaps to <flaps setting>

Confirm flap setting at <flaps setting>

Move flaps to <flaps setting>

Call out "Flaps <flaps setting>"

Periodic monitoring

Airspeed

Altitude

FMAs

Localizer
Example Activity Plan

- ARCHI: 7000 ft
- DUMBA: 4000 ft
- CEPIN FAF+3 FAF+1
- AXMUL: 1800 ft FAF
- 1000 AGL 500 AGL

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

Nominal
Replanning Required
Future Task Group (high level task)

Scrolls this direction
Example Activity Plan

- DUMBA 4000 ft
- CEPIN FAF+3 3000 ft
- AXMUL 1800 ft FAF
- 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

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

Scrolls this direction

- ARCHI 7000 ft
- DUMBA 4000 ft
- CEPIN FAF+3 FAF+1
- AXMUL 1800 ft FAF
- 1000 AGL 500 AGL

Nominal: Green
Replanning Required: Red
Future Task Group (high level task): Blue
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 brakes
   Set auto brakes 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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February 16, 2017
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
Use “Notes” to identify operational limitations
Not Organized by Flight Phase
Make decision about need to divert
No Decision Aid / Support
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 . . . .

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

- **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

- **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

**Dynamic**

- Prioritized NNC selection
- Organized by Phase of Flight
- Ability to Look Ahead for Limitations
- 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