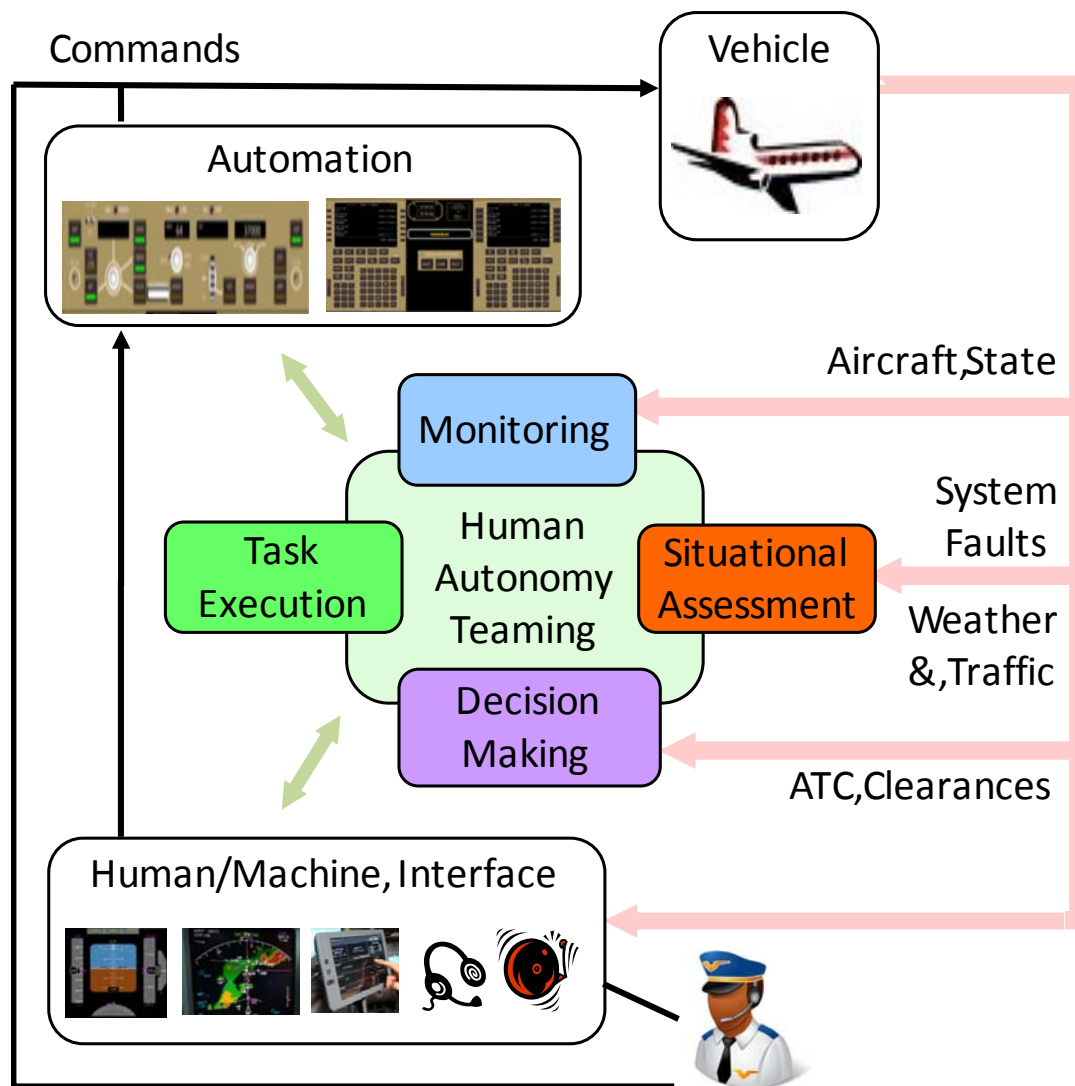
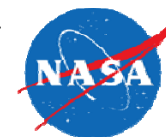
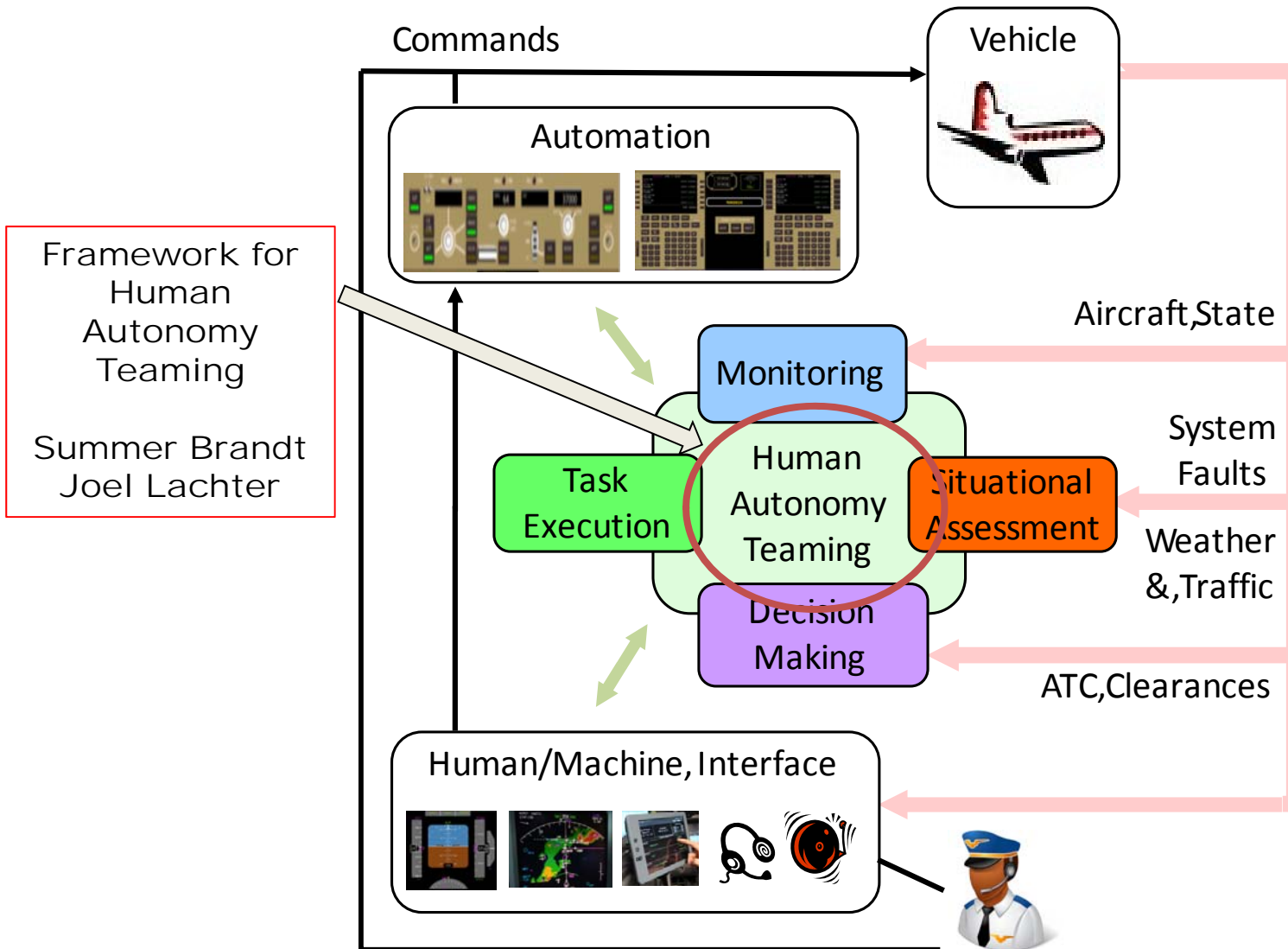


# Understanding Human Autonomy Teaming Through Applications

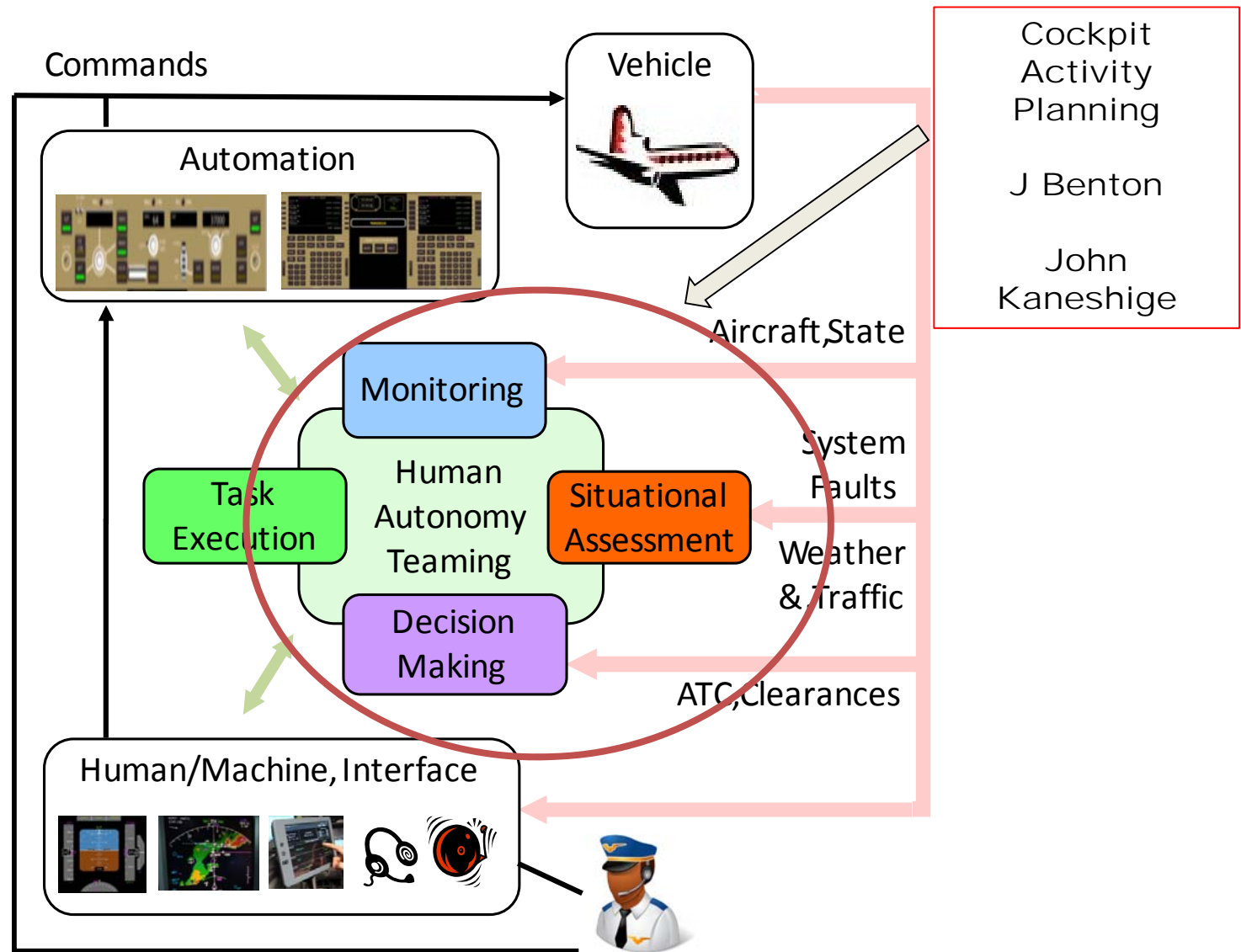
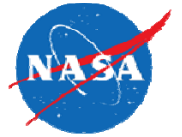
Bimal Aponso, NASA Ames Research Center



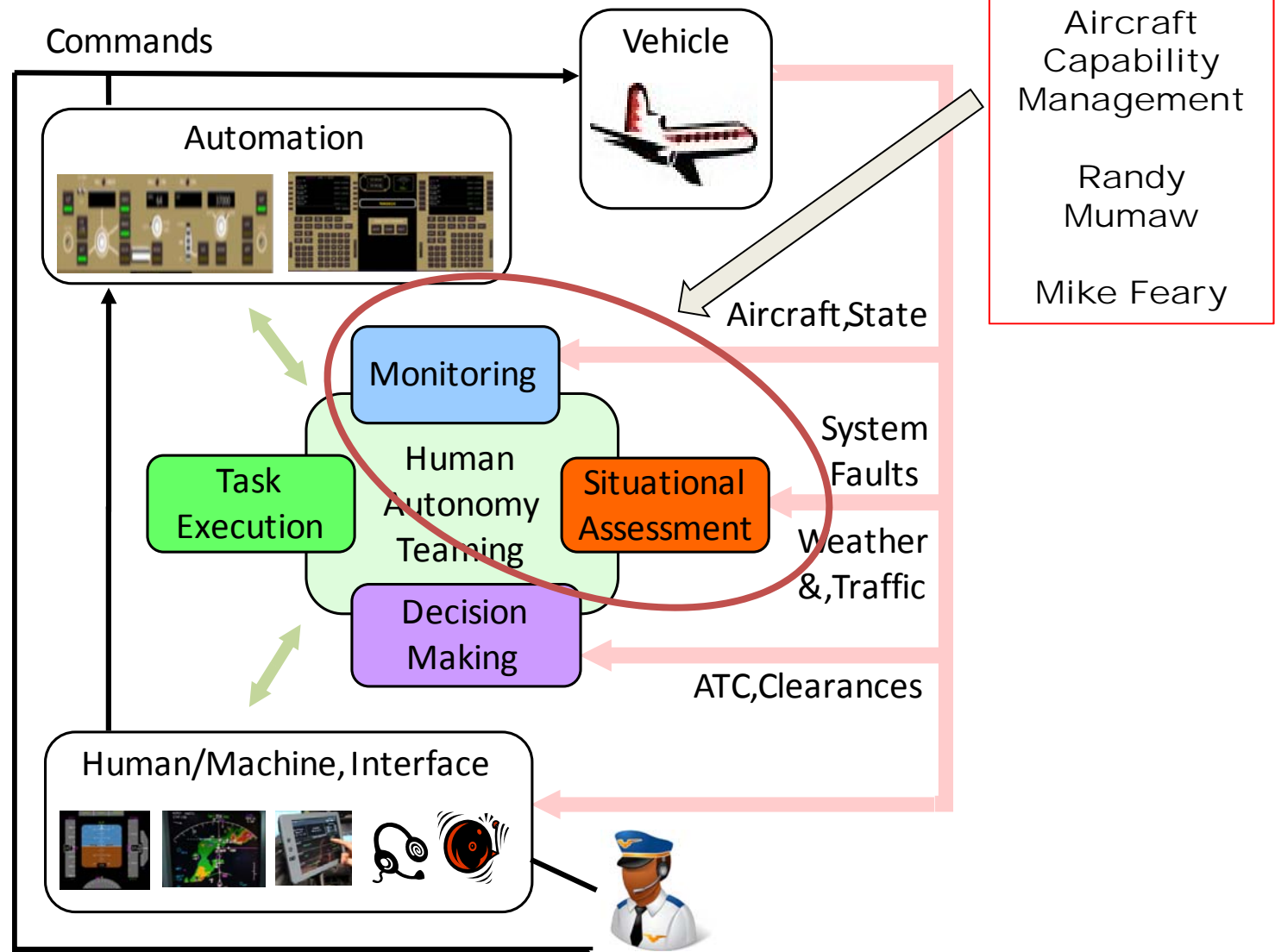
# Understanding Human Autonomy Teaming Through Applications



# Understanding Human Autonomy Teaming Through Applications



# Understanding Human Autonomy Teaming Through Applications





# Human Autonomy Teaming

Summer Brandt  
Joel Lachter  
Jay Shively

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)

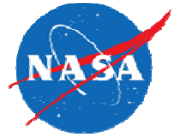
# HAT Solutions to Problems with Automation

---



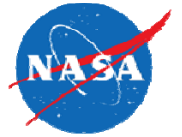
- Brittle
  - **Negotiated decisions** puts a layer of human flexibility into system behavior
- Opaque
  - Requires that systems be designed to be **transparent**, present **rationale** and confidence
  - Communication should be in terms the operator can easily understand (**shared language**)
- Miscalibrated 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)

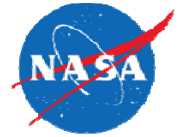


- EAP's
- KPUB,RW26L
- KGJT,RW29
- KCYS,RW27
- KPUB,RW08R,SP
- KGJT,RW11,SP
- KEGE,RW25,XW,SP
- KCOS,RW35R,XW
- KCOS,RW35L,XW

Recommended airports  
- rank ordered.



# Adding HAT Principles to the Ground Station



## With Added Transparency

**KLAX (25L)** Refresh

- ▼ ATIS  
29015G30KT 1SM RA OVC011 BKN021 20/18 29.98 (TWO NINE NINE EIGHT). NO PUBLISHED APPROACH... ADVS YOU HAVE INFO F  
**KLAX, 25L, 11095, ILS25L, 92.51**
- ▼ Path Rating: **Marginal**
- ▶ ENROUTE: **Acceptable**
- ▶ APPROACH: **Acceptable**
- ▼ RUNWAY: **Marginal**  
The runway crosswind conditions are **marginal** for landing. The runway width, the length, the speed because of the tailwind component, and the surface are **acceptable** for landing.

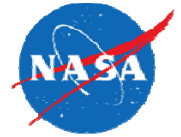
EAP'S

KSAN (27)  
KLAX (25L)

ACFP Airt! RAT Enter Undo Abs Trfc IDs

Reset Execute

# Adding HAT Principles to the Ground Station

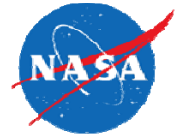


The screenshot displays a flight operations interface with the following components:

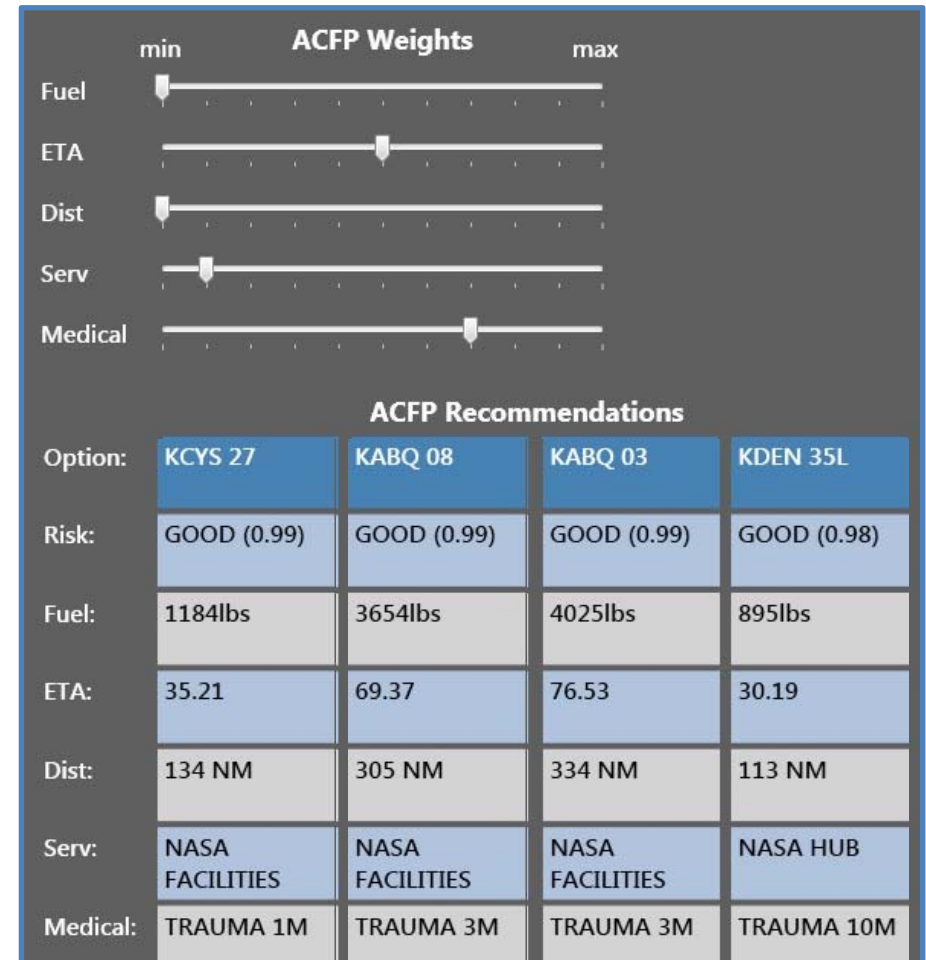
- Flight Time-Line:** A horizontal timeline from 16:00 to 23:00. A vertical line is positioned at 19:01. Aircraft are represented by colored bars indicating their flight paths.
- Aircraft List:** A list of aircraft with their destinations. The selected aircraft is NASA136 (SAN - SJC). Other aircraft include NASA04 (ABQ - DEN), NASA100 (ONT - GEG), NASA106 (PHX - DEN), NASA111 (PHX - SEA), NASA112 (PDX - ABQ), NASA113 (PDX - COS), NASA114 (PDX - DEN), NASA138 (SAN - TUS), NASA139 (SFO - DEN), NASA143 (SFO - PHX), NASA147 (SJC - DEN), NASA15 (DAL - LAX), NASA159 (SEA - LAS), NASA161 (SEA - PHX), NASA165 (TUS - DEN), NASA166 (TUS - LAX), NASA168 (TUS - SAN), NASA20 (DAL - SEA), NASA24 (DEN - BOI), NASA38 (DEN - SJC), NASA39 (DEN - SEA), NASA45 (BOI - OAK), NASA46 (BOI - PHX), NASA63 (LAX - SLC), NASA76 (LAS - PDX), NASA82 (LAS - SJC), NASA83 (LAS - SEA), and NASA86 (OAK - ABQ).
- Medical Emergency Panel:** A panel titled "NASA35 - Medical Emergency" with several checkboxes:
  - SWITCH STATUS TO MEDICAL
  - SUGGEST DIVERT OPTIONS FOR NEAREST SUITABLE
  - MAKE RECOMMENDATION TO PILOT
  - UPLINK AGREED UPON FLIGHT PLAN
  - ADD DETAILS OF ILLNESS TO OPERATOR NOTES
  - CONTACT EMS
  - CONTACT MAINTENANCE
  - CONTACT CUSTOMER SERVICE
  - CONTACT SLOT CONTROL
  - CONTACT CARGO CONTROL
  - ASK IF PILOT NEEDS ADDITIONAL ASSISTANCE
- Aircraft Details Panel:**
  - Aircraft Details:** NASA35: DEN - SLC; ETA 19:39
  - Priority:** EMERGENCY
  - Filed:** DEN / RLG.EKR.LEEHY3.PLAG.ILS34R
  - Alerts:**
    - ▶ Crew: NOLAN STALLMAN
    - ▶ Souls On Board: 88
    - ▶ Equipage: 737-800
    - ▶ Next Waypoint: EKR
  - Operator Notes:** NO ISSUES
  - Diversion:**
    - Buttons: Anti-skid Fail, Anti-ice fail, Windshield Overheat, Wheel Well Fire, Wx Radar Fail, No Auto-Land, Cabin Pressure Fail, Medical Emergency, Auto-Brake Fail, Cabin Fire, Cargo Door Open, Divert, Weather.
  - ACFP Weights:** Sliders for Fuel, ETA, Dist, Serv, Medical.
  - ACFP Recommendations Table:**

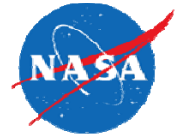
	KABQ 08	KABQ 03	KCYS 27	KDEN 35L
Risk:	GOOD (0.99)	GOOD (0.99)	GOOD (0.99)	GOOD (0.98)
Fuel:	3654lbs	4025lbs	1184lbs	895lbs
ETA:	69.37	76.53	35.21	30.19
Dist:	305 NM	334 NM	134 NM	113 NM
Serv:	NASA FACILITIES	NASA FACILITIES	NASA FACILITIES	NASA HUB
Medical:	TRAUMA 3M	TRAUMA 3M	TRAUMA 1M	TRAUMA 10M

# Adding HAT Principles to the Ground Station



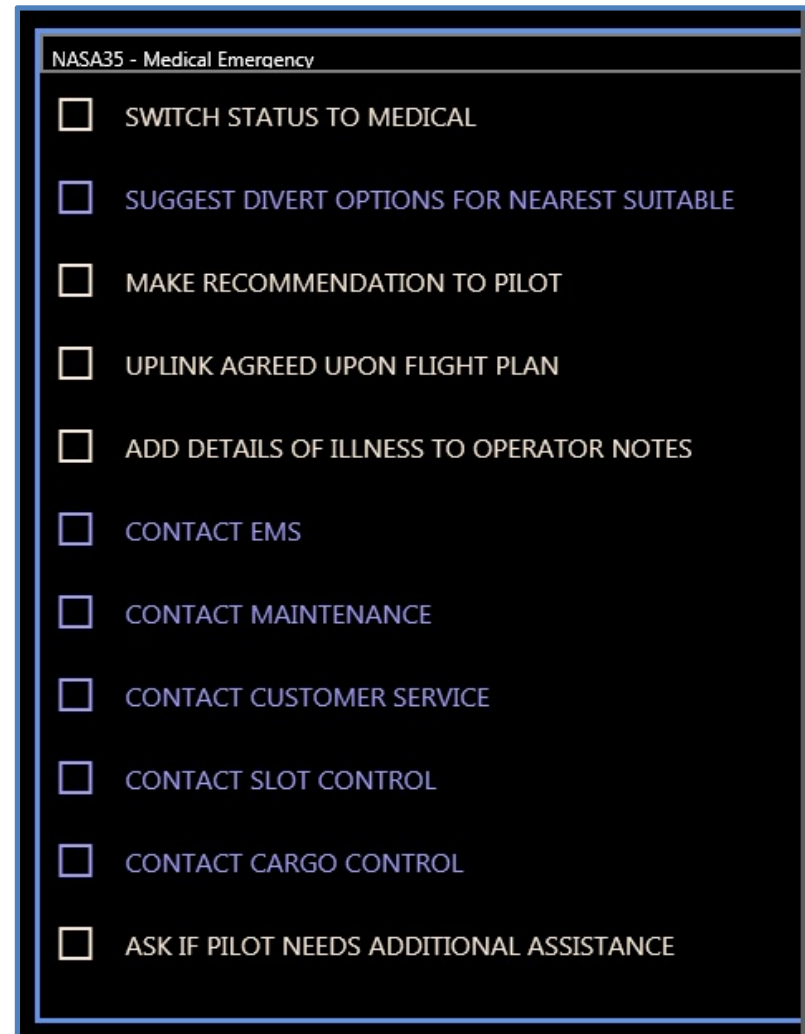
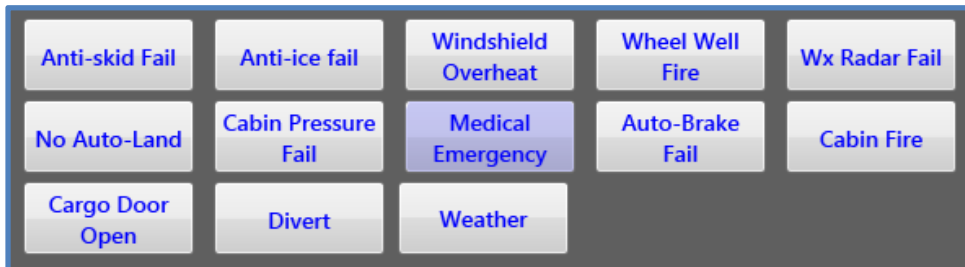
- Transparency: Divert reasoning and factor weights are displayed.
- Negotiation/Dialog: Operators can change factor weights to match their priorities.
- Shared Language/Communication: Numeric output from ACFP was found to be misleading by pilots. Display now uses English categorical descriptions.





# 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

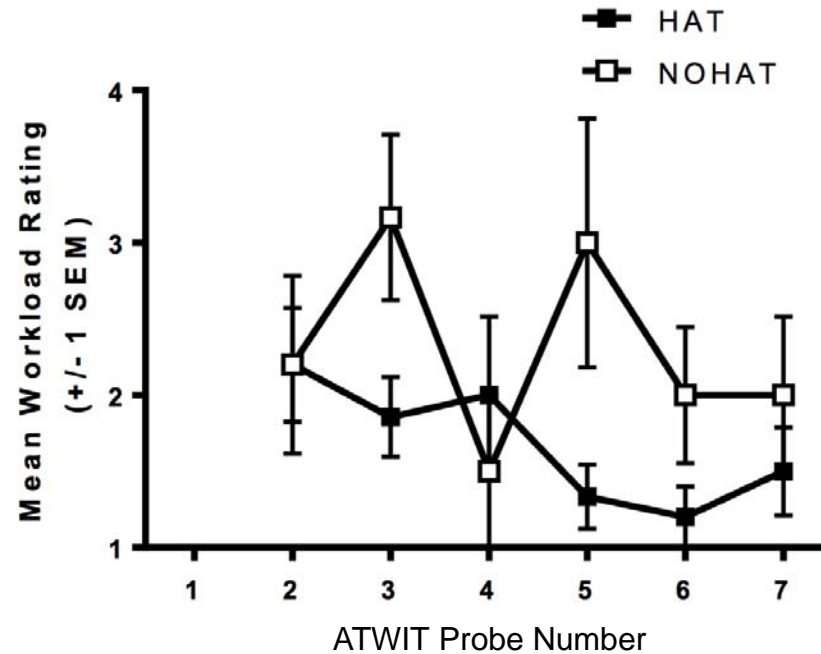
---

- 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,  $p = .07$ )



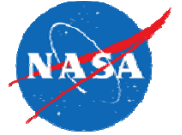




# HAT Simulation: Debrief

---

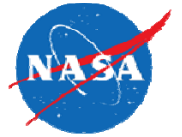
- Transparency/Shared Language
  - “This [the recommendations table] is wonderful.... You would not find a dispatcher who would just be comfortable with making a decision without knowing why.”
- Negotiation
  - “The sliders was [sic] awesome, especially because you can customize the route.... I am able 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

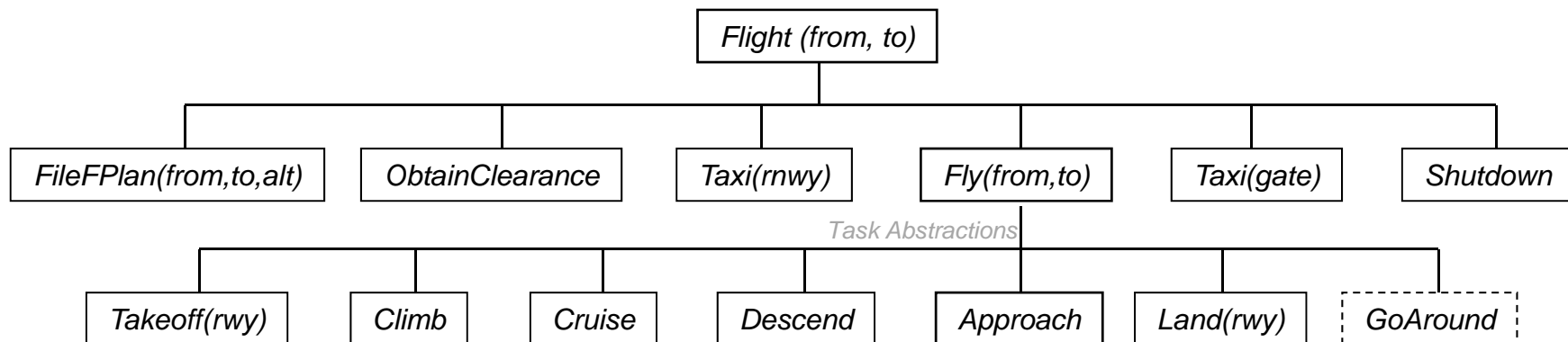
J Benton  
John Kaneshige

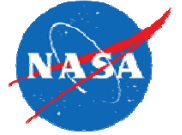
February 16, 2017



# Hierarchical Activity Planning

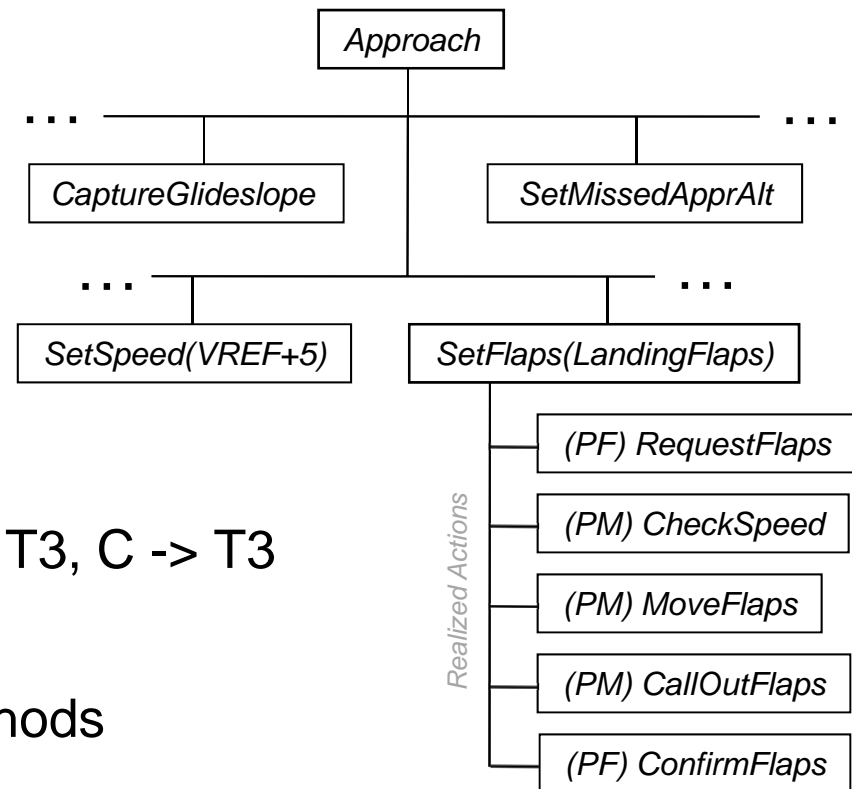
- Abstract idea of what will happen next
  - Abstract plans, not fully defined (instantiated) at start
- Partially ordered, conditions on tasks
  - Some tasks can be completed in any order
  - Timing is dependent on circumstances
- Precise tasks become more clear as time goes on
  - Interleaved execution and expansion
  - Clearance changes, weather, equipment failures, errors cause plan revision
  - Monitoring/projection detects failures, triggers revision





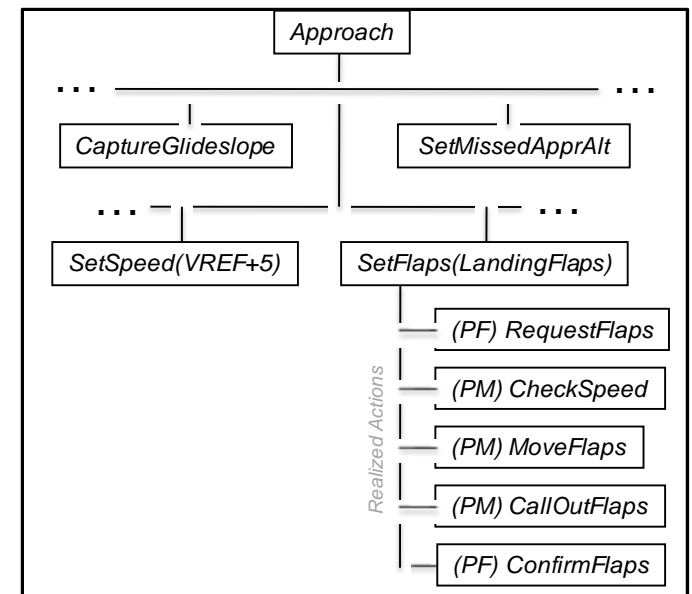
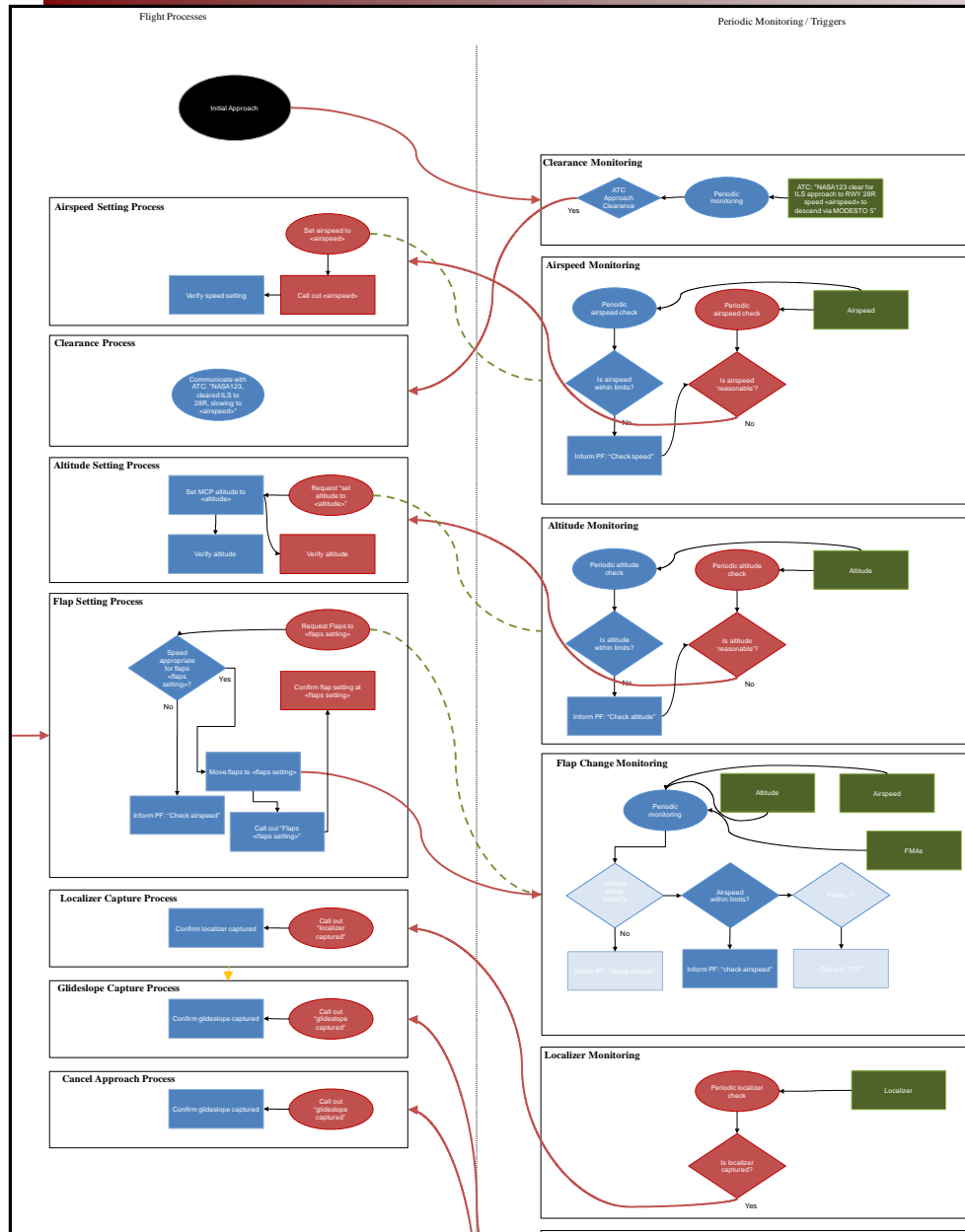
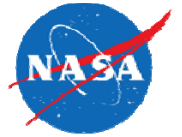
# Activity Plan Components

- 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

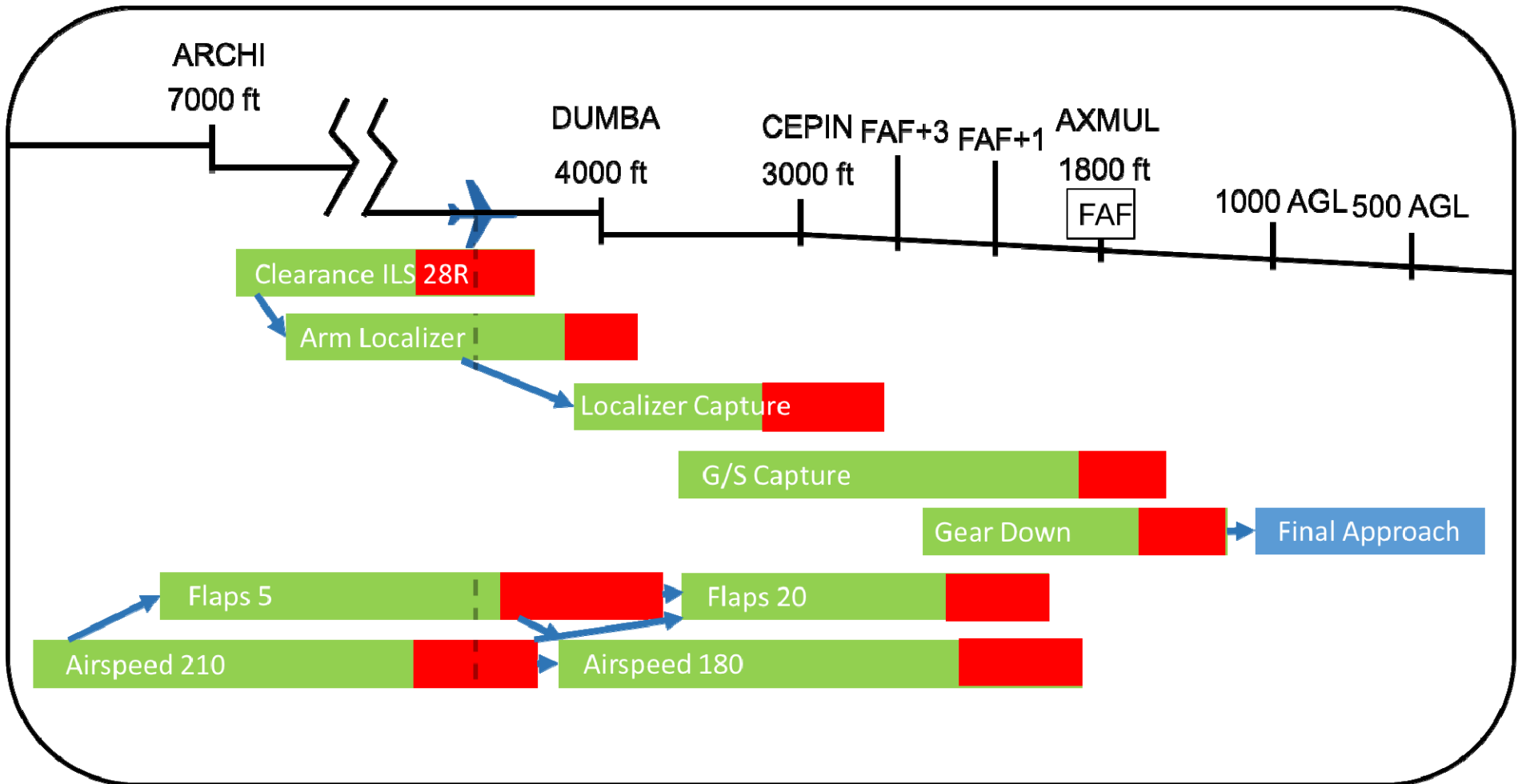
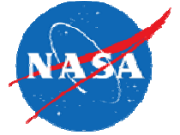




# Activity Plan Construction



# Example Activity Plan

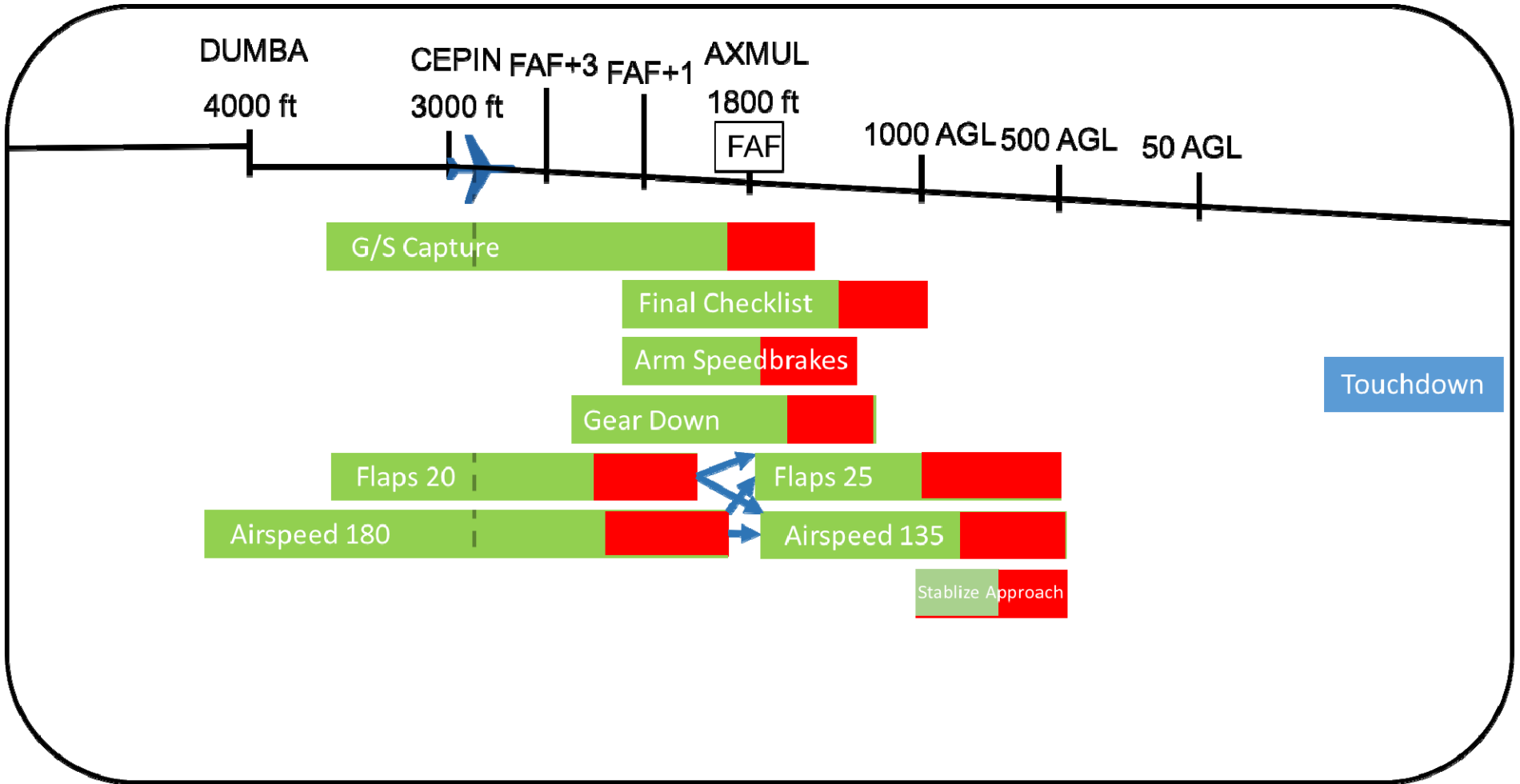
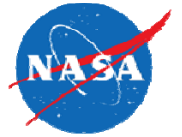


← Scrolls this direction

Nominal
  Replanning Required
  Future Task Group (high level task)

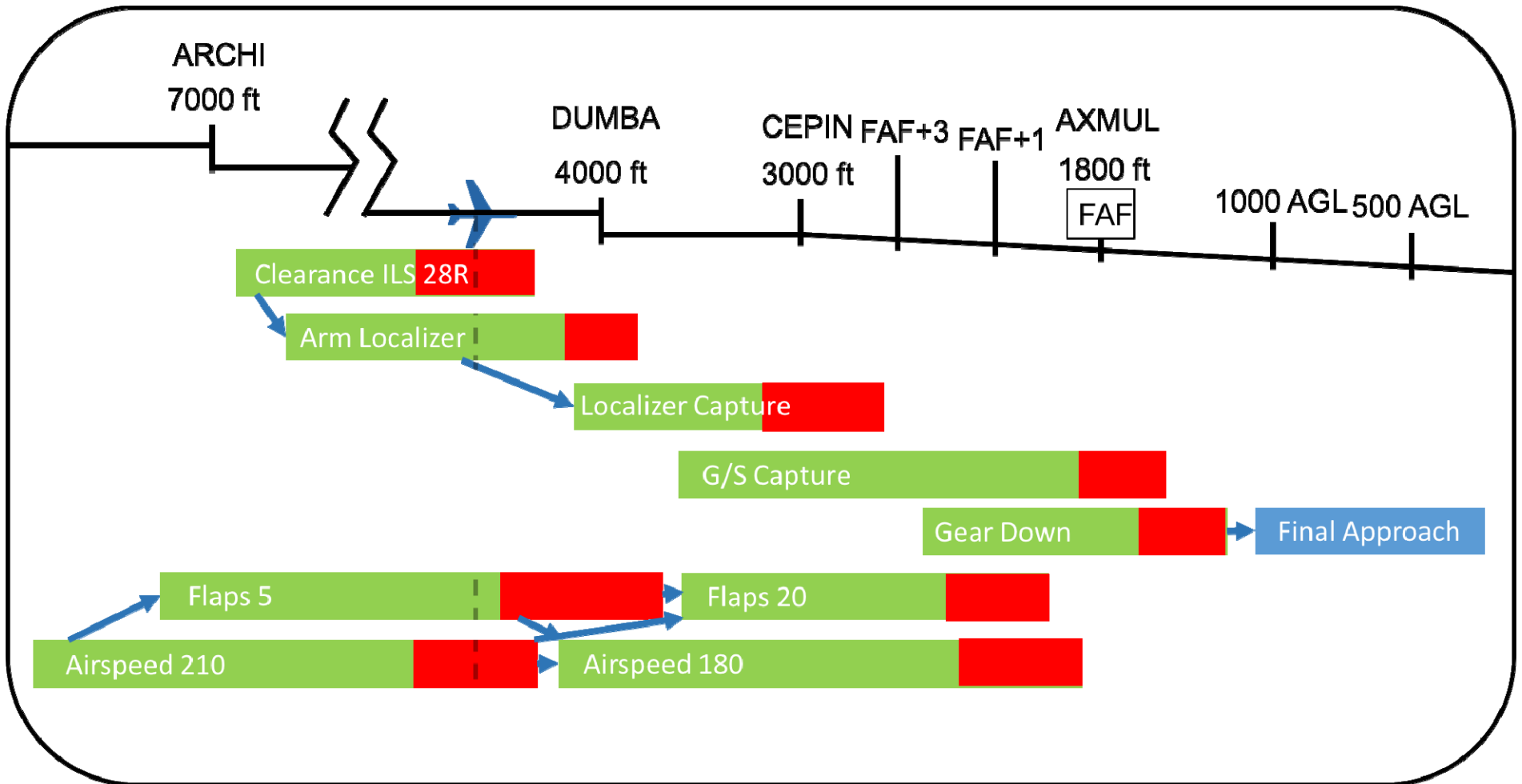


# Example Activity Plan



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

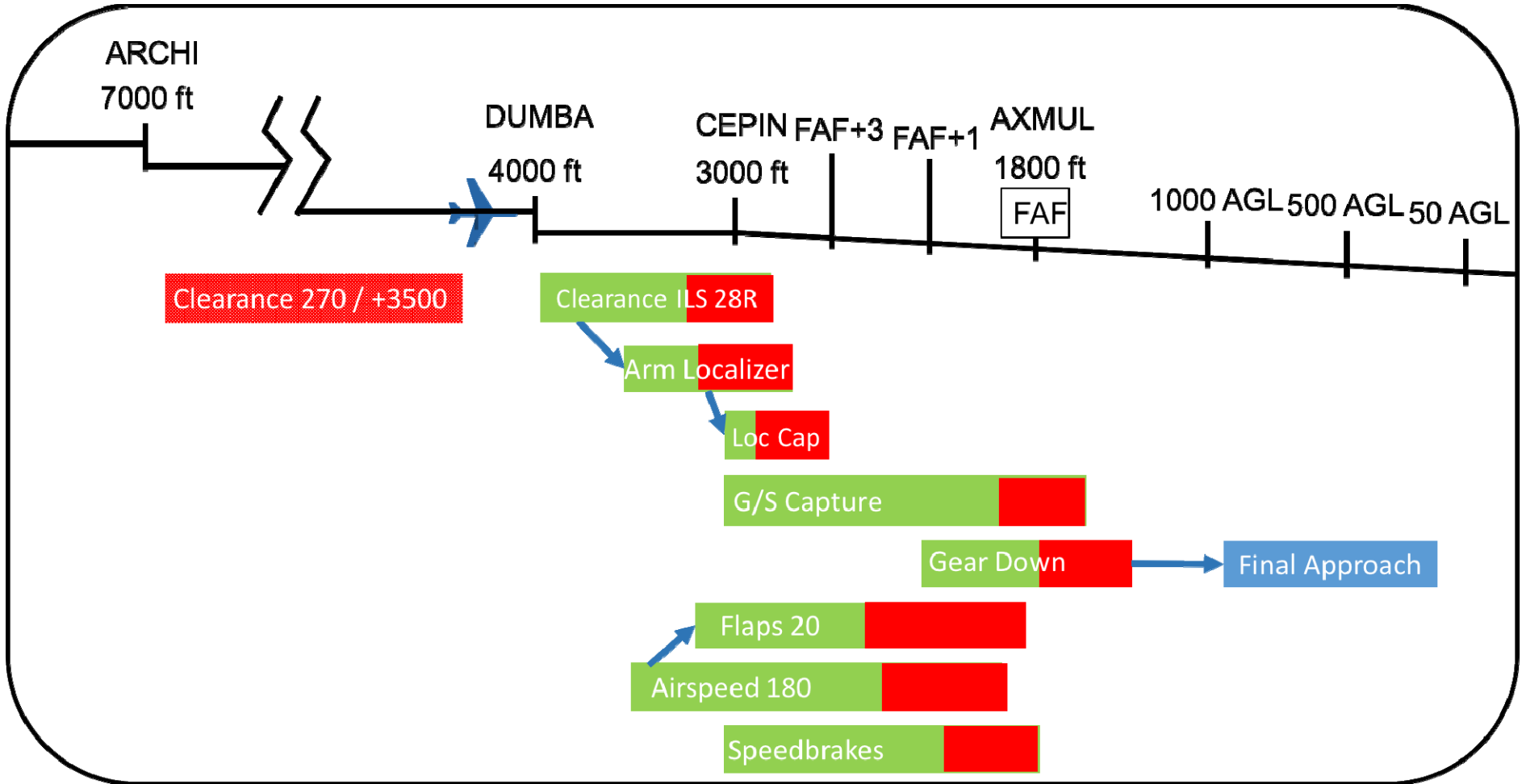
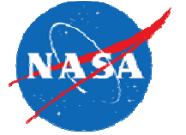
# Example Activity Plan



← Scrolls this direction

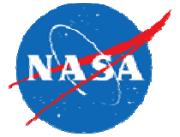
Nominal
  Replanning Required
  Future Task Group (high level task)

# Example Activity Plan

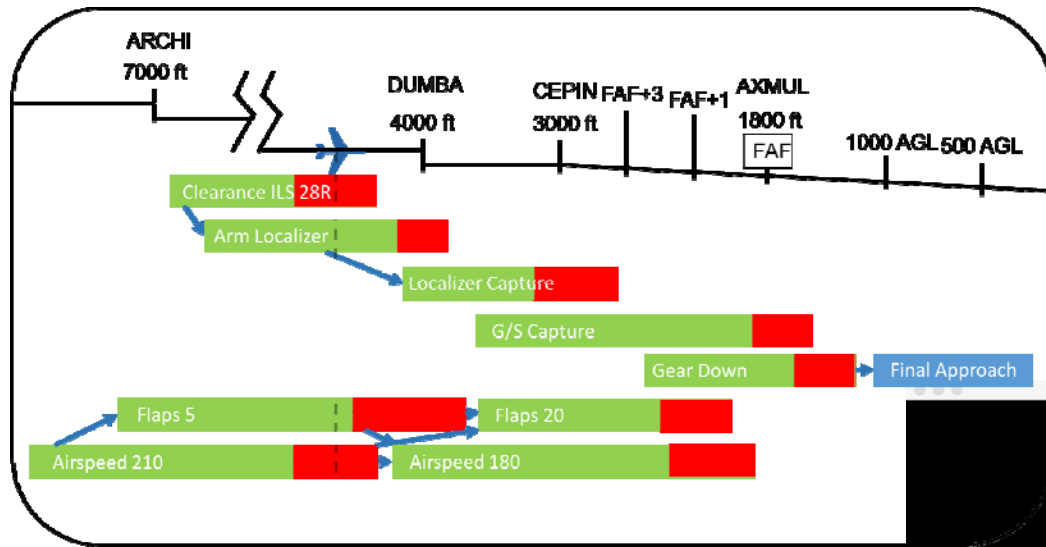


← Scrolls this direction

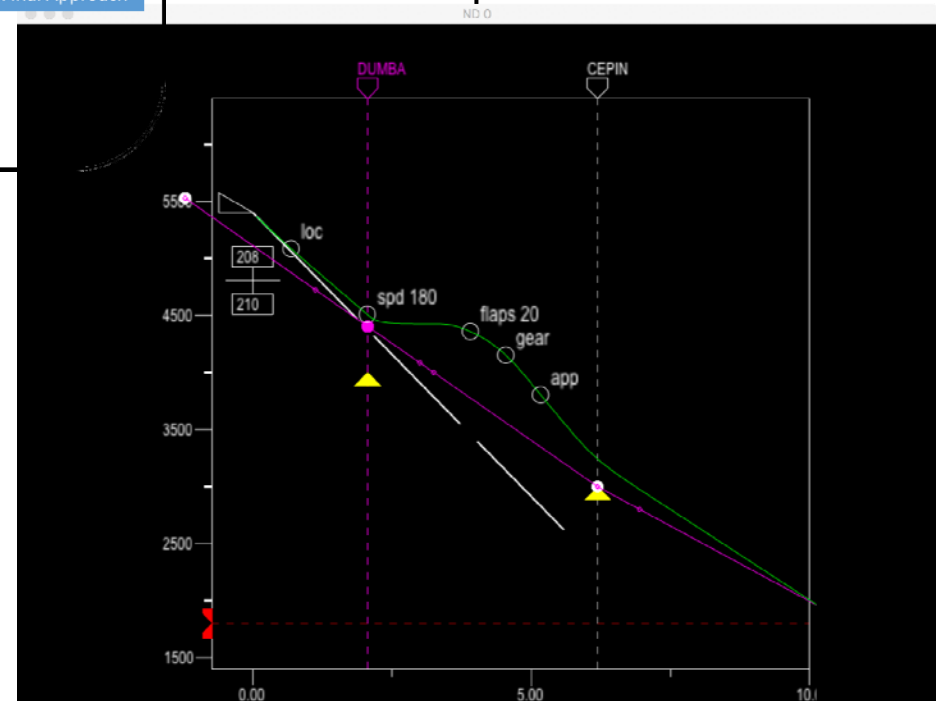
- Nominal
- Replanning Required
- Future Task Group (high level task)



# Projection



Stochastic Sampling & Local Search

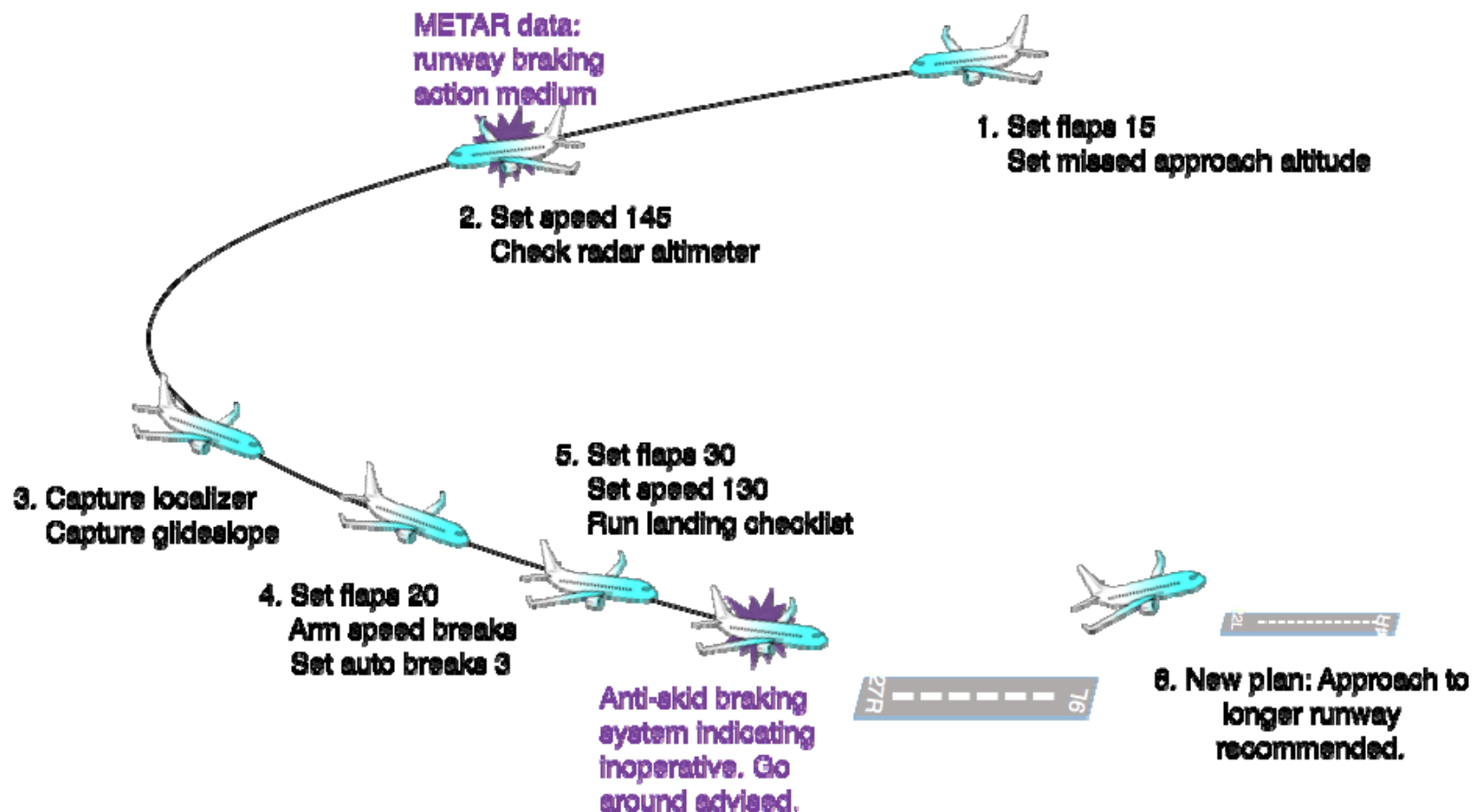


Fast Time Simulation



# Monitors and Reaction

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



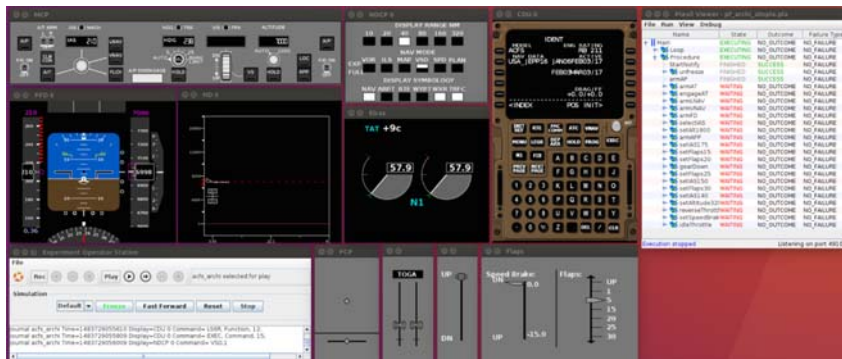


# Testing & Integration

## Flight Simulation Integration with PLEXIL

- Instrument monitoring
- Automated flight

Plan Execution  
Interchange Language



Plexil Viewer - pf\_arch\_simple.plx

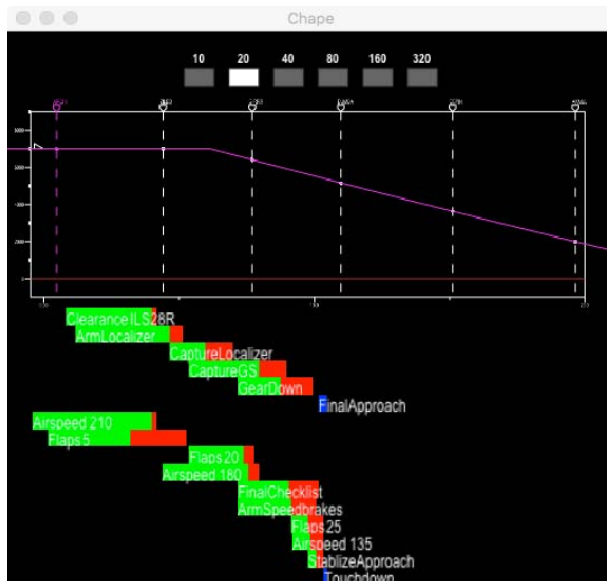
File Run View Debug

Name	State	Outcome	Failure Type
Main	EXECUTING	NO_OUTCOME	NO_FAILURE
Loop	EXECUTING	NO_OUTCOME	NO_FAILURE
Procedure	EXECUTING	NO_OUTCOME	NO_FAILURE
StartNotify	FINISHED	SUCCESS	NO_FAILURE
unfreeze	FINISHED	SUCCESS	NO_FAILURE
armAP	FINISHED	SUCCESS	NO_FAILURE
armAT	WAITING	NO_OUTCOME	NO_FAILURE
engageAT	WAITING	NO_OUTCOME	NO_FAILURE
armLNAV	WAITING	NO_OUTCOME	NO_FAILURE
armVNAV	WAITING	NO_OUTCOME	NO_FAILURE
armFD	WAITING	NO_OUTCOME	NO_FAILURE
selectIAS	WAITING	NO_OUTCOME	NO_FAILURE
setAlt1800	WAITING	NO_OUTCOME	NO_FAILURE
armAPP	WAITING	NO_OUTCOME	NO_FAILURE
setIAS175	WAITING	NO_OUTCOME	NO_FAILURE
setFlaps15	WAITING	NO_OUTCOME	NO_FAILURE
setFlaps20	WAITING	NO_OUTCOME	NO_FAILURE
gearDown	WAITING	NO_OUTCOME	NO_FAILURE
setFlaps25	WAITING	NO_OUTCOME	NO_FAILURE
setIAS150	WAITING	NO_OUTCOME	NO_FAILURE
setFlaps30	WAITING	NO_OUTCOME	NO_FAILURE
setIAS140	WAITING	NO_OUTCOME	NO_FAILURE
setAltitude3200	WAITING	NO_OUTCOME	NO_FAILURE
reverseThrottle	WAITING	NO_OUTCOME	NO_FAILURE
setSpeedBrake	WAITING	NO_OUTCOME	NO_FAILURE
idleThrottle	WAITING	NO_OUTCOME	NO_FAILURE

Execution stopped

Listening on port 49100

Debug Tool



Transition to  
UI

## Prototype UI Design

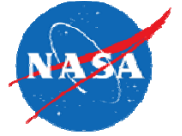
- Timeline view
- Gantt chart style
  - Based on location of aircraft
  - Timeline of best start times (not duration)
- Matches with trajectory vertical profile and waypoints



# Aircraft Capability Management

Randy Mumaw  
Michael Feary

February 16, 2017



# Common Themes

---

- Focus on Operational Decision Making
- Evolution from Pilot Decision Support to Human-Autonomy Teaming





# Explosion of Alert Messages

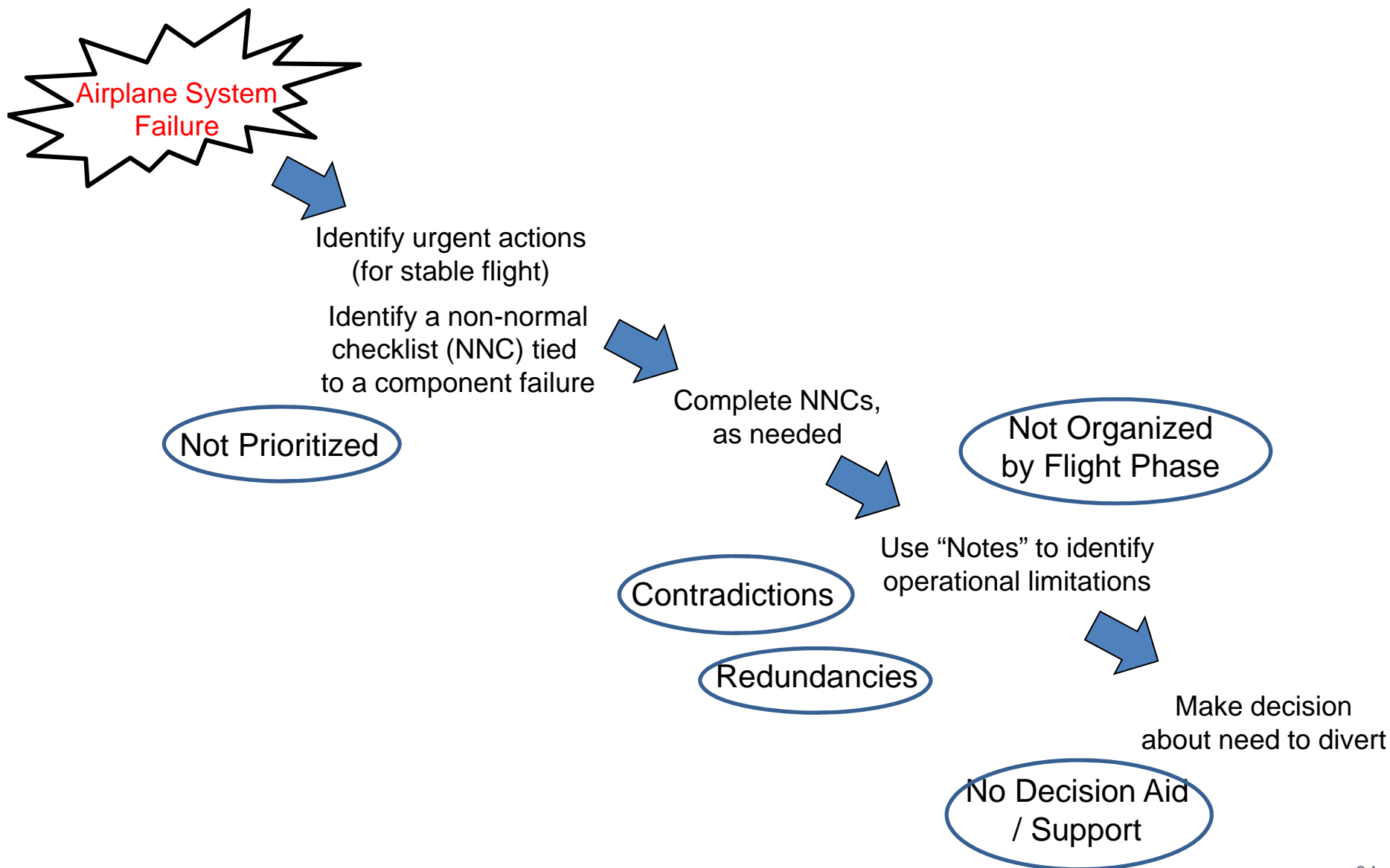
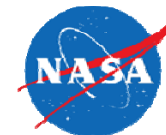
## Qantas A380 Uncontained Engine Failure

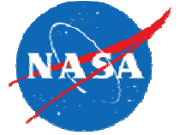
- QF 32; Singapore to Sydney; 469 people on board
- 4 minutes after Take-off, engine no. 2 bursts, severely damaging other equipment
- 43 ECAM messages in first 60 seconds; 10 additional later
- 50 minutes to sort through the non-normal checklists (NNCs)

“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





# 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



Can I Fly?

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

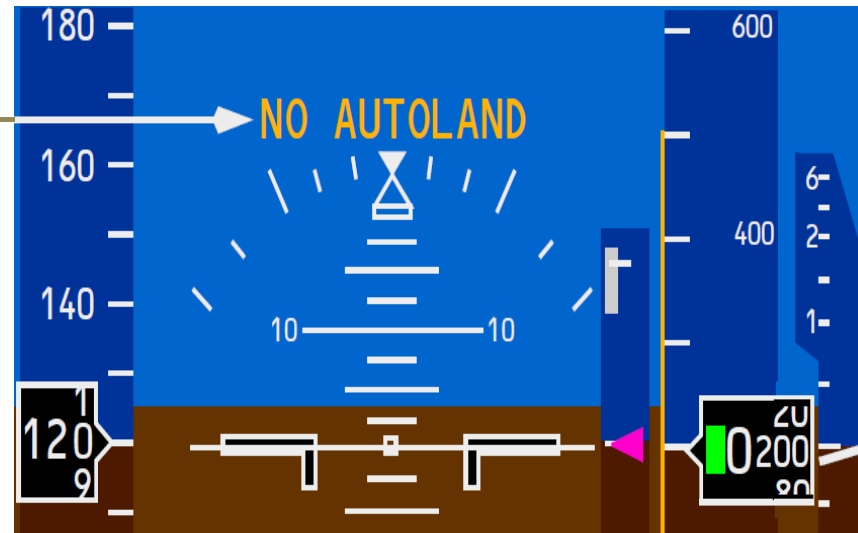


# Explicit Alerting on Capabilities

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

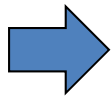


Time Horizon 1

Time Horizon 2

Time Horizon 3

Identify urgent actions  
(for stable flight)

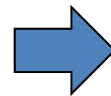


Present an overview of  
airplane capabilities  
(in addition to EICAS/ECAM)

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

Dynamic

Prioritized  
NNC selection

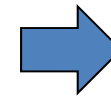


Identify operational  
limitations  
by flight phase

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



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

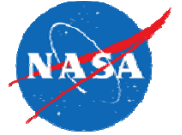




# Thinking about Human-Autonomy Teaming

---

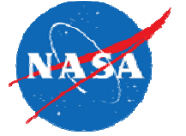
- Initially, we pull together information relevant to mission/diversion; e.g.,
  - airplane compatibility / capability (range)
  - airport information
  - weather information
- Then, organize it in a way that flight crews can benefit, understanding how to present it to support collaborative decision 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