Aircraft Capability Management

Randy Mumaw
Michael Feary

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Primary Messages

- Managing non-normals currently requires pilots to reason about poorly understood airplane systems; they won’t do this well and new airplanes will make it harder.

- Performance can be improved by using an automated agent to translate failures in system components to descriptions of airplane capabilities.

- Automation can perform tasks that humans do poorly, and also help the flight crew get to better decisions.

- As autonomous agents are developed to support these operational tasks, we need to ensure that those agents are effective team members.

Acknowledgment:
Lars Fucke and Jelmer Reitsma of Boeing (Madrid)
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
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
- Maneuver envelope

Airplane system components have failed

What can I do?
Where can I go?
757 Bus Failure

AAL Flight #268; SEA to JFK
September 22, 2008

- En route (CRZ); got several EICAS messages
- Performing STANDBY BUS OFF; initial action had them turn standby power selector to BAT (battery); they ended the checklist at that point
- A light showed that the battery was discharging but they couldn’t determine how to change that situation
- They put the hot battery bus, battery bus, standby AC bus and standby DC bus all on the battery, which was no longer charging.

2 hr, 24 min later, battery power depleted, resulting in these effects (plus others)
- Captain’s displays blanked
- PA failed
- Elevator trim systems failed
- Thrust reversers and spoilers failed to deploy automatically on landing
- Could not shut down the engines with fuel cutoff

None of these effects was expected by the flight crew!!
What Airplane Capabilities were Affected?

What systems are powered by those buses?

How do those systems affect airplane capabilities?

- Range
- Landing Distance
- Ice Protection
- Communication (with cabin)
- Maneuver Envelope
- Fire Detection and Extinguishing
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  

- 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

Pilot System Knowledge

Both types of errors occur:
- Poor understanding of real problems
- Oversensitivity to trivial changes
Managing a Non-normal (airplane system failure)

1. Alert to get attention to system failures
2. Identify immediate threats
3. Stabilize airplane
   - Assess airplane capabilities
   - Identify ops limitations for current phase of flight
   - Contain and Restore, when possible
4. Contain and Restore, when possible
5. Select an NNC that seems most appropriate and work through it to contain and restore as directed
   - Memory items from Warning and Caution items; some PFD guidance
   - “Notes” for ops limitations as encountered in NNC
   - “Notes” for ops limitations
6. Re-assess airplane capabilities
   - Make decision about mission objective
   - Identify ops limitations for remaining phases of flight
7. Re-assess airplane capabilities
   - Select airport
   - Monitor airplane capabilities
   - Adhere to ops limitations
   - Flight plan
   - Re-evaluate airport selection if information changes
8. Flight plan
Managing a Non-normal (airplane system failure)

1. Alert to get attention to system failures
2. Identify immediate threats
3. Stabilize airplane
4. Assess airplane capabilities
5. Contain and Restore, when possible
6. Select an NNC that seems most appropriate and work through it to contain and restore as directed
   - NNCs not prioritized
   - no feedback on effects
7. Monitor airplane capabilities
8. Adhere to ops limitations
9. Re-evaluate airport selection if information changes
10. Select airport
11. Make decision about mission objective
12. Identify ops limitations for remaining phases of flight
13. Notes are not phase of flight oriented
14. Contradictions, redundancies
15. No overview for assessment
16. “Notes” for ops limitations
17. Notes are not phase of flight oriented
18. Contradictions, redundancies
19. No support for mission decision making
20. No overview for assessment

- EICAS / Master Warning / Master Caution
  - Warn, Caut, Adv scheme
  - Memory items from Warning and Caution items; some PFD guidance
  - No overview for assessment
  - Notes are not phase of flight oriented
  - Contradictions, redundancies

- Phys component oriented
- Reverse order of occurrence
- Limited space (overflow)
Managing a Non-normal: Better Support

Alert to get attention to system failures
Identify immediate threats
Stabilize airplane
Assess airplane capabilities
Contain and Restore, when possible

"Big picture" or overview: what capabilities are available
"Big picture" or overview: what capabilities are available

PFD-based guidance
- use valid data
- guidance back to stable flight regime

Identify ops limitations for current phase of flight
Easy to access to ops limitations for current phase of flight

Identify immediate threats
central alerting scheme with salient cues
multi-modal cues

Re-assess airplane capabilities
Make decision about mission objective
Identify ops limitations for remaining phases of flight

Select airport
Monitor airplane capabilities
Adhere to ops limitations
Re-evaluate airport selection if information changes

Flight plan

Monitor any changes that might occur over time
Phase of Flight presentation of ops limitations
Phase of Flight presentation of ops limitations

Land?

easy to locate and execute actions for containing and restoring critical airplane capabilities

easy to determine appropriate order for executing NNCs

easy access to appropriate synoptics
Managing a Non-normal: Better Support

中央警报方案及其显著提示

复审飞机能力

选择机场

监测并评估，当有变化时

概述飞机能力及可恢复

或自动重新配置

概述

在这个非正常情况下，应立即采取以下措施：

1. **Alert to get attention to system failures**
   - 中央警报方案及其显著提示
   - 多模提示

2. **Identify immediate threats**
   - 立即识别威胁

3. **Stabilize airplane**
   - 稳定飞机

4. **Assess airplane capabilities**
   - 评估飞机能力

5. **Contain and Restore, when possible**
   - 封锁和恢复，如果可能

6. **Land?**
   - 降落？

**“Big picture” or overview:**

- 什么能力可用
- 容易获取当前阶段的运营限制
- 监控并重新评估可能的机场选择变化

**Overview of airplane capabilities & What can be restored (or automated reconfiguring):**

- 简要概述
- 复审飞机能力
- 监测并评估
- 落地？

**Phase of Flight presentation of ops limitations:**

- 结合飞机能力信息与潜在机场特征、天气、地形等信息，选择合适的机场
- 监控可能发生的任何变化

**Flight plan:**

- 资助并评估
- 重新评估机场选择，如果信息变化
- 监控并重新评估

**Easy to determine appropriate order for executing NNCs**

- 容易确定适当的顺序来执行NCCs

**Easy access to appropriate synoptics**

- 容易访问适当的地图

**Alerts to get attention to system failures**

- 警报获取系统故障的注意

**Identify immediate threats**

- 识别立即威胁

**Stabilize airplane**

- 稳定飞机

**Assess airplane capabilities**

- 评估飞机能力

**Contain and Restore, when possible**

- 封锁和恢复，如果可能

**Land?**

- 降落？

**“Big picture” or overview:**

- 什么能力可用
- 容易获取当前阶段的运营限制
- 监控并重新评估可能的机场选择变化
Managing a Non-normal: Better Support

Alert to get attention to system failures

Identify immediate threats

Stabilize airplane

Assess airplane capabilities

Contain and Restore, when possible

Land?

Identify ops limitations for current phase of flight

Phase of flight-oriented operational limitations

"Big picture" or overview: what capabilities are available

easy to locate and execute actions for containing and restoring critical airplane capabilities

easy to determine appropriate order for executing NNCs

easy access to appropriate synoptics

Monitor airplane capabilities

Adhere to ops limitations

Phase of Flight presentation of ops limitations

Re-evaluate airport selection if information changes

Monitor any changes that might occur over time

Flight plan

Select airport

Combine airplane capabilities info with other info about (potentially) airport characteristics, weather, terrain, etc to select an appropriate airport

Phase of Flight presentation of ops limitations

Re-evaluate airport selection if information changes

monitor and re-evaluate when there are changes relating to airport selection

Make decision about mission objective

Re-assess airplane capabilities

"Big picture" or overview: what capabilities are available

PFD-based guidance - use valid data - guidance back to stable flight regime

central alerting scheme with salient cues

multi-modal cues

Easy to determine appropriate order for executing NNCs

Easy access to appropriate synoptics

Easy access to appropriate synoptics

Alert to get attention to system failures

Identify immediate threats

Stabilize airplane

Assess airplane capabilities

Contain and Restore, when possible

Land?
Managing a Non-normal: Better Support

Alert to get attention to system failures

Identify immediate threats

Stabilize airplane

Assess airplane capabilities

Contain and Restore, when possible

Identify ops limitations for current phase of flight

Mission planner: Where should I land?

central alerting scheme with salient cues

multi-modal cues

Re-assess airplane capabilities

Make decision about mission objective

Identify ops limitations for remaining phases of flight

Re-evaluate airport selection if information changes

Select airport

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- use valid data
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Mission planner: Where should I land?

"Big picture" or overview: what capabilities are available

easy access to appropriate synoptics

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Mission planner: Where should I land?
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 Planner**
  - Can I still complete the planned mission?
  - If not, where else can I land?
## Initial Ideas about Airplane Capabilities

<table>
<thead>
<tr>
<th>Can I Take–off?</th>
<th>Navigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can I reach my planned destination?</td>
<td>Communication</td>
</tr>
<tr>
<td>Can I land?</td>
<td>Autoflight</td>
</tr>
<tr>
<td>Envelope</td>
<td>Envelope Protection</td>
</tr>
<tr>
<td></td>
<td>Stability Augmentation</td>
</tr>
</tbody>
</table>

### Resources
- Electric Power
- Hydraulic Power
- Pneumatic Power
- Equipment Cooling
- Engines (state)

### Resources
- Cabin/Cargo Environment
- Ice Protection
- Fire Detection & Extinguishing
- Airspace Access
- Approach Access
- Landing Distance
- Runway Directional Control

### Additional Features:
- NNC Prioritization
- Time to fail (or to recover)
- System synoptics (to assess configuration changes)
Mission Decision: Where Should I Land?

**Autonomous Agent**
- Determines set of available airports (within range)
- Selects set of airports that match airplane capabilities
- Assesses risk (or preferences)
- Selects best choice
- Generates flight plan

**Flight Crew / Dispatch**
- Sees set of airports being considered
- Add or remove airports
- Sets priorities
- Reveals airport data
- Provides rationale for airports selected and not selected
- Allows a comparison between 2 or more options
- Revises model inputs
- Has ability to over-ride choice

There is great value in a rapidly generated single choice but Data may be wrong Assumptions may be incorrect

Captain has final authority Flight crew needs to know rationale Flight crew can tweak assumptions Flight crew can check data
Mission Decision: Where Should I Land?

- runway length and width
- runway conditions
- emergency equipment
- medical resources nearby
- maneuver envelope
- terrain
- weather
- winds
- ceiling & visibility
- available instrument approaches
- population exposure
- exposure
- population
Mission Decision: Where Should I Land?

- maneuver envelope
- estimate of range/endurance
- from Emergency Landing Planner
- airspace restrictions
- operational limitations
- from ACM
- terrain
- weather

- limitations on landing performance (e.g., cross wind)
- estimate of required landing distance
- maneuver envelope
- medical resources nearby
- available instrument approaches
- the types of approaches that can be performed

- runway conditions
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Lessons for Human-Autonomy Teaming

- Use autonomous agents to pull together information relevant to managing non-normals (information that humans cannot develop); e.g.,
  - changes to airplane capabilities
  - airport information, airplane compatibility

- Organize it in a way to benefit flight crew decision making

- Develop interface design requirements for an autonomous advisor and a negotiation approach so that the humans can add value
Planned Activities

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

- Develop a set of failure cases

- Develop system models to simulate system failures

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

Next: Descent

Non-normal CL name:
operational limitation A
operational limitation B
ETOPS
Planned
Dest: KSFO
Diversion: KLAX
Basic

KLAX Alternate
ATIS
LDAAvail., LDReq
Etc.

Detailed version of 1 – This is the more complete description of item 1